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RESEARCH ARTICLE

The impact of heterogeneous environmental regulation on innovation of high-tech enterprises in China: mediating and interaction effect

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Abstract

It is important for China's green innovation productivity and sustainable development to study the effect of heterogeneous environmental regulation on microenterprise innovation activities. Based on the panel data of high-tech enterprises in China from 2012 to 2017, the article studies the incentive effect of heterogeneous environmental regulation on technological innovation and the mediation of innovation input and explores whether different types of environmental regulations have interactive effects on enterprise innovation. The results reveal that compared with the command-controlled environmental regulation, the incentive effect of market-incentive environmental regulation and voluntary environmental regulation on enterprise innovation is more significant, where the innovation input fully plays its role as a mediating effect. Further research finds that there is an interactive effect between command-controlled environmental regulation and other two regulatory tools, but no interactive effect between market-incentive environmental regulation and voluntary environmental regulation, which shows that the control-based regulatory tools and more flexible regulatory tools have a complementary effect on enterprise innovation. Through revealing the internal mechanism of environmental regulation on enterprise innovation, the article displays the process of technological innovation, and it also finds that flexible regulation tools and the combination of rigid and flexible tools are more conducive to encourage enterprises to carry out innovation activities.

Keywords Heterogeneous environmental regulation · Enterprises innovation · Mediating effect · Interaction effect

Introduction

Nowadays, the rapid economic development brings great damage to the environment and seriously restricts the sustainable development. In April 2018, China ranked last in the global environmental performance index jointly released by Yale University and other institutions. Due to the negative externality of environmental pollution, market alone can hardly achieve effective regulation. Therefore, government intervention in pollution control and environmental protection is particularly important (Wang and Liu 2019). As the main policy tool of government intervention, environmental regulation is of great significance to the realization of the win-win situation of the environment and economy.

The policy objective of environmental regulation is to improve the environmental treatment evaluation system of enterprises. It requires enterprises to promote green production and green service. In order to meet the requirements and avoid compliance costs, it is essential for enterprises to make innovations. Pollution control expenditures have a positive relationship with R&D expenditures (Hamamoto 2006). New technologies and green products brought by innovation also provide a technical guarantee for sustainable development (Magat 1978). By accelerating technological innovation, companies can achieve the internalization of social costs and

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energy conservation and emission reduction (Mert and Bölük 2016). Therefore, the innovation aiming at the continuous improvement of environmental technology becomes the link between environmental protection and sustainable economic development.

Research on the relationship between environmental regulation and technological innovation has been the focus of scholarly attention in recent years, but common sense has not been reached. The Porter hypothesis supported the implementation of environmental regulation. It is estimated that environmental regulation design can inspire enterprise innovation (Porter and van der Linde 1995). Strong Porter hypothesis argues that effective environmental regulation can promote technological innovation and enhance the competitiveness of enterprises. However, the narrow Porter hypothesis holds that flexible environmental policies will encourage enterprises to innovate more greatly (Jaffe and Palmer 1997). Voluntary environmental regulation promotes enterprise innovation (Bu et al. 2020). Later, Porter's hypothesis has been tested by many scholars with various methods and sample data (Yang et al. 2012; Guo et al. 2017; Fang et al. 2020). However, some studies did not agree with the Porter Hypothesis. Environmental regulation may also suppress innovation investment (Wu et al. 2020). Ouyang et al. (2020) found that the impact of environmental regulation on technological innovation is shown as inhibition before incentive. The relationship between environmental regulation and technological innovation may vary due to different factors influencing the environment.

Only exploring the impact of intensity of environmental regulation or a single environmental regulation tool on innovation ignores the diversity of environmental regulation tools, which may eventually lead to deviations in environmental policy in guiding practice (Wang and Yuan 2018). The research on the relationship between environmental regulation and technological innovation shows that innovation output occupies a large portion, and whether environmental regulation will affect innovation output through the allocation of innovation resources is not explored. In order to analyze the pattern of effect that environmental regulation posed on innovation output, the article selects innovation input as the intermediary variable. Meanwhile, given the synergistic effect of different environmental regulation tools, we study the interaction effect of environmental regulation innovation. Therefore, based on the mediating effect and interaction effect, the article analyzes the impact of heterogeneous environmental regulation on innovation through Chinese high-tech enterprise data.

The contributions of the article are in three aspects: (1) High-tech enterprises are the typical representatives of innovation subjects. The article selects research samples from an innovation perspective to explore the impact of environmental regulation on corporate innovation and expands the Porter hypothesis. (2) The article revealed the mechanism of environmental regulation affecting enterprise innovation output. It is found that the effect of environmental regulation on innovation output was fully mediated by innovation input. The follow-up research on environmental regulation and innovation of high-tech industry can focus on exploring the path of environmental regulation on innovation investment and analyzing how environmental regulation affects the allocation of innovation resources. (3) It is proved that the incentive effect of different types of environmental regulation tools on enterprise innovation is different. The combination of command-controlled environmental regulation tools and flexible tools has complementary effect on enterprise innovation. It has practical significance for improving the environmental regulation system. The government can adopt the policy of combining command control environmental regulation with flexible environmental regulation to promote innovative behavior and dynamically improve the intensity and mode of environmental regulation according to the implementation results and enterprise response.

The remainder of the paper is structured as follows. The "Literature review and hypothesis" section is the literature review and the research hypothesis, the "Sample sources and empirical models" section is the research design, the "Results and analysis" section conducts the empirical analysis, and the "Conclusions and policy implications" section gives the conclusion and relative policy suggestions.

Literature review and hypothesis

Direct effect of environmental regulation on innovation

There are two views on the relationship between environmental regulation and enterprise innovation. First, based on the effectiveness of environmental regulation, most of the studies mainly examine the effects of environmental regulation on innovation. For example, Porter and van der Linde (1995) proposed that high-quality environmental regulation design can stimulate enterprises to carry out technological innovation, and the first-mover advantage from innovation can offset the compliance cost of environmental regulations. Environmental regulation can promote enterprise innovation only by providing enough flexibility to enterprises (Guo et al. 2017, Ramanathan et al. 2017, Johnstone et al. 2017). Environmental regulation not only improves the level of technological innovation but also reduces the environmental pollution (Sen 2015). However, environmental regulation and technological innovation are mutually restrained according to the traditional economic theory. Schmutzler (2001) examined the compensation mechanism of enterprise innovation and found that the innovation benefits from the enterprise's R&D investment cannot make up for the cost. Ziegler and Seijas Nogareda (2009) found that there is no

causal relationship between the environmental management system and technological environmental innovation. Ramanathan et al. (2010) and Kneller and Manderson (2012) also found that environmental regulation has no positive impact on enterprise innovation.

Second, in terms of the diversity of environmental regulation tools, several studies examine the effects of different environmental regulation tools on innovation. As to the classification, Li and Ramanathan (2018) divided environmental regulation into command-controlled regulation, market regulation, and informal regulation. Shen et al. (2019) divided environmental regulation into command-controlled regulation and market-based regulation. From the view of effect, different types of environmental regulation have heterogeneity in the impact of ecological efficiency (Ren et al. 2018). Formal environmental regulation can promote the technological innovation of enterprises, but with regional differences. Command-controlled environmental regulation has spatial heterogeneity on environmental technological innovation (Li et al. 2019). Blind (2012) suggested that mandatory environmental regulations have a significant impact on the technological innovation of enterprises, while weak mandatory environmental regulations cannot significantly affect the technological innovation of enterprises. With the improvement of economic level, environmental regulation shows a "U" relationship of first restraining and then promoting technological innovation (Song et al. 2019).

According to innovation compensation effect in Porter's hypothesis, only when the regulated party is not forced to adopt specific environmental protection technology and fully enjoy the initiative can the environmental regulation design truly play a role in promoting enterprises to carry out technological innovation activities. Xie et al. (2017) analyzed the panel data of China's provincial-level and found that the productivity effect of market-based environmental regulation is stronger than the effect of command-control environmental regulation. Owing to the characteristics of mandatory in command-controlled environmental regulation, command-controlled environmental policies will directly announce regulatory requirements and time limits for corporate environmental protection rectification, which bring difficulties for companies in adjustment periods and adaptation periods, and then discourage companies' enthusiasm for technological innovation. In comparison, market-incentive environmental regulations and voluntary environmental regulations give enterprises more freedom. Market-incentive environmental regulation tools design rules and systems based on market demand, which can provide material incentives for companies to invest in environmental technology, thereby benefiting the technological progress of the whole society and achieving the purpose of guiding corporate behavior through market mechanisms. Voluntary environmental regulations have the characteristics of continuous advancing, prompting companies to improve their environmental performance in stages. Moreover, voluntary environmental regulations, generally speaking, only put forward requirements for environmental goals, and do not make specific requirements for achieving approaches and technologies, leaving enterprises with the broadest room for innovation. Based on the above analyses, we proposed:

> H1: Environmental regulation will affect the enterprises innovation output, and the impact of different environmental regulation tools is different.

Mediating effect of innovation input

There are two ways in which environmental regulations affect corporate innovation input, one is direct and the other is indirect.

From the perspective of direct impact, due to the existence of environmental regulations, companies need to increase innovation investment, develop new products with low energy consumption, and produce fewer pollutants to meet the constraints of environmental regulations (Yang et al. 2012, Banerjee and Gupta 2019). You et al. (2019) concluded that environmental regulation significantly promotes an enterprise's ecological innovation in China. Command-controlled environmental regulation also has the characteristics of high cost. When companies have insufficient funds, resources spent on pollution treatment may squeeze out funds for innovation. Innovation resources cannot be optimized, and innovation effects will not be significantly improved. Market-incentive environmental regulations encourage enterprises to carry out optimal resource allocation plan through the market economy, such as tax reduction and emission fees, which reduces the risk of innovation input and positively affects innovation output. For regulated enterprises, when the cost of technological innovation is lower than the cost of continuing to produce pollution, or when technological subsidies are higher than technological improvements, the enterprises can choose to innovate.

Environmental regulation will also indirectly affect the innovation investment of enterprises, which is mainly reflected in the following three aspects: changes in the financing environment, human capital, and government subsidies. First of all, capital is more motivated to flow to areas with less environmental regulation, which will lead to some restrictions to corporate financing under environmental constraints. Second, bound by environmental regulations, companies need to hire R&D personnel with a certain level of environmental protection technology (Zhao et al. 2019). On the other hand, the intensity of environmental regulations will result in an increase in corporate training costs. Enterprises need to train employees on environmental awareness and develop relevant skills for R&D personnel (Song et al. 2018). Finally, the

existence of environmental regulation policies will have a certain impact on government subsidies (Liu et al. 2018). For polluting enterprises, the government will reduce its financial subsidies, while raise the subsidies for environment-friendly enterprises or enterprises that develop environmental protection products. The increase and decrease of government subsidies will affect the stock of funds available to enterprises, which will have a certain impact on the innovation investment of enterprises. For the purpose of encouragement, enterprises are more likely to receive environmental subsidies in voluntary environmental regulation. Meanwhile, stronger environmental awareness of employees in voluntary regulation will also decrease the training costs. Therefore, in voluntary regulation, the capital constraints of enterprises are small, and the available innovation resources increase.

Endogenous growth theory believes that R&D investment is the source of enterprise innovation and economic growth (Romer 1986). From the perspective of input and output, high-intensity innovation investment has improved the company's internal innovation activities. Increasing the input will help to provide support and guarantee conditions for technological innovation and improve innovation performance. Thus, this article proposes hypothesis 2:

> H2: Environmental regulations have a positive correlation with innovation input, and the effect of environmental regulation on innovation output was mediated by innovation input.

Interaction effect of different environmental regulation tools

The incentive effect of different environmental regulation tools tends to be independent. Yuan (2019) found that the three environmental regulation tools have a synergistic effect on innovation. When a variety of environmental regulations are in parallel, the combination of mandatory and flexible tools is more conducive to the complementary effects of environmental regulation. Different environmental regulatory tools have synergistic effect on corporate innovation. Specifically, command environmental regulation and flexible environmental regulation both enable enterprises to take the initiative to carry out technological innovation. When one of the environmental regulations is enhanced, not only the performance of environmental regulations itself and impact on corporate technological innovation improved, but also the effect of "associated" environmental regulations on technological innovation is simultaneously enhanced. Command-controlled and market-incentive environmental regulations are complementary to each other, enabling companies to choose regulatory methods flexibly at a lower cost, effectively reducing the squeeze on innovation investment and stimulating companies to innovate. Environmental letters and visits can supplement administrative supervision and management to coordinate the collection of pollution discharge fees and environmental letters and visits fees. The more environmental letters and phone calls will lead to more sewage charges paid by industrial companies. Under this mechanism, the voluntary type interacts with the market-incentive type and the command and control type to encourage enterprise innovation. So this article proposed the next hypothesis.

> H3: There is an interactive effect between the two environmental regulation tools on enterprise innovation.

Through the above analysis, we constructed a hypothesis model, as shown in Fig. 1.

The above analysis found that the existing research has the following shortcomings: (1) Current discussions on the relationship between environmental regulation and technological innovation are mostly concentrated on the macro-regional or industry level, and there are large gaps in cross-level research. (2) Only one aspect of innovation input and innovation output is selected for verification, and it is concluded that the results of environmental regulation affecting innovation have limitations. (3) Only studying the intensity of environmental regulation or the impact of a single environmental regulation tool on innovation, while ignoring the diversity of the combination of environmental regulation tools, may bias policy adjustments. Moreover, there is little research on the interaction effects of environmental regulations. Therefore, this paper selects a sample of Chinese-listed high-tech companies to study the relationship between environmental regulation, innovation input, and innovation output. Taking into account the diversity of tools and implementation background, the relationship between interaction items and innovation of different environmental regulation tools is explored. The research helps to correctly understand the impact of macro-environmental regulations on the entire process of micro-enterprises' technological innovation, and enriches cross-level research on related topics.

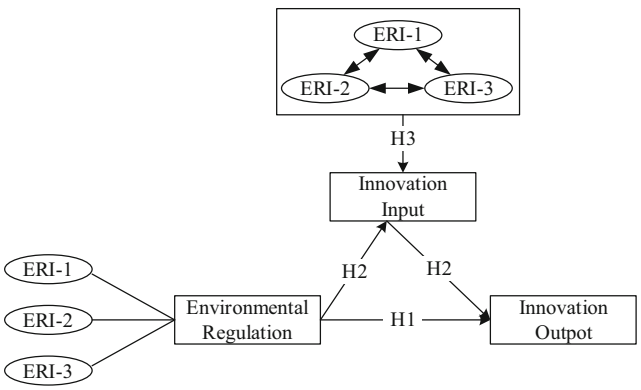

Fig. 1 Hypothesis model

Sample sources and empirical models

Sample sources

The paper takes high-tech enterprises in the Chinese A-share market as a sample, with the sample range being from 2012 to 2017. Due to the lack of an accurate definition of the high-tech enterprises in the Chinese-listed enterprises' categories, the paper uses the most appropriate screening method and selects sample enterprises following the following principles: (1) Include enterprises that were listed in Chinese A-share market before December 31, 2011. (2) According to the "measures for the administration of recognition of high-tech enterprises," enterprises can enjoy the income tax rate of 15% for three consecutive years after obtaining the qualification of high-tech enterprises. In the article, the income tax rate data in the CSMAR database corresponding to the sample of 3 years after the enterprise qualified high-tech enterprise and the relevant stock code are reviewed to further ensure the accuracy of the data. When the two data do not match, we manually read the annual report for confirmation. (3) Some listed companies do not disclose in the annual report whether they have obtained the qualification recognition of high-tech enterprises. To ensure the accuracy of sample selection, the article further confirms whether the samples are qualified for high-tech enterprise identification by combining with the public documents on the "high-tech enterprise identification management network." (4) To avoid the influence of issuing either domestic foreign capital stocks or overseas shares on enterprises' investment behavior, the sample does not contain enterprises that issue B, H, and N shares. (5) Remove some enterprises with incomplete sample data. (6) The samples of ST and *ST-listed companies were removed. (7) This article deletes the financial industry sample. A total of 3438 panel observations are obtained from 573 sample enterprises.

In this study, the relevant data of environmental regulation comes from the China Environmental Yearbook, the financial data comes from the CSMAR database, and the relevant data of the enterprise innovation department comes from the WIND database. The study uses Excel2019 and STATA15 to organize and analyze the data.

Variable definition

Independent variables

Since environmental issues have been concerned, the government has gradually introduced a series of environmental regulation tools. Based on different environmental regulation mechanisms, the paper divides environmental regulation tools into three categories: command-controlled environmental regulation, market-incentive environmental regulation, and voluntary environmental regulation (Wang et al. 2016; Huang et al. 2014).

Command-controlled environmental regulation refers to the direct management and supervision of relevant environmental production activities by administrative departments. Governments, industrial organizations, and environmental protection departments have formulated a variety of environmental protection systems and standards to control environmental pollution sources through the provision of environmental protection standards. Therefore, the command-controlled environmental regulation (ERI-1) is measured by the number of current effective environmental regulations and rules of the year (Lanoie et al. 2011; Testa et al. 2011).

Market-incentive environmental regulation mainly exists in the form of emission trading license and emission tax. As an environmental policy with long implementation time, emission fee not only affects the decision-making of enterprises but also promotes the improvement of emission technology and enterprise innovation (Acemoglu et al. 2011; Meltzer 2014). In the article, the ratio of the amount of pollutant discharge fees collected by each region to the number of discharged households is selected as an alternative variable of market-incentive environmental regulation (ERI-2).

Voluntary environmental regulation is an agreement, commitment, or plan to protect the environment proposed by environmental protection agencies, the public, and other subjects based on the voluntary participation of enterprises. The data of voluntary supervision at the regional level is selected to measure the intensity of voluntary environmental regulation (ERI-3).

Dependent variables

The dependent variables in the paper include innovation input and innovation output. Among them, innovation input (RD) is measured by the logarithm of R&D investment, innovation output (Patent) is measured by the number of patent applications, and innovation quality (Patenti) is measured by the number of invention patent applications.

Control variables include marketization index and enterprise data (Wang and Liu 2020). The detailed variable definitions in the paper are shown in Table 1.

Empirical model

To analyze whether the impact of environmental regulation on the innovation output of enterprises is different, the article builds model 1. Model 2a verifies the impact of different types of environmental regulatory tools on the innovation output (Patent). Model 2b is used to test the impact on innovation quality (Patenti). Meanwhile, considering the time lag of

innovation, the dependent variables in model 1 include the current period and the lag period.

$$\text{Patent}_{i,t}/\text{Patent}_{i,t+1} = \beta_0 + \beta_1 ER_{i,t} + \beta_2 \text{Controls}_{i,t} + \varepsilon \quad (1a)$$

$$\text{Patenti}_{i,t}/\text{Patenti}_{i,t+1} = \beta_0 + \beta_1 ER_{i,t} + \beta_2 \text{Controls}_{i,t} + \varepsilon \quad (1b)$$

Among them, ER includes command-controlled environmental regulation (ERI-1), market-incentive environmental regulation (ERI-2), and voluntary environmental regulation (ERI-3). The relationship and differences between the three types of environmental regulations on the technological innovation of enterprises are judged by comparing the coefficients to test hypothesis 1.

To study the impact of different types of environmental regulation tools on innovation input, the article constructs model 2.

$$RD_{i,t} = \beta_0 + \beta_1 ER_{i,t} + \beta_2 \text{Controls}_{i,t} + \varepsilon \quad (2)$$

Innovation input directly affects innovation output. Therefore, after studying the impact of heterogeneous environmental regulation on innovation output and innovation input respectively, we need to further test whether there is mediating effect between environmental regulation tools and enterprise technology innovation output.

$$\text{Patent}_{i,t} = \beta_0 + \beta_1 ER_{i,t} + \beta_2 RD_{i,t} + \beta_3 \text{Controls}_{i,t} + \varepsilon \quad (3a)$$

$$\text{Patenti}_{i,t} = \beta_0 + \beta_1 ER_{i,t} + \beta_2 RD_{i,t} + \beta_3 \text{Controls}_{i,t} + \varepsilon \quad (3b)$$

Different environmental regulation tools will not play an independent role in the innovation activities of enterprises. Therefore, it is necessary to further verify whether there is an interaction effect between different types of environmental regulation on enterprise technological innovation. The article builds model 4. Model 4a is used to test whether there is an interaction effect between command-controlled environmental regulation and market-incentive environmental regulation on enterprise technological innovation. Innovation includes innovation input ($\text{RD}_{i,t}$) and innovation output ($\text{Patent}_{i,t}$, $\text{Patent}_{i,t+1}$, $\text{Patenti}_{i,t}$, $\text{Patenti}_{i,t+1}$).

$$\text{Innovation}_{i,t} = \beta_0 + \beta_1 ERI{-}1_{i,t} + \beta_2 ERI{-}2_{i,t} + \beta_3 ERI{-}1_{i,t} * ERI{-}2_{i,t} + \beta_4 \text{Controls}_{i,t} + \varepsilon \quad (4a)$$

Model 4b is used to test the interaction effect of market-incentive environmental regulation and voluntary environmental regulation on enterprise technological innovation.

$$Innovation_{i,t} = \beta_0 + \beta_1 ERI{-}2_{i,t} + \beta_2 ERI{-}3_{i,t} + \beta_3 ERI{-}2_{i,t} * ERI{-}3_{i,t} + \beta_4 Controls_{i,t} + \varepsilon \quad (4b)$$

$$Innovation_{i,t} = \beta_0 + \beta_1 ERI{-}1_{i,t} + \beta_2 ERI{-}3_{i,t} + \beta_3 ERI{-}1_{i,t} * ERI{-}3_{i,t} + \beta_4 Controls_{i,t} + \varepsilon \quad (4c)$$

Model 4c is used to test the interaction effect between command-controlled environmental regulation and voluntary environmental regulation on enterprise technological innovation.

Results and analysis

Descriptive statistics

The descriptive statistical results are shown in Table 2.

It can be seen that the average value of R&D investment is 18.246, of which the minimum value is 12.737, the maximum value is 23.285, and the median value is 18.182 which is slightly lower than the average value, indicating that more than 50% of R&D investment of high-tech enterprises has not reached the average level, and enterprises still need to increase R&D investment. From the perspective of technological innovation output, the average value of the whole sample is 3.687, and the maximum value and the minimum value are 8.962 and 0.693, respectively. Therefore, there is a large gap between innovation input and output of different enterprises, and most enterprises are in the state of low input and low output. From the mean and maximum of different types of environmental regulation tools, there are great regional differences in environmental regulation.

Results and analysis

The impact of heterogeneous environmental regulation on enterprises innovation

In the article, we select the balance panel data and use the Hausman test to select the model. The article first verifies the impact of heterogeneous environmental regulation on technological innovation output of enterprises, and the analysis results are shown in Table 3.

Market-incentive environmental regulation and voluntary environmental regulation promote enterprise innovation output (Cheng et al. 2020). From the results in Table 3, it can be seen that whether it is the total number of patents or the number of invention patents, market-incentive environmental regulations and innovation output are positively correlated, and pass the 1% significance test. The impact of voluntary environmental regulation on innovation output also shows a significant positive correlation. The impact of command-controlled environmental regulation on the amount of innovation output is not significant. At a significance level of 10%, the impact of command-controlled environmental regulation on output quality is only 0.002. The results show that more flexible environmental policies have a stronger incentive effect on innovation (Pan et al. 2019), and verify hypothesis 1.

Table 1 Variable definition description

Type	Symbol	Meaning	Definition	Unit of measurement
Dependent variables	RD	Innovation input	The logarithm of R&D investment	Yuan
	Patent	Innovation output	The logarithm of the number of patent applications	Piece
	Patenti	Innovation quality	The logarithm of the number of invention patent applications	Piece
Independent variables	ERI-1	Command-controlled environmental regulation	The number of current effective environmental regulations and rules	Piece
	ERI-2	Market-incentive environmental regulation	The ratio of the amount of pollutant discharge fees collected by each region to the number of discharged households	10,000 yuan/household
	ERI-3	Voluntary environmental regulation	The data of voluntary supervision at the regional level	Piece
Control variables	M-Index	Market index	According to the "overall score of marketization process" in Fan Gang et al. (2016) marketization index system	
	TAX	Enterprise comprehensive tax rate	(Business tax and surcharges + income tax)/total operating income	%
	LEV	Asset liability ratio	Debt/asset	%
	ROA	Return on assets	Net profit/total asset	%
	Dual	Two duty unification	When the two positions of chairman and general manager are combined, it takes 1, otherwise takes 0	1
	NPM	Net operating rate	Net profit/operating revenue	%
	Indir	Proportion of independent directors	Number of independent directors/ Number of directors	%
	S	Equity checks and balances	The sum of the second to tenth largest shareholders/the largest	%
	LnMS	Management incentives	Natural logarithm of total annual salary of directors, supervisors and senior executives	Yuan

With the continuous improvement of China's environmental regulatory system, market-incentive environmental regulations and voluntary environmental regulation tools can make up for the shortcomings of command-controlled environmental regulations. Market-incentive environmental regulation provides enterprises with more ample motion and choice, which better caters to the profit-seeking nature of enterprises. Driven by interests, companies will actively innovate to obtain additional subsidies and tax incentives, as well as reduce pollution taxes. The flexibility characteristics of market-incentive environmental regulation may also be an important factor in stimulating innovation. Enterprises can avoid losses and reduce costs to the maximum during the innovation process. The responsible subject of voluntary environmental regulation is the enterprise. This allows companies to have more autonomy and choice in meeting environmental protection requirements. On the one hand, it is distinct from the mandatory tasks of energy-saving and emission reduction imposed by the government. On the other hand, it ceases to be limited to simple and direct external environmental protection incentives, but an environmental regulation that requires companies to act within their own abilities and proceed from reality, and inspiring companies to innovate from the inside out (Lim and Prakash 2014, Stucki et al. 2018). If the enterprise voluntarily participates in the environmental protection agreement, it indicates that the enterprise has controlled all kinds of pollution emissions within the standard in production activities and complies with pollution prevention and environmental protection. With the continuous improvement of production process, enterprises can obtain a win-win situation of environmental and economic.

Table 2 The descriptive statistical results

Variables	Mean	Std	Min	Max	Median	*N*
RD	18.246	1.222	12.737	23.285	18.182	3438
Patent	3.687	1.322	0.693	8.962	3.638	3438
Patenti	2.786	1.397	0	8.788	2.708	3438
ERI-1	33.778	19.011	3	105	35	3438
ERI-2	6.272	4.050	1.515	33.994	5.471	3438
ERI-3	8.588	0.843	4.700	10.077	8.701	3438
M-Index	8.312	1.578	2.87	10.29	8.89	3438
TAX	0.024	0.030	− 0.316	0.774	0.019	3438
LEV	0.427	0.185	0.007	0.979	0.418	3438
ROA	0.042	0.055	− 0.448	0.361	0.036	3438
Dual	0.273	0.445	0	1	0	3438
NPM	0.063	0.236	− 8.910	2.024	0.058	3438
Indir	0.369	0.053	0.25	0.714	0.333	3438
S	0.836	0.741	0.015	8.173	0.675	3438
LnMS	15.304	0.685	13.045	18.771	15.258	3438

Table 3 Results of the impact of heterogeneous environmental regulation on output of enterprises innovation

Variables	Model 1a			Model 1b		
	Patent			Patenti		
ERI-1	0.002 (1.49)			0.002* (1.70)		
ERI-2		0.020*** (2.87)			0.023*** (3.10)	
ERI-3			0.080* (1.76)			0.101** (2.15)
M-Index	0.213*** (6.75)	0.189*** (5.70)	0.195*** (5.83)	0.252*** (7.08)	0.223*** (5.95)	0.229*** (6.11)
TAX	− 0.084 (− 0.07)	− 0.082 (− 0.07)	− 0.044 (− 0.04)	0.149 (0.13)	0.154 (0.13)	0.200 (0.17)
LEV	0.659*** (3.16)	0.661*** (3.18)	0.656*** (3.14)	0.484** (2.20)	0.485** (2.21)	0.480** (2.18)
ROA	0.337 (0.81)	0.418 (1.01)	0.328 (0.79)	− 0.408 (− 0.83)	− 0.312 (− 0.63)	− 0.420 (− 0.85)
Dual	0.048 (0.85)	0.040 (0.71)	0.047 (0.84)	0.025 (0.40)	0.015 (0.25)	0.024 (0.39)
NPM	− 0.102 (− 1.28)	− 0.110 (− 1.37)	− 0.100 (− 1.24)	0.011 (0.10)	0.001 (0.01)	0.012 (0.11)
Indir	− 0.118 (− 0.24)	− 0.166 (− 0.34)	− 0.088 (− 0.18)	0.095 (0.19)	0.039 (0.08)	0.132 (0.27)
S	0.117*** (2.67)	0.115*** (2.68)	0.114*** (2.62)	0.121** (2.59)	0.120** (2.57)	0.118** (2.52)
LnMS	0.338*** (6.11)	0.318*** (5.79)	0.334*** (6.01)	0.355*** (6.04)	0.332*** (5.74)	0.350*** (5.98)
N	3438	3438	3438	3438	3438	3438
R^2	0.088	0.092	0.089	0.089	0.094	0.090
F-Values	14.75***	14.75***	14.69***	13.81***	13.78***	13.47***

***, **, and * are significant at the level of 1%, 5%, and 10% respectively; *t* value is in brackets

The innovation caused by environmental regulations is substantial. The impact of command-controlled environmental regulations and voluntary environmental regulations on invention patents is more significant than the impact on the total number of patents. The influence coefficient of market-incentive environmental regulations on invention patents (0.023) is also higher than that on the total number of patents (0.020). The strengthening of environmental regulations can not only bring about an increase in the quantity of innovation output but also have a great impact on the quality of output. Patents include invention patents, utility model patents, and appearance designs. Faced with the pressure of environmental regulations, it is not feasible for companies to improve the practicability of products or beautify the appearance of products, and it will even cause greater environmental pressure on the company. The temporary measures taken by enterprises to respond to environmental policies are no longer effective. Driven by long-term economic benefits and environmental benefits, companies must advance production technology, optimize production processes, and produce green products in order to attract more green consumers and achieve sustainable corporate development.

The mediating effects of innovation input

According to the testing method of mediating effect (Wang et al. 2020), the following regression equation models are constructed to test the mediating effects of innovation input. The intermediary effect of command-controlled environmental regulation is not tested, because it has no significant impact on the technological innovation output of enterprises. It can be seen that the influence of main variables is not significant.

Regression analysis results show that hypothesis 2 is verified. As shown in model 3a and model 3b in Table 4, the relationship between environmental regulation tools and innovation effect changes from significant to insignificant after adding the intermediary variable, which shows that the effect of environmental regulation on innovation output was fully mediated by innovation input. The significant positive effect of environmental regulation on innovation effect is that environmental regulation first has incentive effect on innovation input, and then influences innovation output. The implementation of environmental regulation tools affects the innovation output by affecting the allocation of innovation resources.

R&D investment plays a mediating role in the impact of environmental regulation on innovation output. In Table 3, environmental regulation tools significantly positively affect the quantity and quality of innovation output. The results of models 3a and 3b in Table 4 show that when the intermediate variable of R&D investment is added, the positive effect of ERI on innovation output is not significant. This is consistent with hypothesis 2. First, environmental regulations will stimulate companies to increase investment in innovation. At the 1% significance level, the correlation coefficient between ERI-1 and R&D input is 0.004. For every 1% increase in the level of command-controlled environmental regulations, R&D investment has increased by 0.038%. Compared with the above two tools, voluntary environmental regulation tools

Table 4 The mediating effect of innovation input

Variables	Model 2			Model 3a				Model 3b			
	RD			Patent				Patenti			
ERI-1	0.004*** (3.85)			0.0002 (0.15)				0.001 (0.52)			
ERI-2		0.038*** (6.63)			0.006 (0.93)				0.010 (1.41)		
ERI-3			0.215*** (5.75)			0.001 (0.03)				0.024 (0.55)	
RD				0.364*** (7.02)	0.359*** (6.86)	0.364*** (6.99)	0.364*** (7.07)	0.357*** (6.67)	0.349*** (6.46)	0.356*** (6.62)	0.359*** (6.73)
M-index	0.256*** (9.24)	0.208*** (7.19)	0.207*** (7.17)	0.120*** (3.71)	0.114*** (3.47)	0.119*** (3.57)	0.120*** (3.69)	0.161*** (4.38)	0.151*** (4.01)	0.156 (4.12)	0.160*** (4.34)
TAX	−2.361** (−2.18)	−2.341** (−2.14)	−2.260** (−2.10)	0.775 (0.76)	0.757 (0.73)	0.779 (076)	0.779 (076)	0.993 (0.94)	0.971 (0.91)	1.004 (0.95)	1.008 (0.95)
LEV	0.540*** (2.89)	0.543*** (2.97)	0.533*** (2.87)	0.463** (2.42)	0.466** (2.43)	0.462** (2.42)	0.463** (2.42)	0.291 (1.40)	0.296 (1.42)	0.290 (1.40)	0.290 (1.40)
ROA	1.144*** (2.93)	1.290*** (3.25)	1.123*** (2.85)	−0.079 (−0.20)	−0.044 (−0.11)	−0.082 (−0.21)	−0.082 (−0.21)	−0.817* (−1.75)	−0.763 (−1.62)	−0.820* (−1.75)	−0.827* (−1.77)
Dual	0.025 (0.67)	0.010 (0.26)	0.024 (0.64)	0.038 (0.73)	0.036 (0.69)	0.038 (0.73)	0.038 (0.73)	0.016 (0.27)	0.012 (0.21)	0.015 (0.27)	0.015 (0.27)
NPM	−0.095*** (−3.22)	−0.110*** (−3.55)	−0.094*** (−2.92)	−0.067 (−0.88)	−0.071 (−0.92)	−0.067 (−0.88)	−0.067 (−0.88)	0.045 (0.42)	0.039 (0.37)	0.045 (0.43)	0.046 (0.44)
Indir	−0.145 (−0.38)	−0.227 (−0.62)	−0.070 (−0.18)	−0.065 (−0.15)	−0.084 (−0.19)	−0.063 (−0.14)	−0.063 (−0.14)	0.146 (0.34)	0.118 (0.27)	0.157 (0.36)	0.154 (0.35)
S	0.104*** (2.83)	0.103*** (2.87)	0.097*** (2.65)	0.079** (2.02)	0.079** (2.02)	0.079** (2.03)	0.079** (2.03)	0.084* (1.94)	0.084* (1.94)	0.084* (1.92)	0.085* (1.95)
LnMS	0.442*** (8.51)	0.407*** (7.97)	0.428*** (8.25)	0.177*** (3.17)	0.172*** (3.08)	0.178*** (3.16)	0.178*** (3.16)	0.198*** (3.32)	0.190*** (3.23)	0.197*** (3.33)	0.200*** (3.36)
N	3438	3438	3438	3438	3438	3438	3438	3438	3438	3438	3438
R^2	0.234	0.254	0.244	0.147	0.148	0.147	0.147	0.138	0.139	0.138	0.138
F-values	32.55***	32.60***	32.46***	20.55***	20.45***	20.44***	22.44***	17.25***	17.15***	16.92***	18.54***

***, **, and * are significant at the level of 1%, 5%, and 10% respectively; *t* value is in brackets

have the greatest impact on R&D (0.215). Second, R&D investment is an important factor in determining innovation output. Due to environmental regulations, companies need to adjust the energy consumption structure, optimize production processes, and carry out source pollution control. Therefore, they will seek to increase continuous and lasting R&D investment to promote technological innovation (Marin 2014; Raymond et al. 2015). By developing new products with low energy consumption and fewer pollutants, they can meet the constraints of environmental regulations. The increase in innovation input has improved the absorption capacity of enterprises. Enterprises can integrate internal and external resources more smoothly, which has an influence on innovation output. Therefore, environmental regulation enables enterprises to enhance innovation input, and indirectly affects innovation output.

Comparison of the results in Table 4 and Table 3 shows that voluntary environmental regulations have the greatest impact on innovation input, market-incentive environmental regulations have the most significant incentive effect on innovation output, and command-controlled environmental regulations have the worst effect on innovation. In a regulatory environment with a higher degree of freedom, it is easier for companies to obtain innovative resources, such as R&D funds and environmentally conscious researchers, so the investment will increase. However, it is precisely because of the small binding force that companies are often not cautious when increasing R&D investment and lack planning to maximize innovation results. In contrast, although market-incentive environmental regulations have brought financing pressure to companies to a certain extent, they also encourage companies to make fuller use of resources, pay more attention to the input-output process, and maximize efficiency.

The interaction effect of different environmental regulation on innovation

Based on the previous regression results, the paper studies the interaction effect of different environmental regulation on the innovation. The data results are shown in Table 5.

Different environmental regulation tools have interactive effects on corporate innovation. From the results of rows 5–7 in Table 5, it can be found that the interactive items of environmental regulation tools (ERI-1*ERI-2, ERI-2*ERI-3, ERI-1*ERI-3) all have positive effects on enterprise innovation. Different environmental regulation tools have complementary effects on corporate innovation. The positive effects of interaction items on enterprise innovation investment (RD) passed the 1% significance test. ERI-1*ERI-2 and ERI-1*ERI-3 also have a significant positive impact on enterprise innovation output (Patent, Patenti). The positive impact of ERI-2*ERI-3 on innovation output is not significant. It shows that command-controlled environmental regulation and more

Table 5 Results of interaction effect of different environmental regulation on enterprises innovation

Variables	RD			Patent			Patenti		
	Model 4a	Model 4b	Model 4c	Model 4a	Model 4b	Model 4c	Model 4a	Model 4b	Model 4c
ERI-1	0.017 (0.76)		0.066*** (3.29)	− 0.016 (− 0.77)		− 0.009 (− 0.46)	− 0.009 (− 0.42)		0.001 (0.06)
ERI-2	0.197*** (7.34)	0.129*** (6.01)		0.124*** (4.21)	0.095*** (2.95)		0.138*** (4.33)	0.126*** (3.54)	
ERI-3		0.163*** (5.68)	0.163*** (5.24)		0.041 (1.07)	0.086** (2.33)		0.049 (1.24)	0.097** (2.48)
ERI-1*ERI-2	0.072*** (3.49)			0.067*** (3.05)			0.067*** (2.85)		
ERI-2*ERI-3		0.065*** (3.68)			0.028 (1.31)			0.052 (2.15)	
ERI-1*ERI-3			0.056*** (3.62)			0.072*** (3.77)			0.061*** (2.95)
M-index	0.218*** (7.68)	0.190*** (6.45)	0.190*** (6.43)	0.195*** (5.96)	0.187*** (5.44)	0.206*** (6.24)	0.230*** (6.19)	0.226*** (5.82)	0.240*** (6.48)
TAX	− 2.506** (− 2.35)	− 2.376** (− 2.24)	− 2.225** (− 2.03)	− 0.205 (− 0.18)	− 0.135 (− 0.11)	− 0.105 (− 0.09)	0.026 (0.02)	0.052 (0.04)	0.139 (0.12)
LEV	0.535*** (2.92)	0.537*** (2.96)	0.534*** (2.93)	0.654*** (3.14)	0.659*** (3.16)	0.657*** (3.15)	0.478** (2.17)	0.483** (2.20)	0.480** (2.18)
ROA	1.358*** (3.44)	1.288*** (3.26)	1.192*** (3.03)	0.465 (1.12)	0.435 (1.05)	0.323 (0.79)	− 0.263 (− 0.53)	− 0.283 (− 0.57)	− 0.418 (− 0.85)
Dual	0.013 (0.35)	0.011 (0.29)	0.023 (0.61)	0.042 (0.75)	0.040 (0.70)	0.046 (0.81)	0.017 (0.29)	0.014 (0.24)	0.023 (0.38)
NPM	− 0.115*** (− 3.59)	− 0.108*** (− 3.41)	− 0.104*** (− 3.43)	− 0.113 (− 1.37)	− 0.112 (− 1.35)	− 0.096 (− 1.21)	− 0.002 (− 0.02)	− 0.002 (− 0.02)	0.015 (0.14)
Indir	− 0.279 (− 0.75)	− 0.203 (− 0.55)	− 0.153 (− 0.41)	− 0.197 (− 0.40)	− 0.156 (− 0.32)	− 0.102 (− 0.20)	0.005 (0.01)	0.051 (0.11)	0.114 (0.23)
S	0.090** (2.51)	0.087** (2.47)	0.098*** (2.72)	0.106** (2.43)	0.110** (2.54)	0.107** (2.46)	0.110** (2.35)	0.112** (2.39)	0.112** (2.39)
LnMS	0.371*** (7.33)	0.368*** (7.23)	0.408*** (7.84)	0.292*** (5.30)	0.307*** (5.56)	0.315*** (5.69)	0.305*** (5.21)	0.315*** (5.42)	0.332*** (5.64)
N	3438	3438	3438	3438	3438	3438	3438	3438	3438
R^2	0.266	0.273	0.255	0.096	0.093	0.094	0.097	0.097	0.094
F-values	32.41***	32.15***	29.53***	13.40***	12.65***	13.43***	12.49***	12.09***	12.12***

***, **, and * are significant at the level of 1%, 5%, and 10% respectively; *t* value is in brackets

Table 6 The lag effect of environmental regulation on innovation effect

Variables	Model 1a		Model 1b		Model 3a		Model 3b	
	$Patent_{t+1}$		$Patenti_{t+1}$		$Patent_{t+1}$		$Patenti_{t+1}$	
$ERI\text{-}1_t$	− 0.001 (− 0.66)		0.0002 (0.09)		− 0.001 (− 0.88)		− 0.0002 (− 0.09)	
$ERI\text{-}2_t$		0.027*** (2.67)		0.024** (2.31)		0.008 (0.76)		0.005 (0.51)
$ERI\text{-}3_t$			0.086* (1.70)		0.088* (1.71)		0.046 (0.97)	
RDt					0.270*** (5.79)	0.262*** (5.49)	0.264*** (5.83)	0.259*** (5.51)
N	2865	2865	2865	2865	2865	2865	2865	2865
R^2	0.092	0.102	0.091	0.100	0.326	0.329	0.320	0.322
F-values	19.79***	18.92***	12.11***	12.99***	25.32***	24.21***	12.74***	12.83***

							0.049 (1.01)	0.260*** (5.72)
							2865	2865
							0.322	0.316
							12.83***	13.04***

flexible regulation tools have significant complementary effects (Yuan 2019). The results are consistent with hypothesis 3. The implementation of flexible environmental regulation tools is conducive to weakening the inhibitory effect of controlled environmental regulation on innovation. The synergistic effect stimulated by flexible environmental regulation exists significantly. The main reason for this difference is that flexible environmental regulations have the function of self-implementation. The enhancement of regulatory intensity has a greater marginal promotion effect on the formation of compliance habits and awareness of compliance of regulatory objects. Besides, flexible environmental regulations have a strong ability to optimize the implementation of controlled environmental regulations, and the stimulating synergy effect is more obvious.

From the results of other control variables, the higher the degree of marketization, the more favorable it is for enterprises to carry out technological innovation activities. The company's asset-liability ratio, equity checks and balances, and management incentives also have a positive impact on corporate innovation activities. Corporate profitability is a prerequisite for innovative products (Li et al. 2017). From the results of the article, the increase in corporate profitability will cause an increase in innovation input, but the results of innovation output are not significant. The impact of a company's profitability on the innovation process is not significant.

The lag effect of environmental regulation on innovation effect

Because of the time lag of innovation, we considered the lag effect of environmental regulation on innovation output. Enterprise patent data can only be obtained from 2012 to 2017, so the independent variable is selected from 2012 to 2016 to explore the lag effect. The main data results are shown in Table 6. The results of the control variables are not shown in the table.

The result of the lag effect is basically consistent with the result of the non-lag data. Hypothesis 1 and hypothesis 2 still hold in the lag effect. We found that command-controlled environmental regulation on the innovation effect of lag phase is negative. This shows that there is a short-term incentive effect on the impact of command control on innovation, and there may be an "inverted U" relationship. This requires further research.

Conclusions and policy implications

Conclusions

Based on the background of environmental governance protection and innovation transformation, the article explores the

mechanism of heterogeneous environmental regulation on enterprise technological innovation. The conclusions are as follows: (1) The impact of different environmental regulation tools on enterprise innovation is different. Compared with command-controlled environmental regulation tools, market-incentive environmental regulation tools and voluntary environmental regulation tools have a more significant positive impact on the innovation output of enterprises. Among three environmental regulations, market-incentive environmental regulation appears to be the one with the strongest incentive effective on enterprise innovation, voluntary comes second, and command-controlled tends to be the weakest. (2) Environmental regulations not only promote the increase in the number of innovative products but also help improve the quality of innovative products. (3) It is found that the effect of environmental regulation on innovation output was fully mediated by innovation input. (4) The impact of command-environmental environmental regulation and the other two regulatory tools on innovation input is significantly positive. The interaction effect of market-incentive environmental regulation and voluntary environmental regulation on corporate innovation is positive and insignificant. That is, command-controlled environmental regulation and more flexible regulatory tools have significant complementary effects, while the complementary effects of market-incentive environmental regulation and voluntary environmental regulation are not significant.

This article still has the following limitation and future research direction. First, the innovation input and output of this article are measured by R&D input and patent number respectively. But innovation input also includes the input of R&D personnel, and innovation output also includes new product revenue and intangible assets formed by R&D. The incomplete disclosure of corporate information increases the difficulty in collecting the above information. As the market continues to improve, relevant data will be easier to obtain, and comprehensive indicators of input and output can be measured in the future. Secondly, this article only analyzes and researches explicit environmental regulations, and does not study the impact of implicit environmental regulations on enterprise technological innovation activities. Therefore, how to better study the impact of different types of environmental regulatory tools on the technological innovation activities of enterprises remains to be further discussed.

Policy implications

Effective environmental regulation tools can stimulate enterprises to undertake innovation activities. From the point of view of government departments, they should continue to pay attention to environmental protection. Through the rational design of regulatory policies, they can fully mobilize the innovation enthusiasm for enterprises and achieve green economic development. (1) Implement moderately strict command-controlled environmental regulation and strengthen the level of supervision to stimulate the willingness of enterprises to innovate in technology. They should also implement market-incentive environmental regulation and voluntary environmental regulations to give full play to the dynamic adjustment characteristics of flexible regulation tools, promoting enterprises to actively improve their technological innovation capabilities. (2) When choosing the proportion of regulation tools, the principle is that proportion of command-controlled environmental regulation should be small, and the tools with high flexibility should be large. In the long run, the role of direct and indirect promotion of environmental regulation will be better played. (3) The government can dynamically adjust and improve the intensity and methods of environmental regulation based on the implementation results and the company's response, and establish a comprehensive and effective environmental regulation tool system.

Enterprises need to raise awareness of environmental protection management and abide by environmental laws and regulations. They cannot be limited to the lowest level requirements for terminal governance, but should endeavor to meet the higher-level requirements for technological research and innovation. By innovating the manufacturing process and eliminating backward production equipment, enterprises are able to take the road of green innovation and sustainable development. Facing the government's environmental supervision policies, enterprises should start from a rational perspective instead of being passive and slack. They should change the concept of environmental management from passive to active, and actively use their own advantages for R&D innovation.

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