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Research Article

Double Effects of Environmental Regulation on Carbon Emissions in China: Empirical Research Based on Spatial Econometric Model

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This paper theoretically analyzes the direct impact of environmental regulation on carbon emissions and its indirect effects on carbon emissions through foreign direct investment (FDI), energy consumption, industrial structure, and technological innovation. Then, this paper constructs a spatial lag model to empirically test the dual effects of environmental regulation on carbon emissions based on the provincial panel data of 2003–2017 in China. The results show that the average Moran's I value of carbon emissions during 2003–2017 is 0.2506, passing the significance test at 1% level, and carbon emissions have spatial correlation characteristics. The direct impact of environmental regulation on carbon emissions is significant and positive. Environmental regulation could indirectly influence carbon emissions by influencing FDI, energy consumption, and technological innovation, and meanwhile, FDI, energy consumption, and technological innovation help to reduce carbon emissions under the constraint of environmental regulation, specifically. However, the impact of environmental regulation on carbon emissions through industrial structure is not significant.

1. Introduction

China is a major emitter of carbon pollution. In order to address the increasingly serious climate change issues, the government has promised to reduce the CO_2 per unit of GDP by 40%~50% in 2020 compared to that of 2005, and the emission is estimated to peak in 2030 [1–3]. Therefore, the country absorbs more stringent environmental regulation policy for the transition from the environmental-unfriendly extensive development mode to the green development mode [3–5]. The Chinese government has promulgated a number of laws and regulations, including the "Three-Year Action Plan to Win the Blue Sky Defense War" and the "Water Pollution Prevention Action Plan" in 2018 [6]. The total investment in environmental pollution control increased from 116.6 billion yuan in 2001 to 953.9 billion yuan in 2017; there were 186,000 yuan penalty for environmental pollution in the country, with fines of 15.28 billion yuan in 2018, which is 1.32 times that in 2017 and 4.8 times that in 2014 when the new Environmental Protection Law was implemented [6].

Does stricter environmental regulation play a role in reducing carbon emissions? This issue has received extensive attention and heated discussion from the academic circles. Some scholars believe that more stringent environmental regulation will force enterprises to carry out technological innovation, which can not only reduce carbon emissions, but also promote economic growth [7–13]. Some scholars point out that strict environmental regulation may increase business costs and weaken the competitiveness of enterprises [14–20]. How does environmental regulation affect carbon emissions in China? Does environmental regulation directly reduce carbon emissions or indirectly affect carbon emissions through other factors? Bearing these questions in mind, the purposes of this study can be divided into three parts. First, the theoretical framework of indirect effects of environmental regulation on carbon emissions is built. Second, the spatial data analysis technology is used to analyze the spatial correlation between environmental regulation and carbon emissions to test the spatial spillover characteristics of the two. Third, spatial econometric model is used to test the direct and indirect effects of environmental regulation on carbon emissions. This paper attempts to extend the existing research from two aspects. First, when analyzing the impact of environmental regulation on carbon emissions, this article not only analyzes the direct impacts, but also further analyzes the indirect effect of environmental regulation on carbon emissions through FDI, energy consumption, industrial structure, and technological innovation, which is more comprehensive than previous studies that only considered the direct relationship between the two. The second is the introduction of spatial econometric methods in this paper, which takes into account the spatial correlation characteristics of research variables, making the research conclusions more robust.

2. Literature Review

2.1. Direct Effect of Environmental Regulation on Carbon Emissions. Environmental regulation refers to discharge permit system, administrative penalties, and emission taxes put forward by government to adjust the production and business activities of manufacturers in order to achieve the sustainable environment and economic development [21]. Environmental regulation is the most effective way to protect resources and control pollution, and it is very important for China to realize energy-saving and emission-reduction targets which construct a rational environmental regulation policy system [7, 8]. Huang and Xiu found that environmental regulation had an important impact on regional emissions reduction [9, 10]. Hampf and Rødseth analyzed the economic effects of implementing EPA's newly proposed regulations for carbon dioxide (CO_2) on existing US coal-fired power plants, by using nonparametric methods on a sample of 144 electricity generating units, and found that, by adopting best practices, current profits could be maintained even if an intensity standard of 0.88 tons of CO_2 per MWh was implemented [11]. Huang showed that environmental regulation had an inverted "U"-shaped impact on the efficiency of energy conservation and emission reduction [12]. Zhang et al. indicated that environmental policies helped to achieve the objective of reducing carbon emissions [13].

However, some scholars have found that environmental regulation offers no reward for conducting pollution prevention and creates "green paradox," which means that a gradual expansion of demand-reducing public policies, such as increasing ad valorem taxes on carbon consumption and increasing subsidies for replacement technologies, may exacerbate the problem as it gives resource owners the incentive to avoid future price reductions by anticipating their sales [14]. Gani pointed out the significant negative correlation between the level of legal regulation and CO_2 emission [15]. Werf and Maria explored that climate policies typically reduced oil demand only in some geographic areas [16]. Grafton et al. used energy data over the period of 1981–2011 and found that US biofuels subsidies and production had provided a perverse incentive for US fossil fuel producers to increase their rate of extraction that had generated a weak green paradox [17]. Allaire and Brown explored that the subsidies for ethanol increased greenhouse gas emissions, while those for biodiesel had an ambiguous effect [18]. Sterner et al. considered several factors that affected the implementation of environmental regulation policy and product green paradox, including potential spatial carbon leakage to countries [19]. Shao et al. believed that the introduction of renewable energy sources intensified the promotion effect of R&D efficiency as a result of the "green paradox" effect [20].

In addition, some scholars believed that the relationship between the two is uncertain. Wang et al. thought that the impact of environmental regulation on carbon emissions had a threshold effect [22]. Liu et al. suggested that the impact of environmental regulation on environmental pollution was nonlinear [23]. The effect of regulations on carbon emissions was inconsistent [24]. Environmental regulation may have a direct effect on regional carbon emissions, and this effect may be positive and may also be the recurrence of green paradox. Based on the above literature, this paper proposes the following hypothesis:

Hypothesis 1. Environmental regulation has a direct impact on regional carbon emissions.

2.2. Indirect Effects of Environmental Regulation on Carbon Emissions. Environmental regulation would not only have a direct impact on carbon emissions, but also exert an indirect impact through four transmission channels of the energy consumption structure, industrial structure, technological innovation, and FDI [21].

2.2.1. Environmental Regulation, FDI, and Carbon Emissions. The introduction of FDI may lead to "pollution halo" effect or "pollution heaven" effect, which may lead to "forced effect" or "reverse effect" of environmental regulation on regional emission reduction. "Pollution halo" effect holds that foreign-invested enterprises with advanced technologies can deliver green and clean production technologies to enhance environmental protection in production, and thus reduce carbon emissions of the host country [25]. If foreign firms do transfer advanced technology and management know-how to domestic firms, they will thereby help to reduce industrial pollution in developing countries since they are generally believed to be cleaner than the domestic counterparts [26].

The pollution heaven hypothesis (PHH) posits that production within polluting industries will shift to locations with lax environmental regulation [27]. In the light of heavy economic performance as the target function, the local government has to relax the environmental regulation in order to fight the mobility factor motivation [28]. Chung, Chung, and Zhou et al. found strong evidence that polluting industries tended to invest more in countries with laxer environmental regulation [29–31]. Xu et al. explored the relationship among FDI, environmental regulation, and energy consumption and showed that environmental regulation had a negative effect on FDI in both the long and short term [32]. Based on the above literature, this paper proposes the following hypothesis:

Hypothesis 2. Environmental regulation will indirectly affect regional carbon emissions by affecting FDI.

2.2.2. Environmental Regulation, Energy Consumption, and Carbon Emissions. Strengthening the implementation of environmental regulation is one of the key measures to prevent further energy depletion and environmental deterioration [33]. Zhang, Zhang, and Dirckinck-Holmfeld also believed that the intensity of environmental regulation usually affected the energy consumption [34–36]. Zhou et al. discovered that the introduction of regulations would actually curb air emissions and energy consumption [37]. The increasingly intensified environmental regulation will intend to promote corporate change from passive management to active control and from end-of-pipe treatment to cleaner production [38]. As mentioned above, the implementation of government environmental regulation is forcing the enterprises to use emission reduction technologies and clean energy to reduce the demand for high carbon energy and optimize energy consumption structure, which will ultimately reduce energy consumption and carbon emissions. However, the response of energy owners to environmental regulation increases the use of high carbon energy [21]. Zhou and Feng found that energy-saving effects of environmental regulation in China were dynamic and yielded complex results of the "green paradox" and "compliance cost" [33]. Chen and Gong integrated the coupling effects of environmental regulation on energy consumption intensity and energy consumption structure and revealed that energy efficiency policy intensity was not the major effect on the development of low or moderate energy consumption industries [39]. Research shows that the effects of environmental regulation on energy consumption are double-sided. It may lead to low-carbon energy consumption as well as high carbon energy consumption. Therefore, the result of using environmental regulation to affect carbon emissions by adjusting the energy consumption structure is also double-sided, which may reduce or increase carbon emissions. Based on the above literature, this paper proposes the following hypothesis:

Hypothesis 3. Environmental regulation will indirectly affect regional carbon emissions by affecting energy consumption.

2.2.3. Environmental Regulation, Industrial Structure, and Carbon Emissions. Environmental regulation has become one of the most important driving forces underlying sustainable development and the transformation of the pattern of economic development [40]. Environmental regulation expenditures have statistically significant effects on the probabilities of a company's capacity moving to a larger company-size category, so industry structure is affected by environmental regulation [41]. However, the impact of environmental regulation on industrial transformation presented a comparison of distortion effect of resource allocation and technology effect [42]. Environmental regulation will promote industrial transformation when technology effect of environmental regulation is stronger than distortion effect of resource allocation [42]. Particularly, command-control environmental regulation has a significant incentive effect and spillover effect of technological innovation on cleaning industries, but these effects do not exist in pollution-intensive industries [42]. Gao et al. showed that environmental regulation manifested through constraining the entrance of enterprises into the pollution sectors and encouraging high-efficiency technologies has resulted in the optimization of manufacturing industries and the productivity improvement in Wuxi, which also countered the negative impact of rising production costs brought by regulation [40]. Yuan and Xie believed that formal environmental regulation can effectively drive industrial restructuring and can be used as a new impetus for carbon emissions [43]. Zhong et al. revealed that environmental regulation forced the adjustment of the corporate behavior caused by the rising price of pollution-producing factors, which will drive the transformation of the polluting industry to the direction of the low carbon [44]. Azzam et al. developed a comparative statics model of long-run industry equilibrium in the presence of size-based environmental regulation stringency and found environmental regulation has different effect on different sizes of companies [45]. Zhang and Xu found that, compared with technical progress, environmental regulation impacts carbon productivity more significantly [46]. Based on the above literature, this paper proposes the following hypothesis:

Hypothesis 4. Environmental regulation will indirectly affect regional carbon emissions by affecting industrial structure.

2.2.4. Environmental Regulation, Technological Innovation, and Carbon Emissions. A general conclusion is that aggregate policy feedback mechanisms tend to make current climate policies much less effective than is generally assumed. In fact, various policy measures involve a definite risk of "backfiring" and actually increase carbon emissions [47]. This risk is particularly pronounced once effects of climate policies on the pace of innovation in climate technology are considered. Lee examined the effect of environmental regulation on green technology innovation through the supply chain integration, using a multi-industry sample of manufacturing organisations, and found that environmental regulation has an important effect on green technology innovation. Ma et al. explored that environmental regulation can motivate coal enterprises' technology innovation by adding variable [48]. Sun et al. found that the short-term decision of enterprise technological innovation was influenced by the additional cost caused by the environmental regulation, and the long-term decision of enterprise was technological innovation [49]. Chen and Xu showed that environmental regulation has a significant positive effect on research expenditure [50]. Du and Peng explored that the environmental regulation intensity positively moderated the relationship between both of related technological diversification, unrelated technological diversification, and firm's technological innovation performance [51]. Guo et al. discovered that environmental regulation positively influenced technological innovation [52]. Environmental regulation has an important impact on enterprise green technological progress [53, 54].

Then, technological innovation is an important factor impacting carbon emissions, and environmental regulation can effect carbon emissions through technological innovation. Zhang et al. revealed that China's current environmental regulation has not yet been able to effectively reduce carbon emissions by promoting technological innovation [55]. Huang and Xie explored that only when technological innovation level is between the first and second threshold value can stringent environmental regulation improve total factor energy efficiency [56]. Lu and Feng revealed that the environmental regulation does not produce significantly direct impact on carbon emissions performance, but in the lag of 1–3 years; environmental regulation has a significantly indirect effect on carbon emissions performance through technology progress, and this effect is higher than the technological progress itself [57]. Tang et al. found that environmental regulation significantly and positively influenced technological innovation, and technological innovation has a positive impact on regional green growth performance [58]. Wang et al. discovered that environmental regulation regulated the relationship between technological innovation and carbon emissions [59]. Based on the above literature, this paper proposes the following hypothesis:

Hypothesis 5. Environmental regulation will indirectly affect regional carbon emissions by affecting technological innovation.

3. Methods and Research Design

3.1. Model Building. The spillover characteristic of carbon emissions in space has been proven by many scholars, which should not be ignored when analyzing the relationship between environmental regulation and carbon emissions [3, 5, 60–64]. So, this paper will use spatial metrological method to study the impact of environmental regulation on carbon emissions. The spatial econometric model has three advantages: it can visually present the spatial distribution characteristics of social issues firstly, then, it considers the dynamic characteristics of various influencing factors, and it can use the spatial econometric method to regress when analyzing the influencing factors on social issues, and the results are more robust [65]. According to the research of Anselin, classical spatial metrological model includes spatial lag model (SLM) and spatial error model (SEM). The direct effects of environmental regulation on carbon emissions by the SLM and SEM model can be expressed as equations (1) and (2):

$$\ln \mathrm{CO2}_{\mathrm{it}} = \rho w \ln \mathrm{CO2}_{\mathrm{it}} + \beta_0 + \beta_1 \ln \mathrm{ER}_{\mathrm{it}} + \beta_2 \ln X_{\mathrm{it}} + \varepsilon_i. \tag{1}$$

$$\begin{aligned} \ln \mathrm{CO2}_{\mathrm{it}} &= \alpha_0 + \alpha_1 \ln \mathrm{ER}_{\mathrm{it}} + \alpha_2 \ln X_{\mathrm{it}} + \varepsilon_{\mathrm{it}}, \\ \varepsilon_{\mathrm{it}} &= \lambda w \ln \mathrm{CO2}_{\mathrm{it}} + u_{\mathrm{it}}, \end{aligned} \tag{2}$$

where $\mathrm{wlnCO_2}$ is spatial lag variable; ρ is the spatial autoregressive coefficient; λ is spatial error autoregressive coefficient; w is the spatial weight matrix; lnER denotes urbanization level; and lnX represents the collection of control variables. In the spatial econometric model, the spatial weight matrix (w_{ij}) reflects the spatial connection between variables, representing the neighboring relations between the area i and the area j. This paper establishes the spatial weight matrix based on spatial adjacency relation, which is expressed as follows [66]:

$$w = \begin{bmatrix} w_{11} & w_{12} & \dots & w_{1n} \\ w_{21} & w_{22} & \dots & w_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ w_{n1} & w_{n2} & \dots & w_{nn} \end{bmatrix}. \tag{3}$$

In order to analyze the indirect influence of environmental regulation on carbon emissions, this paper introduces the cross terms of environmental regulation and energy consumption structure, industrial structure, technological innovation, and FDI to explore the effects of the four factors on carbon emissions. The SLM and SEM models can be expressed as equations (3) and (4):

$$\begin{aligned} \ln \mathrm{CO2}_{it} = \rho w \ln \mathrm{CO2}_{\mathrm{it}} &+ \theta_0 + \theta_1 \ln \mathrm{ER}_{it} * \ln \mathrm{fdi}_{\mathrm{it}} \\ &+ \theta_2 \ln \mathrm{ER}_{\mathrm{it}} * \ln \mathrm{fdi}_{\mathrm{it}} + \theta_3 \ln \mathrm{ER}_{\mathrm{it}} * \ln \mathrm{ec}_{\mathrm{it}} \\ &+ \theta_4 \ln \mathrm{ER}_{\mathrm{it}} * \ln \mathrm{ic}_{\mathrm{it}} + \theta_5 \ln \mathrm{ER}_{\mathrm{it}} * \ln \mathrm{tec}_{\mathrm{it}} \\ &+ \theta_6 \ln X_{\mathrm{it}} + \varepsilon_i. \end{aligned} \tag{4}$$

$$\begin{aligned} \ln \mathrm{CO2}_{\mathrm{it}} = \omega_0 &+ \omega_1 \ln \mathrm{ER}_{\mathrm{it}} * \ln \mathrm{fdi}_{\mathrm{it}} + \omega_2 \ln \mathrm{ER}_{\mathrm{it}} * \ln \mathrm{fdi}_{\mathrm{it}} \\ &+ \omega_3 \ln \mathrm{ER}_{\mathrm{it}} * \ln \mathrm{ec}_{\mathrm{it}} + \omega_4 \ln \mathrm{ER}_{\mathrm{it}} * \ln \mathrm{ic}_{\mathrm{it}} \\ &+ \omega_5 \ln \mathrm{ER}_{\mathrm{it}} * \ln \mathrm{tec}_{\mathrm{it}} + \omega_6 \ln X_{\mathrm{it}} + \varepsilon_{\mathrm{it}}, \end{aligned} \tag{5}$$

Where lnfdi means foreign direct investment, lnec expresses energy consumption, lnic denotes industrial structure, and lntec represents technological innovation. In addition, economic growth is an important factor that leads to environmental degradation and increases carbon emissions [3, 67]. Based on the research results of Grossman and Krueger and Gani, who believe that there is an inverted U-shaped relationship between economic growth and environmental pollution, gdp and its square term are considered as control variables in the model [15, 68]. The increasing of urban population has led to urban expansion and industrial agglomeration, which will increase the consumption of petrochemical energy and carbon emissions, and population is considered in the model [69].

3.2. Variables Description and Measurement

3.2.1. Carbon Emissions. Carbon emissions are mainly calculated by the method of Intergovernmental Panel on Climate Change (IPCC). Since fossil energy consumption is the main source of carbon emissions, this paper computes the carbon emissions in light of the energy consumption data of the provinces over the years. According to the China Energy Statistical Yearbook, there are ultimately 9 major categories of energy consumption, which includes coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil, natural gas, and electricity [3]. Electricity is produced through the consumption of other types of energy, which is not computed to avoid duplication, and the total energy consumption of the eight types of energy is multiplied by the respective carbon emissions coefficient [3]. The formula is as follows:

$$C_{\mathrm{it}} = \sum E_{\mathrm{ijt}} \cdot \eta_j, \quad (6)$$

where C_{it} is the total CO_2 emission of province i in year t; E_{ijt} is the consumption of the j-th type of energy of province i in year t; and η_j is the carbon emissions coefficient of the j-th type of energy.

3.2.2. Environmental Regulation. The indicators of environmental regulation can be roughly divided into input-oriented indicators and performance-oriented indicators in the existing literature [5]. The former include pollution abatement costs, pollution control investment, frequency of supervision, and inspection and governmental expenditure on environmental protection, while the latter include sewage charges and emissions of major pollutants [5, 50, 57, 64, 70, 71]. This paper focuses on investigating the intensity of environmental regulation of each region, referencing the practice of Li and Zhang, Zhang, and Zhang, and the amount of investment in the pollution control in each region is selected to measure environment regulations [5, 64, 70].

3.2.3. Other Variables. Referring to the study of Zhang, Sun et al., and Ding et al., energy consumption is measured by total energy consumption at the end of the year for each region, and FDI is measured by the amount of the actually used foreign capital [5, 72, 73]. The data of FDI on the yearbook are measured in US dollars, and they are converted into the amount in RMB according to the annual average exchange rate of the year [72]. Learning from Li and Wang and Yang et al., industrial structure is measured by the proportion of the secondary industry in the total industrial output. [74, 75] Drawing lessons from Liu and Feng and Zhang, technological innovation level is measured by the ratio of R&D expenditure to GDP for each region [64, 70]. According to Gani, Zhang, and Zhang, Gross Domestic Product (GDP) is indicated by actual GDP per capita, and population size is indicated by population density of each region [13, 15, 21].

3.3. Data Sources. Since the environmental regulation data has been comprehensively and uniformly recorded in *China Environmental Statistics Yearbook* since 2003, the sample period is from 2003 to 2017 in this paper, and the samples include 30 provinces except Tibet. The data are mainly from the "*Compilation of Fifty-Five Years of Statistical Data of New China,*" "*China Statistical Yearbook,*" "*China Statistical Yearbook on Science and Technology,*" and "*China Statistical Yearbook on Environment.*" Logarithmic processing is carried out during the specific analysis process for all variables to effectively eliminate the dimension of the time series, and the definition of variables and descriptive statistical results are shown in Table 1.

4. Discussion

4.1. Spatial Correlation Test. Table 2 shows the test results of Moran's I values of environmental regulation and carbon emissions in China during 2003–2017. The results show that the Moran's I values of carbon emissions have all reached significant level of 5% and the values of them are positive. The Moran's I values of environmental regulation in 2010 are negative while those of the other years are positive and have reached the significant level of 5%. It shows that China's environmental regulation and carbon emissions are not completely random. There exists obvious spatial dependence, which means significant spatial spillovers and spatial agglomeration effects exist between regional environmental regulation and carbon emissions.

The paper uses Moran scatterplots to further test the spatial correlation between environmental regulation and carbon emissions. Figure 1 shows the Moran scatterplots of environmental regulation and carbon emissions in 2003, 2009, and 2017. According to Figure 1, the distribution of Moran scatterplots of environmental regulation, there are 21 areas located in the first and the third quadrant in 2003 and 2009, and 20 in 2017. The number of the regions in the first and third quadrants accounts for nearly 70% in these three years. Meanwhile, the numbers of the scattered points of carbon emissions in the three years locating in the first and the third quadrants are 17, 17, and 18, which indicates that significant spatial autocorrelation exists between environmental regulation and spatial distribution of carbon emissions.

4.2. Spatial Econometrics Analysis

4.2.1. Model Selection. Before the empirical study, SLM and SEM models are compared and the results are shown in Table 3. The analysis results show that both the SLM and SEM models pass the significance test, while the spatial lag characteristics of the model are more significant than the spatial error characteristics; finally, the spatial lag model is chosen to conduct the empirical research. Furthermore, according to the Hausman test, the test value is 7.7822, degrees of freedom value is 17, and does not pass the significance test, demonstrating that the fixed effect model is superior to the random effect model. Therefore, the fixed effect SLM model is selected to start the empirical analysis.

Table 1: Definition of variables and descriptive statistical results.

Variables	Definition of variables	Minimum	Maximum	Mean	Std. deviation
$\ln co_2$	Carbon emissions	6.0369	10.5274	8.8131	0.7855
lner	Environmental regulation	1.2809	7.2557	4.7549	1.0732
Lnfdi	FDI	−0.0037	7.7219	5.0886	1.6512
Lnec	Energy consumption	6.5280	10.5687	9.1765	0.7365
Lnic	Industrial structure	2.4713	4.0817	3.6410	0.2621
Lntec	Technological innovation	0.5814	4.2480	2.4011	0.6575
Lnpo	Population size	5.2257	8.7495	7.6606	0.6428
Lngdp	per capita GDP	8.0886	11.7679	10.2224	0.7353
ln2gdp	The square of per capita GDP	65.4248	138.4832	105.0364	14.8882

Table 2: Moran's I values for environmental regulation and carbon emissions.

Years	Environmental regulation		CO_2	
	Moran' I	P Value	Moran' I	P Value
2003	0.2728	0.0160	0.2240	0.0230
2004	0.2733	0.0140	0.2586	0.0130
2005	0.3041	0.0040	0.2852	0.0090
2006	0.2674	0.0110	0.2741	0.0080
2007	0.3599	0.0060	0.2747	0.0080
2008	0.3185	0.0040	0.2835	0.0140
2009	0.30938	0.0060	0.2618	0.0100
2010	−0.0071	0.3230	0.2602	0.0140
2011	0.2805	0.0110	0.2652	0.0090
2012	0.2380	0.0170	0.2475	0.0150
2013	0.2767	0.0060	0.2515	0.0110
2014	0.2347	0.0210	0.2355	0.0150
2015	0.1821	0.0350	0.2267	0.0260
2016	0.1905	0.0320	0.2081	0.0280
2017	0.2611	0.0100	0.2029	0.0350

4.2.2. Empirical Results

(1). Direct Effect of Environmental Regulation on Carbon Emissions. Table 4 shows the direct effect of environmental regulation on carbon emissions. The Adjusted R^2 value is 0.9050 and the log likelihood value is 35.3657, which shows the model fits well.

First, carbon emissions have significant spatial correlation characteristics, and the level of carbon emissions in the region will affect the level of carbon emissions in surrounding areas. Table 4 shows that the spatial lag coefficient ρ value which is used to detect the special effect of carbon emissions is 0.242996 and has passed the significance test of 1%, which means carbon emissions have significant spatial positive correlation characteristics, and when carbon emissions of surrounding area increase by 1%, the carbon emissions in the region will increase by 0.242996% in average under the control of other influencing factors. The results of this study are consistent with Yang et al.; the existence of space spillover phenomenon of carbon emissions is proved again, so are the correctness and necessity of choosing a spatial measurement model [3]. The space spillover phenomenon of carbon emissions is attributed to the natural geographical reasons and socioeconomic factors [42, 60]. Natural factors such as wind direction and rain will spread carbon emissions to the surrounding areas, which lead to carbon emissions of the surrounding area to be affected by the area [76]. In addition, industrial transfer as an important socioeconomic factor has led to heavy polluting industries transferring from east to middle and west region, which has enhanced the spatial correlation of regional carbon emissions.

Second, the relationship between environmental regulation and carbon emissions is positive and significant. As can be seen from Table 4, the coefficient of environmental regulation and carbon emissions is 0.081296, which meets the demand of significance test, showing that the correlation between environmental regulation and carbon emissions is significant. The correlation coefficient between them is positive, indicating that strengthening of environmental regulation leads to the increase of carbon emissions, which supports the opinion of Sinn, Allaire et al., and Zhang et al., that green paradox phenomenon happens, and the response of the suppliers to environmental regulation makes energy owners speed up the exploitation and thus aggravate energy consumption, resulting in the increasing of carbon emissions [13, 14]. A large-scale hidden economy exists in China; the increasingly intensified environmental regulation in China will expand the scale of the hidden economy, thereby raising the overall level of pollution [77]. With the strengthening of the government's environmental regulation, in order to save production costs, companies tend to gradually shift export production to hidden economic sectors where there is less government supervision [78]. Because the pollution emissions of hidden economic sectors are not controlled, the overall pollution emission level has risen. Based on the above, it is said that environmental regulation has a direct impact on regional carbon emissions and Hypothesis 1 is confirmed.

In addition, FDI, energy consumption, and technological innovation are important factors affecting carbon emissions, and all of them pass the significance test at the 1% level. According to the values of regression coefficient, FDI and technological innovation are conducive to reducing carbon emissions, while energy consumption increases carbon emissions [79]. The impact of industrial structure on carbon emissions is not significant. The linear term of GDP per capita is positively related to carbon emissions while the quadratic term of GDP per capita is negatively related to carbon emission; both of them do not pass the significance test, which shows that there is not an inverted U relation

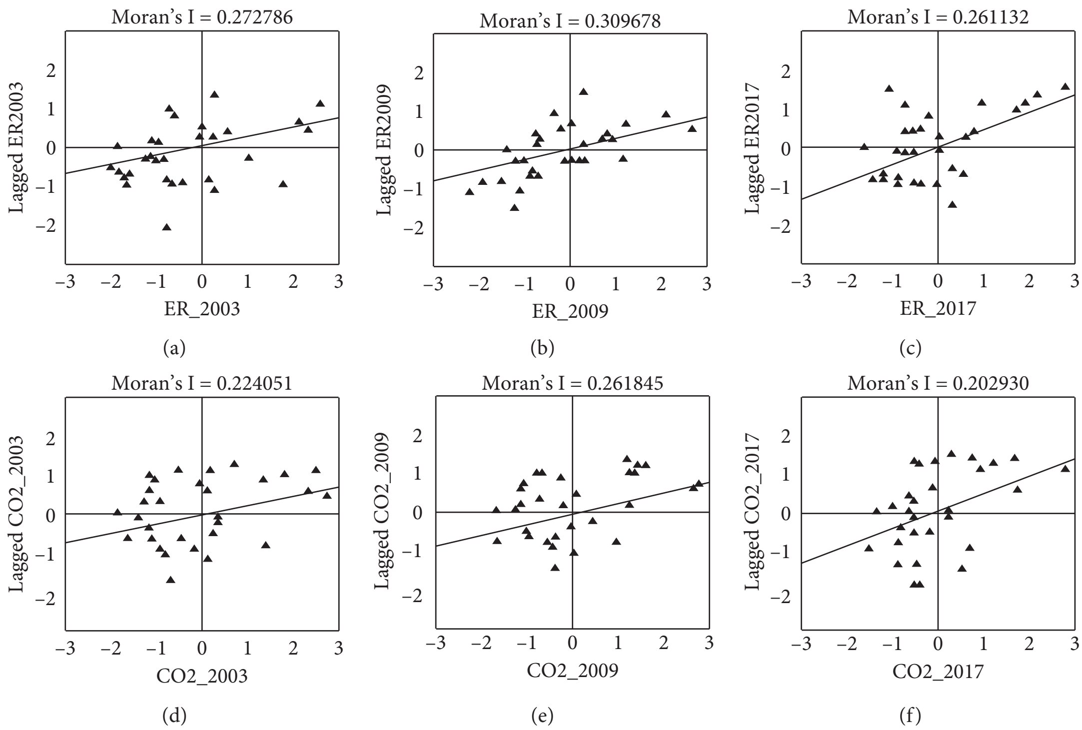

Figure 1: Moran scatterplots of environmental regulation and carbon emissions in 2003, 2009, and 2017.

Table 3: Comparative results of SLM and SEM Model.

Testing method	Teststatistics	*P* value
LM test no spatial lag, probability	75.3955	0.000
Robust LM test no spatial lag, probability	47.6841	0.000
LM test no spatial error, probability	30.9756	0.000
Robust LM test no spatial error, probability	3.2643	0.071

Table 4: Estimated results of direct effects.

Variable	Coefficient	T-stat	T-prob
lner		2.776458	0.005495
Lnfdi	−0.054409	−4.917806	0.000001
Lnec	1.016869	29.378779	0.000000
Lnic	−0.063054	−1.113951	0.265300
Lntec	−0.137021	−5.379258	0.000000
Lnpo	0.031038	1.471861	0.141058
Lngdp	0.222410	0.516086	0.605794
$\ln^2$gdp	−0.008090	9.221287	0.702065
ρ/λ	0.242996	9.221287	0.0000
Adjusted R^2		0.9050	
Log likelihood		35.3657	

Note: ***, **, and * indicate the significance at 1%, 5%, and 10% level, respectively.

Table 5: Estimated results of indirect effects.

Variable	Model 1	Model 2	Model 3	Model 4
lner*lnfdi	−0.05442***	−0.0265***	−0.0264***	−0.01936***
lner*lnec		0.0873***	0.0818***	0.0968***
lner*lnic			0.0164	−0.0045
lner*lntec				−0.0558***
Lnpo	−0.0475	0.0882***	0.0860***	0.1146***
Lngdp	2.9284***	−0.8489	−1.0091	−2.3019***
$\ln^2$gdp	−0.1673***	0.03278	0.0405	0.1123***
ρ/λ	0.1140**	0.2110***	0.2050***	0.2220***
Adjusted R^2	0.5241	0.7940	0.7946	0.8183
Log likelihood	−363.2414	−140.9330	−140.4354	−114.0835

Note: ***, **, and * indicate the significance at 1%, 5%, and 10% level, respectively.

between GDP per capita and carbon emissions. There is a positive but not significant correlation between regional population and carbon emissions.

(2). Indirect Effects of Environmental Regulation on Carbon Emissions. Table 5 shows the indirect effects of environmental regulation on carbon emissions. This paper gradually adds the cross terms of environmental regulation and FDI, energy consumption, industrial structure, and technological innovation in models 1–4 of Table 5 to observe how environmental regulation indirectly influences carbon emissions through those four ways. Regarding the adjusted R^2 values and log likelihood values of models 1–4, those models fit well.

First, the cross term of environmental regulation and FDI has negative impact on carbon emissions, and all coefficients in models 1–4 pass the significant test of 1%. It is shown that FDI helps to reduce carbon emissions under the constraint of environmental regulation, which to some extent confirms the existence of "pollution halo" effect [32]. Foreign enterprises with advanced technology can transfer

Table 6: Robustness test results.

Variables	Direct effect	Model 1	Model 2	Model 3	Model 4
lner2	0.110408***				
Lnfdi	−0.023208**				
Lnec	0.023208***				
Lnic	−0.085222				
Lntec	−0.125868***				
lner2*lnfdi		−0.058906***	−0.081066***	−0.037071**	−0.075673***
lner2*lnec			−0.015135*	0.254117***	0.303214***
lner2*lnic				−0.647536***	−0.634781***
lner2*lntec					−0.297501***
Lnpo	0.04940**	0.063706	0.042817	0.023488	0.062232
Lngdp	0.060437	3.037359**	3.273067***	4.600773***	2.396293**
$\ln^2$gdp	−0.001140	−0.142318**	−0.156494***	−0.221681***	−0.104333*
ρ/λ	0.230983***	0.186991***	0.167976***	0.243962***	0.279989***
Adjusted R^2	0.9113	0.1432	0.1508	0.3580	0.4389
Log likelihood	49.158913	−464.75499	−463.3965	−433.45543	−404.44701

Note: ***, **, and * indicate the significance at 1%, 5%, and 10% level, respectively.

more green and clean production technology to the host country under the constraint of environmental regulation, enhancing environmental protection, and thus reduce carbon emissions of host country [21]. Meanwhile, by raising the level of environmental regulation, the government plays a role in preventing pollution-intensive industries of the developed countries from entering the market and forcing foreign companies to flee form the Chinese market, which helps prevent the host country from becoming the “pollution heaven” of developed countries [32]. The results show that environmental regulation indirectly affects regional carbon emissions by affecting FDI, which confirms Hypothesis 2, and supports the views of Ong [25].

Second, the cross term of environmental regulation and energy consumption is positively related to carbon emissions. As Table 5 shows, the correlation coefficients are 0.0873, 0.0818, and 0.0968 in models 2–4, which are statistically significant at the 1% level indicating that energy consumption is the main cause of the increase of carbon emissions. Firstly, the situation of “rich in coal and poor in oil” determines the domination of the coal in energy consumption structure in China, which is difficult to change in the short term, and restricts the reduction targets [5]. Then, compared with fossil energy, the cost of clean energy is high and is not easy to establish a complete market trading system, leading to the domination of fossil energy in the market [5, 13].

However, comparing the direct impact coefficient of energy consumption on carbon emissions which is 1.016869 in Table 4 and the cross term coefficients of environmental regulation and energy consumption in Table 5, it is found that the latter is much smaller than the former, which means that the role of energy consumption in promoting carbon emissions has been weakened under the constraints of environmental regulation. The introduction of environmental regulation helps enterprises to introduce low-carbon production processes and cleaner production technologies to reduce energy consumption and ultimately reduce carbon emissions [36–38]. Therefore, environmental regulation could indirectly affect regional carbon emissions by affecting energy consumption, which confirms Hypothesis 3.

Third, the cross term of environmental regulation and industrial structure on carbon emissions is not significant. The correlation coefficients of the cross terms from models 3 and 4 are 0.0164 and -0.0045, respectively, failing to pass the significance test, which means that the impact of industrial structure on carbon emissions is not significant under the constraints of environmental regulation. Therefore, environmental regulation cannot indirectly affect regional carbon emissions by affecting industrial, which is unable to prove Hypothesis 4. The main reasons for this result are as follows. Environmental regulation has an important stimulating effect on technological innovation and technology spillovers in clean industries, but the effect is limited confined within highly polluting industries [42, 45]. Simultaneously, environmental regulation leads to higher prices of production factors and higher production costs for polluting enterprise; only when the environmental regulation reaches the threshold can it drive the transfer of polluting industries to low-carbon industries [41, 46].

Fourth, the cross term coefficient of environmental regulation and technological innovation on carbon emissions is −0.0558 in model 4 and passes the significance test at 1% level, which indicates that technological innovation can effectively suppress carbon emissions under the restriction of environmental regulation. Therefore, environmental regulation could indirectly affect regional carbon emissions by affecting technological innovation where Hypothesis 5 is confirmed. By comparing the direct impact coefficient of technological innovation on carbon emissions and the coefficient of the cross term of environmental regulation and technological innovation, it can be found that the former, −0.137021, is much smaller than the latter, −0.0558. Environmental regulation has cost effect and compensation effect on technological innovation, where cost effect means environmental regulation will increase the pollution management cost of an enterprise, and compensation effect means that enterprises will improve their production processes and improve their pollution control capabilities through optimizing the production process and increasing productivity and ultimately reduce or offset the environmental costs that the government's environmental regulation adds to the enterprise [80]. From the above, it can be found that environmental regulation has played a compensation effect on technological innovation.

4.3. Robustness Test. This paper uses the ratio of investment in pollution treatment to GDP as the proxy for environmental regulation and analyzes the direct and indirect effects of environmental regulation on carbon emissions again to perform the robustness test. The test results are shown in Table 6. As shown in Table 6, although the cross term of environmental regulation and industrial structure on carbon emissions is more significant than the above results, the direct and indirect effects results between environmental regulation and carbon emissions are basically coincident with the above results; namely, environmental regulation has significant direct impact on carbon emissions, and environmental regulation also can indirectly influence carbon emissions by influencing FDI, energy consumption, and technological innovation.

5. Conclusions

Based on the panel data of 30 provinces in China from 2003 to 2017, this paper systematically analyzes the direct and indirect effects of environmental regulation on carbon emissions. First, the average Moran's I value of carbon emissions during 2003–2017 is 0.2506 and passes the significance test at 1% level, implying that there is a significant spatial correlation and cluster effect of carbon emissions, which means the level of carbon emissions in the surrounding areas will affect the level of carbon emissions in this region. Second, the direct relationship between environmental regulation and carbon emissions is positive and significant, indicating that environmental regulation has exacerbated regional carbon emissions in China. Third, the cross terms of environmental regulation and FDI, energy consumption, and technological innovation have significant impact on carbon emissions, which implies environmental regulation could indirectly influence carbon emissions by influencing FDI, energy consumption, and technological innovation. Specifically, FDI, energy consumption, and technological innovation help to reduce carbon emissions under the constraint of environmental regulation. However, the cross term of environmental regulation and industrial structure on carbon emissions is not significant.

Based on the results of this study, the following recommendations are provided. First, based on the space spillover characteristics of carbon emissions, the government should firstly identify the spatial agglomeration characteristics of China's carbon emissions in carbon emission management and adopt different governance strategies for different agglomeration areas. At the same time, because the level of carbon emissions in the region will impact the carbon emissions of surrounding areas, the government should seek cross-regional cooperation in the process of carbon emissions governance. Second, while strengthening environmental regulation, the government should intensify the management on hidden economies, so as to prevent and control highly polluting industries from shifting to hidden economies for the sake of circumventing environmental regulation. Third, full consideration should be given to the differential impact of FDI, energy consumption, and technological innovation when formulating environmental regulatory policies. It is necessary to formulate different policies for the full play of environmental regulation in reducing carbon emissions by affecting regional FDI, energy consumption, and technological innovation.

This paper systematically analyzes the direct and indirect effects of environmental regulation on carbon emissions, but it still has the following limitations. First, environmental regulation could affect carbon emissions through many factors, from which this paper only considers the four key elements of FDI, energy consumption, industrial structure, and technological innovation, and other factors such as fiscal decentralization would be studied in future research. Second, in the selection of the spatial econometric model, although the classic spatial lag model is selected in this paper, future research would choose different spatial models, such as the spatial error model and the spatial Durbin model.

Data Availability

The data used to support the findings of this study have been deposited in [https://pan.baidu.com/s/1iQf4fH2Eqe75BbA5GWfLXg].

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] L. Li, Q. Liu, D. Tang, and J. Xiong, "Media reporting, carbon information disclosure, and the cost of equity financing: evidence from China," *Environmental Science & Pollution Research*, vol. 24, no. 10, pp. 1–13, 2017.

[2] H.-p. Sun, W.-f. Sun, Y. Geng, X. Yang, and B. K. Edziah, "How does natural resource dependence affect public education spending?" *Environmental Science and Pollution Research*, vol. 26, no. 4, pp. 3666–3674, 2019.

[3] Y. Yang, G. Niu, D. Tang, and M. Zhu, "Spatial econometric analysis of the effect of government governance on regional emission reduction: evidence from China," *Polish Journal of Environmental Studies*, vol. 27, no. 6, pp. 2833–2842, 2018.

[4] A. Rezza, "A meta-analysis of FDI and environmental regulations," *Environment and Development Economics*, vol. 20, no. 2, pp. 118–208, 2015.

[5] H. Zhang, "Advances in environmental regulation competition," *Environmental Economics Research*, vol. 4, no. 1, pp. 99–112, 2017.

[6] Environment Ministry of External Affairs, *China Eco-Environment Status Bulletin 2018*, Environment Ministry of External Affairs, Jorbagh Road, New Delhi, India, 2019.
[7] X. Du, "Policy constructing of energy-saving and emission-reduction: based on the perspective of environmental regulation," *Ecological Economy*, vol. 3, no. 2, pp. 67–73, 2013.
[8] Q. Huang and M. Guo, "Study on energy conservation and emission reduction effects of environmental regulation-empirical analysis based on panel score," *Science and Science and Technology Management*, vol. 38, no. 1, pp. 30–43, 2017.
[9] R. Huang, Y. Li, and G. Chen, "Environmental audit-based model on the regulation of the energy saving and emission reduction," *Operations Research & Management Science*, vol. 23, no. 1, pp. 23–34, 2014.
[10] J. Xiu and H. Liu, "Energy conservation and emission reduction environmental regulation and Chinese industrial TFP," *Nanjing Journal of Social Sciences*, vol. 1, no. 5, pp. 27–33, 2014.
[11] B. Hampf and K. L. Rødseth, "Optimal profits under environmental regulation: the benefits from emission intensity averaging," *Annals of Operations Research*, vol. 255, pp. 1–24, 2014.
[12] Q. Huang and M. Gao, "A research on the energy conservation and emission reduction effect of environmental regulation tools in China," *Science Research Management*, vol. 1, no. 1, pp. 30–43, 2016.
[13] K. Zhang, Z.-Y. Zhang, and Q.-M. Liang, "An empirical analysis of the green paradox in China: from the perspective of fiscal decentralization," *Energy Policy*, vol. 103, pp. 203–211, 2017.
[14] H.-W. Sinn, "Public policies against global warming: a supply side approach," *International Tax and Public Finance*, vol. 15, no. 4, pp. 360–394, 2008.
[15] A. Gani, "The relationship between good governance and carbon dioxide emissions: evidence from developing economies," *Journal of Economic Development*, vol. 37, no. 1, pp. 77–94, 2012.
[16] V. D. E. H. Werf and C. D. Maria, "Imperfect environmental policy and polluting emissions: the green paradox and beyond," *International Review of Environmental & Resource Economics*, vol. 6, no. 2, pp. 153–194, 2013.
[17] R. Q. Grafton, T. Kompas, N. V. Long, and H. To, "US biofuels subsidies and CO_2 emissions: an empirical test for a weak and a strong green paradox," *Energy Policy*, vol. 68, no. 5, pp. 550–555, 2014.
[18] M. Allaire and S. P. A. Brown, "The green paradox of U.S. Biofuel subsidies: impact on greenhouse gas emissions," *Economics of Energy & Environmental Policy*, vol. 4, no. 2, pp. 83–101, 2016.
[19] T. Sterner, S. Jensen, K. Mohlin, and K. Pittel, *The Green Paradox: A Brief Introduction to Climate Policy and Intertemporal Emissions Leakage*, pp. 1223–1228, AGU Fall Meeting, Washington, D.C., USA, 2015.
[20] S. Shao, L. Yang, C. Gan, J. Cao, Y. Geng, and D. Guan, "Using an extended LMDI model to explore techno-economic drivers of energy-related industrial CO_2 emission changes: a case study for Shanghai (China)," *Renewable and Sustainable Energy Reviews*, vol. 55, pp. 516–536, 2016.
[21] H. Zhang and X. Wei, "Green paradox or forced emission-reduction: dual effect of environmental regulation on carbon emissions," *China Population Resources and Environment*, vol. 24, no. 9, pp. 21–29, 2014.
[22] Y. Wang, Y. Zuo, W. Li, Y. Kang, and H. Chen, "Does environmental regulation affect CO_2 emissions? Analysis based on threshold effect model," *Clean Technologies and Environmental Policy*, vol. 3, no. 7, pp. 565–577, 2018.
[23] Y. Liu, Q. Sun, X. Zhang, and Y. Wu, "Research on the scheduling problem of movie scenes," *Discrete Dynamics in Nature and Society*, vol. 2019, no. 4, Article ID 6065396, 8 pages, 2019.
[24] H. Zhang, "Exploring the impact of environmental regulation on economic growth, energy use, and CO_2 emissions nexus in China," *Natural Hazards*, vol. 84, no. 1, pp. 213–231, 2016.
[25] L. H. Ong, "The apparent "paradox" in China's climate policies," *Asian Survey*, vol. 52, no. 6, pp. 1138–1160, 2012.
[26] J. Zhang, *FDI and Environmental Regulations in China*, pp. 332–353, Palgrave Macmillan, London, UK, 2013.
[27] D. L. Millimet and J. Roy, "Empirical tests of the pollution haven hypothesis when environmental regulation is endogenous," *Journal of Applied Econometrics*, vol. 31, no. 4, pp. 623–645, 2016.
[28] W. B. Sun and Z. Y. Wang, "Game analysis of environmental regulation performance of FDI competition under green economy perspective," *Advanced Materials Research*, vol. 1073, pp. 2669–2674, 2015.
[29] C. Zhou, Y. Du, and A. Peng, "Does environmental regulation affect the location choice of FDI in China?-Empirical study based on cost perspective," *World Economic Studies*, vol. 1, no. 1, pp. 110–120, 2016.
[30] S. Chung, "Environmental regulation and the pattern of outward FDI: an empirical assessment of the pollution haven hypothesis," *Departmental Working Papers*, vol. 47, no. 2, pp. 463–467, 2012.
[31] S. Chung, "Environmental regulation and foreign direct investment: evidence from South Korea," *Journal of Development Economics*, vol. 108, pp. 222–236, 2014.
[32] J. Xu, M. Zhou, and H. Li, "ARDL-based research on the nexus among FDI, environmental regulation, and energy consumption in Shanghai of China," *Natural Hazards*, vol. 84, no. 1, pp. 1–14, 2016.
[33] X. Zhou and C. Feng, "The impact of environmental regulation on fossil energy consumption in China: direct and indirect effects," *Journal of Cleaner Production*, vol. 142, no. 4, pp. 3174–3183, 2016.
[34] J. S. Zhang and X. Zhou, "Impact of environmental regulation on Chinese high energy consumption products: crude steel production as an example," *Advanced Materials Research*, vol. 726-731, pp. 1012–1016, 2013.
[35] J. S. Zhang and M. N. Yao, "Chinese environmental regulation and energy consumption: 1998~2012," *Advanced Materials Research*, vol. 962-965, pp. 1685–1689, 2014.
[36] K. Dirckinck-Holmfeld, "The options of local authorities for addressing climate change and energy efficiency through environmental regulation of companies," *Journal of Cleaner Production*, vol. 98, no. 1, pp. 175–184, 2015.
[37] Q. Zhou, H. Yabar, T. Mizunoya, and Y. Higano, "Exploring the potential of introducing technology innovation and regulations in the energy sector in China: a regional dynamic evaluation model," *Journal of Cleaner Production*, vol. 112, pp. 1537–1548, 2016.
[38] Y. Wang, J. Liu, L. Hansson, K. Zhang, and R. Wang, "Implementing stricter environmental regulation to enhance eco-efficiency and sustainability: a case study of Shandong Province's pulp and paper industry, China," *Journal of Cleaner Production*, vol. 19, no. 4, pp. 303–310, 2011.
[39] X. Chen and Z. Gong, "DEA efficiency of energy consumption in China's manufacturing sectors with environmental

regulation policy constraints," *Sustainability*, vol. 9, no. 2, pp. 210–216, 2017.

[40] S. Gao, Y. D. Wei, and W. Chen, "Effects of environmental regulation on the structure optimization and performance of manufacturing industry in Wuxi City," *Journal of Lake Sciences*, vol. 24, no. 1, pp. 17–26, 2012.

[41] D. M. Burton, I. A. Gomez, and H. A. Love, "Environmental regulation cost and industry structure changes," *Land Economics*, vol. 87, no. 3, pp. 545–557, 2011.

[42] W. Liu, J. Tong, and X. Yue, "How does environmental regulation affect industrial transformation? A study based on the methodology of policy simulation," *Mathematical Problems in Engineering*, vol. 2016, no. 4, Article ID 2405624, 10 pages, 2016.

[43] Y. Yuan and R. Xie, "A study on the effect of industrial regulation on environmental regulation-an empirical test based on the provincial panel data of China," *China Industrial Economy*, vol. 08, pp. 57–69, 2014.

[44] M. Zhong, M. Li, and W. Du, "Can environmental regulation force industrial structure adjustment: an empirical analysis based on provincial panel data," *China Population, Resources and Environment*, vol. 25, no. 8, pp. 107–115, 2015.

[45] A. Azzam, G. Nene, and K. Schoengold, "Hog industry structure and the stringency of environmental regulation," *Canadian Journal of Agricultural Economics/Revue Canadienne D'agroeconomie*, vol. 63, no. 3, pp. 333–358, 2015.

[46] H. Zhang and K. Xu, "Impact of environmental regulation and technical progress on industrial carbon productivity: an approach based on proxy measure," *Sustainability*, vol. 8, no. 8, pp. 819–833, 2016.

[47] S. Fölster and J. Nyström, "Climate policy to defeat the green paradox," *Ambio*, vol. 39, no. 3, pp. 223–235, 2010.

[48] Y. Ma, H. Yin, and W. Cui, "Research on technology innovation of coal industry under environmental regulation," *Advanced Materials Research*, vol. 734-737, pp. 815–818, 2013.

[49] X. Sun, Y. Wang, and W. Guo, "The research of environment regulation on enterprise technological innovation," *Journal of Convergence Information Technology*, vol. 8, no. 5, pp. 326–335, 2013.

[50] Q. Chen and W. Yu, "Environmental regulations and industrial technology innovation," *Journal of Tongji University*, vol. 42, no. 12, pp. 1935–1940, 2014.

[51] J. Du and J. Peng, "Technological diversification, environmental regulation and technological innovation performance in chemical firms," *Chimica Oggi*, vol. 34, no. 6B, pp. 66–76, 2016.

[52] L. L. Guo, Y. Qu, and M.-L. Tseng, "The interaction effects of environmental regulation and technological innovation on regional green growth performance," *Journal of Cleaner Production*, vol. 162, no. 162, pp. 894–902, 2017.

[53] Y. Sun, J. Du, and S. Wang, "Environmental regulations, enterprise productivity, and green technological progress: large-scale data analysis in China," *Annals of Operations Research*, vol. 1, pp. 1–16, 2019.

[54] Y. Song, T. Yang, and M. Zhang, "Research on the impact of environmental regulation on enterprise technology innovation—an empirical analysis based on Chinese provincial panel data," *Environmental Science and Pollution Research*, vol. 26, no. 1, pp. 21835–21848, 2019.

[55] X. Zhang, X. Han, and J. Wu, "Relationship between environmental regulation and carbon emission: reverse effect or regressive effect," *Soft Science*, vol. 28, no. 7, pp. 136–139, 2014.

[56] L. Y. Huang and H. Q. Xie, "Threshold effects of environmental regulation on total factor energy efficiency in China," *The Open Fuels & Energy Science Journal*, vol. 8, no. 1, pp. 33–37, 2015.

[57] Z. Lu and Y. Feng, "The influence of environmental regulations on carbon emissions performance from the perspective of technological progress," *Science & Technology Management Research*, vol. 8, no. 35, pp. 31–37, 2016.

[58] D. Tang, L. Li, and Y. Yang, "Spatial econometric model analysis of foreign direct investment and haze pollution in China," *Polish Journal of Environmental Studies*, vol. 25, no. 1, pp. 317–324, 2016.

[59] G. Zhou, W. Liu, L. Zhang, and K. She, "Can environmental regulation flexibility explain the porter hypothesis?—an empirical study based on the data of China's listed enterprises," *Sustainability*, vol. 11, no. 1124, pp. 1–14, 2019.

[60] L. Ma and X. Zhang, "Spatial effects of regional air pollution and the impact of industrial structure, *China Population*," *Resources and Environment*, vol. 7, pp. 157–164, 2014.

[61] H. Wu, "Carbon emission reduction in China: spatial and temporal pattern, evolution mechanism and policy suggestions-theory and method based on spatial econometrics," *Management World*, vol. 11, pp. 3–10, 2015.

[62] G. Zhao, G. Zhao, L. Chen, and H. Sun, "Spatiotemporal evolution and transition mechanism of carbon emission intensity in China, *China's Population*," *Resources and Environment*, vol. 10, pp. 84–93, 2017.

[63] Q. Chao and C. Tian, "Estimation of carbon emission intensity and emission reduction potential in 2030 in China, *China Population*," *Resources and Environment*, vol. 7, pp. 62–69, 2016.

[64] H. Zhang, "A study on the strategic interaction of regional environmental Regulation-An explanation of the incomplete execution of environmental regulation," *China Industrial Economy*, vol. 4, no. 7, pp. 74–90, 2016.

[65] Y. Yang, G. Niu, D. Tang, and M. Zhu, "Does environmental regulation affects the introduction of FDI in China?--Empirical research based on spatial Durbin model," *Polish Journal of Environmental Studies*, vol. 28, no. 1, pp. 415–424, 2019.

[66] L. Li, D. Tang, Y. Kong, Y. Yang, and D. Liu, "Spatial analysis of haze-fog pollution in China," *Energy & Environment*, vol. 27, no. 6-7, pp. 726–740, 2016.

[67] H. Sun, S. Attuquaye Clottey, Y. Geng, K. Fang, and J. Clifford Kofi Amissah, "Trade openness and carbon emissions: evidence from belt and road countries," *Sustainability*, vol. 11, no. 9, pp. 2682–2691, 2019.

[68] G. M. Grossman and A. B. Krueger, "Economic growth and the environment," *Quarterly Journal of Economics*, vol. 110, no. 2, pp. 353–357, 1994.

[69] L. Ma, S. Liu, and X. Zhang, "Energy structure, traffic mode, and haze pollution-a study based on spatial econometric model," *Finance and Trade Economy*, vol. 37, no. 1, pp. 147–160, 2016.

[70] H. Li and Z. Zhang, "Local officials term, corruption and corporate r&d investment," *Studies in Science of Science*, vol. 32, no. 5, pp. 744–757, 2014.

[71] X. Wang and Q. Shao, "Non-linear effects of heterogeneous environmental regulations on green growth in G20 countries: evidence from panel threshold regression," *The Science of the Total Environment*, vol. 660, pp. 1–11, 2019.

[72] X. Ding, N. Tang, and J. He, "The threshold effect of environmental regulation, FDI agglomeration, and water utilization efficiency under "double control actions"-an empirical test based on yangtze river economic belt," *Water*, vol. 11, no. 3, pp. 452–464, 2019.

[73] H. Sun, Y. Geng, L. Hu, L. Shi, and T. Xu, “Measuring China’s new energy vehicle patents: a social network analysis approach,” *Energy*, vol. 153, pp. 685–693, 2018.
[74] G. Li and B. Wang, “Research on the construction of global system quality measurement system,” *Journal of Northwest Normal University*, vol. 52, no. 4, pp. 122–131, 2015.
[75] Y. Yang, D. Tang, and P. Zhang, “Effects of fiscal decentralization on carbon emissions in China,” *International Journal of Energy Sector Management*, vol. 14, no. 1, pp. 213–228, 2019.
[76] Q. Wang, X. T. Jiang, and R. Li, “Comparative decoupling analysis of Energy-Related carbon emission from electric output of electricity sector in shandong province in China,” *Energy*, vol. 127, pp. 77–88, 2017.
[77] H. Zhan, “Analysis of the threshold effect of trade openess on carbon emissions in China,” *World Economic Research*, vol. 2, pp. 38–49, 2017.
[78] M. Shahbaz, G. Gozgor, P. K. Adom, and S. Hammoudeh, “The technical decomposition of carbon emissions and the concerns about FDI and trade openness effects in the United States,” *International Economics*, vol. 159, pp. 1–48, 2019.
[79] Q. Shi, F. Guo, and S. Chen, ““Political blue sky” in fog and haze governance-evidence from the local annual “two sessions” in China,” *China Industrial Economy*, vol. 5, pp. 40–56, 2016.
[80] F. Jiang, Z. Wang, and J. Bai, “The dual effect of environmental regulations’ impact on innovation–an empirical study based on dynamic panel data of Jiangsu manufacturing,” *China Industrial Economics*, vol. 1, no. 7, pp. 44–55, 2013.