Hindawi
Journal of Environmental and Public Health
Volume 2023, Article ID 4564446, 8 pages
https://doi.org/10.1155/2023/4564446

Research Article

Mathematical Analysis on the Action Mechanism of Different Intensities of Environmental Regulation on Regional Economy

Ling Lin [1] and Hai Sun [2]

[1] *School of Marxism, China West Normal University, Nanchong 637009, China*
[2] *School of Mathematics & Information, China West Normal University, Nanchong 637009, China*

Correspondence should be addressed to Ling Lin; linling501@stu.cwnu.edu.cn

Received 2 June 2022; Revised 30 June 2022; Accepted 6 July 2022; Published 7 July 2023

Academic Editor: Aboul Ella Hassanien

An in-depth understanding of environmental regulation and its action mechanisms on the regional economy helps the regional government make correct and reasonable decisions on environmental and industrial policy. So far, relatively few scholars have analyzed the influence of different intensities of environmental regulation on the spatial evolution of regional economies. Drawing on the existing results, this paper carries out a mathematical analysis of the action mechanism of different intensities of environmental regulation on the regional economy. The action paths of environmental regulation on the regional economy were identified, and the basic assumptions were provided for the action mechanism. Furthermore, the authors discussed the energy conservation and emission reduction (ECER) cost and economic benefit under the effect of environmental regulation. Finally, the empirical results were obtained through the experiments. It is concluded that the ecological efficiencies of the regional economy in the study area demonstrated heterogeneous spatial correlations.

1. Introduction

Since the reform and opening-up, China's economy has developed rapidly under the motivation of industrialization [1–6]. However, industrialization leads to more and more intense environmental pollution, making it difficult for China to improve the ecological efficiency of regional industry [7–12]. To devise economic development strategies under different intensities of environmental regulation, the following question must be answered: whether the regional environmental regulation, which intends to eliminate and prevent environmental pollution, can effectively constrain pollution discharge by enterprises, positively affect the ecological efficiency of industry, and push up the production and operation costs of enterprises [13–17]. An in-depth understanding of environmental regulation and its action mechanisms on the regional economy helps the regional government make correct and reasonable decisions on environmental and industrial policy.

Meng and Shao [18] constructed a regression model based on the panel data of 100 prefectures in 9 provinces and autonomous regions in the Yellow River Basin from 2006 to 2017 and adopted fixed effect estimation to examine how environmental regulation and industrial structure upgrading and rationalization affect the green economic growth efficiency of the Yellow River Basin. With the aid of a super slack-based measure (Super-SBM), Bi and Liu [19] measured the green economic efficiency of 29 provinces considering unexpected output. The results show that environmental regulation affects the green economic efficiency of different provinces differently. The effect is positive in the eastern region and unobvious in other regions. To verify the Porter hypothesis, panel models were employed to analyze the influence of environmental regulation on green economic efficiency. Improving manufacturing ecological efficiency helps to break the environmental and resource constraints on industrial development and further promotes the coordinated development of the economy and the environment. Yuan et al. [20] collected the panel data of 28 subsectors of China's manufacturing industry from 2003 to 2013 and divided these subsectors into high, medium, and low categories, according to the level of ecological efficiency. After that, they investigated the impact of environmental regulation on technological innovation (weak Porter hypothesis) and ecological efficiency (strong Porter hypothesis). Green development is fundamental to the high-quality development of the marine economy. The realization of the green development goal of the marine economy depends on the decision-making preferences of local governments and reasonable environmental regulation instruments related to the marine economy. Based on the panel data of China's coastal provinces from 2007 to 2016, Ye et al. [21] used a differential Gaussian mixture model (GMM) to empirically analyze the impact of government preferences and environmental regulation on green development of the marine economy. Although more and more people call for stricter environmental regulation, some express the concern that environmental regulation may hinder the rapid growth of China's foreign trade. Wang et al. [22] employed feasible generalized least squares (FGLS) and seemingly unrelated regression (SUR) to characterize the different categories of products in international trade, in the light of the Standard International Trade Classification (SITC).

To sum up, domestic and foreign scholars have performed detailed analysis on environmental regulation and the factors affecting regional economic development. The influence of environmental regulation on regional economic development has been expounded theoretically, quantified thoroughly, and empirically researched. However, there is little report on the influence of the spatial pattern on the evolution of regional economies at different intensities of environmental regulation. Drawing on the previous results, this paper innovatively carries out a mathematical analysis on the action mechanism of different intensities of environmental regulation on regional economy and presents the empirical results.

Combined with empirical analysis, this study tests the relationship of environmental regulation with the regional economy and industrial layout. The research findings provide a realistic reference for the government to adopt more suitable environmental regulation instruments, prepare more practical development policies for the regional economy, better solve environmental pollution, and further realize the green development of the regional economy.

2. Basic Hypotheses

As a core content of social regulation, environmental regulation refers to the government's regulation of the economic activities of manufacturers and other entities by formulating relevant policies and measures (industrial pollution control and urban environmental protection) to coordinate the environment with economic development in the face of the external uneconomic properties of environmental pollution.

During the pursuit of the green development of the regional economy, the government often implements environmental regulation with the aim to restrain the production behavior of enterprises, reduce the emission of harmful pollutants in the production process, and maintain the coordinated development of the regional environment and the economy. Figure 1 shows the action paths of environmental regulation on the regional economy. It can be learned that environmental regulation mainly constrains the behavior of producers and consumers. The producer behavior constraints include green consumption technology, pollution prevention, and waste reduction technology. The consumer behavior constraints include the green consumption concept, green consumption credit, and green consumption points.

Figure 2 shows the action paths of environmental regulation on production enterprises. This paper holds that environmental regulation affects the development decisions of production enterprises by affecting the capital flow and investment direction, new technologies and new processes, and the selection of product price and sales market.

The spatial heterogeneity of regional economic development under different environmental regulation intensities not only comes from the unified economic policies of the state but also stems from the regional difference in economic development efficiency, which originates from the regulation of local governments and the active pursuit of benefits of enterprises. This study does not intend to focus on spatial heterogeneity. Under different environmental regulation intensities, there may be differences in the economic development efficiency between regions. Therefore, this paper intends to focus on the spatial heterogeneity of economic development efficiency driven by regional industrial development under different environmental regulation intensities. Specifically, the spatial heterogeneity is reflected by the effects and benefits of regional economic development under different environmental regulation intensities. The spatial disequilibrium is related to the action mechanism of environmental regulation intensities. Therefore, this paper analyzes the mathematical mechanism and action paths of different environmental regulation intensities on regional economic development, laying the basis for further calculation and spatial heterogeneity analysis of regional economic development efficiency.

The government's measures and means for environmental protection introduce economic attributes to the environmental pollution caused by industrial development. Some industrial production strategies may generate pollutants. If these strategies are not changed, the economic benefits of industrial production will be greatly affected. The amount of pollutants being emitted directly hinges on the production strategy. To clarify the action mechanism of environmental regulation on regional economic development, this section mathematically models the action mechanism of environmental regulation on regional economic development and studies the basic action mechanism of regional economic development in the production process of enterprises.

Suppose the study area has two industrial producers X and Y. The former implements relatively relaxed environmental regulation, while the latter implements relatively intense environmental regulation. The expected output and

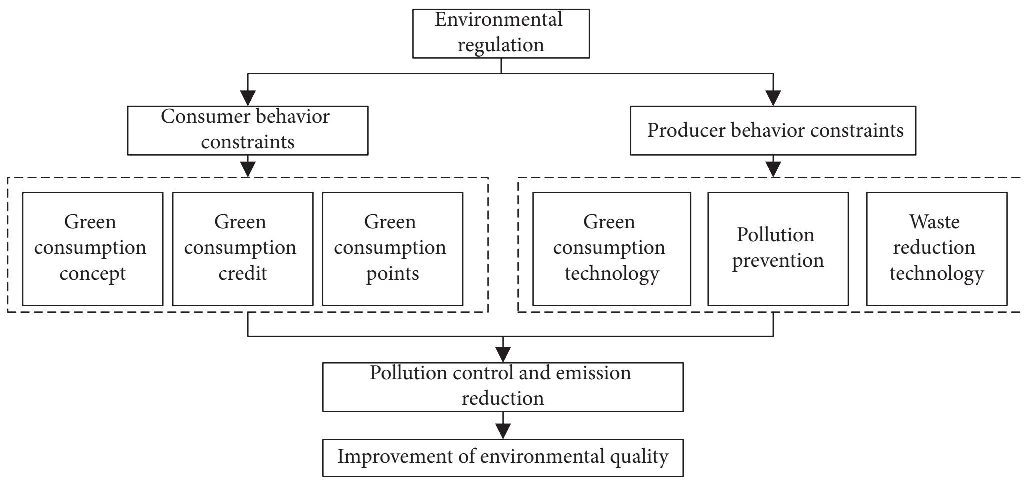

Figure 1: Action paths of environmental regulation on the regional economy.

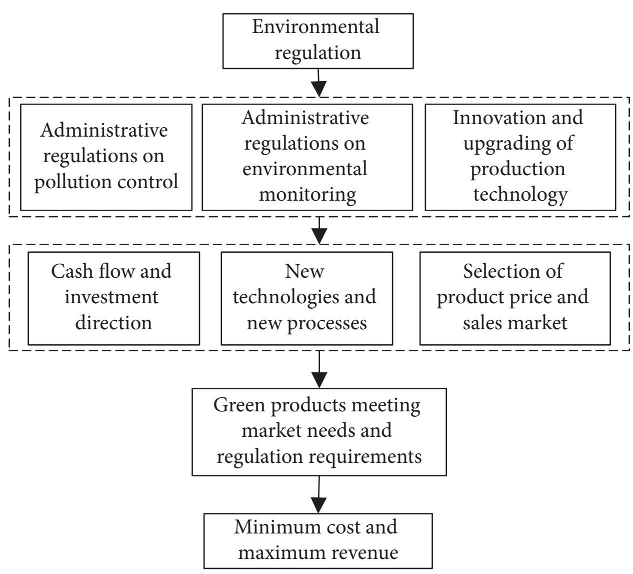

Figure 2: Action paths of environmental regulation on production enterprises.

pollution emissions of X are denoted by x and v, respectively. The expected output of Y is denoted by y. No pollutants are generated by Y. Let k and o be the prices of y and x, respectively. Both X and Y input capital and labor, denoted by L and E, respectively. The benefit and factor endowment of L are denoted by s and l_0, respectively; the benefit and factor endowment of E are denoted by q and e_0, respectively.

The production output of X includes the expected output (product) x and pollutant v. When the environmental regulation on the pollution in the production process is relaxed, the $x - v$ ratio remains constant. Then, the production function of X can be expressed as

$$\begin{aligned} G\left(l_x, e_x\right) &= l_x^{\xi} l_x^{1-\xi}, \\ v = x &= G\left(l_x, e_x\right). \end{aligned} \tag{1}$$

The production function of product y of Y can be expressed as

$$G\left(l_y, e_y\right) = l_y^{\alpha} l_y^{1-\alpha}. \tag{2}$$

Under different intensities of environmental regulation, an enterprise would add different degrees of energy conservation and emission reduction (ECER) activities to the production process. Let ω be the proportion of ECER input of X in production process; $\psi(\omega)$ be the actual effect of ECER activities. The two parameters satisfy $\partial\psi/\partial\omega < 0$, $\psi(\omega) = 1$, and $\psi(1) = 0$. Then, the production functions of x and $v$can be respectively expressed as

$$\begin{aligned} a\left(l_x, e_x\right) &= G\left[(1-\omega)l_x, (1-\omega)e_x\right] \\ &= (1-\omega)G\left(l_x, e_x\right) = (1-\omega)l_x^{\xi} l_x^{1-\xi}, \\ v &= \psi(\omega)G\left(l_x, e_x\right). \end{aligned} \tag{3}$$

To simplify the mathematical calculation, the above formulas can be simplified as

$$\psi(\omega) = (1-\omega)^{(1/\beta)}, \quad (4)$$

where x belongs to the range of (0, 1). The production function of pollutant output $v$can be expressed as

$$v = \psi(\omega)G(l_\beta, e_\beta) = (1-\omega)^{(1/\beta)}G(l_\beta, e_\beta) = (1-\omega)^{(1/\beta)}l_\beta^\xi l_\beta^{1-\xi}. \quad (5)$$

Furthermore, the output of the expected product x can be obtained as

$$x = v^\beta G^{1-\beta} = v^\beta\left(l_\beta^\xi l_\beta^{1-\xi}\right)^{1-\beta}. \quad (6)$$

3. ECER Cost under Environmental Regulation

The ECER cost should be minimized to maintain a high output profit. For this purpose, an objective function that minimizes the ECER cost was established. The cost $d^y(q,s)$ per unit output of Y can be expressed as

$$d^y(q,s) = \min_{l_y,k_y}\{sl_y + qk_y\colon F(l_y, e_y) = l_y^\alpha l_y^{1-\alpha} = 1. \quad (7)$$

Based on the first-order condition, $d^y(q,s)$ can be transformed as

$$\begin{aligned} d^y(q,s) &= l_y(q,s)\times s + e_y(q,s)\times e,\\ &= \frac{(1-\alpha)^{\alpha-1}}{\alpha^\alpha}s^\alpha q^{1-\alpha} = Ns^\alpha q^{1-\alpha}, \end{aligned} \quad (8)$$

where $N=(1-\alpha)^{\alpha-1}/\alpha^\alpha s^\alpha q^{1-\alpha}$ is greater than zero. The constant returns to scale are satisfied under the effect of environmental regulations of the same intensity. Thus, the total production cost can be regarded as the product of the total output of y and the unit cost. Then, we have

$$D^y(q,s) = d^y(q,s)\times y. \quad (9)$$

For X, the emission of pollutant output $v$will not consider any economic cost if it does not adopt relatively few ECER measures to cope with environmental regulation. To maximize the output profit and minimize the cost per unit output, the enterprise will reduce the intensity of ECER activities to the lowest possible level, and even to zero. Then, the minimization of the cost per unit output of X can be expressed as

$$d^G(q,s) = \min_{l_x,k_x}\{sl_x + qe_x\colon F(l_x, e_{xx}) = l_x^\xi l_x^{1-\xi} = 1\}. \quad (10)$$

Similarly, the cost per unit output can be expressed as

$$\begin{aligned} d^G(q,s) &= l_x(q,s)\times s + e_x(q,s)\times e,\\ &= \frac{(1-\xi)^{\xi-1}}{\xi^\xi}s^\xi q^{1-\xi} = Ms^\xi q^{1-\xi}, \end{aligned} \quad (11)$$

where M=$(1-\xi)^{\xi-1}/\xi^\xi s^\xi q^{1-\xi}$ is greater than zero. Of course, the government's environmental regulations have strict requirements on the actual industrial production and limit the pollutants emitted by the production process from multiple angles. The main instrument is collecting the pollution charge. During the production activities, X will face a cost arising from ECER activities. When pollution charge is the only regulation measure, the charge per unit of pollutant emissions is denoted by ρ. Then, the minimization of the cost per unit output of X can be expressed as

$$d^x(q,s,\rho) = \min_{c,G}\{\rho v + d^G(q,s)\colon v^\beta G^{1-\beta} = 1\}. \quad (12)$$

Based on the first-order condition, we have

$$\frac{v}{G} = \frac{1-\beta}{\beta} = \frac{d^G}{\rho}. \quad (13)$$

To ensure that the output products can enter and exit freely during market transactions, then the following equation exists under the condition of zero profit:

$$ox = d^G G + \rho v. \quad (14)$$

Let φ be the pollution density. Combining formulas (13) and (14), the pollutant emissions per unit output of X can be calculated by

$$\phi = \frac{v}{x} = \frac{\beta o}{\rho} \le 1. \quad (15)$$

The above analysis suggests that the higher the price o of product x, X can obtain more profits by emitting more pollutants. When the environmental regulation is relaxed, the enterprise will not autonomously conduct ECER activities, but pursue higher profits by emitting more pollutants through reducing activity intensity and increasing pollution density.

4. Economic Benefit under Environmental Regulation

Facing intense environmental regulation, Y does not produce pollutants. The profit of Y can be calculated by

$$\pi^y = F(l_y, e_y) - sl_y - qe_y. \quad (16)$$

Considering the ECER cost, the profit of X can be calculated by

$$\begin{aligned} \pi^x &= ox(l_x, e_x) - sl_x - qe_x - \rho v,\\ &= (o-\rho\phi)x(l_x, e_x) - sl_x - qe_x,\\ &= o(1-\beta)x(l_x, e_x) - sl_x - qe_x,\\ &= o(1-\beta)(1-\omega)G(l_x, e_x) - sl_x - qe_x. \end{aligned} \quad (17)$$

Suppose $oG = o(1-x)\ (1-\omega)$. The following equilibrium conditions need to be satisfied to maximize the output profit. Firstly, the market can be entered and exited freely, when the profit of any enterprise is zero:

$$\begin{aligned} d^G(q,s) &= o^G,\\ d^y(q,s) &= 1. \end{aligned} \quad (18)$$

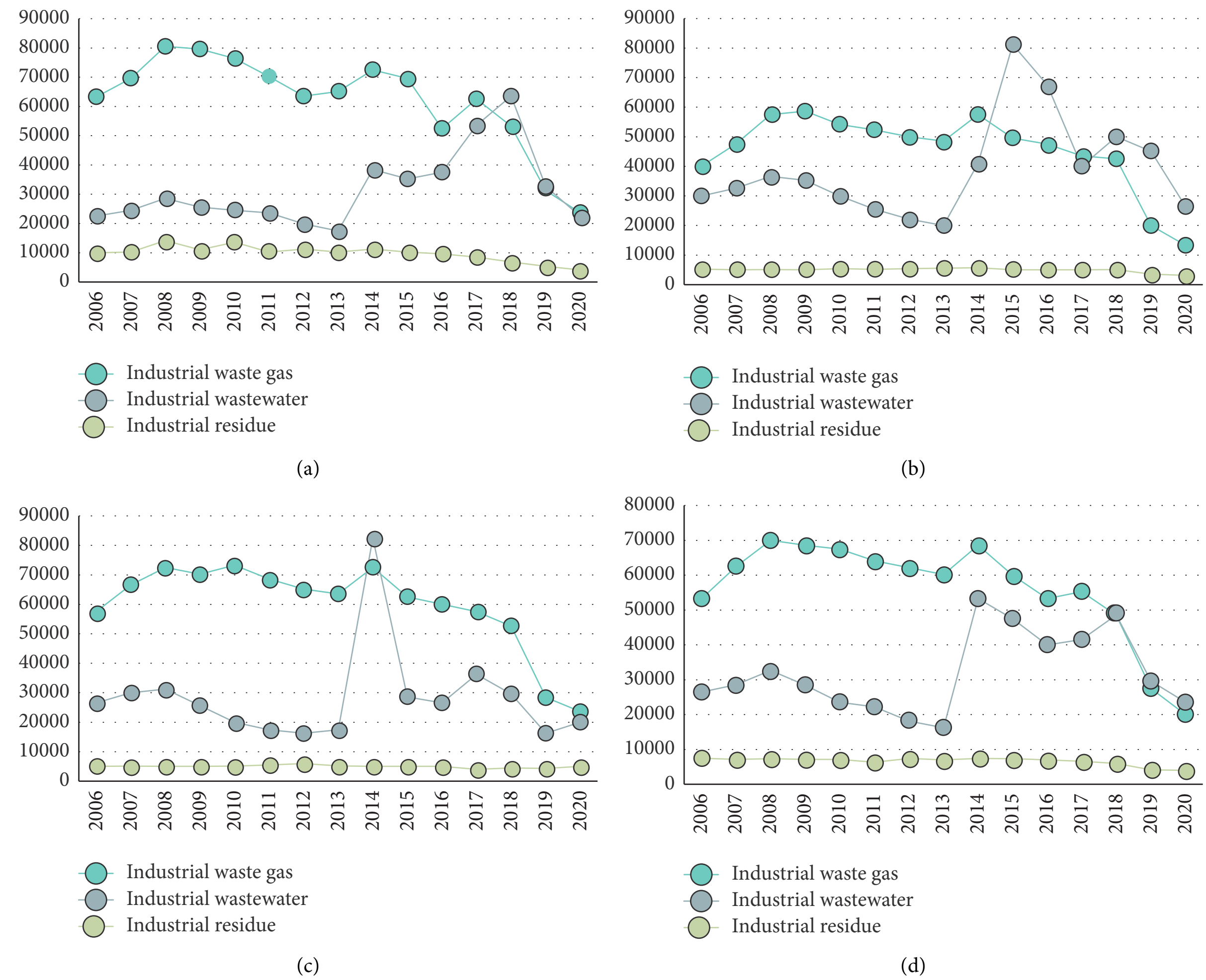

Figure 3: Trend of regional economic outputs. (a) region A, (b) region B, (c) region C, and (d) entire study area.

Thus,

$$\begin{aligned} s\left(o^G\right) &= M^{((\alpha-1)/(\xi-\alpha))} M^{((1-\xi)/(\xi-\alpha))} \left(o^G\right)^{((1-\alpha)/(\xi-\alpha))} \\ &= RU\left(o^G\right)^{((1-\alpha)/(\xi-\alpha))}, \\ q\left(o^G\right) &= M^{(-\alpha/(\alpha-\xi))} N^{(\xi/(\alpha-\xi))} \left(o^G\right)^{(\alpha/(\alpha-\xi))} \\ &= W\left(o^G\right)^{(\alpha/(\alpha-\xi))}, \end{aligned} \tag{19}$$

where $RU = M^{\alpha-1/\xi-\alpha} N^{1-\xi/\xi-\alpha} > 0$; $W = M^{-\alpha/\alpha-\xi} N^{\xi/\alpha-\xi} > 0$.

Secondly, the various production factors should be fully utilized, i.e., the supply of these factors should be balanced with the demand.

According to Shephard's lemma, the demand for a production factor can be obtained by solving the partial derivative of the factor price in the cost function. The production factors required to output each unit of products can be expressed as

$$\begin{aligned} l_y(q,s) &= \frac{\partial d^y(q,s)}{\partial s} = N\alpha s^{\alpha-1} q^{1-\alpha}, \\ e_y(q,s) &= \frac{\partial d^y(q,s)}{\partial q} = N(1-\alpha) s^{\alpha} q^{-\alpha}, \\ l_G(q,s) &= \frac{\partial d^G(q,s)}{\partial s} = M\xi s^{\xi-1} q^{1-\xi}, \\ e_y(q,s) &= \frac{\partial d^G(q,s)}{\partial q} = M(1-\xi) s^{\xi} q^{-\xi}. \end{aligned} \tag{20}$$

During industrial production, the total demand for production factors equals the product between the production factors required for each unit of product and the yield of the products. The full utilization of a single production factor can be expressed as

$$\begin{aligned} l_y(q,s)y + l_G(q,s)G &= \bar{l}, \\ k_y(q,s)y + k_G(q,s)G &= \bar{k}. \end{aligned} \tag{21}$$

Table 1: Spatial autocorrelations in the research period.

		MI/DF	Value	Prob
Phase I	Moran's I (error)	0.2613	2.1547	0.0263
	LM (lag)	2	0.4163	0.1485
	R-LM (lag)	2	0.0481	0.7963
	LM-(error)	2	3.1526	0.0472
	R-LM-(error)	2	1.4194	0.0269
Phase II	Moran's I (error)	0.2958	2.0512	0.0369
	LM (lag)	2	0.9154	0.0375
	R-LM (lag)	2	0.3481	0.5139
	LM-(error)	2	3.6485	0.0147
	R-LM-(error)	2	1.4852	0.0293
Phase III	Moran's I (error)	0.1384	1.4285	0.1629
	LM (lag)	2	0.5137	0.1748
	R-LM (lag)	2	0.1392	0.5125
	LM-(error)	2	3.6885	0.0341
	R-LM-(error)	2	2.4189	0.0685

Note: MI/DF, Value, Prob, LM, and R-LM are short for Moran's I/degree of freedom, value, probability, Lagrange multiplier, and robust Lagrange multiplier, respectively.

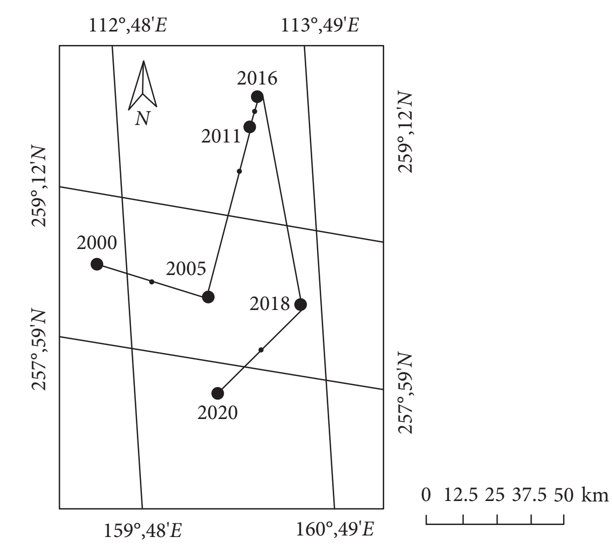

Figure 4: Migration trajectory of the center of gravity of environmental regulation intensity in the study area during the research period.

Through the above analysis, the following equation can be derived from the above formulas:

$$y\left(o^G,\bar{l},\bar{k}\right)=\frac{\xi W\left(o^G\right)^{(\alpha/(\alpha-\xi))}\bar{k}-(1-\xi)RU\left(o^G\right)^{((1-\alpha)/(\xi-\alpha))}\bar{l}}{\xi-\alpha},$$
$$x\left(o^G,\bar{l},\bar{k}\right)=(1-\omega)G\left(o^G,\bar{l},\bar{k}\right)=\frac{(1-\alpha)RU\left(o^G\right)^{((1-\alpha)/\xi-\alpha)}\bar{l}-\alpha W\left(o^G\right)^{(\xi/(\alpha-\xi))}\bar{k}}{o(1-\beta)(\xi-\alpha)}. \quad (22)$$

This paper mainly discusses the influence of the intensity of environmental regulation on regional economic development; that is, how the equilibrium output of regional enterprises changes with the intensity of environmental regulation. Taking the core measure of pollution charge as an example, the partial derivative of this core measure can be obtained as

$$\begin{aligned} \frac{\partial y}{\partial \rho} &= \frac{\partial y}{\partial o^G}\cdot\frac{\partial o^G}{\partial \rho} = \frac{\xi\alpha W\left(o^G\right)^{(\xi/(\xi-\alpha))}\overline{k} - (1-\xi)(1-\alpha)RU\left(o^G\right)^{(1-\alpha/\xi-\alpha)}\overline{l}}{(\xi-\alpha)^2}\cdot\frac{\partial o^G}{\partial \rho} > 0, \\ \frac{\partial x}{\partial \rho} &= \frac{\partial x}{\partial o^G}\cdot\frac{\partial o^G}{\partial \rho} = \frac{(1-\alpha)^2 RU\left(o^G\right)^{((1-\xi)/(\alpha-\xi))}\overline{l} - \alpha^2 W\left(o^G\right)^{(\xi/(\alpha-\xi))}\overline{l}}{(\xi-\alpha)^2}\cdot\frac{\partial o^G}{\partial \rho} < 0. \end{aligned} \tag{23}$$

The above analysis indicates that, if the intensity of environmental regulation decreases, the output of product x that generates additional pollutants will increase, and the output of product y that does not generate additional pollutants will decrease. The two changed in opposite directions. In this case, the total emissions of environmental pollutants from industrial production will increase. If the intensity of environmental regulation increases, the output of product x will decrease, while the output of product y will increase. In this case, the total emissions will decline. The intensity of environmental regulation can affect both product yield and the emissions of additional pollutants.

5. Experiments and Results Analysis

Figures 3(a)–3(d)3(b)3(c) present the trend of economic output for Region A, Region B, Region C, and the entire study area, respectively. Overall, the emissions of industrial waste gas declined with fluctuations in 2006–2020, particularly in the most recent period of 2015–2020. It can be seen that the regional environmental regulations effectively constrain industrial production in the study area. The emissions of industrial residue changed stably, with no obvious variation in the research period. The emissions of industrial wastewater exhibited a complex trend: the emissions were originally stable, then soared, and finally dropped year by year. The trends in Regions A, B, and C were similar to the trends in the entire study area.

To verify the action mechanism of environmental regulation on regional economies, this paper carries out spatial econometric measurement and ordinary least squares (OLS) estimation of the spatial correlation between regional economies under different intensities of environmental regulation. Table 1 lists the spatial autocorrelation in the research period. According to the spatial autocorrelations in phases I–III at different intensities of environmental regulation, the ecological efficiencies of the regional economy in the study area demonstrated heterogeneous spatial correlations.

Figure 4 shows the migration trajectory of the center of gravity of environmental regulation intensity in the region during the research period. From phase I to phase III, the center of gravity of environmental regulation intensity changed between 159°–160°E and 257°–259°N, i.e., the overlap between the heavy industry area and the economic development area. In general, the center of gravity first moved to the east and then moved to the west. Specifically, from 2000 to 2005, the center of gravity appeared in the most southeast direction, mainly in the center of a region. In that region, industrial production emitted lots of industrial waste gas, industrial wastewater, and industrial waste residue, and the environmental regulation was intense. From 2005 to 2016, the center of gravity migrated to the northeast. From 2016 to 2018, the center started to shift towards the southeast. From 2018 to 2020, the center moved to the southwest. The main reason for the migration of the center of gravity is that regional enterprises are motivated by the numerous environmental regulations released by the government to carry out ECER, resulting in a continuous decline in the emissions of industrial waste gas, industrial wastewater, and industrial waste residue in each region. The heavy industry area, which originally emitted lots of industrial waste gas, industrial wastewater, and industrial waste residue, saw an effective improvement in environmental pollution. The center of gravity for environmental regulation intensity quickly moved to the regions with slow improvement in environmental pollution. In each region, the emissions of industrial waste gas, industrial wastewater, and industrial waste residue tended to be stable. In the late phase, the migration speed of the center of gravity would gradually slow down.

6. Conclusions

Drawing on the literature, this study mathematically analyzes the action mechanism of different intensities of environmental regulation on the regional economy, displays the action paths of environmental regulation on the regional economy, and provides the basic assumptions for the action mechanism. In addition, the ECER cost and economic benefit were analyzed under the effect of environmental regulation. Through experiments, the authors conducted spatial econometric measurement and OLS estimation of the spatial correlation between regional economies under different intensities of environmental regulation and performed the spatial autocorrelation measurement in the research period, aiming to verify the action mechanism of environmental regulation on regional economies. Finally, the authors provided the migration trajectory of the center of gravity of environmental regulation intensity in the region during the research period and analyzed the reasons for the migration. It is concluded that the ecological efficiencies of the regional economy in the study area demonstrated heterogeneous spatial correlations.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] C. Zeng and J. Liang, "An empirical study on the agglomeration effect of sports industry on Chinese economy," in *Proceedings of the 2021 International Conference on Health Big Data and Smart Sports (HBDSS)*, pp. 202–205, Guilin, China, 2021.

[2] X. Li, Q. Liu, W. Li et al., "A breakthrough in the artificial cultivation of Chinese cordyceps on a large-scale and its impact on science, the economy, and industry," *Critical Reviews in Biotechnology*, vol. 39, no. 2, pp. 181–191, 2019.

[3] Y. Li, R. Ding, L. Cui, Z. Lei, and J. Mou, "The impact of sharing economy practices on sustainability performance in the Chinese construction industry," *Resources, Conservation and Recycling*, vol. 150, Article ID 104409, 2019.

[4] E. Gerden, "Chinese nonwovens industry aims for massive export growth this year: stagnant economy, lower yuan value have led producers to look outside of China for growth," *Nonwovens Industry*, vol. 50, no. 4, 2019.

[5] X. Sun, Z. Chen, T. Shi, G. Yang, and X. Yang, "Influence of digital economy on industrial wastewater discharge: evidence from 281 Chinese prefecture-level cities," *Journal of Water and Climate Change*, vol. 13, no. 2, pp. 593–606, 2022.

[6] S. Suratno and B. P. Ichtiarto, "Reduce carbon emissions of logistic transportation using eight steps approach in Indonesian automotive industry," *Journal Européen des Systèmes Automatisés*, vol. 54, no. 6, pp. 819–826, 2021.

[7] A. Karmaker, M. Hasan, and S. Ahmed, "A modified approach to industrial pollution projection system for the assessment of sectoral pollution loads in Bangladesh," *Environmental Monitoring and Assessment*, vol. 194, no. 6, pp. 406–413, 2022.

[8] H. W. Wang, X. M. Zhou, X. Y. Liu, X. Y. Fu, and H. S. Zhao, "Production-living-ecology nexus of land-use functions in the mountainous areas: a case study of Chongqing, China," *International Journal of Sustainable Development and Planning*, vol. 16, no. 6, pp. 1071–1080, 2021.

[9] S. Banerjee, A. Banerjee, and D. Palit, "Ecosystem services and impact of industrial pollution on urban health: evidence from Durgapur, West Bengal, India," *Environmental Monitoring and Assessment*, vol. 193, no. 11, pp. 744–818, 2021.

[10] O. Popovicheva, E. Molozhnikova, S. Nasonov et al., "Industrial and wildfire aerosol pollution over world heritage lake Baikal," *Journal of Environmental Sciences*, vol. 107, pp. 49–64, 2021.

[11] U. Shah and B. R. Bakshi, "Toward nature-positive manufacturing by adapting industrial processes to pollution uptake by vegetation," *ACS Sustainable Chemistry & Engineering*, vol. 9, no. 49, pp. 16709–16718, 2021.

[12] V. Marhasova, O. Garafonova, O. Popelo, S. Tulchynska, A. Pohrebniak, and T. Tkachenko, "Environmentalization of production as a direction of ensuring the sustainability of production activities of enterprises and increasing their economic security," *International Journal of Safety and Security Engineering*, vol. 12, no. 2, pp. 159–166, 2022.

[13] X. Li, Y. Xu, and X. Yao, "Effects of industrial agglomeration on haze pollution: a Chinese city-level study," *Energy Policy*, vol. 148, Article ID 111928, 2021.

[14] M. Charles and B. R. Bakshi, "Designing industrial landscapes for mitigating air pollution with spatially-explicit techno-ecological synergy," *AIChE Journal*, vol. 67, no. 10, Article ID e17347, 2021.

[15] W. H. Cheng and C. S. Yuan, "Using a micro sampler on a drone to extract organic vapors—a case study of monitoring industrial pollution," *Aerosol and Air Quality Research*, vol. 21, no. 2, Article ID 200359, 2021.

[16] H. Wang and W. Wei, "Coordinating technological progress and environmental regulation in CO2 mitigation: the optimal levels for OECD countries & emerging economies," *Energy Economics*, vol. 87, Article ID 104510, 2020.

[17] T. Kiso, "Environmental policy and induced technological change: evidence from automobile fuel economy regulations," *Environmental and Resource Economics*, vol. 74, no. 2, pp. 785–810, 2019.

[18] W. S. Meng and F. Q. Shao, "Influence of environmental regulation and industrial structure on the growth efficiency of green economy in the yellow river Basin," *Water Resources Protection*, vol. 36, no. 6, pp. 24–30, 2020.

[19] X. Bi and P. Liu, "Research on the influence of environmental regulation on the efficiency of green economy in China," *IOP Conference Series: Earth and Environmental Science*, vol. 252, no. 4, Article ID 42014, 2019.

[20] B. Yuan, S. Ren, and X. Chen, "Can environmental regulation promote the coordinated development of economy and environment in China's manufacturing industry? a panel data analysis of 28 sub-sectors," *Journal of Cleaner Production*, vol. 149, pp. 11–24, 2017.

[21] F. Ye, Y. Quan, Y. He, and X. Lin, "The impact of government preferences and environmental regulations on green development of China's marine economy," *Environmental Impact Assessment Review*, vol. 87, Article ID 106522, 2021.

[22] Z. Wang, B. Zhang, and H. Zeng, "The effect of environmental regulation on external trade: empirical evidences from Chinese economy," *Journal of Cleaner Production*, vol. 114, pp. 55–61, 2016.