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Collaborative Governance and Environmental Regulation Measures for Pollution Reduction and Carbon Reduction in the Yangtze River Basin under the "Double Carbon" Goal

Yang Li [1,2] and Lei Zhang [1,*]

[1] School of Economics and Management, China University of Mining and Technology, Xuzhou 221000, China
[2] School of Business Administration, Xuzhou College of Industrial Technology, Xuzhou 221000, China
* Correspondence: 6020040082@jsnu.edu.cn

Abstract: The Yangtze River Basin occupies an important position in the overall layout of China's economic development. However, due to the increasing water pollution, the environment of the Yangtze River Basin continues to deteriorate, which hinders the long-term development and sustainable development goals of the Yangtze River Economic Belt. Therefore, this study started from the perspective of the reduction of coordinated pollution carbon. Then, through empirical analysis, the impact of environmental regulation measures in the Yangtze River Basinon industrial pollution control was studied. At the same time, the spatial eigenvector mapping (SEVM) method was used to explore the spatial impact of environmental regulation on carbon emissions. The results showed that the increase in the intensity of environmental regulation would lead to the expansion of the hidden economy, which would lead to the effect of environmental regulation weakening. There was an inverted "U" relationship between per capita real gross domestic product (GDP)and environmental pollution indicators. In addition, the expansion of foreign trade in the Yangtze River Economic Belt hada less inhibitory effect on ecological environmental protection than a promotional one. At the same time, command-type environmental regulation had a "green paradox" effect on carbon emissions in the Yangtze River Basin. The carbon emission reduction effect of implicit environmental regulation was different under different levels of incentive-type environmental regulation. The research showed that the multi-agent governance model could be further constructed from the interaction between the environmental regulation system and the administrative management system. It had a good effect on the coordinated treatment of pollution reduction and carbon reduction under the "double carbon" goal.

Keywords: pollution reduction and carbon reduction; hidden economy; environmental regulation; Yangtze River Economic Belt; SEVM; threshold effect

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1. Introduction

"Carbon peak" and "carbon neutrality" are the final effects that the "double carbon" goal needs to achieve. The proposal of the double carbon goal is conducive to the adjustment of China's economy, energy and industrial structure, the realization of transformation and upgrading and the protection of the ecological environment. It is of great significance [1–3]. In order to achieve the "double carbon" goal, the government proposed the concept of coordinated pollution reduction and carbon reduction, which combined pollution control, carbon reduction and environmental protection [4,5]. The Yangtze River Basin is a key area of China's economic development, and the ecological environment pollution in the Yangtze River Basin is also relatively serious [6]. The ecological environment of the Yangtze River Basin could be adjusted and improved by taking measures to reduce pollution and carbon reduction. As such, it could respond to the country's "double carbon" goals and achieve the long-term development and sustainable development goals. In the environmental management of the Yangtze River Basin, the government has invested a lot of money [7,8]. Industrial pollution has an impact on the cost of environmental governance, industrial structure and policy adjustment. In order to reduce the impact of industrial pollution on the environment, the government invested a large amount of capital to carry out environmental governance, resulting in the rise of environmental governance costs. This led the government to continuously adjust policies to reduce the harm of industrial pollution and forced the adjustment of the industrial structure of enterprises. Industrial pollution control accounted for the largest proportion of the total investment in environmental governance (Figure 1). In the environmental governance of the Yangtze River Basin, it mainly focused on the impact of industrial pollution on the environment.

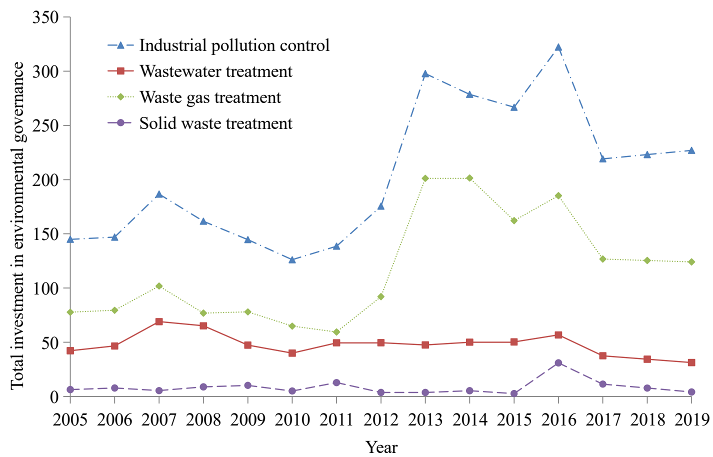


Figure 1. Total investment in environmental governance in the Yangtze River basin from 2005 to 2019 (Note: the data are from the statistical yearbooks of various regions in the Yangtze River basin from 2005 to 2020, and the missing data are supplemented by interpolation).

Carbon emission is the main factor causing environmental pollution in industrial production. There are many factors affecting carbon emission, and the problem is relatively complicated [9–12]. Figure 2 shows the comparison results of the growth rate of carbon emissions in the Yangtze River Basin and the country from 2005 to 2019. It can be seen that the carbon emission behavior of the Yangtze River Basin shows a negative downward trend as a whole. In addition, through the comparison of growth rates, the growth rate of carbon emissions in the Yangtze River Basin is lower than the growth rate of carbon emissions in the country. However, there has been an upward trend in recent years, indicating that the government's environmental control measures have achievements to a certain extent, but the effect is not stable. Therefore, further research is needed on the factors that affect carbon emissions in the Yangtze River Basin.

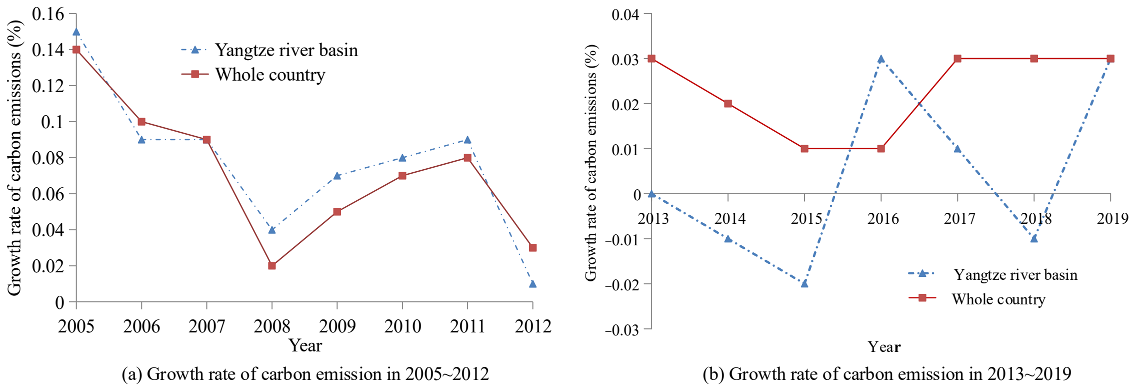


Figure 2. Growth rate of carbon emissions in the Yangtze River basin and the whole country from 2005 to 2019 (Note: the data are from the statistical yearbooks of various regions in the Yangtze River basin from 2005 to 2020, and the missing data are supplemented by interpolation).

Environmental regulation is an intersecting concept that includes regulation and environmental science. At present, there is no unified definition of environmental regulation [13–15]. Regulation generally means that the government restricts individuals and their behavior according to certain rules. With the improvement of researchers' understanding and research, environmental regulation can be understood as the policy measures adopted by the government. The policy measures can intervene in economic activities to protect the ecological environment [16–18]. From the perspective of means, environmental regulation can be divided into command-type environmental regulation, incentive-type environmental regulation and implicit environmental regulation. Command-type environmental regulation includes measures such as order, control and enforcement, and has certain mandatory and hard constraints. Incentive-type environmental regulations are implemented by using market means according to market mechanisms and market signals, mainly including measures such as pollution discharge taxes, discharge permits, pollution permits and environmental subsidies. Implicit environmental regulations include measures such as environmental management certification and voluntary agreements, which have independent sex and soft constraints [19–21]. Studies have shown that environmental regulation has an unstable impact on economic growth in the short term. In addition, environmental regulation has a certain role in promoting the economy in the long term [22]. The research results on the effectiveness of environmental regulation show that the technological innovation and organizational management capabilities of enterprises will increase with the strengthening of environmental regulation, and market resources can be optimally allocated to promote green economic development [23,24]. The goals first of all, is to reduce emissions. It should actively promote the green transformation and upgrading of the industrial structure and adopt advanced energy-saving and emission reduction technologies. As such, it can improve the comprehensive utilization technology of energy and improve the efficiency of resource utilization. The second is to open source, such as promoting the innovation of energy-saving technology, transforming the traditional use of fossil energy, promoting energy transformation and enabling green development. In economically developed areas, there are usually serious environmental pollution problems. In addition, punitive environmental regulations have a positive effect on the ecological and economic recovery of the area.

The hidden economy is one of the main sources of industrial pollution, and environmental regulations have an important impact on it [25,26]. When the government adopts high-intensity environmental regulations, companies will use the hidden economy to avoid the impact of the system in order to maximize profits [27]. The hidden economy is a product derived from the government's policy supervision and economic system. China's hidden economy caters to the government's system and behavior to a certain extent [28,29]. In the process of environmental system implementation, the hidden economy may reduce the effect of environmental regulation [30]. Therefore, the research on pollution in the Yangtze River Basin under environmental regulation needs to consider the hidden economy in the analysis. For this, a research model including the environmental system, hidden economy and industrial environmental pollution is established in this experiment. The relationship among the three is discussed in depth. In the economic field, regression analysis can be used to analyze the impact of different factors on economic development and environment. However, for traditional regression analysis, data with spatial nature cannot be analyzed. The spatial filtering method based on SEVM can separate the spatial correlation of the samples to be analyzed. In the SVEM regression model, this can be used as a separate explanatory variable for data analysis, so as to improve the processing ability of traditional econometric models for data with spatial correlations. In order to further study the impact of environmental regulation on carbon emissions, this experiment uses the modified SEVM spatial filtering method to analyze the carbon emissions and environmental regulation in the Yangtze River Basin in detail. It is hoped that the study will provide policy options for the ecological environment protection of the Yangtze River Basin direction and management methods.

2. Coordinated Pollution Reduction and Carbon Reduction in the Yangtze River Basin under Environmental Regulation

2.1. Research on the Impact of Environmental Regulation on Industrial Environmental Pollution under the Background of Hidden Economy

The hidden economy has an important impact on environmental pollution. In order to study the impact of environmental regulation on industrial environmental pollution under the background of the hidden economy, it is necessary to include the hidden economy in the analysis. In this experiment, a research model including the environmental system, hidden economy and industrial environmental pollution is established. In addition, the relationship between the three is deeply discussed and studied. Assuming that the total output y of the macroeconomic system is the output of the non-recessive economy y^m plus the output of the implicit economy y^u, the total economic output can be expressed as $y = y^m + y^u$. It is assumed that there is no difference in the products produced by enterprises that need sewage treatment in the market. Thus, the production cost of enterprises c can be expressed as $c = c(y) = (y^m + y^u)$, which is satisfying $dc(y)/dy > 0$ and $d^2c(y)/dy^2 > 0$.This function is a monotonically increasing concave function. The formula refers to the literature [31].

Assuming that enterprises need to emit unit pollution when obtaining unit output, pollution can be discharged in both the hidden economy and the non-recessive economy. In addition, the internal production capacity in the hidden economy and the non-recessive economy can be freely transferred at no cost. The environmental regulation strength value of is r set in the range [0, 1]. When $r = 0$, it is stated that the government would not take environmental regulation measures to regulate the pollution discharge of enterprises. When $r = 1$, it is stated that the government would take environmental regulation measures to completely regulate the pollution discharge of enterprises. Assuming that under environmental regulation, the non-implicit economic sectors need to pay a reduction cost of $a(r)$ when obtaining unit output, when the value of r is higher, enterprises need to take more efforts to reduce emissions; that is, $da/dr > 0$. At the same time, enterprises in the non-recessive economy also need to pay a certain percentage of taxes, and the payment ratio is expressed as τ, and its range is between [0, 1].

In order to maximize profits, enterprises will use the hidden economy to avoid the impact of the environmental system. Assuming that the government finds that the probability that the enterprise uses the hidden economy to transfer production behavior is p , then it $p(y^u)$ is also an increasing concave function, and it satisfies both $dp/d(y^u) > 0$ and $d^2 p/d(y^u)^2 > 0$. When the government finds that the production behavior of the enterprise has shifted, then the enterprise will be punished by output ky^u, in which k means a constant. According to the content of the above analysis, the enterprise profit function in formula (1) can be obtained.

$$\Pi = y^m + y^u - \tau y^m - a(r)y^m - kp(y^u)y^u - c(y) \quad (1)$$

We need to solve the first-order partial derivative r in formula (1) and set its value to 0. Then y^m derivates the intensity value of environmental regulations, and the sorted results are shown in formula (2).

$$\frac{d(y^m)}{dr} = -\frac{da/dr}{d^2c/dy^2} < 0 \quad (2)$$

We need to solve the first-order partial derivative r in formula (1), and set its value to 0, and then y^u derivates the intensity value of environmental regulations. See formula (3) for the sorted results.

$$\frac{d(y^u)}{dr} = \frac{da/dr}{2kdp/d(y^u) + ky^u d^2 p/d(y^u)^2} > 0 \quad (3)$$

From formulas (2) and (3), it can be seen that the r value is opposite the change direction of the total economic output. In addition, the r value is consistent with the change direction of the output of the hidden economy, indicating that the total economic output is different from the output of the non-recessive economy. The direction of change is opposite. Based on the above theoretical research, we put forward Hypothesis 1: In a certain period of existence of the hidden economy, the strengthening of environmental rules will increase the output of the hidden economy, while reducing the output of the non-recessive economy and the total economic output. In order to deeply analyze the relationship between environmental regulation and environmental pollution, it is assumed that both the recessive economy and the non-recessive economy of the enterprise have pollution discharge behaviors. If we assume that the total amount of pollution discharged by the enterprise is TP, then the formula (4) can be obtained.

$$TP = (1-r) * y^m + y^u \quad (4)$$

Deriving the intensity r of environmental regulations in formula (4), after sorting out, formula (5) can be obtained.

$$\partial TP / \partial r = -y^m + (1-r) * dy^m / dr + d(y^u)/dr \quad (5)$$

In formula (5), the sign of the first term y^m is negative. Because of $(1-r) > 0$ and $dy^m/dr < 0$, it can be seen that the sign of the second term $(1-r) * dy^m/dr$ is negative. From the analysis results in the above Hypothesis 1, it can be seen that $d(y^u)/dr$,the sign of the third term, is positive. As the r value increases, the first and second terms indicate that the amount of pollution caused by non-recessive economic emissions decreases. It shows that environmental pollution is directly affected by environmental regulation. The third item indicates that as the r value increases, the government will reduce the economic activities related to the non-recessive economy, which will lead to the expansion of the hidden economy and eventually increase the pollution of the environment. It shows the indirect effect of environmental regulation on environmental pollution. From the above research and analysis, the direct and indirect effects of environmental regulation on environmental pollution determine the sign of the total effect

$\partial TP/\partial r$. Based on the above theoretical research, we put forward Hypothesis 2: the intensity of environmental regulation has a direct effect on the pollution discharge of the non-recessive economy, and it is negatively correlated. The intensity of environmental regulation has an indirect effect on the pollution discharge of the hidden economy, and they are positively correlated, so the total effect $\partial TP/\partial r$ remains to be determined.

According to the above theoretical elaboration and the existing research basis, 11 provinces and cities in the Yangtze River Basin are used to analyze the relationship between environmental regulation and environmental pollution against the background of the hidden economy. The econometric model set is shown in formula (6).

$$ep_{it} = \phi_0 + \phi_1 er_{it} + \phi_2 he_{it} + \phi_3 er_{it} * he_{it} + \varphi c_{it} + \mu_{it} + \varepsilon_{it} \quad (6)$$

In formula (6), *I* is a province and city, *t* is time, ep_{it} is the comprehensive environmental pollution index of province and city *I* in year *t*. er_{it} is the environmental regulation strength of province and city *i* in year *t*. he_{it} is the recessive economy of province and city *i* in year *t*. $er_{it} * he_{it}$ represents the indirect effect between environmental pollution and regulation. c_{it} denotes the control variables such as per capita GDP and its square, industrial structure and degree of opening to the outside world that affect environmental pollution in province *I* in year *t*. μ_{it} represents the individual fixed effect. ε_{it} represents the random disturbance term. Due to the nature of continuous accumulation and dynamic changes of environmental pollution, the current pollution will be affected by the previous pollution. Thus, it is introduced on the basis of formula (6) ep_{it-1} to represent the first-order lag item of environmental pollution, see formula (7).

$$ep_{it} = \phi_0 + ep_{it-1} + \phi_1 er_{it} + \phi_2 he_{it} + \phi_3 er_{it} * he_{it} + \varphi c_{it} + \mu_{it} + \varepsilon_{it} \quad (7)$$

2.2. Research on the Nonlinear Impact of Environmental Regulation on Carbon Emissions in the Yangtze River Economic Belt

Carbon emissions in the Yangtze River Basin have certain spatial and regional characteristics. In order to improve the accuracy of research on the impact of environmental regulations on carbon emissions in the Yangtze River Basin, it is necessary to analyze the characteristics of time and space [32,33]. For traditional regression analysis, data with spatial properties cannot be analyzed [34,35]. In related studies, the researchers improved and optimized the econometric model. Among them, the SEVM-based spatial filtering method can separate the spatial correlation of the sample to be analyzed and use this as a separate explanatory variable in the regression model for data analysis. Thereby, it can improve the processing ability of the traditional econometric model for data with spatial correlation [36,37]. In the SEVM spatial filtering method, the calculation formula of the matrix is shown in formula (8).

$$\Omega = (I - 11^T/n)W(I - 11^T/n) \quad (8)$$

In formula (8), I represents the identity matrix of order size $n \times n$. W represents the space weight matrix of order size $n \times n$, which means the mutual adjacency relationship of different objects in space. The number 1 represents a vector $n \times 1$ containing 1. Based on the existing analysis and research on the spatial effect relationship between carbon emissions and environmental regulations in the Yangtze River Basin, this study chooses the modified SEVM filtering method for data processing. The main steps of this method are four. The first step is to calculate the eigenvector of the spatial weight matrix. Then it adds the calculated eigenvector *E* into the regression model for least squares (Ordinary Least Square, OLS) regression analysis. In addition, it screens out information criteria

(Akaike information criterion, AIC), with a significance level of 10%. It also satisfies the feature vector that the model residual does not have spatial correlation. Next, the vectors generated by the linear combination of the eigenvectors that meet the requirements are used as the required proxy variables. Finally, the carbon emission data of different years are processed, and finally the filter factor SF is obtained.

In the experiment, the relevant influencing factors and the carbon emissions of the Yangtze River Basin were analyzed by benchmark regression. On this basis, a panel threshold model pair was established, with command, incentive and implicit environmental regulations as threshold variables. Energy structure (ESC), energy consumption intensity (EI), technical level (IN), foreign investment (FDI), population size (POP) and economic development level (PGDP) are control variables. The threshold effects of different environmental regulations on carbon emissions in the Yangtze River Basin are investigated, respectively. Formula (9) is the construction method of the model.

$$\begin{aligned}\ln CO_{2it} &= \mu_i + \beta_1 \mathrm{er}_{it} \mathrm{I}(\mathrm{er}_{it} \le \lambda_1) + \beta_2 \mathrm{er}_{it} \mathrm{I}(\lambda_1 < \mathrm{er}_{it} \le \lambda_2) \\ &+ \beta_3 \mathrm{er}_{it} \mathrm{I}(\mathrm{er}_{it} > \lambda_2) + \theta \mathrm{Xcon}_{it} + \delta \mathrm{SF} + \varepsilon_{it}\end{aligned} \quad (9)$$

In formula (9), $I(*)$ represents the indicative function, Xcon is the control variable, SF is the filter factor, λ_1 and λ_2 is the threshold value to be calculated, β is the coefficient of the explanatory variable, θ is the coefficient of the control variable, δ is the coefficient of the filter factor and ε_{it} represents the random disturbance item. Before the application of the panel threshold model, a threshold test is required. Then, panel threshold regression analysis is performed according to the results of the threshold test, so it can obtain the impact of imperative, incentive and implicit environmental regulations on carbon emissions in the Yangtze River Basin. The selected control variables are described in Table 1.

Table 1. Description of control variables.

Variable	Representation Symbol	Measures	Company
Energy-resource structure	ESC	Total energy consumption of coal × 100	%
Energy consumption intensity	EI	Total energy consumption/real GDP	10000 tons/million yuan
Technical level	IN	Patent applications/100	Hundred
Foreign investment	FDI	Foreign Investment × Annual Average Exchange Rate/Nominal GDP × 100	%
Population size	POP	Total population of each region at the end of the year	Ten million people
Economic development level	PGDP	Real GDP per capital	Thousand yuan

3. Research Conclusions on Environmental Regulations for Pollution Reduction and Carbon Reduction in the Yangtze River

3.1. Case Analysis of Environmental Regulation and Industrial Environmental Pollution under the Hidden Economy

In the example analysis of the relationship between industrial environmental pollution and environmental regulation in the Yangtze River Basin under the recessive economy, environmental pollution is the explained variable. Environmental regulation and the recessive economy are the core explanatory variables. Per capita GDP (Y) and its square (Y2), urbanization level (U), degree of opening to the outside world (O), industrial structure (I) and R&D intensity I are used as control variables. The data of the hidden economy comes from the results of the previous calculation experiments. Regression analysis is carried out on the relevant data combined with the econometric model in formula (6). At the same time, after the Hausman test, the fixed effect model is selected based on the test results. The results are shown in Table 2.

Table 2. Validation results of fixed effects.

Variable	(1) $Ln(SO_2)$	(2) Ln(S)	(3) Ln(W)	(4) $Ln(SO_2)$	(5) Ln(S)	(6) Ln(W)
Er	−3.294***	−63.305***	−3164.571***	−1.251**	−687.923*	−76.825**
	(−8.67)	(−5.28)	(−7.26)	(−3.86)	(−2.65)	(−2.56)
he	0.002***	0.014**	1.654***	0.001	683.651*	0.026
	(11.57)	(2.68)	(10.57)	(1.24)	(2.46)	(1.62)
Erhe	0.348**	8.679***	416.398***	0.039	689.152*	6.765*
	(−8.78)	(5.88)	(8.54)	(1.26)	(2.45)	(2.24)
Y	-	-	-	0.000***	0.000	0.000***
				(−6.29)	(0.68)	(−4.53)
Y^2	-	-	-	0.000***	0.000	0.000**
				(3.69)	(−0.32)	(2.98)
o	-	-	-	−0.003	−0.055	−0.749**
				(−0.76)	(−0.08)	(−2.47)
I	-	-	-	0.029***	0.821	1.136
				(4.26)	(0.26)	(1.73)
u	-	-	-	0.029**	−2.549	1.539
				(2.65)	(-.63)	(1.46)
R	-	-	-	0.031**	−2.536	1.236***
				(2.87)	(−0.52)	(1.27)
Constant	−0.002**	0.139**	2.587*	0.001	−6.279	3.268***
	(−3.16)	(3.65)	(2.36)	(0.43)	(−2.27)	(5.26)
Sample size	174	174	174	174	174	174
R^2	0.429	0.583	0.593	0.679	0.732	0.597
f	32.88	60.14	60.31	30.98	45.19	17.53

Note: ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

From the estimated results (1)~(3) in Table 2, the environmental factors have a significant inhibitory effect on the amount of SO_2 discharged (SO_2), the amount of waste water discharged (W) and the amount of industrial smoke (powder) dust discharged (S) when other factors are ignored. At the same time, the recessive economy has a positive impact on relevant pollution indicators. This shows that the government has a restraining effect on the environmental pollution of the non-recessive economy through environmental regulation. However, due to the existence of the recessive economy, the degree of environmental pollution is further aggravated. The result of the case analysis is consistent with the theoretical analysis in the previous article. In the regression analysis results of implicit economy and environmental regulation, environmental regulation has a positive indirect effect on environmental pollution. This shows that the expansion of the scale of the recessive economy will lead to the opposite effect of the policy; that is, the increase in the intensity of environmental regulation will lead to an increase in the cost of pollution discharge of enterprises. This promotes the transfer of enterprises' pollution behavior to the hidden economy and expands the degree of pollution. From the estimation results (4)–(6) in Table 2, the estimation results remain robust after the introduction of control variables such as GDP per capita. The estimated coefficient sign of per capita GDP for SO_2 and wastewater emissions is negative. The sign of the estimated coefficient of the square of GDP per capita is positive. This shows that the increase of per capita income has led to the change of environmental pollution in the Yangtze River basin, which is aggravated first and then weakened. The increase in the degree of trade openness in the Yangtze River Basin has caused the promotion effect of environmental protection to be greater than the inhibition effect of environmental protection. Industrial structure can promote the improvement of related pollution indicators such as SO_2 emissions, which is not conducive to ecological protection. R&D intensity has a negative relationship with pollutant indicators, which is good for environmental protection. The level of urbanization will increase the emission of SO_2 and wastewater, which will lead to environmental damage to a certain extent. However, it will also inhibit the emission of industrial smoke (powder) dust, indicating that the improvement of environmental supervision has been achieved in the process of urbanization.

According to the econometric model in formula (7), it can be seen that the explanatory variable contains the first-order lag item of the explained variable, environmental pollution. Therefore, this study chooses the system Generalized Moment Method (GMM) for empirical analysis. The results are shown in Table 3. The results of (1)–(6) in Table 3 show that there is no second-order autocorrelation among the variables, and the serial correlation test has passed. The results of the Sargan test all show $p > 0.1$, indicating that the variable selection of the above model is effective. In the results in Table 3, ep_{it-1} has a positive and significant impact on environmental pollution, indicating that environmental pollution is dynamic. In addition, the previous environmental pollution has an aggravating effect on the current environmental pollution. Environmental pollution is negatively affected by environmental regulation, and positively affected by the interaction term. It is consistent with the results of the fixed effect, confirming that environmental regulation does have an effect on improving ecological pollution. However, the impact of environmental regulation has two sides. Strict regulation can expand the hidden economy, aggravate environmental pollution and reduce the effect of environmental regulation. Consistent with the results of fixed effects, the increase of per capita income has led to the change of environmental pollution in the Yangtze River basin, which is intensified first and then weakened. The amount of SO_2 discharged (SO_2), the amount of wastewater discharged (W) and the amount of industrial smoke (dust) discharged (S) are all negatively affected by the degree of trade openness. It shows that provinces and cities in the Yangtze River basin can be encouraged to open up. The degree of environmental pollution is positively affected by the degree of industrialization and urbanization. Urbanization and industrial development in the Yangtze River Basin have greatly damaged the ecological environment. However, enterprises pay more attention to short-term benefits in production practice. Environmental governance increases the degree of difficulty. At the same time, environmental pollution is negatively affected by technological innovation and technological progress. In addition, the improvement of R&D intensity has a positive impact on the protection of the ecological environment. Our country's emphasis on scientific and technological innovation continues to increase, and the proportion of government investment in research and development has increased significantly. These measures have a certain role in promoting environmental protection.

Table 3. Analysis results of dynamic GMM cases.

Variable	(1) Ln(SO_2)	(2) Ln(S)	(3) Ln(W)	(4) Ln(SO_2)	(5) Ln(S)	(6) Ln(W)
Ept−1	1.063***	0.983***	−0.931***	0.973***	0.977***	0.796**
	(14.45)	(39.08)	(39.52)	(23.00)	(29.48)	(12.74)
Er	−0.466***	−0.230**	−1.933***	−0.384**	−0.245**	−0.207*
	(6.20)	(−2.16)	(−3.08)	(−2.51)	(−2.23)	(−1.83)
he	0.558***	0.155**	0.200***	0.446**	0.109*	0.021
	(8.13)	(2.77)	(1.78)	(2.47)	(1.75)	(1.25)
Erhe	0.454**	0.390***	0.084***	0.412***	1.852*	1.776**
	(6.17)	(2.12)	(3.11)	(4.23)	(1.89)	(1.99)
Y	-	-	-	−5.659	2.172	−1.376
				(−1.02)	(0.99)	(−0.74)
Y^2	-	-	-	2.777	−1.068	−0.554
				(1.04)	(−0.98)	(0.58)
o	-	-	-	0.000	0.000	0.000
				(−0.42)	(−1.41)	(−1.09)
I	-	-	-	0.0152***	0.008***	0.005
				(3.02)	(2.96)	(1.15)
u	-	-	-	0.0589	−0.147**	0.304*
				(0.16)	(2.32)	(1.81)
R	-	-	-	−0.139	−0.050	−0.227**
				(−1.26)	(−1.17)	(−2.86)
Constant	−0.540**	0.566**	1.584*	−6.207***	−1.450*	0.455***
	(−2.63)	(2.08)	(1.86)	(1.82)	(−1.86)	(2.83)
Sample size	174	174	174	174	174	174
Wald test	43.763	675.566	3609.335	2944.704	1646.747	1754.956
AR(1)	0.019	0.040	0.018	0.019	0.041	0.149
AR(2)	0.228	0.121	0.145	0.415	0.119	0.341
Sargan test	151.547	115.277	140.208	116.580	112.611	112.180
	(0.16)	(0.53)	(0.11)	(0.49)	(0.61)	(0.68)

Note: ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

The core explanatory variables in this study are the recessive economy and environmental regulation. In the previous study, the recessive economy of the Yangtze River Basin was measured and calculated through the construction of a dynamic equilibrium general model. However, there is no unified standard for the measurement and calculation of environmental regulation. In this study, the intensity value of environmental regulation is calculated as the ratio between the total amount of environmental governance invested in the Yangtze River Basin and the fixed asset investment in 11 provinces and cities. The new expression of environmental regulation intensity is Er′. In order to verify the validity and accuracy of the model established in the method part, the robustness estimation was carried out, and the results are shown in Table 4. Comparing the results in Table 4 with those in Tables 2 and 3, the sign directions of the estimated coefficients of the explanatory variables, the explained variables and the control variables in the table are basically the same. This shows that the result of Er1 estimation is consistent with that of the fixed effect and GMM estimation method. That the estimation result is robust and reliable has been proved.

Table 4. Robustness estimation results.

Variable	(1) Ln(SO_2)	(2) Ln(S)	(3) Ln(W)	(4) Ln(SO_2)	(5) Ln(S)	(6) Ln(W)
Er′	0.000***	−0.230*	−0.794	0.000*	0.000	−0.479***
	(−6.60)	(−1.71)	(−4.24)	(−1.73)	(−0.10)	(−3.07)
he	0.002***	1.355**	0.387	0.002***	0.005	1.161**
	(10.72)	(3.62)	(1.90)	(10.46)	(4.34)	(1.96)
Erhe	0.000***	3.020*	7.907	−4.116***	0.356**	3.743***
	(−7.47)	(1.64)	(4.57)	(−7.37)	(2.25)	(2.78)
Y	-	-	-	−0.000	1.131	−1.782
				(−0.07)	(0.40)	(−0.47)
Y^2	-	-	-	−0.000	1.098	0.305
				(0.98)	(0.79)	(0.15)
o	-	-	-	−0.002	−0.003*	−0.007*
				(−0.98)	(−1.761)	(−1.90)
I	-	-	-	0.004	0.020	0.029***
				(0.60)	(2.73)	(3.28)
u	-	-	-	0.003	−2.380	2.395***
				(0.37)	(−3.12)	(2.40)
R	-	-	-	0.000	−0.595**	−0.181
				(−0.34)	(−2.78)	(−0.60)
Constant	−0.001	3.086***	3.500***	−0.001	−3.766*	6.470*
	(−1.15)	(3.59)	(3.61)	(−0.41)	(1.76)	(1.67)
Sample size	174	174	174	174	174	174
With R^2	0.506	0.556	0.389	0.513	0.741	0.546
f	24.402	16.366	23.863	19.9332	89.6798	52.332

Note: ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

3.2. Threshold Test Results of Environmental Regulations and Carbon Emissions in the Yangtze River Economic Belt

In this study, environmental regulation is subdivided into command-type environmental regulation Er1, incentive-type environmental regulation Er2 and implicit environmental regulation Er3. The impact of different environmental regulations on carbon emissions in the Yangtze River basin is specifically studied. Due to the time-lag nature of the implementation of policies on environmental regulation issued by the government, the effect of the policies has a lagging effect. Therefore, in the process of data analysis, the data of command-type environmental regulation Er1, incentive-type environmental regulation Er2 and implicit environmental regulation Er3 are lagged behind for one period. The selected panel data is the data of the Yangtze River Basin from 2008 to 2021 for analysis.

Table 5 shows the baseline regression results of environmental regulations on carbon emissions in the Yangtze River Basin based on the fixed effect model. The results in the table show that when the control variable is introduced into the regression analysis, the regression coefficient value of Er1 increases continuously. The sign of the regression coefficient is positive when the significance level is 10%. The signs of the regression coefficient of Er2 are all positive. The signs of the regression coefficients are all negative, but there is no significant difference. The “green paradox” is defined as the phenomenon where in the implementation of policies and measures aimed at limiting climate change leads to the accelerated exploitation of fossil energy. This, in turn, accelerates the accumulation of greenhouse gases in the atmosphere, resulting in environmental deterioration. The results show that the command-type environmental regulation has a “green paradox” effect on the carbon emissions of the Yangtze River Basin; that is, the command-type environmental regulation first increases and then weakens the carbon emissions of the Yangtze River Basin. The incentive-type environmental regulation has a positive effect on the carbon emissions of the Yangtze River Basin. Implicit environmental regulation has a certain inhibitory effect on carbon emissions in the Yangtze River Basin, but there is no significant effect.

Table 5. Benchmark regression results.

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Er1	0.01	−0.009	−0.037	0.013	0.019	0.027	0.031*
Er2	0.348***	0.325**	0.185**	0.133**	0.14**	0.059*	0.037*
Er3	−0.126	−0.095	−0.051	−0.027	−0.016	−0.029	−0.016
ESC	-	−0.521**	1.197***	1.014***	1.061***	1.169***	1.148***
QUR	-	-	−0.597***	0.016	0.03	0.625***	0.697***
LnIN	-	-	-	0.188***	0.193***	0.019	0.021
LnFDI	-	-	-	-	−0.028*	−0.015	−0.007
LnPGDP	-	-	-	-	-	0.804***	0.824***
LnPOP	-	-	-	-	-	-	0.409***
SF	0.163	0.232	0.422**	0.176	0.152	0.072	0.039
cons	8.776***	9.101***	10.966***	6.967***	6.854***	0.671	−1.377*
R^2	0.014	0.08	0.542	0.825	0.828	0.931	0.937

Note: ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

Before the panel threshold model is used in data analysis, three types of environmental regulations need to be used as threshold variables to test the existence of the threshold. The results are shown in Table 6. When incentive-type environmental regulation is used as the threshold variable, the three kinds of environmental regulations all have single-threshold effects. In addition, their *p* values are significant at the levels of 0.001, 0.01 and 0.05, respectively. Therefore, in order to analyze the impact of the three environmental regulations on carbon emissions in the Yangtze River Basin, a single-threshold panel model is chosen for data analysis in this study.

Table 6. Threshold inspection results.

Variable	Threshold Variable	Threshold Type	*f*	*p*	Critical Value			Bootstrap Times
					0.01	0.05	0.001	
Er3	Er1	Single threshold	7.732	0.265	10.602	13.065	16.052	300
		Double doorsill	8.105	0.255	10.807	12.575	14.474	300
		Triple threshold	5.625	0.719	15.373	20.883	24.217	300
	Er2	Single threshold	10.927	0.029	8.443	10.179	12.318	300
		Double doorsill	3.920	0.454	8.485	10.409	16.802	300
		Triple threshold	6.674	0.385	14.926	20.141	29.418	300
	Er3	Single threshold	2.881	0.840	14.073	17.306	23.609	300
		Double doorsill	7.546	0.186	9.755	11.603	16.446	300
		Triple threshold	3.410	0.676	10.536	15.391	21.182	300
Er3	Er1	Single threshold	9.477	0.029	10.416	12.072	16.201	300
		Double doorsill	10.163	0.121	10.536	12.448	15.338	300
		Triple threshold	2.862	0.820	15.576	20.131	32.821	300
	Er2	Single threshold	15.082	0.052	12.727	15.192	18.766	300
		Double doorsill	8.614	0.154	11.979	19.276	43.560	300
		Triple threshold	5.341	0.385	14.198	21.363	38.223	300
	Er3	Single threshold	5.047	0.673	15.013	17.545	23.243	300
		Double doorsill	5.762	0.474	11.464	14.165	18.025	300

		Triple threshold	5.655	0.624	13.930	18.385	27.146	300
		Single threshold	2.303	0.866	8.680	10.469	13.557	300
	Er1	Double doorsill	2.234	0.869	9.426	10.798	16.667	300
		Triple threshold	5.037	0.372	9.050	10.335	15.660	300
		Single threshold	16.464	0.039	13.367	14.914	22.393	300
Er3	Er2	Double doorsill	13.318	0.131	16.129	26.933	37.521	300
		Triple threshold	3.283	0.742	17.735	25.273	34.592	300
		Single threshold	7.105	0.510	19.575	22.985	31.462	300
	Er3	Double doorsill	6.635	0.336	10.241	12.871	17.133	300
		Triple threshold	4.969	0.526	11.068	13.814	16.312	300

According to the above threshold test results, the selected threshold variable is incentive environmental regulation. In addition, the regional control variables are command type, incentive type and implicit environmental regulation. Then, the panel threshold model is used for regression analysis; the results are shown in Table 7. When the value of Er2 is less than or equal to 0.1128, the elastic coefficient of Er1 presents a significant difference at the level of 0.01, and the regression coefficient value is −0.135. When the value of Er2 is greater than 0.1128, the elastic coefficient of Er1 shows a significant difference at the level of 0.001, and the regression coefficient value is 0.0393. It shows that when the Er2 level is low, increasing the intensity of Er1 can promote the carbon emission reduction in the Yangtze River Basin. However, when the intensity of Er2 is higher than 0.1128, the role of Er1 changes from inhibiting carbon emission reduction to promoting carbon emission reduction. This may be because the increase in taxes and fees has affected the carbon emission behavior of enterprises. When taxes and fees are low, enterprises can increase technological reforms and other measures to reduce CO_2 emissions. Maximization may expand the scale of production to weaken the impact of tax increases, resulting in increased energy consumption and carbon emissions.

Table 7. Result of threshold regression analysis.

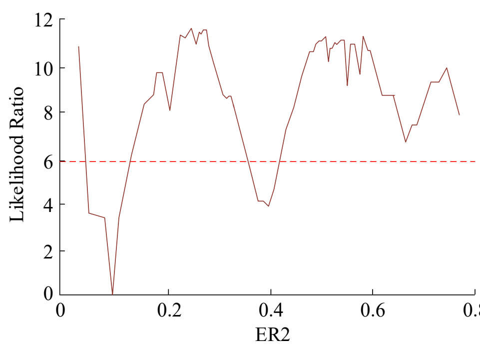
Variable	Regression Coefficient	Variable	Regression Coefficient	Variable	Regression Coefficient
Er	0.0299	Er	0.0332	Er	0.0313
Er3	0.0059	Er3	0.0225	Er3	0.0172
ESC	1.1475	ESC	1.1446	ESC	1.1299
QUR	0.7193	QUR	0.6958	QUR	0.7232
LnIN	0.0188	LnIN	0.0186	LnIN	0.0158
LnFDI	−0.0101	LnFDI	−0.0034	LnFDI	0.2783
LnPGDP	0.8447	LnPGDP	0.8251	LnPGDP	0.8526
LnPOP	0.3185	LnPOP	0.4037	LnPOP	0.0460
SF	0.0365	SF	0.0348	SF	−0.1362
$Er_1 \cdot I$ ($Er_2 \leq$ 0.1006)	0.0135**	$Er_2 \cdot I$ ($Er_2 \leq$ 0.1006)	0.0567**	$Er_3 \cdot I$ ($ER_2 \leq$ 0.1006)	−0.0094***
$Er_1 \cdot I$ ($Er_2 >$ 0.1006)	0.0393***	$Er_2 \cdot I$ ($Er_2 >$ 0.1006)	−0.0105*	$Er_3 \cdot I$ ($ER_2 >$ 0.1006)	−1.1162*
cons	−1.2220*	cons	−1.3416	cons	0.0313***
R^2	0.9458	R^2	0.9447	R^2	0.9464

Note: ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

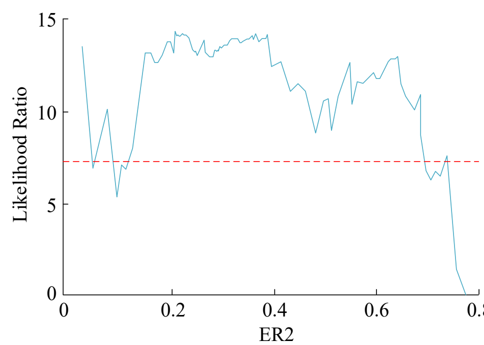
When the value of Er2 is less than or equal to 0.7094, the elastic coefficient of Er2 presents a significant difference at the level of 0.01, and the regression coefficient value is 0.0567. When the value of Er2 is greater than 0.7094, the elastic coefficient of Er2 presents a significant difference at the level of 0.05, and the regression coefficient value is −0.0105.

It shows that when the Er2 level is low, increasing the intensity of Er2 will increase the carbon emission. However, when the intensity of Er2 is greater than 0.7094, the regression coefficient value of Er2 on carbon emission reduction in the Yangtze River Basin becomes smaller and negative, and it is significant at the 0.05 level. At this time, increasing the intensity of Er2 will inhibit carbon emissions. This may be because companies are making different choices when taxes and fees change. When taxes and fees increase, in order to pursue survival or maximize profits, enterprises will try to expand their scale to weaken the impact of tax and fee increases, resulting in increased energy consumption and carbon emissions. When the tax increase exceeds the critical value, enterprises will seek green production technology in order to reduce production costs, thereby reducing energy consumption and carbon emissions. It can be seen that the effect of Er2 on carbon emissions in the Yangtze River Basin presents an inverted "U" shape, first promoting and then inhibiting.

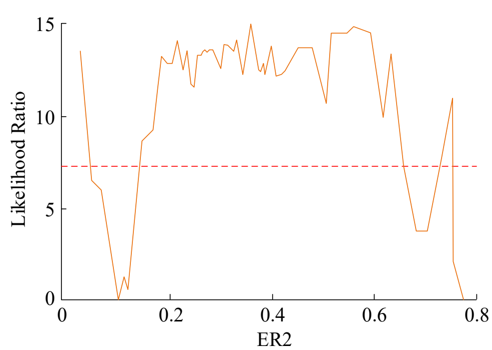
When the value of Er2 is less than or equal to 0.0893, the elastic coefficient of Er3 shows a significant difference at the level of 0.001, and the regression coefficient value is −0.0094. When the value of Er2 is greater than 0.0893, the elastic coefficient of Er3 shows a significant difference at the level of 0.05, and the regression coefficient value is −1.1162. It shows that when Er2 level is low, increasing the intensity of Er3 can promote carbon emission reduction. When Er2 levels exceed 0.0893, Er3 inhibits carbon reduction. This may be because when the level of taxes and fees is low, companies use low-carbon technologies to adapt to the enhancement of public awareness of environmental protection, which promotes carbon emission reduction. However, when the tax level is high, it may weaken the carbon emission reduction of enterprises and increase carbon emission. On the whole, increasing the intensity of Er3 is beneficial to curbing the carbon emission of enterprises. Figure 3 visually shows the threshold estimates and confidence intervals for the three types of environmental regulation.



(a) Threshold estimate and confidence interval of ER1



(b) Threshold estimate and confidence interval of ER2



(c) Threshold estimate and confidence interval of ER3

Figure 3. Threshold estimates and confidence intervals of three types of environmental regulations. Note: Different colors represent the change trend of different indicators.

4. Results and Discussion

The Yangtze River Economic Belt is a key development area in my country, covering 11 provinces and cities including Sichuan, Shanghai and Jiangsu. In the development and construction of the Yangtze River Economic Belt, green development and ecological priority are put forward, and it is necessary to focus on environmental protection and pollution control in the Yangtze River Basin [38–40]. In the study of the recessive economy and environmental regulation, researchers used different spatial econometric models to analyze the collaborative governance of environmental pollution and put forward suggestions [41–43]. The result shows that the model has a good application effect. Therefore, the analysis model with spatial attributes is also selected in this paper. In the study of environmental governance in the Yangtze River Basin, this paper starts from the perspective of coordinated governance of pollution reduction and carbon reduction. Through empirical analysis, this paper studies the impact of environmental regulation measures on industrial pollution control in the Yangtze River basin under the recessive economy. At the same time, the spatial eigenvector mapping SEVM spatial filtering method is used to explore the spatial impact of environmental regulation on carbon emissions. The results of robustness analysis show that after introducing control variables such as per capita GDP, the econometric analysis model established in the study is robust. Therefore, a more objective conclusion can be drawn: the increase in the intensity of environmental regulation will lead to the expansion of the hidden economy. It will lead to the weakening of the effect of environmental regulation. When the intensity of Er2 is higher than the critical value, the role of Er1 changes from inhibiting carbon emission reduction to promoting carbon emission reduction. The effect of Er2 on carbon emission in the Yangtze River Basin presents an inverted "U" shape, first promoting and then inhibiting. On the whole, increasing the intensity of Er3 is beneficial to curb the carbon emission of enterprises. Based on the above experimental results, here are some suggestions. First of all, it is necessary to optimize and improve the management system of the Yangtze River Basin, adopt appropriate environmental regulation policies and control the scale of the hidden economy as much as possible [44]. Then it can further construct the multi-agent governance model from the interaction between the environmental regulation system and the administrative management system [45]. Secondly, it should continue to promote the reduction of pollutant emissions and realize the coordinated governance of pollution reduction and carbon reduction. In addition, the provinces and cities in the Yangtze River Basin can be encouraged to open up to the outside world, increasing enterprises' investment in high-tech R&D and promoting the exchange of advanced technologies at home and abroad.

5.Conclusions

From the above results, in the case analysis of the Yangtze River basin, the increase in the intensity of environmental regulation will lead to the expansion of the scale of the hidden economy. In order to pursue the maximization of survival or interests, the recessive economy will lead enterprises to try to expand their scale to reduce the impact of environmental regulation. This will lead to an increase in energy consumption and carbon emissions, thus weakening the effect of environmental regulation. Therefore, when formulating relevant rules and regulations, it is necessary to comprehensively consider different environmental regulation tools and select reasonable environmental regulation policies. At the same time, relevant environmental regulations need to be optimized and improved to form a multi-agent governance model. Through these means, the hope is to reduce environmental pollution, reduce carbon emissions and promote the development of low-carbon economy. There are still some deficiencies in this paper; for example, the selection of indicators is not comprehensive enough; the impact of time and other factors on environmental governance needs to be considered in the follow-up study. At the same time, the article only analyzes the Yangtze River basin; it has not studied the environmental governance of other places in the country. In the follow-up study of national environmental governance, representative studies of different regions are also needed.

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