Impact of Environmental Regulation on Green Technological Innovation: Chinese Evidence of the Porter Effect

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When pursuing regional pollution control through environmental regulation in China, the region may face new problems such as the relocation of polluting industrial facilities and redirection of investment to other fields. In order to test the effectiveness of relevant regulatory measures, this paper examines the relationship between environmental regulation and green technological innovation based on provincial panel data. A major finding is that collecting pollutant discharge fees and increasing government spending on environmental protection are more effective than meting out environmental administrative punishment and promulgating local environmental rules and regulations. Therefore, the key to promote green technological innovation through environmental regulation lies in the choice of regulatory tools. Generally, financial instruments, taxes, fees and other market-based environmental regulation tools are more suitable for the specific conditions in China. Test of the mediating effect shows that pollutant discharge fees and government spending on environmental protection can force enterprises to step up R&D efforts, and thus boost green technological innovation, and that the role of these two tools in pushing for green technological innovation exhibits a threshold effect as their influence grows from weak to strong and from insignificant to significant. It is noteworthy that severe environmental administrative punishment hinders green technological innovation and that local environmental rules and regulations have no significant impact on green technological innovation regardless of their intensity. In order to strengthen environmental governance and promote green technological innovation, it is necessary to build a market-based environmental regulation system, lay stress on relevant top-level design, and appropriately increase the intensity of environmental regulation.

Keywords: environmental regulation, green technological innovation, mediating effect, threshold effect

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1. Introduction

In recent years, with China's economy entering a stage of high-quality development and people's life becoming more comfortable, environmental regulation has become a major concern and hot topic of discussion in various fields. In view of the strong externality of environmental problems, government's use of regulatory measures to control pollution caused by enterprises is an inextricable topic in policy evaluation. However, the environmental regulation is a means rather than an end. According to the Porter hypothesis, appropriate environmental regulation will stimulate technological innovation (Porter and Van-der-Linde, 1995). It is clear that the ultimate goal of designing and implementing environmental regulation is to promote green technological innovation by forcing or encouraging enterprises to increase R&D investment, improve their capacity of pollution control and enhance the technology content of products.

However, can environmental regulation definitely promote green technological innovation? Obviously, the answer is "not necessarily". Firstly, enterprises have various strategies to evade environmental regulation. For example, they may move to areas where environmental regulation is relatively loose (Fu, 2008; Shen *et al.,* 2017), or they may turn to low-pollution businesses such as quasi-finance (Wang and Xu, 2015). These strategies may lessen environmental pollution for a while, but from a cross-regional perspective, they are essentially a zero-sum game and may damage the foundation of the manufacturing industry. Secondly, the environmental regulation is a package containing various policy tools. Different environmental regulation tools influence the production behavior of polluting enterprises either through financial means, taxes, fees, or other economic means, or through administrative means such as direct orders and decrees. Some environmental regulation tools focus on after-event punishment, while others focus on pre-event guidance. Different environmental regulation tools have different mechanisms of action, and naturally have different effects on green technological innovation. Thirdly, environmental regulation intensity has an indirect but very important correlation with green technological innovation. On the one hand, a low intensity makes no difference in the game equilibrium between polluting enterprises and the government, nor can it alter the strategic choice of enterprises to continue polluting the environment. On the other hand, a high intensity may cause a large number of enterprises to move out of the region or deteriorate their financial situation, neither of which is conducive to green technological innovation.

Among all relevant research findings so far, the Porter hypothesis seems to represent the best scenario concerning the relationship between environmental regulation and green technological innovation. However, does this optimal scenario exist in reality? If environmental regulation has indeed promoted green technological innovation in China, which environmental regulation tool actually did the job and what is the intensity that produces the best effect? We constructed the provincial panel data of China from 2006 to 2010, used the sum of the number of patents granted for green technologies and the number of awards granted for such technologies to measure the level of green technological innovation, introduced the four most frequently used environmental regulation tools–pollutant discharge fees, environmental administrative punishment, government spending on environmental protection, and local environmental rules and regulations, and empirically analyzed the effect, heterogeneity and threshold value of environmental regulation's promotion of green technological innovation.

2. Literature Review

Literature related to the research topic of this paper can be divided into two categoreis. The first focuses on the study of environmental regulation itself, including the connotation and extension of environmental regulation, the classification of environmental regulation tools, and the selection of environmental regulation strategies; while the second focuses on the economic and social effects of environmental regulation.

As far as the first part of literature is concerned, although the strong negative externality of environmental issues has long been a consensus, the connotation and extension of environmental regulation are still going through changes and adjustments. At first, environmental regulation only covered control orders and decrees issued by the government through administrative means, such as bans, rules, regulations, non-market transferable licenses, etc. Later, market-based economic incentives and restraint policies (such as environmental taxes, subsidies, etc.) and behavioral norms (such as information disclosure and public reporting) based on the environmental awareness of the general public were also brought into the scope of environmental regulation (Zhao *et al.*, 2009). On this basis, most scholars categorize environmental regulation tools into three types: the command-controlled type with administrative orders, laws and regulations as the carrier; the economic incentive and restraint type with market regulation as basic means; and the implicit type associated with the concept, awareness, perception of and attitude toward environmental protection (Testa *et al.*, 2011). Of course, environmental regulation tools can also be categorized in other ways (Böcher, 2012; Yuan and Liu, 2013). In essence, regardless of the type of a specific environmental regulation tool, its way of action is to internalize the costs of polluting enterprises, thus changing the game equilibrium between polluting enterprises and the government that represents public interests (Pan *et al.*, 2015) and urging enterprises to re-select production strategies that are conducive to the environment. However, after considering such factors as local economic development, industrial policy, environmental endowment and competition between local governments (Han *et al.*, 2016), the selection strategy of environmental regulation becomes particularly important, especially in choosing the intensity and tools of environmental regulation (Ambec *et al.*, 2013; Li *et al.*, 2013).

Faster research progress and richer content are seen in the second part of literature. Research at the level of economic effects involves environmental regulation and productivity (Lanoie *et al.*, 2008; Albrizio *et al.*, 2017; Xu and Qi, 2017); environmental regulation and enterprise location (Levinson, 1996; Dechezleprêtre and Sato, 2017; Shen *et al.*, 2017); environmental regulation and regional economic growth (Zhao, 2014; Oueslati, 2014; Özokcu and Özdemir, 2017); environmental regulation and industrial structure transformation (Yuan and Xie, 2014; Zhong *et al.*, 2015); environmental regulation and foreign trade (He, 2006; Ren and Huang, 2015). Their views roughly fall into three categories. The first is that environmental regulation improves the production behavior of enterprises and produces positive economic effects. The second is that environmental regulation increases the extra cost of enterprises, which is not conducive to economic development. The third is that, influenced by the specific type of environmental regulation tools and the intensity of environmental regulation, some inverted U-shaped, threshold-type or other non-linear relationships exist between environmental regulation and economic indicators. Research on social effects mainly focuses on whether environmental regulation is beneficial to pollution control. For example, Goldar and Banerjee (2004) examined the relationship between environmental regulation and water pollution control in India; Wang and Xu (2015) examined the relationship between environmental regulation and air pollution control in China; Fan and Zhang (2018) constructed a theoretical framework that incorporates enterprise investment in pollution control and two environmental regulation policies of the government - environmental tax and emission reduction subsidy, and simulated its equilibrium solution. These studies all support the conclusion that environmental regulation is beneficial to pollution control, but there are different views on the role of environmental regulation in pollution control. The main controversy focuses on whether the Porter effect really exists. One of the two negative views is represented by the “polluting industry relocation” hypothesis, or the “pollution haven” hypothesis; the other is represented by the hypothesis of investment field change, believing that environmental regulation will force polluting enterprises to give up their manufacturing business with higher pollution intensity and turn to invest in the service sector such as the quasi-financial industry with lower pollution intensity.

The most direct way to prove the existence of the Porter effect is to examine whether environmental regulation promotes green technological innovation. However, in spite of positive attempts, prior studies were deficient in some aspects due to the fact that environmental regulation and pollution control are endogenous, that green technological innovation is difficult to measure accurately, and that the effect of environmental regulation is non-linear. For example, Hernandez-Sancho *et al.* (2000) and Domazlicky (2004) used total pollutant emissions or compliant-emission rate as environmental regulation indicators, but due to regional differences in initial pollution level, a region's environmental regulation intensity cannot be simply considered high when its pollutant emission is low and compliance rate is high. Johnstone *et al.* (2010), Jiang *et al.* (2013) and Chakraborty and Chatterjee (2017), measured the level of technological innovation by the number of patent applications and R&D investment, but failed to clearly distinguish green technological innovation from non-environmental technology innovation. Li *et al.* (2013) estimated the green technology efficiency and green total factor productivity of the industrial sector by taking into account the undesirable output, thus avoiding the problem that green technological innovation cannot be distinguished from non-environmental technological innovation. However, Zhang *et al.* (2015) found that the improvement of green technology efficiency and green total factor productivity of enterprises is caused not only by their own green technological innovation, but also by the introduction and transformation of green technologies. Guo *et al.* (2017) used a structural equation model (SEM) to explore the relationship between environmental regulation and green economic efficiency, pointing out that the role of environmental regulation in improving green economic efficiency is rather vague. Xie *et al.* (2017) evaluated the green productivity of the industrial sector of Chinese provinces based on the SBM method and the Luenberge productivity index, distinguished command-controlled environmental regulation from market-regulated environmental regulation, and analyzed the impact of different types of environmental regulation on green productivity. The disadvantage of their research is that they failed to clearly answer the question of whether environmental regulation's promotion of green productivity originates from green technological innovation. Mi *et al.* (2018) expanded the test of Porter effect from one-dimensional environmental regulation to multi-dimensional environmental regulation, focusing on the interaction between different environmental regulation measures, but lacking an examination of the relationship between environmental regulation and green technological innovation.

In summary, this paper points out that to carefully examine the relationship between environmental regulation and green technological innovation, it is necessary to overcome two obstacles. Firstly, it is necessary to find a way to measure the intensity of environmental regulation, and distinguish between regulatory measures and governance effects so as to solve the endogenous problem between environmental regulation and pollution control. Secondly, it is necessary to extract enterprise-level green technological innovation indicators to measure the green technological innovation level and eliminate the impact of non- environmental technological innovation. To deal with the first obstacle, this paper used the amount of pollutant discharge fees collected, the number of environmental administrative punishment cases, the amount of government spending on environmental protection and the number of local environmental rules and regulations to directly measure environmental regulation intensity, thus overcoming the endogenous problem between environmental regulation and pollution control. To address the second obstacle, we cited the number of patents granted for green technologies and the number of awards granted for green technologies from the *Annual Statistical Report on Environment in China* as the proxy variable of regional green technological innovation level, thus distinguishing between green technological innovation and non-environmental technological innovation.

3. Design of the Study

3.1. Econometric Model Construction

The research design of this paper follows the idea shown in Figure 1. First, unlike prior studies which mostly focus on environmental regulation-forced relocation of polluting industries or change of investment fields as a means to realize regional pollution control, this paper focuses on testing the Porter effect, that is, environmental regulation achieves regional pollution control by promoting green technological innovation. Second, based on the benchmark model we introduce a mediating effect model, take the R&D intensity of enterprises as a mediating variable (denoted by *R&D*), and analyze how environmental regulation promotes green technological innovation. Finally, in view of the fact that environmental regulation with different intensities will have heterogeneous effects on green technological innovation, we construct a threshold regression model to analyze the non-linear relationship between environmental regulation and green technological innovation.

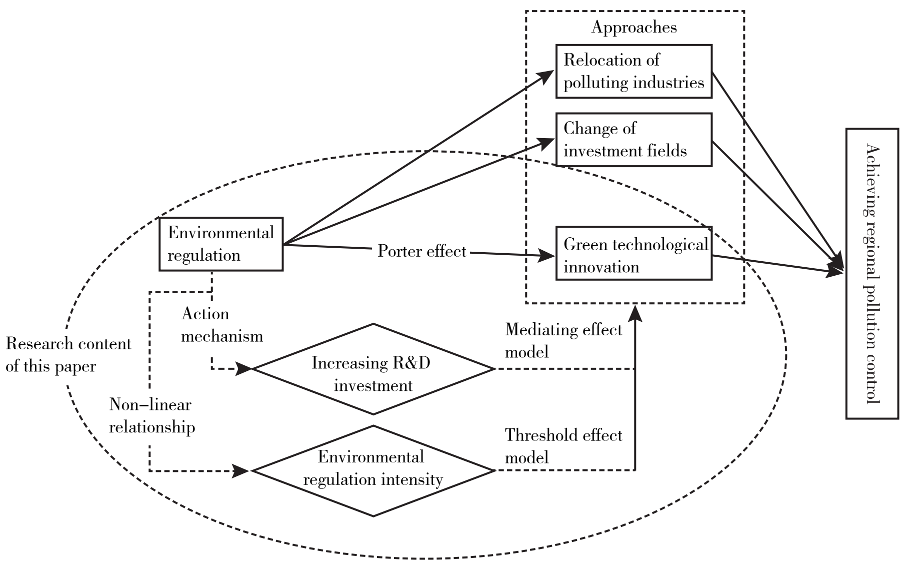

Figure 1. Research Design for the Promotion of Green Technological Innovation Through Environmental Regulation

3.1.1. Benchmark Regression Model

This paper takes green technological innovation indicator as the explained variable (denoted by GTI_{it}) and environmental regulation tool as the core explanatory variable (denoted by *RE*), and incorporates control variable *X* to construct an econometric model as shown in Formula (1). Considering that environmental regulation may have a time lag in promoting green technological innovation, the paper simultaneously incorporates one period lagged GTI_{it+1} and two period lagged GTI_{it+2} into the following econometric model as explained variables:

$$GTI_{it}, GTI_{it+1}, GTI_{it+2} = \alpha + \beta RE_{it} + \gamma X_{it} + \mu_i + \upsilon_t + \varepsilon_{it} \tag{1}$$

where, *i* and *t* represent the region and the year respectively, μ, υ and ε represent region-fixed effect, time-fixed effect and random disturbance term. This paper selects the four environmental regulation tools that are most frequently used by local governments, i.e., pollutant discharge fees (denoted by *fee*), environmental administrative punishment (denoted by *pun*), government spending on environmental protection (denoted by *fin*), and local environmental rules and regulations (denoted by *law*)

In view that environmental administrative punishment and pollutant discharge fees are usually punishments meted out to polluting enterprises by local government authorities after finding their polluting behavior while government spending on environmental protection and local environmental rules and regulations are usually already in place before such behaviors, in order to further investigate the heterogeneous effect of environmental regulation time point on green technological innovation, this paper classifies *fee* and *pun* as post-event punitive environmental regulation (denoted by *RE-after*) while *fin* and *law* as pre-event incentive environmental regulation (denoted by *RE-before*). In addition, considering the interaction between different environmental regulation tools such as new local environmental rules and regulations which may increase the number of environmental administrative punishment cases and the amount of pollutant discharge fees collected, this paper introduces the cross terms of environmental regulation tools: *law* × *pun* and *law* × *fee*. Based on this, Formula (1) can be expanded to:

$$\begin{aligned} GTI_{it}, GTI_{it+1}, GTI_{it+2} = \alpha + \underbrace{\beta_1 fee_{it} + \beta_2 pun_{it}}_{RE-after} + \underbrace{\beta_3 fin_{it} + \beta_4 law_{it}}_{RE-before} + \beta_5 law_{it} pun_{it} \\ + \beta_6 law_{it} fee_{it} + \beta_7 pun_{it} fee_{it} + \gamma X_{it} + \mu_i + \upsilon_t + \varepsilon_{it} \end{aligned} \tag{2}$$

3.1.2. Mediating Effect Model

In order to test the validity of environmental regulation promoting green technological innovation and realizing pollution control, this paper takes the R&D intensity of enterprises as the mediating variable (denoted by *R&D*), and constructs a mediating effect model as shown in Formulas (3) and (4):

$$R\&D_{it} = \alpha + \theta RE_{it} + \varepsilon_{it} \tag{3}$$

$$GTI_{it} = \alpha + \beta' RE_{it} + \sigma R\&D_{it} + \gamma X_{it} + \mu_i + \upsilon_t + \varepsilon_{it} \tag{4}$$

In Formula (3), coefficient θ tests the relationship between environmental regulation and enterprises' R&D intensity, and the expected regression coefficient is significantly positive. On the basis of Formula (1), Formula (4) incorporates the mediating variable *R&D*. In the mediating effect model, this paper mainly focuses on the variation of environmental regulation coefficient β' Relative to Formula (1), if the coefficient decreases, i.e., $\beta'<\beta$ and the coefficient (σ) of R&D intensity is significantly positive, then it shows that environmental regulation has promoted green technological innovation by encouraging enterprises to intensify R&D (Cheng *et al.*, 2015; Zhang *et al.*, 2018).

3.1.3 Threshold Regression Model

There is no doubt that the promotion effect of environmental regulation on green technological innovation is affected by the intensity of environmental regulation. Therefore, the paper takes the four above-mentioned environmental regulation tools as threshold variable T to build a threshold regression model. If it is assumed that there are *k* thresholds, then the effect of environmental regulation on green technological innovation will be cut into (*k*+1) sections, as shown in Formula (5):

$$\begin{aligned} GTI_{it} = \alpha &+ \delta_1 RE_{it}\left(T \le \lambda_1\right) + \delta_2 RE_{it}\left(k_2 < T \le \lambda_2\right) + \cdots + \delta_{k+1} RE_{it}\left(\lambda_k < T\right) \\ &+ \gamma X + \mu_i + \upsilon_t + \varepsilon_{it} \end{aligned} \tag{5}$$

where, *T* successively represents *fee*, *pun*, *fin*, and *law*; λ1, λ2…λ_k are threshold values to be estimated; δ_k represents the effect an environmental regulation tool's regulation intensity on green technological innovation after crossing Threshold (*k*-1).

3.2. Variables and Data

3.2.1. Variables

(1) Explained variable: In this paper, the green technological innovation level of a region in a certain year is measured by the sum of the number of patents granted for

green technology and the number of awards granted for such technology in the year, thus limiting technological innovation to the category of green technological innovation only. (2) Core explanatory variables: the intensity of environmental regulation is measured by four variables—the region's per capita paid-in pollutant discharge fees (denoted by *fee*), per capita environmental administrative punishment cases (denoted by *pun*), the proportion of the region's government spending on environmental protection in its general budget (denoted by *fin*), and the number of local environmental rules and regulations promulgated (denoted by *law*), where the influence of regional economic scale has been eliminated for the first variable, and the fourth variable itself has nothing to do with regional economic scale, so its total number is used directly. (3) Mediating variable: the R&D intensity (*R&D*) of enterprises is measured by the proportion of R&D expenditure in the main business income of industrial enterprises above the designated scale. (4) Control variables: Referring to the research of other scholars in related fields, we use gross regional product per capita (denoted by *gdp*) to control the impact of economic development level, the proportion of gross output value of the secondary industry in gross regional product to control the impact of industrial structure (denoted by *str*), and the proportion of total foreign investment in gross regional product to control the impact of the region's attraction to foreign direct investment (denoted by *FDI*), and the proportion of permanent urban residents in the year-end total population to control the impact of the region's urbanization rate (denoted by *urb*).

3.2.2. Data

The data used in this paper are cited from the *Annual Statistical Report on Environment in China*, *China Statistical Yearbook on Environment*, and *China Statistical Yearbook*. Since this paper limits technological innovation to the category of green technological innovation only, and the indicator is available in the *Annual Statistical Report on Environment in China* for years 2006–2020, we construct balanced panel data of the years 2006–2010, which cover 30 provinces. Table 1 reports descriptive statistical results of major variables.

Table 1. Descriptive Statistical Results of Major Variables

Variable	Unit	Sample size	Mean value	Standard deviation	Minimum value	Maximum value
GTI	case	150	10.5337	33.3415	0	167
fee	yuan/person	150	13.6395	11.0275	1.5824	81.5985
pun	cases/10, 000 persons	150	0.6635	0.8797	0.0000	7.7072
fin	%	150	3.1237	1.4467	0.5734	8.4131
law	—	150	1.7333	2.6789	0.0000	23.0000

Variable	Unit	Sample size	Mean value	Standard deviation	Minimum value	Maximum value
R&D	$\%\times10^{-6}$	150	0.1537	0.1832	0.0000	0.9511
gdp	10, 000 yuan/person	150	2.5919	1.5155	0.6339	7.4537
str	%	150	48.0540	7.4466	23.4966	57.9922
FDI	%	150	2.5654	2.0787	0.0004	8.1983
urb	%	150	49.2947	14.3109	27.4526	89.2749

4. Analysis of Empirical Results

4.1. Benchmark Regression Model

Hausman test shows that the p value is 0.0000 and rejects the original hypothesis that the disturbance term is not related to individual characteristics. Therefore, this paper chooses the fixed effect model for regression analysis. Table 2 reports the regression results of the benchmark model. Considering the time lag between environmental regulation implementation and green technological innovation promotion, one period and two periods lagged *green technological innovation* are also added to the explained variable. The regression results are shown in Models (2) and (3), respectively.

Seen from Table 2, in Model (1) where *GTI* is not lagged and in Model (3) where *GTI* is lagged by two periods, the regression coefficient β of none of the four environmental regulation tools can pass significance test; while as shown in Model (2) where *green technological innovation* is lagged by one period, both *fee* and *fin* produce a significant promotion effect on green technological innovation. The regression results show that, on the one hand, there is a time lag between the implementation of environmental regulation and the outcome of green technological innovation, and on the other hand, environmental regulation forces enterprises to reduce pollution within a short time, or they will still be subject to punishment or supervision in the following year. Therefore, green technological innovation has a shorter cycle than other kinds of innovation.

Table 2. Benchmark Regression Results of Environmental Regulation and Green Technological Innovation

Model	(1)	(2)	(3)
Explained variable	*GTI*	*L1.GTI*	*L2.GTI*
fee	0.0123 (1.26)	0.0144* (2.01)	0.0061 (0.97)
pun	−0.0007 (−0.11)	−0.0093 (−0.48)	0.0015 (0.17)
fin	0.0416 (1.81)	0.0900*** (3.47)	0.0476 (0.90)

Model	(1)	(2)	(3)
Explained variable	*GTI*	*L1.GTI*	*L2.GTI*
law	0.0904 (0.17)	0.0765 (0.42)	0.0802 (0.46)
Law × pun	0.0004* (2.21)	0.0005* (2.32)	0.0001 (1.47)
Law × fee	0.0067 (0.12)	–0.0007 (–1.39)	0.0029 (0.80)
pgdp	0.4167 (0.27)	5.7361* (2.14)	3.8013 (1.69)
str	–2.0471** (–2.58)	–2.0404** (–2.49)	–0.0338 (–0.62)
FDI	0.0503 (0.85)	0.0782 (0.70)	0.0209 (0.52)
urb	0.0004 (0.18)	0.0004 (0.14)	0.0003 (0.06)
FE	Yes	Yes	Yes
R-sq	0.2140	0.2283	0.1035
Prob > F	0.0001	0.0013	0.3892
Obs	150	120	90

Notes: Values in brackets are T values of regression coefficients; marks ***, ** and * mean that the regression coefficients have passed 1%, 5% and 10% significance tests, respectively.
Source: Calculations are obtained by using STATA 15.0, the same below.

Comparing the two post-event punitive environmental regulation tools, it is found that *fee* is more effective than *pun* in promoting green technological innovation. A possible reason is that the collection of pollutant discharge fees will directly affect the input and output of enterprises and drive polluting enterprises to internalize external costs. Moreover, the collection of pollutant discharge fees can cover almost all polluting enterprises, while environmental administrative punishment is often targeted at those with serious pollution. In addition, some punishment measures such as warnings, fines and suspension of business for rectification are difficult to implement in some cases.

Comparing the two pre-event environmental regulation tools that are mainly intended for guidance and encouragement, *fin* is more effective than *law* in promoting green technological innovation. A possible reason is that government spending on environmental protection can make up for the cost of green technological innovation of enterprises and reduce the risk of green technological innovation. Moreover, the use of government spending on environmental protection is supervised by relevant authorities and is more targeted at solving environmental problems.

The regression results of cross items show that the cross term *law*×*pun* of local environmental rules and regulations and environmental administrative punishment significantly promotes green technological innovation, indicating that local environmental rules and regulations are conducive to consolidating the deterrent power of environmental administrative punishment and force enterprises to carry out green technological innovation activities. However, the cross term *law×fee* of local environmental rules and regulations and the amount of pollutant discharge fees collected has no significant impact on green technological innovation. A possible reason is that local governments have mature plans and polluter lists for the collection of pollutant discharge fees, and the promulgation of new local environmental rules and regulations has a rather limited impact on such collection.

4.2. Mediating Effect Model

This paper uses *green technological innovation*$_{it+1}$ as explained variable. Table 3 summarizes the regression results of mediating effect of R&D in the process of environmental regulation promoting green technological innovation. The upper part of Table 3 reports the regression results of the four environmental regulation tools for R&D; the lower part of Table 3 reports the regression results of environmental regulation for green technological innovation when R&D is used as a mediating variable. The following facts can be seen from Table 3.

Firstly, among the four environmental regulation tools, *fee*, *pun*, and *fin* significantly enhance R&D, while the regression coefficient of *law* for R&D is insignificant. After the mediating variable is included, the regression coefficient of R&D for *green technological innovation* is significantly positive, indicating that the enhancement of R&D intensity can significantly promote green technological innovation.

Secondly, comparing the mediating effects of R&D intensity in the two post-event punitive environmental regulation tools, we can find that after the mediating variable is included, the regression coefficient of *fee* for *green technological innovation* decreases from 0.0144 to 0.0007 and changes from statistically significant to statistically insignificant. At the same time, although the regression coefficient of *pun* for *green technological innovation* also shows a decline, it is still statistically insignificant. Based on this, we find out the mechanism of how the two post-event punitive environmental regulation tools promote green technological innovation: Environmental administrative punishment and the collection of pollutant discharge fees, as two post-event punitive environmental regulation tools, increase enterprises' cost of environmental pollution and force them to improve the capability of pollution control and the technology content of products by investing more in R&D, thus improving the regional green technological innovation level. However, the collection of pollutant discharge fees is more effective than meting out environmental administrative punishment in influencing the input and output of enterprises, helping them internalize external costs, and promoting green technological innovation.

Table 3. Regression Results of the Mediating Effects of Environmental Regulation and Green Technological Innovation

Environmental regulation variable		*fee*	*pun*	*fin*	*law*
Formula (3)	Explained variable	*R&D*			
	Regression coefficient of environmental regulation variable	4.2608*** (2.88)	33.0166** (2.22)	49.6140*** (2.92)	34.4525 (0.17)
Formula (4)	Explained variable	*L*1.*green technological innovation*			
	Regression coefficient of environmental regulation variable	0.0007 (0.16)	−0.0366 (−1.51)	0.0265*** (4.97)	−0.1261 (−0.44)
	Regression coefficient of mediating variable *R&D*	0.0030*** (24.16)			
	Law pun	0.0002** (2.79)			
	Law fee	−0.0014 (−0.62)			
	pgdp	4.3400* (1.85)			
	str	−1.2981** (−2.76)			
	FDI	0.0701 (0.23)			
	urb	0.0004 (0.54)			
	FE	Yes			
	R-sq	0.8580			
	Prob > F	0.0000			
	Obs	120			

Thirdly, comparing the mediating effects of R&D intensity in the two pre-event environmental regulation tools that are mainly intended for guidance, we can find that the regression coefficient of *fin* for *green technological innovation* is still significantly positive after the mediating variable is included, and the coefficient value drops from 0.0900 to 0.0265, while the regression coefficient of *law* for *green technological innovation* still fails to pass the significance test. Based on this, we find out the green technological innovation-promotion mechanism of the two pre-event environmental regulation tools that are mainly intended for guidance: the expansion of government spending on environmental protection by local governments makes up for the costs of green technological innovation activities, reduces green technological innovation-related risks, and significantly encourages enterprises to carry out green technological innovation, thus improving the regional green technological innovation level on the whole. However, since the top-level design and specific implementation of local environmental rules and regulations depend on much more detailed policy measures, local environmental rules and regulations play a relatively indirect role in encouraging enterprises to increase R&D expenditure. Therefore, local environmental rules and regulations do not have a significant effect on the promotion of green technological innovation.

Fourthly, comparing the post-event punitive environmental regulation tools with the pre-event environmental regulation tools that are mainly intended for guidance, we find that the time point of environmental regulation has no significant heterogeneity effect on green technological innovation. Based on this, it is believed that the key to whether environmental regulation tools can promote green technological innovation is not the time point of intervention but the carrier and means of these tools. Generally speaking, financial, taxation, fee and other market-regulated environmental regulation tools are more effective than command-controlled environmental regulation tools with government orders and regulations as carriers.

4.3. Threshold Regression Model

Table 4 reports the single-threshold and double-threshold values of environmental regulation and green technological innovation, as well as the regression results in the corresponding threshold interval. In single-threshold regression, when per-capita *fee* is less than 12.4392 yuan, its regression coefficient for green technological innovation is negative but not significant; when per-capita *fee* exceeds the threshold value of 12.4392 yuan, its regression coefficient for green technological innovation becomes significantly positive, indicating that low intensity of pollutant discharge fee collection cannot completely cover the external cost of environmental pollution of enterprises and that only after the intensity of pollutant discharge fee collection fully internalizes such external cost will polluting enterprises turn to green technological innovation. The results of double-threshold regression show more clearly the relationship between green technological innovation and the intensity of PDF collection: when per-capita *fee* is less than 12.4392 yuan, its regression coefficient for green technological innovation is negative but not significant; when it exceeds the first threshold of 12.4392 yuan but is lower than the second threshold of 14.2071 yuan, its regression coefficient for green technological innovation becomes positive but remains not significant; when it exceeds the second threshold of 14.2071 yuan, however, its regression coefficient for green technological innovation becomes significantly positive.

According to the single-threshold regression results of *pun*, when the number of environmental administrative punishment cases per 10, 000 people is below the threshold value of 0.4719, the regression coefficient of the punishment for green technological innovation is negative but not significant; when it exceeds the threshold value of 0.4719, its regression coefficient for green technological innovation becomes significantly negative, which means that too low an administrative punishment intensity cannot significantly promote green technological innovation while too high an administrative punishment intensity hinders the development of regional green technological innovation. A similar conclusion is drawn from double-threshold regression results of *pun*. The explanation given in this paper is: under a low punishment intensity, the probability of enterprises being caught polluting the environment is low, and even if they are caught, they usually receive less severe punishments such as warnings or fines; under a high punishment intensity, the probability of enterprises being caught polluting the environment is greatly increased and they will be faced with much more severe punishments such as "stopping production, closing down, withholding/revoking business license or other permits". Because of the inertia of production activities and the rigidity of environmental administrative punishment, when faced with severe punishment, most enterprises have no time to adjust production activities, which will not only damage the basis of normal production and operation, but also hinder the regional green technological innovation.

Table 4. Threshold Regression Results of Environmental Regulation and Green Technological Innovation

Threshold variable		Threshold interval	Regression coefficient	Threshold variable		Threshold interval	Regression coefficient
fee	Single threshold	*fee*≤12.4392	−0.0011 (−0.22)	*pun*	Single threshold	*pun*≤0.4719	−0.1300 (−0.72)
		fee>12.4392	0.0764*** (5.81)			*pun*>0.4719	−0.4352*** (−3.88)
	Double threshold	*fee*≤12.4392	−0.0144 (−0.78)		Double threshold	*pun*≤0.4719	−0.7282 (−1.02)
		12.4392<*fee*≤14.2071	0.0069 (0.13)			0.4719<*pun*≤0.5882	−0.1414 (−1.17)
		fee>14.2071	0.0783*** (5.92)			*pun*>0.5882	−0.4396*** (−4.21)
fin	Single threshold	*fin*≤2.8461	−0.0230 (−0.21)	*law*	Single threshold	*law*≤1	5.8718 (0.65)
		fin>2.8461	0.0815* (2.06)			*law*>1	0.6001 (0.83)
	Double threshold	*fin*≤2.7038	−0.0770 (−0.59)		Double threshold	*law*≤1	5.8693 (0.72)
		2.7038<*fin*≤2.8461	0.0453 (1.68)			1<*law*≤3	4.0534 (0.46)
		fin>2.8461	0.0841* (2.04)			*law*>3	0.3058 (0.76)

The conclusion drawn from the threshold regression result of *fin* is similar to that drawn from the threshold regression result of *fee*, that is, when *fin* (the proportion of the region's government spending on environmental protection in its general budget) is too low (lower than the first threshold value of 2.7038%), it will hinder green technological innovation, but not significantly; as it grows and exceeds the first threshold value of 2.7038% and the second threshold value of 2.8461% successively, its promotion effect on green technological innovation will definitely increase and become statistically more and more significant.

The threshold regression results of *law* for green technological innovation show that with the increase in the number of local environmental rules and regulations, its regression coefficient for green technological innovation is positive, but not significant in different threshold intervals, and the coefficient value shows a trend of decline. The reason for this is given as follows: firstly, multifarious regulations may be seen by enterprises as mere “slogans” rather than real “actions”, thus making their threshold effect on green technological innovation attenuate; secondly, local environmental rules and regulations are mostly top-level designs of local governments for environmental protection, but their enforcement depends on much more detailed and specific measures, so their effect on green technological innovation is indirect.

5. Conclusions

In the process of realizing regional pollution control through environmental regulation, China will encounter many problems such as relocation of polluting industries and change of investment fields, which are intended to avoid regulation. This paper, by directly examining the relationship between environmental regulation and green technological innovation, finds that among the four most-commonly-used environmental regulation tools, government spending on environmental protection and the collection of pollutant discharge fees are more effective than administrative punishment and local environmental rules and regulations in promoting green technological innovation. So, the key to promote green technological innovation through environmental regulation lies in the choice of regulatory tools. Generally speaking, financial means, taxes, fees and other market-based environmental regulation tools are more effective than command-controlled environmental regulation tools with government orders and regulations as carriers, because the former are more direct and flexible than the latter. Test of the mediating effect shows that the collection of pollutant discharge fees increases the cost of environmental pollution and forces enterprises to improve their own capability of pollution control by increasing R&D expenditure and the technology content of their products, and that government spending on environmental protection can make up for the cost of green technological innovation of enterprises and reduce green technological innovation-related risks. Therefore, both of the two environmental regulation tools can promote green technological innovation by encouraging enterprises to intensify R&D. Threshold effect tests show that with the increase in environmental regulation intensity, government spending on environmental protection and the collection of pollutant discharge fees exhibit a non-linear effect on green technological innovation as it goes from weak to strong, from insignificant to significant. It is worth noting that severe environmental administrative punishment has a significant negative impact on green technological innovation, and the promulgation of local environmental rules and regulations has no significant effect on green technological innovation, regardless of the regulatory intensity.

The research detailed in this paper has important theoretical and practical value for clarifying the relationship between environmental regulation and green technological innovation and for promoting environmental protection through green technological innovation-based pollution control. On this basis, the paper puts forward the following policy recommendations:

Firstly, it is necessary to build an environmental regulation system with market regulation as the main carrier and means. Financial, taxation, fee and other market-regulated environmental regulation tools are more effective than indirect, rigid command-controlled environmental regulation tools because the former is more direct in realizing internalization of the external costs of polluting enterprises and their implementation basis is clearer, more specific and more targeted than the latter. So, in pursuing high-quality economic development, China should choose market-regulated and more flexible environmental regulation tools.

Secondly, China needs to strengthen the top-level design of environmental regulation and ensure the implementation of specific measures. Local governments' environmental regulation policies play a very important role in pollution control and environmental protection, but there is also the problem of "more slogans than actions", causing polluting enterprises to struggle with complicated regulations. Therefore, local governments need to formulate a complete set of policies and measures from top-level design to specific implementation so as to improve implementation effect.

Thirdly, the environmental regulation intensity of pollutant discharge fee collection and government spending on environmental protection can be appropriately increased at the present stage. As proved by the research results of this paper, the impact of pollutant discharge fee collection and government spending on environmental protection on green technological innovation promotion presents a threshold effect from weak to strong, from insignificant to significant. Therefore, it is necessary to gradually increase the intensity of pollutant discharge fee collection, government spending on environmental protection, and other environmental regulation measures in order to internalize the external costs of polluting enterprises and promote green technological innovation.

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