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The Impact of Environmental Regulation on Technological Innovation of Resource-Based Industries

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Abstract: The development of the resource-based industry has obvious negative externality, and the government's environmental regulation on the resource-based industry will force the technological innovation of the resource-based industry. This paper selects the panel data of 12 resource-based industries in China from 2003 to 2019 and tests the impact of environmental regulation on technological innovation of resource-based industries by constructing the econometric model. The results show that environmental regulation can promote the technological innovation of resource-based industries. Specifically, environmental regulation has no significant positive impact on the immediate product innovation of 12 resource-based industries in China, but it has a significant positive impact on the product innovation lagging behind one period and two periods. Environmental regulation has no significant impact on the process innovation of current period, but has a significant positive impact on the process innovation of lagging one period. Industrial scale has a significant positive impact on product innovation of resource-based industries. The input of scientific and technological activity personnel has a significant positive impact on the product innovation of current period, and in the long run, it promotes both product innovation and process innovation. On this basis, this paper puts forward the relevant measures and suggestions for the formulation of environmental regulation policies. The government departments should subdivide the resource-based industries, formulate environmental rules and policies by classification, encourage industrial enterprises to carry out technological innovation, reasonably implement fiscal and taxation policy tools and increase the investment in R&D funds, and improve the training mechanism of scientific and technological personnel.

Keywords: environmental regulation; resource-based industry; technological innovation

1. Introduction

Resources are the main foundation and basic power of a country's economic development. Since the reform and opening up, relying on energy and mineral resources, China has achieved rapid economic growth through large-scale development and expansion of resource-based industries. Especially since 2002, the annual growth rate of China's GDP has reached more than 9%. In China's resource industrial structure, coal accounts for about 70% of the total, but long-term coal mining has a serious negative impact on the environment, such as air pollution, soil pollution, geological

damage, water resource leakage, etc. In recent years, the government has constantly introduced regulatory measures to strengthen the management of coal mining. With the rapid development of industrialization, China's resource-based industries such as the coal mining industry and oil and gas extraction industry have developed rapidly. However, the development of resource-based industries has a negative externality of the environment, which needs to consume a lot of resources and pollute the environment. Control environmental pollution has become an important prerequisite for the sustainable development of China's resource-based industries. Strengthening environmental regulation is an inevitable choice to effectively promote the development of resource-based industries, but the high cost of environmental pollution control also brings problems for the development of resource-based industries.

In recent years, China's total investment in the abatement of environmental pollution shows a trend of increasing year by year, and the level of environmental regulation is gradually strengthened. The total national investment in environmental pollution control increased by 5.5 times from 175 billion Yuan in 2003 to 953.9 billion Yuan in 2018; among them, the investment in industrial pollution source abatement increased by about three times from 22.18 billion Yuan in 2003 to 68.15 billion Yuan in 2018. After more than ten years of construction of environmental regulations, China's environmental governance has gradually achieved results, industrial wastewater and industrial solid waste emissions have been moderately controlled, but industrial waste gas emissions are still high. Therefore, China's environmental pollution problem is still relatively serious, and the rationality of environmental regulation policy is facing challenges. Technological innovation is an important driving force and decisive factor of a country's long-term economic development, and an effective way of environmental protection and economic development. Therefore, it is of great significance to study the impact of environmental regulation on the technological innovation of resource-based industries.

However, how to enhance the coordinated development of environmental regulation and resource-based industries is the core issue of the high-quality development of resource-based industries in China. With the development of science and technology, technological innovation has become the main way for the coordinated development of resource-based industries and the environment. Many scholars at home and abroad hold different opinions on the relationship between environmental regulation and technological innovation. On the one hand, the Porter hypothesis is put forward by scholars represented by Porter, which holds that reasonable environmental regulation can promote technological innovation of regulated enterprises and reduce environmental pollution [1]. On the other hand, new classical economics represented by Walley argues that environmental regulation can restrain the innovation activities of enterprises to a certain extent because environmental regulation increases the production cost of enterprises [2]. Although the Porter hypothesis holds that environmental regulation has a positive correlation with technological innovation, Walley's economic theory holds that environmental regulation restrains technological innovation of enterprises, but it needs to be tested by practical experiences.

In this research paper, we aim to address the following two key issues: For the resource-based industries, can environmental regulation promote or restrain the technological innovation of resource-based industries? How can the government use environmental regulation tools to promote the high-quality development of resource-based industries? This paper will focus on the above two key issues, we apply the panel data of 12 resource-based industries in China from 2003 to 2019 and establish econometric models to demonstrate the impact of environmental regulation on technological innovation of resource-based industries. Therefore, based on the existing research results, this paper studies the impact of environmental regulation on the technological innovation of resource-based industries and further proposes the collaborative policy of environmental regulation and technological innovation, which provides decision-making reference for the government to formulate environmental regulation policies of resource-based industries.

Around the key issues, the existing research focuses more on the manufacturing industry, while this paper takes the resource-based industry as the research object, constructs an econometric model based

on the Cobb-Douglas function to test the impact of environmental regulation on the technological innovation of resource-based industries. The following section provides the literature review, Section 3 provides the establishment of econometric model and data description, Section 4 is the empirical test results; and Section 5 is the conclusion and policy recommendations.

2. Literature Review

Environmental regulation is an important means to protect the ecological environment, and technological innovation is an important measure to reduce pollution emissions and promote cleaner production [3,4]. Due to the relationship between environmental regulation and technological innovation, scholars at home and abroad have launched intense arguments. A large number of literary studies from a static point of view show that environmental regulations are not conducive to the technological innovation of enterprises, on the premise that the technological level, production process and consumption demand of enterprises remain unchanged, environmental protection hinders the productivity level and international market competitiveness of manufacturers due to high economic costs [5–8]. At the same time, many scholars think from a dynamic point of view that environmental regulation is one of the factors that force technological innovation of enterprises. Facing the problem of environmental regulation, large and medium-sized enterprises are more likely to solve it through technological innovation [9–13]. Jaffe and Palmer studied the relationship between environmental regulation and technological innovation [14]. Baker et al. took pollution control costs as the variable of environmental regulation and used the data of the American manufacturing industry to show that there was a positive correlation between environmental regulation and R&D investment of manufacturing enterprises [15]. Many scholars use patent data to study the relationship between environmental regulation and technological innovation. Brunnermeier and Cohen showed that there was a positive correlation between technological innovation and environmental regulation, but the intensity was weak [16]. Popp further used the international patent data of the manufacturing industry in the United States and Japan and found that there was a positive correlation between the patent of pollution control and the government's environmental regulations on exhaust emissions [17]. Del Rio Gonzalez found that environmental regulations drive enterprises to apply clean technology through data analysis of the paper industry [18]. Johnstone et al. showed that environmental regulation policies to a certain extent affected the technological progress of renewable energy in enterprises [19].

At the same time, relying on technological innovation and cooperation to deal with climate change has become an international consensus. Due to the complexity of climate change, many governments have adopted mitigation and application mechanisms; however, the research in this area is scattered and uncoordinated. Some survey found that government subsidies were not the biggest driving force in most industries, while voluntary agreements were the biggest driving force for the introduction of environmental innovation in the manufacturing industry. The United Nations and other countries in the world fight against the effects of climate change through mitigation technology measures. Due to the externality of climate governance, the development of new technologies needs a lot of financial support from the government. Most of the EUs R&D funding for low-carbon energy technologies comes from public funding from the EU Member States. Qin et al. found that a country's propensity for climate technology innovation was affected by carbon dioxide and other greenhouse gas emissions [20]. For the research on the relationship among government policies, environmental protection technology, and greenhouse gas emissions, the existing literature is conducted from the perspective of government supporting technological innovation to influence climate change [21–25]. However, will climate change caused by greenhouse gas emissions affect the innovation of ecological technology? The existing research in this area is still very rare.

The research on the relationship between environmental regulation and technological innovation in China is relatively late, and most of the existing research is from a macro perspective. Jiang used China's manufacturing data and found that environmental regulation had a significant positive impact on China's manufacturing enterprises' technological innovation [26]. Yin et al. and Liu et al. established

a time series data model to empirically show that environmental regulation had a positive effect on innovation investment in the coal industry [27,28]. Through further analysis of the model, Huang and Liu found that environmental regulations not only reduced pollution and increased direct costs but also stimulated a certain degree of technological innovation [29]. Zhang et al. used the data envelopment model to analyze the impact of environmental regulation on China's heavy chemical industry, the results showed that they supported the Porter hypothesis [30]. Dong et al. and Ji et al. tested the data of China's interprovincial panel, and the results showed that the impact of environmental regulations on regional clean technology innovation with different levels of economic development presented threshold characteristics [31,32]. Jiang and Jiang et al. used China's Regional Panel data to show that there is a "U" relationship between environmental regulation and technological innovation of enterprises [33,34]. Some scholars also think that the impact of environmental regulation on technological innovation is uncertain, and different environmental regulation policies may have a non-monotonic relationship with technological innovation [35–37]. Li and Tao further found that environmental regulation promotes technological innovation of heavily polluting enterprises, and the relationship between environmental regulation and technological innovation of light polluting enterprises is "U-shaped" [38]. Under the constraints of environmental regulations, technological innovation is also affected by institutional and cultural factors, which may change the degree of technological innovation. Therefore, the dynamic analysis of the relationship between environmental regulation and technological innovation can more truly reflect the relationship between them. The main studies in the literature related to environmental regulation and innovation are shown in Table 1.

Table 1. Studies in the literature related to environmental regulation and innovation.

Authors/Year	Industry Focus	Results
Gray (1987)	Environmental regulation and innovation	Environmental regulation restrains innovation
Porter (1995)	Environmental regulation and innovation	Environmental regulation stimulates innovation
Jaffe and Stavins (1995)	Environmental protection and innovation	Environmental protection causes high cost and hinders innovation
Jaffe and Palmer (1997)	Environmental regulation and innovation	Environmental regulation promotes innovation in the long run
Popp (2006)	Patent and environmental regulation	The patent is affected by the regulation of SO_2 emission
Huang and Liu (2006)	Environmental regulation and innovation	Environmental regulation stimulates innovation to some extent
Del (2009)	Regulation and clean technology	Regulation is the driving force of clean technology
Jiang and Lu (2011)	Environmental regulation and technological innovation	Environmental regulation has no significant positive impact on technological innovation
Zhang et al. (2012)	Environmental regulation and heavy chemical industry	Environmental regulation promotes innovation of the heavy chemical industry
Li and Tao (2012)	The inflection point of environmental regulation intensity of different industries	The relationship between environmental regulation and technological innovation is "U"
Wang and Jiang (2015)	Environmental regulation and green technology innovation	The impact of environmental regulation on product innovation is not obvious
Yin et al. (2016)	Environmental regulation on industrial innovation investment	Environmental regulation has a positive impact on innovation investment

Source: Authors' compilation.

Based on the above, the existing literature analyzes the impact of environmental regulation on technological innovation from different perspectives, which provides a reference for this study, but the existing literature focuses on the manufacturing industry to study the impact of environmental

regulation on technological innovation. Due to the great difference in production input and output between the resource industry and manufacturing industry, it is of great practical significance to study the impact of environmental regulation on technological innovation of resource-based industries in the background of strict environmental regulation.

Since industrial technology innovation is embodied in product innovation and process innovation, product innovation uses the number of patents authorized and the proportion of new product sales revenue as measurement indicators, and process innovation uses R&D investment as a measurement index [39]. Therefore, this paper puts forward two main hypotheses as follows:

1.   Environmental regulation is positively correlated with product innovation of resource-based industries.
2.   Environmental regulation is positively correlated with process innovation of the resource-based industry.

3. Model and Empirical Analysis

3.1. Model Setting and Variable Description

Based on the sample self-effect, this paper uses a fixed effect panel data model to demonstrate the impact of environmental regulation on technological innovation of resource-based industries. Specifically, based on the C-D production function, this paper constructs a panel data model of the impact of environmental regulation on technological innovation of resource-based industries. The explained variable is industrial technological innovation, which is embodied in product innovation and process innovation. Product innovation is measured by the number of patent authorizations and the proportion of new product sales revenue, the first model and the second model are the models of the impact of environmental regulations on product innovation in resource-based industries. Process innovation uses R&D investment as a measure index, and the third model is the model of the impact of environmental regulation on resource-based industry process innovation. The explanatory variable is the intensity of environmental regulation. Since many factors are affecting technological innovation, the model needs to increase control variables [40,41]. This paper mainly takes industrial scale, industrial concentration, and input of scientific and technological personnel as control variables.

To eliminate the multicollinearity of variables and the heteroscedasticity of equations, this paper takes the form of a natural logarithm for all variables. The basic equations of measurement are as follows:

$$Ln(Patent_{it}) = \alpha_0 + \alpha_1 Ln(ERI_{it}) + \alpha_2 Ln(IS_{it}) + \alpha_3 Ln(IC_{it}) + \alpha_4 Ln(TPI_{it}) + \alpha_5 Ln(CC_{it}) + \varepsilon_{it}$$
$$Ln(Sale_{it}) = \alpha_0 + \alpha_1 Ln(ERI_{it}) + \alpha_2 Ln(IS_{it}) + \alpha_3 Ln(IC_{it}) + \alpha_4 Ln(TPI_{it}) + \alpha_5 Ln(CC_{it}) + \varepsilon_{it}$$
$$Ln(R\&D_{it}) = \alpha_0 + \alpha_1 Ln(ERI_{it}) + \alpha_2 Ln(IS_{it}) + \alpha_3 Ln(IC_{it}) + \alpha_4 Ln(TPI_{it}) + \alpha_5 Ln(CC_{it}) + \varepsilon_{it}$$

In the model, it represents the industry and time, respectively, Patent represents the number of patent authorizations, Sale represents the proportion of new product sales revenue, R&D represents the investment of research and development funds, ERI represents the intensity of environmental regulation, IS and IC represents the industrial scale and industrial concentration, respectively, TPI represents the input of scientific and technological personnel, CC stands for climate change, ε represents the random interference item. Specifically, the meaning of each variable in the model is presented in the following section.

3.1.1. Explained Variable

Industrial technology innovation can be measured by innovation input and innovation output. Considering the availability of data, the indicators of innovation output are mainly represented by the number of patents authorized, the proportion of new product sales revenue, etc., and the indicators of innovation input are mainly R&D funds. The indicators can be explained in the following way:

(1) Patent authorization quantity: Patent authorization quantity is an important index to reflect the capability and output of industrial-technological innovation. This paper uses patent authorization quantity to measure product innovation.

(2) The proportion of new product sales revenue: The proportion of new product sales revenue refers to the proportion of new product sales revenue to total product sales revenue, which is the most objective and direct indicator to measure the output of industrial-technological innovation. Therefore, this paper uses the proportion of new product sales revenue to represent the output of industrial product innovation.

(3) R&D Investment: R&D investment is the foundation and guarantee of industrial technology innovation activities. The more R&D investment is, the faster the R&D speed of new processes in the production process is, and the higher the level of industrial technology innovation is. Therefore, R&D investment is an important indicator to measure the level of process innovation.

3.1.2. Explanatory Variable

Environmental regulation intensity (ERI): Referring to the methods used by previous scholars, this paper uses the cost index of pollution control expenditure to measure the intensity of environmental regulation, which can better reflect the intensity of industrial environmental regulation. Enterprise production is affected by the cost of pollution control, the cost of pollution control expenditure increases with the increase of the intensity of environmental regulation. The stricter the environmental regulation, the more the cost of pollution control. Considering the scale difference of different industries [42], this paper divides the cost of pollution control by the total output value of the industry as a measure of the intensity of environmental regulation. The calculation formula is environmental regulation intensity = (pollution control cost ÷ total industrial output value).

3.1.3. Control Variables

(1) Industrial-scale (IS): To some extent, the industrial-scale affects the technological innovation ability and innovation level of the industry. In this paper, the industrial scale is measured by the total industrial output value of the industry.

(2) Industrial concentration (IC): It reflects the total number and scale distribution of enterprises and has a certain correlation with the level of technological innovation [43]. It is measured by the Herfindahl index of the top 10 enterprises in the market share of the industry. The calculation formula is IC = $\sum(\text{Mshare}_{jti})^2$, where Mshare_{jti} represents the market share of J industry in i (i = 1~10) enterprises before t year.

(3) The input of science and technology personnel (TPI): The input of scientific and technological personnel refers to the number of personnel engaged in scientific and technological activities in resource-based industries. This paper uses the proportion of the number of scientific and technological personnel in the whole industry to measure the input of scientific and technological personnel.

(4) Climate change (CC): Climate change has an impact on technological innovation. To deal with climate change, a country needs to carry out research and development of climate mitigation technology and form technology patents for climate change mitigation. This paper mainly selects carbon dioxide emissions to measure climate change.

3.2. Industry Selection and Data Sources

The resource-based industry is the basic industry to support the development of the national economy, which is gradually developed based on specific natural resources. Chinese scholars define resource-based industries including energy and mineral resources related industries, covering the mining industry (class B), manufacturing industry (class C) and power, gas and water production and supply industry (class D). International scholars such as Pigou et al. defined more widely than Chinese scholars. According to the narrow definition of the resource-based industry, according to the national economic industry classification, the resource-based industry is divided into six mining and

washing industries and seven primary processing industries. Considering the statistical classification and data availability of industrial industries, we selected 12 sample industries, whose names, codes and categories are shown in Table 2.

Table 2. Classification, name, and code of resource-based industries.

Mining and Washing Industry		Primary Processing Industry	
Code	Name	Code	Name
B06	Coal mining and washing industry	C25	Petroleum processing and coking industry
B07	Oil and gas extraction	C26	Chemical raw materials and chemical products manufacturing industry
B08	Ferrous metal mining and beneficiation industry	C30	Nonmetallic mineral products industry
B09	Nonferrous metal mining and processing industry	C31	The ferrous metal smelting and rolling industry
B10	Nonmetal mining and processing industry	C32	The nonferrous metal smelting and rolling industry
		C33	Metal products industry
		D44	Power and heat production and supply industry

Source: Authors' compilation.

The data used in this study are mainly from the China Science and Technology Statistical Yearbook, China Environment Yearbook, Industrial Enterprise Science and Technology Activity Statistical Yearbook, China Industrial Economy Statistical Yearbook, and China Statistical Yearbook. Among them, some variable index data can be directly obtained through the above Yearbook, such as research and development fund investment, number of patent authorization, sales revenue of new products, industrial-scale and input of scientific and technological activities personnel, carbon dioxide emissions; the other part of variable data is obtained through sorting and calculation, such as environmental regulation intensity and market concentration. The variables and data sources of each variable are shown in Table 3.

Table 3. Variables and data sources.

Variables	Data Sources
Research and development fund investment	China Science and Technology Statistical Yearbook
Number of patent authorization	Industrial Enterprise Science and Technology Activity Statistical Yearbook
Sales revenue of new products	China Science and Technology Statistical Yearbook
Environmental regulation intensity	China Environment Statistical Yearbook
Industrial-scale	Industrial Enterprise Science and Technology Activity Statistical Yearbook
Industrial concentration	Industrial Enterprise Science and Technology Activity Statistical Yearbook
The input of scientific and technological activities personnel	Industrial Enterprise Science and Technology Activity Statistical Yearbook
Carbon dioxide emissions	China Environment Statistical Yearbook

Source: Authors' compilation.

All variables in this paper take a natural logarithm to reduce data fluctuation, and the descriptive statistical results of each variable are shown in Table 4.

Table 4. Descriptive statistics of variables.

	Mean Value	Standard Deviation	Minimum Value	Maximum Value
Patent	5.156679	1.655712	0.591833	9.235176
Sale	2.101872	0.757336	0.201557	3.787531
R&D	11.87467	1.350221	7.931580	15.83928
ERI	7.376185	0.792446	0.617639	36.15573

Table 4. *Cont.*

	Mean Value	Standard Deviation	Minimum Value	Maximum Value
IS	7.536654	1.137928	4.962886	10.68324
IC	0.007365	0.008560	0.000110	0.042670
TPI	2.511476	1.535743	0.341723	7.075952
CC	1.616523	0.513718	0.183075	3.532619

Source: Authors' calculation.

4. Results

Based on the panel data of China's resource-based industries, this paper uses Stata 12.0 software to test the correlation among the variables of the first model, the second model, and the third model, and the results show that there is no correlation among the variables. Due to the lag period of technological innovation to the intensity of environmental regulation, this paper examines the impact of environmental regulation at sight and lags 1, 2, and 3 periods of patent authorization, the proportion of new product sales revenue, and R&D investment. We use Stata 12.0 software to test three panel data models of fixed effect, and the results are shown in Tables 5–7. In addition, we further test the impact of lag of scientific and technological personnel on technological innovation, the test results of lag of scientific and technological personnel on technological innovation are shown in Table 8.

Table 5. Test results of the impact of environmental regulations on patent authorizations.

Explanatory Variable	Explained Variable: Ln(Patent)							
	At Sight		Lag 1 Period		Lag 2 Periods		Lag 3 Periods	
	Estimate	Std Deviation	Estimate	Std Deviation	Estimate	Std Deviation	Estimate	Std Deviation
C	−5.162 ***	−2.473						
Ln(ERI)	0.402	2.218	0.312 *	1.923	0.463 ***	2.712	0.287	1.553
Ln(IS)	0.862 ***	8.735						
Ln(IC)	4.935	9.257						
Ln(TPI)	0.212 *	1.010						
Ln(CC)	0.326 ***	3.317						
Adjusted R^2	0.937		0.932		0.929		0.925	
F value	99.61		96.67		94.74		89.29	
D.W. statistic	2.03		1.98		1.67		2.18	

Note: ***, * represent significance at the level of 1% and 10%, respectively. Source: Authors' calculation.

Table 6. Test results of the impact of environmental regulations on the proportion of new product sales revenue.

Explanatory Variable	Explained Variable: Ln(Sale)							
	At Sight		Lag 1 Period		Lag 2 Periods		Lag 3 Periods	
	Estimate	Std Deviation	Estimate	Std Deviation	Estimate	Std Deviation	Estimate	Std Deviation
C	6.175	0.659						
Ln(ERI)	0.163	1.532	0.093	0.927	0.203 *	1.863	0.078	0.773
Ln(IS)	0.154 *	1.498						
Ln(IC)	3.878	9.874						
Ln(TPI)	0.254 *	1.313						
Ln(CC)	0.217	2.103						
Adjusted R^2	0.926		0.935		0.942		0.937	
F value	98.23		97.38		93.73		84.38	
D.W statistic	2.06		2.26		1.95		1.84	

Note: * represent significance at the level of 10%. Source: Authors' calculation.

Table 7. Test results of the impact of environmental regulation on the investment of R&D funds.

Explanatory Variable	Explained Variable: Ln(R&D)							
	At Sight		Lag 1 Period		Lag 2 Periods		Lag 3 Periods	
	Estimate	Std Deviation	Estimate	Std Deviation	Estimate	Std Deviation	Estimate	Std Deviation
C	5.538 ***	0.516						
Ln(ERI)	0.047	0.521	0.102 **	1.176	0.063	0.784	0.035	0.313
Ln(IS)	0.021	0.327						
Ln(IC)	−9.024 *	8.913						
Ln(TPI)	0.580	5.527						
Ln(CC)	0.369 *	3.651						
Adjusted R^2	0.865		0.893		0.881		0.915	
F value	87.48		85.92		83.77		86.12	
D.W statistic	2.02		2.27		2.39		2.46	

Note: ***, **, * represent significance at the level of 1%, 5%, and 10%, respectively. Source: Authors' calculation.

Table 8. Test results of the lag of scientific and technological personnel input on technological innovation.

Explanatory Variable	Explained Variable:								
	Ln(Patent)			Ln(Sale)			Ln(R&D)		
C	5.272 ***	5.346 ***	6.261 ***	6.416	7.629	8.641	5.929 ***	6.798 ***	7.595 ***
	(2.684)	(3.473)	(3.795)	(2.661)	(3.071)	(3.249)	(3.841)	(4.819)	(5.332)
Ln(ERI)	0.375	0.332	0.316	0.146	0.072	0.058	0.034	0.022	0.017
	(2.618)	(2.437)	(2.322)	(1.054)	(0.602)	(0.574)	(2.662)	(2.377)	(2.136)
Ln(IS)	0.673 ***	0.652 **	0.643 **	0.091 *	0.073 *	0.046 *	0.019	0.011	0.028
	(6.458)	(6.204)	(6.031)	(0.879)	(0.668)	(0.565)	(0.269)	(0.147)	(0.351)
Ln(IC)	4.662	4.740	4.809	3.202	3.306	3.398	−7.028 *	−7.083 *	−7.127 *
	(8.674)	(9.258)	(9.927)	(8.923)	(9.424)	(9.752)	(6.436)	(7.238)	(7.745)
Ln(TPI-1)	0.252 *			0.391			0.591		
	(1.617)			(2.518)			(5.712)		
Ln(TPI-2)		0.239 **			0.378			0.597 *	
		(1.348)			(2.264)			(5.865)	
Ln(TPI-3)			0.232 **			0.303 *			0.609 *
			(1.265)			(2.019)			(5.936)
Ln(CC)	0.328 ***	0.332 ***	0.337 ***	0.233	0.226	0.207	0.324 *	0.339 *	0.348 *
	(3.052)	(3.017)	(2.994)	(2.425)	(2.249)	(2.081)	(2.393)	(2.816)	(3.224)
Adjusted R^2	0.971	0.958	0.925	0.848	0.885	0.932	0.938	0.923	0.904
F value	107.78	102.16	97.74	94.47	90.30	88.46	126.56	105.87	97.13
D.W statistic	1.96	1.73	2.28	2.08	2.01	1.93	2.05	2.13	2.28

Note: ***, **, * represent significance at the level of 1%, 5%, and 10%, respectively. Source: Authors' calculation.

Based on the above test results, the following conclusions can be drawn:

(1) According to the above Table 5, for resource-based industries, the relationship between environmental regulations and the number of patent authorizations at the moment is positively correlated, but the degree of impact is not significant; however, environmental regulations have a significant positive impact on the number of patent authorizations lagging one period, with a regression coefficient of 0.312 and a significance level of 10%. Environmental regulations also have a significant positive impact on the number of patent authorizations lagging two periods, the regression coefficient was 0.463, and the significance level was 1%. This shows that environmental regulation has a significant positive impact on the product innovation of 12 resource-based industries in China, which validates hypothesis 1.

(2) According to the above Table 6, environmental regulation has a positive correlation with the proportion of new product sales revenue at sight and lagging one period, and its influence degree is not significant. However, environmental regulation has a significant positive impact on the number of patent authorizations lagging two periods, with a regression coefficient of 0.203 and a significance level of 10%; that is to say, the proportion of new product sales revenue increases by 0.20% every time the intensity of environmental regulation increases by 1%. This further shows that environmental regulation has a significant positive impact on the product innovation of resource-based industries

in China, which also validates hypothesis 1. The stricter the government's environmental regulation policy is, the more it can promote the product innovation of resource-based industries.

(3) According to the above Table 7, environmental regulation has no significant effect on R&D investment at sight, but it has a significant positive effect on the lagged R&D investment. The regression coefficient is 0.102, and the significance level is 5%, that is to say, for every 1% increase in the intensity of environmental regulation, the R&D investment increases by 0.10%. This shows that environmental regulation has a significant positive impact on process innovation of resource-based industries, which validates hypothesis 2. The more stringent the government's environmental regulation policy is, the more it promotes process innovation of resource-based industries.

(4) The industrial-scale has a significant impact on the number of patent authorizations and the proportion of new product sales revenue, with regression coefficients of 0.862 and 0.154, respectively, corresponding to the significance level of 1% and 10%, respectively; for each 1% increase in industrial scale, the number of patent authorizations increases by 0.86%, and the proportion of new product sales revenue increases by 0.15%. However, the impact of industrial-scale on R&D investment is not significant, but it shows that industrial-scale has a positive impact on technological innovation to some extent.

(5) Industrial concentration has a significant negative effect on R&D investment. The regression coefficient is −9.024, and the significance level is 10%. That is to say, for every 1% increase in market concentration, R&D investment decreases by 9.02%. This shows that the higher the market concentration of resource-based industries, the lower the level of competition in the industry, and then reduce the investment in research and development. However, industrial concentration has no significant impact on the number of patent authorizations and the proportion of new product sales revenue.

(6) There is a significant positive effect on the number of patent authorizations and the proportion of new product sales revenue by the input of scientific and technological personnel, with the corresponding coefficients of 0.212 and 0.254, respectively, and the significance level of 10%. For each 0.01% increase in the input of scientific and technological personnel, the number of patent authorizations and the proportion of new product sales revenue increase by 0.21% and 0.25%, respectively. This shows that the input of scientific and technological personnel has a significant positive impact on the product innovation of resource-based industries.

(7) The regression coefficient of carbon dioxide emissions on the number of patents granted is 0.326 and its significance level is 1%, which indicates that carbon dioxide emissions have a significant positive impact on technological innovation; the impact of carbon dioxide emissions on new product sales revenue is not significant, while the regression coefficient of carbon dioxide emissions on R&D investment is 0.369 and its significance level is 10%, which indicates that carbon dioxide emissions have a significant positive impact on R&D investment.

(8) The TPI of lag one period has a significant positive impact on the number of patent grants, and the significance level is 10%. While the TPI of lag two and three periods has also a significant positive effect on the number of patent grants, and the significance level is all 5%. This shows that the input of scientific and technological personnel has a significant positive impact on the number of patent grants. However, the TPI of lag one period and two periods has a positive effect on the new product sales revenue, but it is not significant. The TPI of lag three periods has a significant positive effect on the new product sales revenue, and the significance level is 10%. This shows that the TPI cannot bring new product sales revenue growth in the short term, but can promote new product sales revenue growth in the long term. Furthermore, the TPI of lag one period has a positive effect on the R&D investment, but it is not significant. While the TPI of lag two and three periods has a significant positive effect on the R&D investment, and the significance level is all 10%. This shows that the increase of TPI will not lead to an increase in R&D investment in the short term, but will lead to an increase in R&D investment in the long term.

5. Conclusions and Policy Implications

Compared with the existing research, some of them think that environmental regulation has a negative impact on industrial technological innovation, while others think that environmental regulation has a positive impact on industrial technological innovation. Since the development of resource-based industries has obvious negative environmental externalities, the government departments have more and more strict environmental regulations on resource-based industries in the process of industrialization in China, which will force resource-based industries to carry out technological innovation. This paper focuses on the impact of environmental regulation on technological innovation of resource-based industries, specifically selects the panel data of 12 resource-based industries in China from 2003 to 2019, from the perspective of resource-based industries, and carries out an empirical test by constructing the measurement model of environmental regulation on technological innovation of resource-based industries. The results show that environmental regulation has no significant impact on the current product innovation of 12 resource-based industries in China, but has a significant positive impact on the product innovation lagging one period and two periods, which shows that there is a significant positive correlation between government environmental regulation and the product technology innovation in the late stage of resource-based industries.

There is a significant positive relationship between environmental regulation and technological innovation of resource-based industries, and there is a positive relationship between industrial scale and technological innovation. The reason is that the production and operation of resource-based industries need specific production process equipment, and environmental regulations play a positive role in promoting their production process innovation. The advanced degree of production process equipment largely determines the innovation performance of resource-based industries. Under environmental regulations, the higher the innovation degree of production process equipment of resource-based industries, the more product innovation of resource-based industries, the more promotion dynamic technology innovation and improvement of performance level. The input of scientific and technological activity personnel plays an important role in promoting technological innovation in the long run. Furthermore, carbon dioxide emissions have a significant positive impact on the technological innovation of resource-based industries. Therefore, environmental regulation policies not only affect the innovation performance of resource-based industries but also affect the production cost of resource-based industries. Based on this, this paper proposes the following policy recommendations:

5.1. Formulate Environmental Rules and Policies by Category

China is in the new normal stage of economic development, and environmental protection and economic performance need coordinated development. Due to the negative externality of the environment in the development of resource-based industries, government departments need to subdivide the resource industry and formulate and implement environmental regulation policies. To implement high-intensity environmental regulation policies for high pollution resource industries, guide industrial enterprises to innovate production processes to control environmental pollution and improve performance; to implement low-intensity environmental regulation policies for low pollution resource industries, to promote industrial product innovation and high-quality development through environmental regulation policies.

5.2. Encourage Industrial Enterprises to Carry out Technological Innovation

According to the industrial characteristics of resource-based industries, the government should improve the environmental regulation standards, gradually strengthen the regulation intensity, and force the technological innovation of resource-based industries. On the one hand, in accordance with the principle of energy conservation and consumption reduction, industrial enterprises are encouraged to carry out product innovation in R&D design, production equipment, marketing services, and other aspects to produce energy-saving products with high added value; on the other hand,

industrial enterprises are encouraged to increase R&D investment, accelerate R&D innovation and transformation of production processes, or directly introduce new processes and equipment, upgrade existing production process equipment, and realize at present, energy conservation and emission reduction of resource-based industries are developing in coordination with performance growth.

5.3. Reasonably Select the Implementation Policy Tools

Environmental regulation policy tools not only reflect the effectiveness of regulatory policies but also reflect the response capacity of resource-based industries. According to the specific situation of resource-based industries, the government departments should reasonably choose environmental regulation policy tools and encourage technological innovation of resource-based industries. Specifically, we should choose environmental regulation policy tools based on market-orientation, give more financial subsidies to enterprises in terms of capital, formulate tax preference, carbon emission trading system, pollution permit system, etc., and reform and improve the existing environmental regulation policy tools.

5.4. Increase in R&D Investment

In the face of environmental regulation policies, resource-based industries should increase investment in R&D, enhance industrial technological innovation capacity by recruiting more R&D personnel, implement cleaner production, develop a circular economy, to improve industrial performance and competitive advantage; at the same time, the government should give more R&D capital support to large enterprises, encourage technological innovation of resource-based enterprises, and reduce operating costs of resource-based industries, which can not only control pollution, but also promote industrial technological innovation, and achieve the dual goals of pollution control and economic performance improvement.

5.5. Develop Technologies to Reduce Carbon Dioxide Emissions

Climate change caused by carbon dioxide emissions is positively correlated with technological innovation, which indicates that technological innovation response to carbon dioxide emissions is strong. Governments and enterprises should pay more attention to the research and development of technologies to reduce carbon dioxide emissions, and take more investment measures to encourage climate technology innovation. Coping with climate change is the common responsibility and mission of all mankind. Technological innovation is the most important solution to coordinate environmental governance, climate change, and economic development. Due to the influence of technology protection, intellectual property rights, and other factors, different countries and regions may have great differences in the ability of key technological innovation to cope with climate change. Therefore, different countries and regions need to strengthen cooperation in technological innovation.

5.6. Improve the Training Mechanism of Scientific and Technological Personnel

Although the impact of scientific and technological activity personnel on the number of patent grants is significant, its impact on new product sales revenue and R&D investment is not significant in the short term, which shows that the effect of scientific and technological activity personnel on technological innovation is not obvious in the short term. With the accumulation of practical experience and the maturity of technology, scientific and technological activity personnel plays a significant role in promoting technological innovation in the long run. Therefore, industrial enterprises should strengthen the training of scientific and technological personnel, establish a training mechanism for scientific and technological personnel, improve their knowledge level and R&D efficiency, and expand the knowledge spillover effect. At the same time, industrial enterprises should establish a reasonable salary incentive mechanism, create a harmonious atmosphere of organizational innovation, and improve their enthusiasm and innovation efficiency.

The contribution of this paper is to empirically test the impact of environmental regulation on technological innovation of resource-based industries from the perspective of resource-based industries, the results show that environmental regulation has a significant positive impact on the product innovation of resource-based industries, and environmental regulation has a significant positive impact on process innovation of resource-based industries in China. On this basis, this paper puts forward policy suggestions but does not involve the cost and risk of innovation too much.

Since the previous studies focus more on the manufacturing industry to study the impact of environmental regulation on technological innovation, compared with previous studies, this paper theoretically researches the impact of environmental regulation on the technological innovation from the perspective of resource-based industries and further proposes the collaborative policy of environmental regulation and technological innovation, which provides decision-making reference for the government to formulate environmental regulation policies. Therefore, this paper provides a new theoretical framework for interdisciplinary research of resource-based industries and innovation theory.

This paper empirically analyses the impact of environmental regulation on technological innovation of resource-based industries from the perspective of resource-based industries, but it has not yet tested the regional differences and spatial heterogeneity of the impact of environmental regulations on technological innovation of resource-based industries. Further, we can analyze the impact of environmental regulations on the technological innovation of resource-based industries from the perspective of regional differences and spatial heterogeneity, which needs to be further tested.

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