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The Impact of Different Environmental Regulatory Tools on Technological Innovation in China's Manufacturing Industry

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Abstract

There are different types of environmental regulation tools, such as command and control, economic incentive and public participation, and the combination of environmental regulation tools can be divided into command and control and economic incentive, economic incentive and public participation, command and control and public participation and so on. Using the panel data of China's listed manufacturing enterprises from 2010 to 2018, this paper empirically analyzes the impact of three combinations of environmental regulation tools, namely command and control type and economic incentive type, economic incentive type and public participation type, command and control type and public participation type, on the technological innovation of China's manufacturing enterprises. The results show that the combination of command and control type and economic incentive type, economic incentive type and public participation type can promote the technological innovation of manufacturing enterprises, while the combination of command and control type and public participation type is not conducive to the technological innovation of China's manufacturing enterprises. Regression is conducted with economic incentives of Environmental regulation as the threshold variable, found the command control type and the public participation in environmental regulation on manufacturing technology innovation is double threshold effect, and with the increase of the economic strength of the motivational tool, command control type and the public participating the effect of environmental regulation tools are also enhanced. The research in this paper shows that when environmental regulation of China's manufacturing enterprises is carried out, the combination of command and control type and economic incentive type and economic incentive type and public participation type can play a role in promoting technological innovation in China's manufacturing industry.

Keywords

China's Manufacturing Industry, Environmental Regulation, Combination of Environmental Regulation, Technological Innovation, Threshold Effect

1. Introduction

China's manufacturing industry consists of light and textile industry, resource processing industry, machinery and electronics manufacturing industry, which is the foundation and pillar of its production capacity and national economy, and represents its comprehensive strength and international competitiveness to a great extent. Since 2010, China has been the world's largest manufacturing country for many consecutive years. By 2018, the scale of China's manufacturing industry exceeded 30 trillion yuan, accounting for more than 28 percent of the world market share (data from: 2018 China Manufacturing Industry Research Report). However, compared with developed countries, China's manufacturing industry still exists the phenomenon of being "large but not strong", lacking independent innovation ability and core technology being controlled by others. Meanwhile, China's manufacturing industry is meaning body of pollution discharge, the matter of environmental pollution occurs frequently in recent years (Yu & Hu, 2016). In order to drive green development of the economy, China positively promotes environmental pollution improvement and makes relevant environmental policy regulation tools. And what is the effect of environmental regulation? Researches show that a single environmental regulation tool is difficult to urge technological progress of enterprises of China's manufacturing industry (Xu & Qi, 2017; Jiang, Wang, & Bai, 2013). This paper examines the combination of relevant environmental policy instruments that can promote technological progress in China's manufacturing sector.

2. Literature Review

Environmental regulation is a binding force with environmental protection as the purpose, individuals or organizations as the object, and tangible institutions or intangible consciousness as the form of existence (Zhao, 2009). From the perspective of policy tools, environmental regulation can be divided into different types such as command and control, economic incentive and public participation (Zhang et al., 2021b). The impact of a single environmental regulation tool on the technological innovation of China's manufacturing industry still remains controversial in academia. For example, in terms of the influence of command-and-control regulation tools, Yin et al. (2022) from a long-term perspective believed that under the government-mandated environmental regulation, enterprises would choose cleaner production technologies to maximize their own interests. By analyzing the data of manufacturing industries with different levels of competition, Zhang et al. (2020) concluded that due to the man-

datory characteristics of command-and-control environmental regulation, enterprises can only passively accept the internalization of external costs of environmental governance, which is not conducive to enterprise technological innovation. In terms of the influence of economic incentive regulation tools, Yin et al. (2022) believed that through market behaviors such as emission permits, emission rights trading, and emission taxes (fees), economic incentive environmental regulation tools play an active role in guiding China's manufacturing industry to reduce emissions. However, Zhang and Qiao (2012) pointed out that China's current market for trading pollution discharge is incomplete, so economic incentive environmental regulation cannot perform a function on promoting technological innovation. In terms of the influence of public participation regulation tools, the academic community mostly holds a positive view (Tu et al., 2018; Wang & Wang, 2018).

Some other scholars studied the interaction of different environmental regulation tools, discussing the impact of different combinations of policy tools on the technological innovation of China's manufacturing industry. Through a questionnaire survey of some manufacturing enterprises in Zhejiang Province, Li Dongqin (2018) found that a single environmental regulation cannot fully and effectively stimulate enterprises to carry out technological innovation, while the combination of command-and-control and economic incentive tools can play a greater positive role in enterprise technological innovation. Peng and Li (2016) believed that for areas with high pollution level and backward economic development level, command-and-control environmental regulation coupled with economic incentive environmental regulation should be emphasized; For the areas with low pollution level and strong technological innovation ability, the combination of economic incentive type and public participation type environmental regulation is more conducive to environmental regulation to play their respective advantages. Zhao and Guan (2018) built a dynamic simulation model of environmental technology innovation of manufacturing enterprises based on the computational experiment method of social science, and analyzed the impact of different combinations of policy instruments on enterprise environmental technology innovation by simulating the process of enterprise environmental technology innovation under different environmental policy scenarios, and also reached the same conclusion. Gao, Yang and Xie (2020) explored the interaction effect between public participation and other environmental regulation measures, and believed that at present, public participation and formal environmental regulation instruments could not cooperate with each other, and the coefficients of interaction terms with formal environmental regulation were all negative.

In conclusion, the academia has done a lot of research on the impact of environmental regulation on the technological innovation of China's manufacturing industry, there are still some problems: First of all, the existing research still has some shortcomings in explaining the single policy instrument and its limitations. Some scholars have proposed that a single command-and-control or eco-

nomic incentive tool is not conducive to the technological progress of Chinese manufacturing enterprises. But many studies have shown that if we combine command-and-control with economic incentive, or economic incentive with public participation, the effect of command-control or economic incentive on enterprise technological innovation will turn from negative to positive. Why has the role of these policy instruments changed so much? This is difficult to explain from the perspective of a single regulatory instrument. Secondly, some scholars have studied the impact of the interaction of different types of environmental regulation on technological innovation in manufacturing, but there are still some problems in this research. For example, the study which is only based on the command control model and economic incentive combination, or the public participation in combination with other environmental regulation tools has not comprehensively and systematically analyzed the impact of various combinations of environmental regulation tools on the technological innovation of China's manufacturing industry. In addition, some studies also have problems such as simple empirical methods and small amount of data.

From this, this paper takes the panel data of China's listed manufacturing enterprises from 2010 to 2018 as the research sample to explore the differences in the impact of different types of environmental regulation and their combinations on the technological innovation of China's manufacturing enterprises.

3. Action Mechanism and Research Hypothesis

3.1. Impact of Different Types of Environmental Regulation Tool Combinations on Technological Innovation in China's Manufacturing Industry

1) The impact of the combination of command-and-control tools and economic incentive tools on technological innovation in manufacturing industry.

Due to different characteristics and action modes of different types of environmental regulation, no one single environmental policy instrument can perfect solve all currently facing environmental problems, we should pursue the combination of rules and regulations in the existing conditions, give full play to the synergistic effect between different types of environmental regulation, achieve the utility maximization of rules and regulations, and at the same time avoid conflict between regulation. The implementation of command-and-control environmental regulation will increase production costs of enterprises, squeeze out non-environmental protection funds, and have a crowding-out effect on technological innovation of enterprises, which is not conducive to technological innovation of manufacturing enterprises. Economic incentive-based environmental regulation often controls price and quantity through the market mechanism, so that enterprises take the initiative to make environmental investment, research and development activities, which can encourage and guide enterprises to carry out technological innovation. However, at present, China's market mechanism is not sound, so that the effect of economic incentive environmental regulation is difficult to work. Therefore, the single command-and-

control or economic incentive environmental regulation is difficult to effectively promote the technological innovation of manufacturing enterprises, but the combination of these two policy measures is conducive to promoting the technological innovation of manufacturing enterprises. The reason is that when the two policy tools play a role, manufacturing enterprises are not only facing pressure from the government, but also have economic profit motive, so they are willing to promote technological innovation. On the one hand, manufacturing enterprises have economic motivation to carry out technological innovation. In the effect of economic incentive environmental regulation, through economic means such as pollution taxes, emissions trading and tax subsidy system to control prices by market mechanisms, which can not only implement the "who pollution, who governance" by levying tax pollution properly and executing tradable pollutant discharge permit system, but also spur and guide the manufacturing enterprise technological innovation by green subsidies and tax breaks. On the other hand, command-and-control environmental regulation puts pressure for enterprises to control environmental pollution through mandatory means, so that enterprises must meet the environmental standards, emission standards and technical standards required by environmental regulation policies, forcing enterprises to carry out technological innovation. In a word, in the case of both command-and-control tools and economic incentive tools, the benefits brought by technological innovation of manufacturing enterprises are greater than the costs brought by command-and-control or economic incentive environmental regulation.

Based on this, this paper puts forward the research hypothesis:

H1: The combination of command-and-control and economic incentive environmental regulation tools is conducive to technological innovation in manufacturing.

2) The impact of the combination of economic incentive tools and public participation tools on technological innovation in manufacturing industry.

According to the above analysis, China's market mechanism is not perfect at present, so that the effect of economic incentive environmental regulation is difficult to work. The pressure of public opinion caused by public participation forms a soft constraint on the production decision-making behavior of enterprises, which further affects the R & D activities of enterprises and makes up for the market failure of R & D. Therefore, the combination of these two policies favor in the technological progress of the manufacturing industry. The reason is that economically incentive environmental regulation is directly related to the interests of manufacturing enterprises. At present, the market mechanism is still underdeveloped and perfect, the effect of pure economic incentive tools is limited, but when we add public participation policy tools, the situation is different. Public participation environmental regulation is dominated by public behavior. Although it is not mandatory, it can influence the strategic behavior of enterprises through external supervision and public opinion pressure. The higher the public pays attention to environmental issues, the more conducive it is to

stimulate the innovation potential of enterprises and transform the cost pressure into innovation power. In the case of public participation, it is easier to make the rights and responsibilities of environmental governance clear, stimulate the technological innovation activities of enterprises, and provide power for enterprises to actively reduce pollution emissions. Therefore, the combination of economic incentive and public participation tools is conducive to the manufacturing industry to increase R & D investment, improve technology actively, increase emission reduction efforts, and carry out technological innovation.

Based on this, this paper puts forward the research hypothesis:

H2: The combination of economic incentive and public participation environmental regulation tools is conducive to technological innovation in manufacturing.

3) The impact of the combination of command-and-control tools and public participation tools on technological innovation in manufacturing industry.

The above analysis shows that command-and-control environmental regulation will increase the production cost of enterprises and have a crowding-out effect on the technological innovation of enterprises. The pressure of public opinion caused by public participation forms a soft constraint on the production decision-making behavior of enterprises, which further affects the R & D activities and makes up for the market failure of R & D. The combination of command-and-control and public participation environmental regulation policy tools can achieve the purpose of promoting the technological innovation of manufacturing enterprises. Public participation in environmental management is mainly through government departments to supervise the behavior of enterprises through environmental letters and visits etc. The public about the environment is very sensitive, who can carry on the real-time feedback promptly to the relevant authorities and reflect the environmental demands and position to the local government, which is advantageous to the relevant departments in a timely manner to the current regulation policy implementation by the moderate supplement and adjustment. The government will crack down on the relevant companies and impose administrative penalties on them for their pollution. Integrating the public into the environmental regulation system can effectively supervise the implementation of environmental protection by the government and enterprises. The combination of the two is beneficial to improving the performance of environmental governance, promoting the implementation of environmental regulation policies in place, and reducing the supervision cost of regulation. Public participation is a supplement to government environmental management, which can limit the abuse of government power, help deepen local governments' attention to the environment, and improve the openness and transparency of government decision-making.

Based on this, this paper puts forward the research hypothesis:

H3: The combination of environmental regulation tools based on government mandate and public participation is conducive to technological innovation in

manufacturing.

3.2. Threshold Effect of Environmental Regulation Tools on Technological Innovation in China's Manufacturing Industry

The impact of environmental regulation and the combination of environmental regulation on the technological innovation of manufacturing enterprises is not only a simple linear relationship, but may have inflection points. With the gradual enhancement of command-and-control environmental regulation, the restraint effect of environmental regulation policies on enterprises begins to exert force, and the market can better motivate enterprises to carry out technological innovation, making the compensation effect of innovation gradually strengthen and exceed the compliance cost effect. As the intensity of economic incentive environmental regulation increases, market price signals can better guide the technological innovation activities of manufacturing enterprises, which also makes enterprises' attitude towards the government's command-and-control of environmental regulation change from passive response to active obedience. The effective role of public participation is based on the role of economic incentive environmental regulation and the effective implementation of command-and-control environmental regulation. With the enhancement of the intensity of economic incentive environmental regulation and the effective implementation of command-and-control environmental regulation policies, the public participation tools play a more significant role in promoting the technological innovation of manufacturing enterprises.

Based on this, this paper puts forward the research hypothesis:

H4: With economic incentive environmental regulation as the threshold variable, command-and-control environmental regulation and public participation environmental regulation have double threshold effects on the technological innovation of Chinese manufacturing enterprises.

4. Empirical Analysis

4.1. Source of Sample Data

Based on the industry categorization standard 2012 of China Securities Regulatory Commission (CSRC), due to the lack of data of core variable indicators in recent years, this paper selects A-share listed manufacturing enterprises in Shanghai and Shenzhen from 2010 to 2018 as research samples. The sample selection procedure is as follows: 1) eliminate ST, *ST companies and companies listed after 2010; 2) Exclude companies with abnormal asset-liability ratio (greater than 1 or less than 0); 3) Eliminate enterprises with missing key financial indicators. Due to the large number of missing data in Tibet, enterprises in Tibet are removed, and 534 companies with a total of 4806 observations are finally obtained. To eliminate the effect of extreme values, we winsorize all continuous variables at the 1% level. Since the environment of the enterprise investment data is more difficult to gain and loss, and environmental regulation is

controlled by the government itself, in the same area environmental controls are the same, so this article USES the enterprise province environmental regulation data measured by the intensity of environmental regulation, environmental regulation data through the environment statistical yearbook, the China environment yearbook collection, The data of environmental letters and visits come from the environmental status bulletin-sheets of various provinces, which are manually collected and sorted by the authors.

4.2. Variable Selection

4.2.1. Explanatory Variables

Environmental regulation (EI). Researchers now working on environmental regulating techniques typically classify them into three groups: command-and-control, economic incentive and public participation. According to Yu et al. (2016), command-and-control environmental regulation was measured using the emissions of the "three wastes" produced by industry and the money invested in industrial pollution control initiatives this year. Zhang (2016) measured economic incentive environmental regulation by looking at per capita sewage charge income and investments in reducing environmental pollution. Zhan and Li (2015) measured the quantity of environmental letters to measure the environmental regulation based on public participation.

Given the accessibility, validity, and reliability of the data, this study selected the provinces' industrial pollution treatment project investment as a share of regional industrial production to measure government-ordered environmental regulation, the provinces' environmental pollution treatment investment as a share of GDP to measure economic incentive environmental regulation, and word frequency to measure each province's environmental performance.

4.2.2. Explained Variables

Technological innovation (R & D intensity). For the measurement of technological innovation, Ma et al. (2011) measured the input and output of technological innovation, while Xu et al. (2015) measured the technological innovation ability and level of enterprises from the development and transformation ability of technological innovation. Considering the availability of indicators, this paper draws on Miao et al. (2019) to use the proportion of R & D investment funds in main business income of each industry as an indicator to measure technological innovation.

4.2.3. Control Variables

Drawing on existing research (Peng & Tan, 2017; Wu et al., 2021), this paper selects some variables that have a great impact on enterprise technological innovation except environmental regulation as control variables, including: 1) capital intensity (KI); 2) Internet development level (Internet); 3) Degree of market competition (M); 4) Enterprise performance (ROA). Specific variable definitions are shown in **Table 1**.

Table 1. Variable definitions.

Variable type	Variable name		Variable symbol	Variable declarations
Explained variable	Technological innovation		R & D intensity	• Internal R & D expenditure of enterprises/Prime operating revenue
Explanatory variable	Environmental regulation	Command-and-control type	EI2	• Investment in regional industrial pollution source control projects • /Gross industrial production of the region
		Economic incentive type	EI4	• Investment in environmental pollution control by province • /GDP of each province
		Public participation type	EI6	• Frequency of environmental protection words in each province
Control variable	Capital intensity		KI	• Enterprise capital/Number of employees
	• Level of Internet development		Internet	• Ln (the internet penetration rate * Length of optical cable)
	Enterprise Performance		ROA	• Return on total assets of enterprises
	• Degree of market competition		M	• Herfindahl index of the industry in *t* year

4.3. Model Construction

1) Benchmark regression model. In order to verify hypotheses H1, H2 and H3, namely, the impact of different combinations of environmental regulations on technological innovation in the manufacturing industry, the following model is constructed with reference to Zhang et al. (2021a):

$$\text{R\&D intensity}_{it} = \alpha_0 + \beta_1 \text{EI2} * \text{EI4}_{it} + \beta_2 X_{it} + \varepsilon_{it} \quad (1)$$

$$\text{R\&D intensity}_{it} = \alpha_0 + \beta_1 \text{EI4} * \text{EI6}_{it} + \beta_2 X_{it} + \varepsilon_{it} \quad (2)$$

$$\text{R\&D intensity}_{it} = \alpha_0 + \beta_1 \text{EI2} * \text{EI6}_{it} + \beta_2 X_{it} + \varepsilon_{it} \quad (3)$$

$$\text{R\&D intensity}_{it} = \alpha_0 + \beta_1 \text{EI2} * \text{EI6}_{it} + \beta_2 X_{it} + \varepsilon_{it} + \beta_5 \text{EI4} * \text{EI6}_{it} + \beta_6 \text{EI2} * \text{EI6}_{it} + \beta_7 X_{it} + \varepsilon_{it} \quad (4)$$

where i represents different enterprises and t represents different years; EI2, EI4 and EI6 respectively represent command-and-control environmental regulation, economic incentive environmental regulation and public participation environmental regulation. R & D intensity represents the level of enterprise technological innovation; EI2 * EI4, EI4 * EI6, EI2 * EI6 respectively represent the combination of command-control and economic incentive environmental regulation tools, the combination of economic incentive and public participation environmental regulation tools, and the combination of command-control and public participation environmental regulation tools. X_{it} represents the control variables used in this paper, including capital intensity (KI), foreign direct investment (FDI), market competition (M) and enterprise performance (ROA); ε_{it} is the random disturbance term.

2) Panel threshold model. In order to verify Hypothesis H3, that is, whether

different types of environmental regulation have nonlinear effects and threshold conditions on the technological innovation of manufacturing enterprises, a nonlinear model is further constructed. The corresponding threshold values are estimated according to the panel threshold regression model proposed by Hansen (1999), and whether there are significant differences in the parameters of the sample groups at different threshold intervals is tested. Referring to Chen et al. (2022), this paper takes economic incentive-based environmental regulation as the threshold variable and takes the double threshold as an example to establish the following model

$$\begin{aligned}&\text{R\&D intensity}_{it}\\&=\alpha_0+\text{EI4}+\text{EI6}+\beta_1\text{EI2}*I\left(\text{EI4}\le r_1\right)+\beta_1\text{EI2}*I\left(r_1<\text{EI4}\le r_2\right)\\&\quad+\beta_3\text{EI2}*I\left(\text{EI4}>r_2\right)+\beta_4X_{it}+\varepsilon_{it}\end{aligned}\tag{5}$$

$$\begin{aligned}&\text{R\&D intensity}_{it}\\&=\alpha_0+\text{EI2}+\text{EI4}+\beta_1\text{EI6}*I\left(\text{EI4}\le r_1\right)+\beta_1\text{EI6}*I\left(r_1<\text{EI4}\le r_2\right)\\&\quad+\beta_3\text{EI6}*I\left(\text{EI4}>r_2\right)+\beta_4X_{it}+\varepsilon_{it}\end{aligned}\tag{6}$$

where $I(\bullet)$ represents the indicator function, and when the expression in parentheses is positive, the value is 1; Otherwise, the value is 0; q_{it} represents the threshold variable, namely, government-mandated, economic-incentive and public-participation environmental regulation; r is the corresponding threshold value, where $r_1 < r_2$, and the names and meanings of the remaining variables are the same as before.

4.4. Empirical Test and Result Analysis

This paper selects the panel data of A-share listed manufacturing companies in Shanghai and Shenzhen Stock exchanges from 2010 to 2018 as the research object, and uses Stata 15.0 statistical software for empirical analysis. Firstly, the Hausman test is conducted on the samples, and the results show that the fixed effect model is more reasonable.

4.4.1. Descriptive Statistical Analysis

This paper conducts descriptive statistics on 534 listed manufacturing companies, and the specific results are shown in **Table 2**. It can be seen from **Table 2** that different types of environmental regulation have different characteristics, and the intensity of environmental regulation varies greatly, and the intensity of the same type of environmental regulation varies greatly in different regions, among which the command-and-control environmental regulation has the most obvious difference. Combined with the control variables, it can be seen that the minimum value of R & D intensity is 0, and the maximum value is 15.161, with significant differences, indicating that the technological innovation vitality and level of different enterprises are quite different. The standard deviations of KI and M are relatively large, indicating that there are great differences in the conditions of enterprises and the degree of market competition in the sample interval.

Table 2. Descriptive statistics of variables.

Variable name	Mean	Standard deviation	Minimum	Maximum
R & D intensity	3.361	2.756	0.000	15.161
EI2	2.153	0.590	0.515	3.559
EI4	0.771	0.268	0.336	1.445
EI6	1.585	0.355	0.751	2.594
KI	1.805	1.060	0.415	6.565
Internet	9.275	0.886	7.065	10.795
ROA	2.275	0.170	1.792	2.773
M	2.130	4.654	0.000	27.430

4.4.2. Benchmark Regression Analysis

Table 3 lists the empirical results of different types of combinations of environmental regulation and technological innovation of Chinese manufacturing enterprises. In order to avoid the bias of empirical results caused by multicollinearity caused by the addition of interaction terms, the core explanatory variables are decentralized.

As can be seen from Table 3, compared with the effect of single environmental regulation on the technological innovation of manufacturing enterprises, the combination of different types of environmental regulation plays a greater role in the technological innovation of manufacturing enterprises, which can make up for the defect that single environmental regulation cannot play a role. Specifically, single command-and-control and economy-incentivised environmental regulation have an inhibitory effect on the technological innovation of manufacturing enterprises, The coefficients are −0.015, which is significantly inhibited at 1% level, and −0.005, which is not significant, but the regression coefficient of the interaction term between command-and-control and economy-incentivised environmental regulation on the technological innovation of manufacturing enterprises is 0.158, which is significantly positive at the level of 1%. This shows that the power of combination is far greater than that of a single environmental regulation tool. On the basis of command-and-control environmental regulation, the role of the market can be effectively played, the combination makes the firm's innovation compensation effect greater than the compliance cost effect, which is conducive to technological innovation of manufacturing enterprises. Hypothesis H1 is valid. The regression coefficient of the interaction term between economic incentive and public participation environmental regulation on the technological innovation of manufacturing enterprises is 0.218, which is significantly positive at the level of 5%. The single public participation type of environmental regulation is conducive to manufacturing technological innovation, which is 0.055 and significantly positive at the level of 1%. However, the economically incentive-type environmental regulation has an insignificant inhibitory effect, with a coefficient of −0.038. This means that public participation

Table 3. Impacts of different combinations of environmental regulations on technological innovation in China's manufacturing industry.

Variable	(1)	(2)	(3)	(4)
	R & D intensity	R & D intensity	R & D intensity	R & D intensity
EI2 * EI4	0.158***			0.140***
	(3.95)			(5.04)
EI4 * EI6		0.218**		0.246**
		(2.13)		(2.54)
EI2 * EI6			−0.016	−0.055**
			(−0.87)	(−2.27)
EI2	−0.015***		−0.026***	−0.021***
	(−4.35)		(−3.38)	(−4.40)
EI4	−0.005	−0.038		−0.013
	(−0.20)	(−1.49)		(−0.51)
EI6		0.055***	0.053***	0.061***
		(3.81)	(3.90)	(5.55)
KI	0.143***	0.141***	0.143***	0.143***
	(11.58)	(11.20)	(11.83)	(11.54)
Internet	0.113***	0.110***	0.112***	0.107***
	(20.60)	(15.16)	(18.93)	(18.98)
ROA	0.028*	0.028*	0.027*	0.028*
	(1.79)	(1.89)	(1.77)	(1.91)
M	−0.027***	−0.027***	−0.027***	−0.027***
	(−5.00)	(−4.90)	(−4.86)	(−4.81)
Constant	0.009	−0.049	−0.037	−0.018
	(0.14)	(−0.60)	(−0.56)	(−0.26)
Class of models	Fixed Effects	Fixed Effects	Fixed Effects	Fixed Effects
Observations	4806	4806	4806	4806

Note: ***, ** and * indicate the significance test of 1%, 5% and 10%, respectively.

environmental regulation, relying on economic incentive environmental regulation, can better stimulate enterprises to carry out technological innovation activities. Similarly, the higher the degree of public participation is, the more economically incentive-oriented environmental regulation can promote the technological innovation of manufacturing enterprises. Hypothesis H2 is valid. The regression coefficient of the interaction term between command-and-control and public participation environmental regulation on the technological innovation of manufacturing enterprises is −0.055, showing a significant inhibitory ef-

fect at the level of 5%, so Hypothesis H3 is falsifiable. Possible reasons: on the one hand, due to the mismatch between policies, public participation depends on the effective implementation of command-and-control environmental regulation to play its role. On the other hand, due to the high risk, high uncertainty and externalities of technological innovation, the lack of guidance from market mechanism, and the restriction of enterprise behavior only relying on mandatory orders and the public's own environmental awareness, without corresponding incentive measures and internal motivation to promote the transformation of enterprises, it is difficult to stimulate enterprises to take the initiative to innovate and change their own production mode. There could also be a green paradox, and a near-displacement of pollution.

4.4.3. Threshold Effect Test

Referring to the panel threshold regression effect proposed by Hansen, this paper adopts the Bootstrap method to simulate the progressive distribution of F statistics, and obtains the corresponding *p* value and confidence interval to test the threshold effect of environmental regulation on the technological innovation of manufacturing enterprises. This paper takes economic incentive-based environmental regulation as the threshold variable to conduct single threshold, double threshold and triple threshold tests. The estimates and confidence intervals of the threshold values are shown in Table 4. As can be seen from Table 4, When economically incentivized environmental regulation is the threshold variable, Model (5) with command-and-control environmental regulation as the core explanatory variable and model (6) with public participation environmental regulation as the core explanatory variable have significant double threshold effects, the threshold values are 1.019 and 0.766, respectively.

The specific parameter estimation results are shown in Table 5. When the economic incentive environmental regulation is used as the threshold variable, the impact of command-and-control environmental regulation on the technological innovation of manufacturing enterprises has a double threshold effect, and the threshold values are 1.019 and 0.766. When EI4 < 0.766, the influence of EI2 on the technological innovation of manufacturing enterprises is significant at the level of 5% with a coefficient of −0.028. When 0.766 < EI4 < 1.019, the influence of EI2 on the technological innovation of manufacturing enterprises is not

Table 4. Threshold value estimation results.

Threshold variable	Core explanatory variable	Threshold test	The threshold estimate	95% confidence interval
EI4	EI2	• The first threshold value	1.019	(1.012, 1.026)
		• The second threshold value	0.766	(0.757, 0.770)
	EI6	• The first threshold value	1.019	(1.012, 1.026)
		• The second threshold value	0.766	(0.757, 0.770)

Table 5. Parameter estimation results of the threshold model.

Threshold variable	Core explanatory variable	Strength of threshold	Coefficient of estimate	standard deviation	*t*-value	*p*-value
EI4	EI2	EI4 < 0.766	−0.028	0.014	−2.06	0.039
		0.766 < EI4 < 1.019	−0.007	0.014	−0.48	0.634
		EI4 > 1.019	0.043	0.018	2.45	0.015
	EI6	EI4 < 0.766	0.008	0.023	0.35	0.727
		0.766 < EI4 < 1.019	0.041	0.022	1.89	0.058
		EI4 > 1.019	0.130	0.028	4.58	0.000

significant with a coefficient of −0.007. The impact of EI2 on the technological innovation of manufacturing enterprises is significantly positive at the 5% level, with a coefficient of 0.043. This shows that the two complement each other.

At the same time, when economic incentive-based environmental regulation is used as the threshold variable, the impact of public participation environmental regulation on the technological innovation of manufacturing enterprises also has a double threshold effect. When the economic incentive environmental regulation crosses the first threshold and the second threshold respectively, the promotion effect of public participation environmental regulation on the technological innovation of manufacturing enterprises is enhanced, from insignificant to significant at the level of 10% and then significant at the level of 1%. This means that the effective role of public participation is based on the role of economic incentive environmental regulation. The pressure of public opinion on enterprises is more effective in guiding enterprises' technological innovation, which also verifies H2.

4.4.4. Endogeneity and Robustness Test

1) Endogeneity test

The bidirectional causality between the explanatory variable and the explained variable is an important reason for the endogeneity of the econometric model. The presence of endogeneity can lead to biased and inconsistent results. On the one hand, the implementation of environmental regulation will affect the technological innovation activities of enterprises; on the other hand, the improvement of technological innovation of enterprises will also reduce the regional pollution degree and affect the intensity of environmental regulation. Due to the endogenous relationship between environmental regulation and technological innovation, there may be endogeneity problems in the process of model estimation.

2) Robustness test

Outliers are excluded. In order to reduce the interference of outliers on the research results, this paper conducts bilateral windings at the 5% quantile on the main explanatory variables and conducts regression again. Therefore, the above

results are robust.

Supplementary variables. Considering that the enterprise Size is also one of the important factors affecting the technological innovation of enterprises, the enterprise size is added to the control variable, and the natural logarithm of the total assets of the enterprise is used to measure it. In addition to the change of coefficient size, the coefficient sign and significance level do not change significantly, which indicates that the estimation results of the model are relatively robust.

5. Conclusions and Suggestions

This article selects 2010-2018 Listed companies in Shanghai and Shenzhen A-share manufacturing industry as research samples. On the basis of controlling the level of capital intensity, Internet development, enterprise performance and degree of competition in the market, adopting the panel fixed effect and threshold regression models to analyze the influence of different types of combinations on the technological innovation of Chinese manufacturing enterprises. The research shows that the combination of command-and-control type and economic incentive type, and economic incentive type and public participation type can promote the technological innovation of manufacturing enterprises, while the combination of command-and-control type and public participation type is not conducive to the technological innovation of Chinese manufacturing enterprises. In the case of combinations of different types of environmental regulation tools, the combination of command-and-control type and economic incentive type is more conducive to manufacturing enterprises' technological innovation, making up for the defect that single environmental regulation tool cannot work. The guidance and incentive of economic means can weaken the negative effect of environmental regulation on enterprises' technological innovation. The combination of economic incentive and public participation environmental regulation tools makes the complementary advantages of the tools, which can better stimulate the effectiveness of the regulation tools, encourage enterprises to transform from pipe-end treatment to pollution prevention, and improve the technological innovation ability of enterprises. However, the combination of command-and-control tools and public participation tools is not conducive to the technological innovation of manufacturing enterprises. Threshold regression showed that the economic motivation type tool is double threshold effect: With the continuous enhancement of economic incentive type environmental regulation, the effect of command-and-control environmental regulation gradually changes from inhibition to promotion, while the influence of public participation environmental regulation changes from insignificant to significant promotion.

Accordingly, the following suggestions are put forward:

First, giving full play to the synergistic and linkage role of different types of environmental regulation combinations. For Chinese manufacturing enterprises,

they can achieve complementary advantages through the combination of environmental regulations and play the role of "1 + 1 > 2". At the same time, the relationship between the three should be clarified: Although the command type environmental regulation is characterized by one-size-fits-all and mandatory, we should envisage dominant position rather than ignore. Economic incentive environmental regulation as the main means and channels can perform mediating and positive guiding functions. Economic incentive and command-and-control type environmental regulation complement and reinforce each other. The public participation environmental regulation can feedback the effect of environmental governance, and encourage them to participate in actively, which can provide supervision and feedback on whether the government and the market are effectively implementing it.

Second, improve related laws and regulations to environmental regulation. Due to attributes of public goods of the environment, the rights and responsibilities of environmental pollution are unclear, meanwhile there are limitations of a single environmental regulation tool, formulating relevant combinations of environmental regulations is the key to environmental governance. On the one hand, according to different regions and their own environment of different enterprises, formulate a reasonable and flexible policy mix of environmental regulation instead of one-size-fits-all approach. On the other hand, improve the efficiency of environmental regulation policy instruments to give full and effective play to the role of environmental regulation, reducing the occurrence of government and market failures.

Third, reinforcing investment in manufacturing research and development, and promoting the concept of green environmental protection. Innovation is the primary productive force. Increasing R & D investment in manufacturing enterprises and guiding them to have the courage to carry out innovative R & D are conducive to enhancing the production efficiency of manufacturing enterprises and enhancing their own market competitiveness. At the same time, promoting the concept of green environmental protection actively, increasing environmental protection education to the public, popularize public awareness of environmental protection, and achieving the purpose of making environmental protection deeply rooted in people's hearts. Paying attention to the key role of meeting consumers' demand for green environmental protection in the green technology innovation of manufacturing enterprises, improving enterprises themselves environmental awareness, and making economic development and environmental protection to work together.

However, there are still some shortcomings in this paper that deserve further research. For example, for the measurement of environmental regulation and technological innovation, whether the measurement of different types of environmental regulation intensity is consistent with reality, and whether there is a gap between the formulation and implementation of environmental regulation policies, the measurement of technological innovation is relatively single, and no further distinction is made between GTI and non-GTI.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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