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## Heterogeneous Environmental Regulations, R&D Innovation and Manufacturing Enterprises' Export Technological Sophistication

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# Heterogeneous Environmental Regulations, R&D Innovation and Manufacturing Enterprises' Export Technological Sophistication

**Abstract:** Based on the combined data of China Patent Database, China Industrial Firm Database and China Customs Trade Database from 2004-2010, this paper investigates the impact of heterogeneous environment regulation on the export technological sophistication of manufacturing enterprises. The results show that: the impact of control-type environmental regulation on enterprises' export technological sophistication is U-shaped, and has negative effect on mixed trade enterprises, eastern enterprises and foreign-funded enterprises. The impact of incentive-type environmental regulation on the enterprises' export technological sophistication is inverted U-shaped, and has positive effect on processing trade enterprises, mixed trade enterprises, domestic and foreign-funded enterprises. The impact of participative-type environmental regulation on the enterprises' export technological sophistication has an inverted U-shaped characteristic and has a positive effect on all kinds of trade pattern and ownership of enterprises. The result of mechanism analysis shows that control and participative environmental regulation affect enterprises' export technological sophistication through fundamental innovation and practical innovation, while incentive environmental regulation also affects enterprises' export technological sophistication through design innovation. Considering environmental governance issues has clear policy implications for enhancing the R&D innovation of the whole industrial chain and improving the export competitiveness of China's manufacturing enterprises.

**Keywords:** Environmental Regulation; R&D Innovation; Export Technological Sophistication; DVA; Manufacturing

## 1. Introduction

After more than three decades of development, China has achieved rapid export growth by relying on low production costs. According to the WTO's report on Global Trade Data and Prospects, China's total export of goods reached \$2.49 trillion in 2018, accounting for 12.8 percent of the world's total trade and ranking first in the world. However, China's long-standing trade strategy of "two sides out, big in and big out" has created a "miracle" of export growth and produced many negative effects. There are universally lack of competitiveness and lower quality of goods among enterprises. The deepening of the globally specialized division is not effective to improve Chinese enterprises in the low-end of the global value chain from the link and status, and with high input, high consumption and high pollution of extensive mode of production also caused the domestic natural environment worsening and a series of social problems in the field of environment. Meanwhile, the world economy is still undergoing profound adjustment. Influenced by the

escalation of trade frictions and economic uncertainty, the growth rate of global trade in 2018 is about 3.0%, much lower than expected, and China's export trade growth is under great pressure. In this situation, the party middle committee based on our country's economy has been rapid growth from high quality Development Stage of the Basic Fact, released "the Middle Committee of the Communist Party of China, the State Council on Promoting Trade" Instructional Advice on the development of high quality, high quality to promote China's trade development, speed up the trade characteristics from "big in and big out" to "superior in and superior out ", which pointed out the direction of the shift. The 19th National Congress of the Communist Party of China (CPC) raised environmental governance to an unprecedented new level by explicitly requiring that major environmental problems be solved and pollution prevention and control actions be continuously implemented.

At present, clarifying the relationship between environmental governance and high-quality development of foreign trade has gradually become a research hotspot in related fields. Environmental regulation has always been the core content of environmental economics, while the export technological sophistication (export technological sophistication) is an important aspect of export competitiveness. Then, how does heterogeneous environment regulations affect enterprises' export technological sophistication? What is the role of enterprises' R&D innovation between them? To answer the above questions, this paper derived from the heterogeneous environment regulations perspective to investigate impact on enterprises' export technological sophistication has definite theoretical and practical significance: in the construction of environmental protection and economic growth, there is a common concept, namely the government in promoting the construction of ecological environment and the implementation cannot agree on a policy objective of economic growth. The reason is that the introduction of environmental protection policies and measures will "internalize" the cost of environmental pollution and bring about the production cost of local manufacturing enterprises, making them resist. Based on the theory of "race to bottom", due to the intense competition between local governments have been GDP tournament, local authorities in the environmental protection policy, increasing the intensity of environmental regulation on worry that the strengthening of environmental regulation will damage the investment promotion and capital introduction, compelling local enterprises transfer to other areas, so the tradeoff in carrying out environmental protection and to promote economic growth will naturally leans to the latter, thus cannot be effectively implemented on the environmental regulation policies. This paper investigates the rationality of heterogeneous environmental regulation to improve enterprises' export technological sophistication through R&D innovation, which provides theoretical support for relevant decision makers to give consideration to ecological environmental governance and high-

quality development of foreign trade.

This paper has two marginal contributions to the existing research: Firstly, existing literature basically measures the export technological sophistication from the national or industrial level. Unlike this, this paper calculates the index of export technological sophistication based on the data at the micro firm level, such as Hausmann et al. (2007) and Xu (2007). Besides, the existing literature are based on country or industry such as level measurement on the basis of the total amount of export trade export technological sophistication, and considering the international division of labor deepening production and intermediate trade proportion continue to improve, such background, this article based on the added value of products are exported to domestic manufacturing as a new measure to improve the accuracy of enterprises' export technological sophistication. This approach will help to shed more light on the evolving characteristics of the export technological sophistication of Chinese manufacturers' exports. Secondly, in view of the existing problems in the research on the relationship between environmental regulation and export technological sophistication, this paper, based on the perspective of heterogeneous environmental regulations, conducts a more systematic and comprehensive study on the different impact of environmental regulation on the enterprises' export technological sophistication.

The remaining structure of this paper is as follows: The second part is literature review and theoretical analysis. The third part is the research design. The fourth part is the empirical results and analysis. The fifth part is the conclusions and discussions.

## **2. Literature review and theoretical analysis**

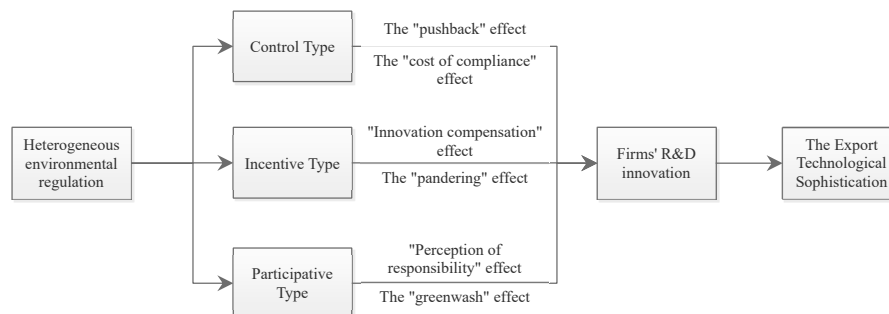
### **2.1 Literature review**

In recent years, the relationship between environmental regulation and the export technological sophistication has attracted more and more academic attention. Scholars have conducted many beneficial explorations on the impact of environmental regulation on the export technological sophistication. Yu (2015) investigated the impact of environmental regulations on the U-shaped characteristics of manufacturing export technological sophistication. Xiao & Chen (2019) demonstrated the double threshold effect of environmental regulation on the export technological sophistication based on the analysis of inter-provincial data. Other scholars have also made relevant explorations based on the industrial or regional level (Pu, 2015; Mao & He, 2017; Xie & Liao, 2017). With the deepening of research, some scholars try to use micro data to investigate the impact of environmental regulation on the export technological sophistication. Based on micro-firm data, Gao & Yuan (2020) investigated and found the significant promoting effect of cleaner production environmental regulations on the enterprises' export technological sophistication by using the multiplier method.

Through combing relevant literature, it is found that there are many limitations in existing studies. First, the definition of environmental regulation is too narrow. In the construction and measure of environmental regulation intensity, relevant literature usually chooses several indicators to try to build a comprehensive one to reflect and measure the overall level of environmental regulation, but this approach is not appropriate. As a matter of fact, environmental regulation, as an external constraint mechanism to interfere with the production activities of enterprises, has a relatively broad concept and can be divided into different categories based on different standards. For example, based on the perspective of regulatory tools, environmental regulation can be divided into three main types: control type, incentive type and participative type, and there are essential differences between different types of regulatory tools. Second, although relevant literature examines the export technological sophistication from the perspective of environmental regulation, in terms of the category of index selection, in most cases they are control or incentive types, and the latter is only a part of the tools of environmental regulation. Third, no scholars have yet incorporated different types of environmental regulations into a unified framework to conduct comparative analysis on the impact of export technological sophistication.

## 2.2 Theoretical analysis

Based on the standard of regulatory tools, this paper divides China's environmental regulations into three types: control type, incentive type and participative type, and analyzes the theoretical mechanism of the impact of various environmental regulations on the export technological sophistication. A large number of studies have confirmed that firm innovation is a key factor determining the change of export technological sophistication (Guo & Yang, 2010; Hyo & Wang, 2014; Zhu & Fu, 2013). Therefore, in the theoretical analysis part of this paper, the mediating role of R&D innovation in the relationship between heterogeneous environmental regulation and export technological sophistication is mainly analyzed. The theoretical mechanism is shown in *Fig. 1*.



**Fig. 1 The theoretical mechanism of the influence of heterogeneous environmental regulations on the enterprises' export technological sophistication**

### 2.2.1 The impact of control type environmental regulation on the enterprises' export

### technological sophistication

So-called control type environmental regulation, mainly refers to the administrative department of government through legislation and regulation rules to determine the specific targets, standards of environmental regulation, and the executive order means mandatory regulation compliance with the operation in violation of the corresponding standard unrealized regulation target enterprises to economic and political punishment (Liu & Wang, 2017; Zhao et al., 2009). Depending on the basis of standard setting, specific means of environmental regulation with control mainly include environment-related technical standards and performance standards (Guo, 2009).

Referring to the study of Montero (2002), it is considered that there are two representative enterprises in a certain region, and both of them have a competitive relationship and aim at profit maximization. When the region begins to implement regulatory environment, enterprises 1 will improve its export competitiveness through R&D and innovation, while firm 2 will not choose R&D and innovation. Without loss of generality, it is assumed that firm 1 and firm 2 produce homogeneous products with the quantity of  $Q_1$  and  $Q_2$  respectively, the unit production cost of both enterprises is  $z$ , and the counterdemand curve of the firm is  $P = m - n(Q_1 + Q_2)$ . Where,  $P$  is the production price of the product, and  $(Q_1 + Q_2)$  is the total output of the region. In the process of product production, unexpected outputs such as pollutants will be produced. When environmental regulation with control imposes constraints on enterprises, firm 1 will reduce unit pollutants by means of R&D and innovation. Referring to the setting of Yan et al. (2016), the emission reduction cost of enterprises is  $as^2 / 2$ , where  $a$  is the R&D innovation coefficient, and the R&D innovation cost is  $A^2 / 2$ , and  $A' = A'(a) < 0$ . Firm 2 is not subject to regulatory punishment for reducing pollution emissions through R&D innovation, and the penalty cost is  $X$ . Then the profit functions of firm 1 and firm 2 are respectively:

$$\pi_1 = [m - n(q_1 + q_2) - z]q_1 - as^2 / 2 - A^2 / 2 \quad (1)$$

$$\pi_2 = [m - n(q_1 + q_2) - z]q_2 - X \quad (2)$$

$$s.t. \quad bq_1 - s = \bar{E} \quad b \in [0, 1] \quad (3)$$

Where, in constraint formula 3,  $b$  is the pollutant discharge coefficient, which is the proportion of pollutant discharge in the product output of the firm,  $bQ_1$  is the pollutant discharge amount of firm 1, and  $\bar{E}$  is the emission limit specified by regional environmental regulation. Therefore, the economic significance of constraints lies in the fact that firm 1 must discharge less than or equal to the emission limit set by the environmental regulation of bundle type. By constructing The Laplace function, the partial derivatives of the above formula are obtained by taking the partial derivatives of the output  $Q_1$  and  $Q_2$ , the emission reduction  $s$  and the Laplace multiplier  $\lambda$ . After algebraic operation according to the above analytic formula can be obtained, the equilibrium output

$q_1 = (m - 2asb - z) / 3n$  and  $q_2 = (m + asb - z) / 3n$ , and the two profit functions can be subtracted to obtain:

$$\Delta\pi_o = \pi_1 - \pi_2 = X - (m + asb - z)asb / 3n - as^2 / 2 - A^2 / 2 \quad (4)$$

It is not hard to see from Eq. 4 that the profit difference of enterprises is affected by various factors, such as regulatory penalty cost  $X$ , R&D innovation level  $a$ , emission reduction cost  $as^2 / 2$  and R&D innovation cost  $A^2 / 2$ , etc. In the case of regulatory environment regulation, only when  $\Delta\pi_o > 0$ , enterprises pursuing profit maximization will have the internal motivation of R&D innovation. The economic significance of the above mathematical model is that the impact of regulatory environment on the manufacturing enterprises' exports technological sophistication is bidirectional and has both potential positive and negative effects.

On the one hand, control environmental regulation has a positive impact on the technological sophistication of manufacturing exports through the mechanism of "backforce" effect. "Porter hypothesis" is put forward for the environmental regulation is to promote firm provides theory basis for production technology research and development (Porter & Linde, 1995), a control type environmental regulation due to the defined standards for pollutants discharge of government departments, the environmental technical standards and other rigid index as firm must accept and comply with environmental regulation, the threshold for enterprises are mandatory and obedience of rules and regulations, or bear the additional costs of regulation strength ascension produced, or strengthen technology research and development, to improve their own mode of production and improve production quality, and raise export technological sophistication. Through literature summarization, environmental regulation with control can promote the improvement of technological sophistication of enterprises' export through three potential channels: First, strengthen enterprises' technological research and development at the production and emission end such as waste discharge reprocessing and waste reuse, thus forming the effect of "pollution control progress" (Jiang et al., 2013). Second, strengthen firm research and development in the intermediate link of product production, and reduce the pollution degree of unit product production by improving technology and increasing labor productivity. Thirdly, based on the "strong Porter hypothesis", environmental regulations break the original production mode of enterprises and transition to a new production mode.

On the other hand, control environmental regulation also has a negative impact on the manufacturing exports technological sophistication through the effect mechanism of "compliance cost". When the government tightens its control and punishment on enterprises, enterprises' disregard of environmental regulations will be subject to severe "regulatory punishment", such as suspension of work or imposition of fines or even cancellation of licenses. To this end, enterprises

will raise the cost of environmental governance, compliance cost, so as to meet the relevant standards set by the government. Enterprises' R&D results are highly uncertain, which is accompanied by high risks. Meanwhile, the flow of R&D personnel will also bring high adjustment costs to enterprises (Hall, 2002). Therefore, R&D innovation activities' funds of enterprises mainly come from internal support rather than external financing platforms. The implementation of control type environmental regulation will directly increase the production cost of enterprises, aggravate the financing constraints faced by enterprises, and thus squeeze out and divert the original R&D funds. In addition, based on the "expensive regulation hypothesis", tighter regulation will accelerate bankruptcy and bankruptcy of enterprises (Jaffe & Palmer, 1996).

### 2.2.2 The impact of incentive environmental regulation on the export technological sophistication

So-called incentive environmental regulation, mainly refers to the government in accordance with the principles of economic cost-benefit, by means of economic lever to adjust, to the firm economic behavior guidance, encouragement and support, etc., the essence is the externality of environment into the firm interior, achieve the purpose of environmental goods privatization, such as subsidies for a particular industry, pollution charge and emissions trading policy or method.

Instead of setting emission limit standard, the incentive environmental regulation takes emission fee or emission right transaction as the main means. Assuming that the region collects environmental tax, the tax rate is, then the profit function of firm 1 and firm 2 can be modified as follows:

$$\pi_1 = [m - n(q_1 + q_2) - z]q_1 - (bq_1 - s)r - as^2 / 2 - A^2 / 2 \quad (5)$$

$$\pi_2 = [m - n(q_1 + q_2) - z]q_2 - bq_1r \quad (6)$$

Where the cost part of firm 1 increased by  $(bq_1 - s)r$ , while the cost part of firm 2 increased by  $bq_1r$ . Through algebraic operation, the analytic solution of the equilibrium output of the firm  $q_1 = q_2 = (m - z - br) / 3n$  is obtained. Then the profit difference between the two enterprises is:

$$\Delta\pi_m = \pi_1 - \pi_2 = sr - as^2 / 2 - A^2 / 2 \quad (7)$$

Integrate  $r = as$  into Eq. 7, it can be transformed into  $\Delta\pi_m = \pi_1 - \pi_2 = as^2 / 2 - A^2 / 2$ , the economics meaning is clear, namely firm profit difference is equal to the cost brought by the firm research and development innovation to reduce the difference between the cost of extra income and the firm research and development innovation, only when  $\Delta\pi_m > 0$ , the incentive environmental regulation can promote firm innovation research and development, and export competitiveness, the opposite will bring inhibitory effect on the latter.

On the one hand, incentive environmental regulation promotes the improvement of manufacturing enterprises' export technological sophistication through the effect mechanism of "innovation compensation". The incentive environmental regulation has many policy measures,



such as sewage charge, environmental tax, subsidy and so on. From the perspective of the diversity of regulation means, the incentive environmental regulation can affect export technological sophistication through three transmission channels technology sophistication: First, according to the signal transmission theory, the government by increasing pollution taxes to convey the environment marginal cost of using the signal of ascension in firm technical innovation saves the marginal cost and accept to make a choice between the original high marginal cost reduction. When the increase of additional costs caused by environmental taxes leads to the decline of enterprises' output and export competitiveness, enterprises will increase their R&D innovation efforts to promote the export technological sophistication to ensure the stability of market share. Second, incentive type environmental regulation causes the price of some exports with pollution-intensive characteristics to rise by means of environmental taxes or subsidies, thus making the import demand preference of export destination countries shift to cheaper substitutes. Thus, demand-oriented technology R&D activities are launched to guide enterprises to carry out R&D innovation, and gradually transform production technologies, production processes or final products into environment-friendly product types (Wustenhagen & Bilharz, 2006). Thirdly, incentive type environmental regulation can realize the transfer of wealth funds between enterprises and the state through pollutant discharge taxes and fees. As technological innovation is a public product with a long R&D cycle and high risks, the state collects funds in the form of pollutant charges and then transfers the funds to the R&D units through the establishment of a R&D fund account, thus forming a top-down technological innovation.

On the other hand, incentive environmental regulation can also inhibit the increase in enterprises' export technological sophistication through the "catering" effect mechanism. In the process of obtaining the initial distribution right of pollutant discharge right, enterprises are motivated by rent-seeking, while the high rent-seeking cost and too many government-firm relations are bound to have a negative impact on enterprises' R&D activities (Yu et al., 2016). In addition, for tax breaks that incentive environmental regulation policy, related industries will be targeted to this kind of industry to invest, and excessive investment and production to cater to the support of the government for a particular industry and subsidy policy. Thus, over-investment and over-production will cause the vicious competition between the domestic export enterprises, which is not conducive to export product technology level of ascension (Wang, 2014).

### **2.2.3 The impact of participative environmental regulation on the export technological sophistication**

Participative environmental regulation is a regulatory tool with the highest degree of freedom for the producer, enterprises. It is initiated by the government, industrial organizations or independent third parties to encourage and call enterprises in related industries to promise and practice to

improve the environment, health and ecological safety.

In the case of participative environmental regulation, the government and the public more recognize enterprises with environmental awareness and environmental responsibility, which will generate a potential hidden benefit, including corporate reputation, benign relationship between government and firm. Therefore, the basic model in the case of participative environmental regulation is modified to:

$$\pi_1 = [m - n(q_1 + q_2) - z]q_1 - as^2 / 2 - A^2 / 2 + I \quad (8)$$

$$\pi_2 = [m - n(q_1 + q_2) - z]q_2 - vI \quad (9)$$

$$s.t. \quad bq_1 - s = \bar{E} \quad b \in [0,1] \quad (10)$$

Where  $I$  means that enterprises accept participative environmental regulation, so as to actively carry out research and development innovation, reduce pollution emissions, and convey to the society a signal of enterprises with environmental responsibility, so as to obtain hidden benefits.  $v$  represents the enthusiasm of the public for participation. Through algebraic calculation, the analytic solution of the equilibrium output corresponding to the firm is obtained:  $q_1 = (m - 2asb - z) / 3n$  and  $q_2 = (m + asb - z) / 3n$ , then the profit difference of the firm is:

$$\Delta\pi_p = I + vX - (m + asb - z)asb / 3n - as^2 / 2 - A^2 / 2 \quad (11)$$

According to Eq. 11, it is not difficult to find that when the public's enthusiasm for environmental protection participation  $v$  increases, or when the firm accepts the hidden income generated by participative environmental regulation  $I$  increases, the profit difference of the firm  $\Delta\pi_p$  will be higher. But only when  $\Delta\pi_p > 0$ , participative environmental regulation can really promote enterprises' R&D innovation level and export competitiveness, otherwise it may become a "greenwashing" tool for some bad enterprises.

On the one hand, participative environmental regulation can promote the improvement of export technological sophistication of manufacturing enterprises through the effect mechanism of "responsibility awareness". The transmission channels are as follows: First, according to the theory of system and part of the export enterprises tend to foreign consumers and investors "environment-friendly enterprises" signals, especially when export destination countries of consumers, producers and other stakeholders, or multinational companies headquartered stakeholders is more sensitive to environmental behavior of enterprises, enterprises will be transmitted by using participative environmental regulation tools "environment-friendly enterprises" positive signals, especially for enterprises located in weak environment management ability, host countries enterprises' motivation for utilizing of participative environmental regulation tools packaging "beautification" is more intense (Cao & Zhang, 2015; Yu & Yang, 2017). Second, the stronger a firm's organizational resource acquisition ability and its existing environmental management and pollution prevention

ability are, the stronger its motivation to use participative environmental regulation will be (Darnall, 2007). Enterprises expect to generate invisible income through R&D innovation to achieve their own economic interests or behavior in line with moral standards. The establishment and improvement of the public awareness of environmental protection will lead to the improvement of the "marginal willingness to pay" for the scarce goods such as the environment, and the tolerance of the products produced by enterprises with high pollution and high energy consumption will be greatly reduced, and there will be resistance behaviors (Cao & Cao, 2007; Qin et al., 2008).

On the other hand, participative environmental regulation also inhibits the improvement of export technological sophistication of manufacturing enterprises through "greenwashing" effect mechanism. Joining in environmental regulation of earnings has strong externality, which fulfill the participated the rules of environmental regulation requirements firm investment cost, and good reputation produced by subsequent gains are shared by all the rules and regulations involved in enterprises, so for industry association participated by environmental regulation, companies have a strong motivation to join but not to implement regulation requirements, the "free rider" behavior is also known as "greenwashing". Friedman (1970) pointed out that social responsibility behavior is a burden to enterprises, and environmental regulation, as an important part of corporate social responsibility, provides motivation for the generation of "greenwashing" behavior. Because participative environmental regulation is more flexible and arbitrary than control environmental regulation, enterprises may produce "greening-green" behaviors in production by means of double standards, open fraud, deliberate concealment, exaggerated publicity, and evading concepts.

### 3. Research Design

#### 3.1 Econometric model specification

In order to investigate the impact of heterogeneous environmental regulations on the export technological sophistication of manufacturing enterprises, this paper constructed the following econometric model:

$$TSI_{it} = \alpha_1 + \beta_0 OER_{ct} + \beta_1 OERS_{ct} + \beta_2 AGE_{it} + \beta_3 SALE_{it} + \beta_4 FS_{it} + \beta_5 TFP_{it} + \beta_6 HHI_{it} + \beta_7 SOE_{it} + \beta_8 SUB_{it} + \beta_9 MARKET_{pt} + \eta_t + \gamma_i + \varepsilon_{it} \quad (12)$$

$$TSI_{it} = \alpha_1 + \beta_0 MER_{pt} + \beta_1 MERS_{pt} + \beta_2 AGE_{it} + \beta_3 SALE_{it} + \beta_4 FS_{it} + \beta_5 TFP_{it} + \beta_6 HHI_{it} + \beta_7 SOE_{it} + \beta_8 SUB_{it} + \beta_9 MARKET_{pt} + \eta_t + \gamma_i + \varepsilon_{it} \quad (13)$$

$$TSI_{it} = \alpha_1 + \beta_0 PER_{pt} + \beta_1 PERS_{pt} + \beta_2 AGE_{it} + \beta_3 SALE_{it} + \beta_4 FS_{it} + \beta_5 TFP_{it} + \beta_6 HHI_{it} + \beta_7 SOE_{it} + \beta_8 SUB_{it} + \beta_9 MARKET_{pt} + \eta_t + \gamma_i + \varepsilon_{it} \quad (14)$$

The above equations are respectively the econometric regression models of the impact of control  $OER_{ct}$ , incentive  $MER_{ct}$  and participative  $PER_{ct}$  environmental regulations on the export technological sophistication of manufacturing enterprises. Where subscripts  $i$ ,  $c$ ,  $p$  and  $t$  represent the firm, city, province and year, respectively. In order to investigate the nonlinear effect

of heterogeneous environmental regulations on the export technological sophistication, the square terms corresponding to various environmental regulations  $OERS_{ct}$ ,  $MERS_{ct}$  and  $PERS_{ct}$  are included. The control variable  $AGE_{it}$  represents the age of the firm,  $SALE_{it}$  represents the total sales volume of the firm,  $FS_{it}$  represents the size of the company,  $TFP_{it}$  represents the productivity of the firm,  $HHI_{it}$  represents the industry concentration degree faced by the firm,  $SOE_{it}$  represents the ownership of state-owned enterprises,  $SUB_{it}$  represents the subsidies received by the firm, and  $MARKET_{pt}$  represents the marketization level of the province.  $\eta_t$ ,  $\gamma_i$  and  $\varepsilon_{it}$  represent time fixed effect, firm fixed effect and error term, respectively.

### 3.1.1 Heterogeneous environmental regulation

In China, there is no relevant institution specially issuing classified or comprehensive environmental regulation indicators. In the actual environmental regulation, there is neither fixed government intervention mode nor independent regulation tool, which brings great difficulties to the real measurement (Li & Tao, 2012). After reviewing the existing literature, this paper uses weighted linear and method with high domain recognition to measure the intensity of heterogeneous environment.

In terms of control environmental regulation indicators, five indicators are selected, including "three simultaneous" project investment, industrial solid waste comprehensive utilization rate, industrial wastewater discharge up to standard rate, sulfur dioxide emission up to standard rate and industrial soot emission up to standard rate. In terms of incentive environmental regulation indicators, referring to the practices of Zhang et al. (2016) and Yu et al. (2017), three single indicators are selected, namely pollutant charge, annual investment of industrial pollution control projects and investment of pollution control. In terms of participative environmental regulation indicators, taking into account the availability of data, two single indicators, such as the number of enterprises with environmental label product certification in each province and the number of environmental pollution and damage accident reports, were selected.

This paper refers to the practice of Wang & Liu (2014), the comprehensive index measure method of environmental regulation at the industrial level is extended to the regional level. To be specific, this paper selects a total of 384 individual index data of prefecture-level cities, adopts weighted linear sum method, and calculates the comprehensive index of control type, incentive type and participative type of environmental regulation in turn based on the second-level single index of various environmental regulations. Specifically divided into three steps:

The first step is to nondimensionalize the above single indicators successively:

$$ER_{irt}^s = \frac{ER_{irt} - MIN(ER_{it})}{MAX(ER_{it}) - MIN(ER_{it})} \quad (15)$$

Where subscript  $r$ ,  $i$  and  $t$  represent the region, firm and year, respectively.  $ER_{irt}$  denotes

the second-level single index of heterogeneous environmental regulation,  $MAX(\cdot)$  and  $MIN(\cdot)$  denotes the maximum and minimum values of a single index at the regional level respectively, and  $ER_{irt}^s$  denotes the single index after nondimensionalization.

The second step is to refers to Zhao & Wang (2016) and Li (2019), based on the regional level five single parameter adjustment coefficient  $M_{irt}$  are calculated respectively, considering the emission proportion of each index in different areas, there is different degree of pollutant emissions within the same region is also different, so need to each single index weight given in various areas in each of the different, in order to accurately reflect the change of regional pollution emissions intensity (Shen et al., 2017). The adjustment coefficient is as follows:

$$M_{irt} = \frac{EMI_{irt} / \sum_r EMI_{irt}}{GDP_{rt} / \sum_r GDP_{rt}} \quad (16)$$

Where subscript  $i$ ,  $r$  and  $t$  represent the individual, region and year, respectively.  $M_{irt}$  represents the ratio between the proportion of individual indicators' emissions in the national total ( $EMI_{irt} / \sum_r EMI_{irt}$ ) and the proportion of regional GDP in the national total ( $GDP_{rt} / \sum_r GDP_{rt}$ ).

Third, according to nondimensionalize the value and adjustment coefficient of each single indicator  $M_{irt}$ , the weighted average treatment of each single indicator can obtain the comprehensive index of environmental regulation intensity of each district in each year successively:

$$ER_{rt} = \frac{1}{N} \sum_i M_{irt} \cdot ER_{irt}^s \quad (17)$$

### 3.1.2 Export technological sophistication

In this paper, the Hausmann et al. (2007), expand and improve the two-step: First, the existing literature to export technological sophistication index calculation using the national level or industry data, based on China's data as a basis to measure at micro-firm level, and with the added value of enterprises in various industries on the export of domestic export enterprises accounted for the ratio of the gross domestic output as the weighting export firm technological sophistication. Secondly, the export volume contains a considerable proportion of the value added returned by enterprises and the value added abroad. In the calculation of the second step, if the weight is directly calculated, the export technological sophistication of enterprises will be significantly biased. This paper takes the proportion of export domestic added value as the weight, which can measure the export technological sophistication of enterprises. Thirdly, take the robustness into consideration, this paper further revises the calculated export technological sophistication.

First, in the first step, calculate the export technological sophistication index at the product level:

$$PRODY_{pt} = \sum_j [(E_{pjt} / E_{jt}) / (E_{pt} / E_{wt})] \cdot Y_{jt} \quad (18)$$

Where  $p$  represents a HS code 6-digit product,  $j$  represents the country,  $E_{pj}$  represents the export

volume of country  $j$ 's product  $p$ ,  $E_j$  represents the total export volume of country  $j$ ,  $E_p$  represents the total world export volume of products  $p$ ,  $E_w$  represents the total world export volume,  $Y_j$  represents the gross domestic product per capita of the country  $j$ . Weights are also known as comparative advantage indices  $\sum_j [(E_{pj} / E_j) / (E_p / E_w)]$ . For the sake of robustness, this paper refers to the method of Xu (2007) to adjust the quality of the calculated firm export technological sophistication. Firstly, the product relative price index is adopted to measure the product quality:  $Q_{cpt} = price_{cpt} / \sum_n (A_{np} \cdot price_{npt})$ ,  $price_{cpt}$  is the annual price of country  $c$ 's products  $p$  in year  $t$ , and  $A_{np}$  is the proportion of the export volume of country  $n$ 's products  $p$  to the total export volume of world's product  $p$ . After quality correction, the export technological sophistication index at the product level is:  $PRODY_{pt}^* = (Q_{cpt})^\lambda \cdot PRODY_{pt}$ , followed the practice of Wang et al. (2010),  $\lambda$  is set to 0.2.

Secondly, calculate the export technological sophistication at the firm level:

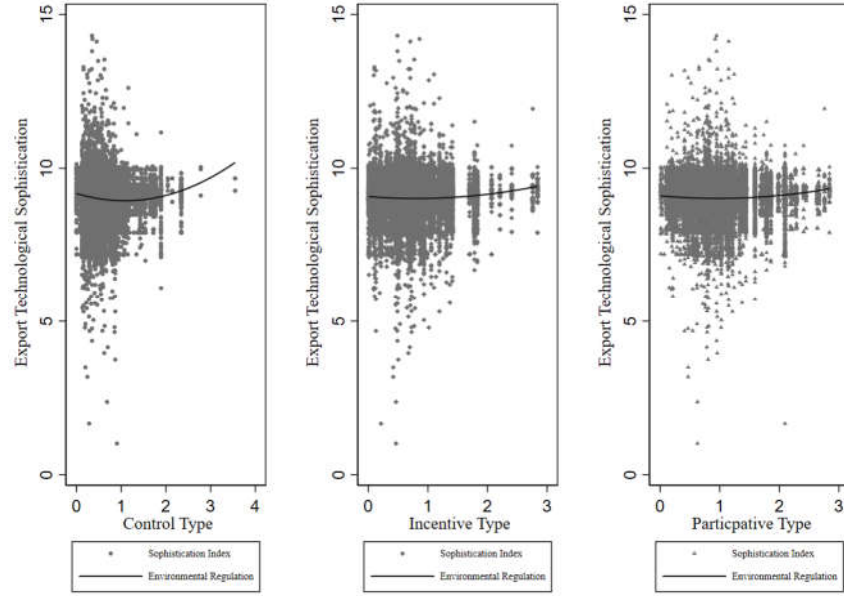
$$TSI0_{it} = \sum_p (DVA_{ipt} / DVA_{it}) \cdot PRODY_{pt} \quad (19)$$

$$TSI1_{it} = \sum_p (DVA_{ipt} / DVA_{it}) \cdot PRODY_{pt}^* \quad (20)$$

Where  $TSI0_{it}$  represents firm's export technological sophistication with traditional measure,  $TSI1_{it}$  represents firm's export technological sophistication after quality adjustment,  $DVA_{ip}$  represents the domestic added value of export of firm  $i$ ' product  $p$ ,  $DVA_i$  represents the total domestic added value of export of firm  $i$ , and the proportion of the two is used to measure the proportion of export of products. For the calculation of the domestic added value of enterprises' exports, this paper refers to the practices of Kee & Tang (2011) and Zhang et al. (2013), takes into account the matter of trade agents, capital goods import, indirect import of intermediate goods and so on, and recalculates the index of domestic added value of enterprises' exports<sup>1</sup>.

In this paper, a scatter diagram reflecting the relationship between the regulation of heterogeneous environment and the export technological sophistication of manufacturing enterprises is presented, as shown in Fig. 2. From which it is not hard to see, control type, incentive type and participative type environmental regulation and export technological sophistication are U nonlinear relationship, namely environmental regulation intensity at the beginning of the ascension, inhibits the export technological sophistication and when environmental regulation more than a certain threshold, will help the export technological sophistication. However, it is worth noting that the reference value of the variable relationship presented in the case of ignoring the control variables and fixed effects is limited, so more complex methods are needed to make an in-depth investigation of the variable relationship.

<sup>1</sup> Due to space limitations, the steps of relevant indicator construction and measurement are not detailed. For details, please refer to the literature of Kee & Tang (2011) and Zhang et al. (2013).



**Fig. 2 Scatter diagram of heterogeneous environmental regulation and enterprises' export technological sophistication during 2004-2010**

### 3.2 Data sources and processing

The research sample period is from 2004 to 2010, and a total of 6 sets of data are used in this paper. The first one is Chinese Industrial Firm Database. Considering the existing problems such as sample mismatch, missing indicators and abnormal indicators, we refer to the practices of Tian & Yu (2014) to deal with them: (1) Eliminate enterprises with fewer than 8 employees; (2) Excluding enterprises with negative total assets, total fixed assets, intermediate inputs and payable wages; (3) Excluding enterprises founded before 1949. The second one is China Customs Trade Database. Due to the Chinese enterprises to rely on trade agent problems in the import and export, in accordance with the method of Ahn et al. (2011), the firm name contained in the "Import and Export", "Commercial Trade", "Technological Trade", "Industrial Trade", "Trade" and "Foreign Commerce" words of observations, and the monthly data aggregation to the annual data, eliminate abnormal observations. The one is the World Input-Output Database (WIOD). According to the input and output information between the states and the sectors, KWW model is used to decompose and calculate the return value added rate of each industry and the value-added rate of export. The fourth one is China Urban Statistical Yearbook and China Environmental Statistical Yearbook, from which a single indicator is selected to construct heterogeneous environmental regulation. The fifth one is the Chinese Firm Patent Database. The basic, practical and design innovation variables are identified. The sixth one is UN-Comtrade Database. In this paper, 5224 products from 141 countries were selected to calculate the export technological sophistication of HS code 6-digit level products. Among the control variables, the firm age is expressed as the difference between each year and the year of establishment of the firm, while other variables are directly obtained from Chinese Industrial

Firm Database. The marketization index is from the China National Economic Research Institute.

The data used in this article is distributed across multiple databases, so a matching merge is required before use. Referring to the practice of Brandt et al. (2012) and Nie et al. (2012), and referring to the suggestion of Chen (2018), Industrial Firm Database was merged with firm code and firm name in different years respectively, and then matched and merged with Customs Trade Database according to the firm name. Finally, merge the data with other data needed for the combining: merge with WIOD data based on the industry and year variable, merge with urban statistical yearbook and statistical yearbook data environment based on the provinces and cities and year variable, merge with China Patent Database based on the firm name and year variable, merge with UN Comtrade Database based on the year and 6-digits HS code, merge with marketization index data based on the province and year variable. In terms of coding processing, HS2017 standard was used to unify the data related to customs HS codes by using the code conversion table provided by UN Statistics Division. BEC-Rev. 4 standard was used for classification of final products, capital goods and intermediate products, and SITC-Rev. 3 standard was used for classification of industry types.

## **4. Empirical results and analysis**

### **4.1 Benchmark results analysis**

The benchmark results of the impact of heterogeneous environmental regulations on the enterprises' export technological sophistication are shown in *Table 1*. The dependent variables are the enterprises' export technological sophistication with traditional measure and the enterprises' export technological sophistication with adjusted measure.

Columns (1)-(2) present results of the impact of control environmental regulation on manufacturing enterprises' export technological sophistication, coefficients of first and secondary variables are -0.601 and 0.191, -0.722 and 0.230, respectively, met 5%-10% level of significance test, and U-shaped test values were 1.54 and 1.80, 5%-10% level of statistical significant, respectively. It's indicated that the impact of control environmental regulation on export technological sophistication is a U-shape nonlinearity<sup>2</sup>. Column (3)-(4) present results of the impact of incentive environment regulation on manufacturing enterprises' export technological sophistication, coefficients of first and secondary variables were 0.740 and -0.247, 0.865 and -0.284, both met the 1% level of significance test, and U-shaped test values were 2.33 and 2.30, respectively, were 1%-5% level of statistical significant, suggests that the impact of incentive environmental regulation on export technological sophistication is inverted U-shaped nonlinear characteristics. Column (5)-(6) present results of the impact of participative environmental regulation on

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<sup>2</sup> The U-shaped test method is derived from Lind & Mehlum (2007).



manufacturing enterprises' export technological sophistication, coefficients of first and secondary variables were 0.730 and -0.226, 0.863 and -0.260, met the 1% level of significance test, and U-shaped test values were 2.81 and 2.42, respectively, at 1% level of statistical significance, showed that the impact of participative environmental regulation on export technological sophistication is inverted U-shaped nonlinear characteristics. Further analysis shows that the inflection points of the impact of control environmental regulation on the export technological sophistication are 1.573 and 1.570, respectively, and the overall level of China's control environmental regulation intensity is 0.465, which has not crossed the inflection point of nonlinear influence and is still in the negative impact interval. When the inflection points of the impact of incentive environmental regulation on the export technological sophistication are 1.498 and 1.523, the overall level of China's incentive environmental regulation intensity is 0.663, which has not crossed the inflection point of nonlinear influence and is still in the positive impact interval. The inflection points of the impact of participatory environmental regulation on the technical sophistication of export are 1.615 and 1.660, and the overall level of China's participatory environmental regulation intensity is 0.891. The inflection point of nonlinear impact has not been crossed yet, and it is still in the positive interval.

**Table 1 Benchmark results**

variable	(1) <i>TSIO</i>	(2) <i>TSII</i>	(3) <i>TSIO</i>	(4) <i>TSII</i>	(5) <i>TSIO</i>	(6) <i>TSII</i>
<i>OER</i>	-0.601*** (0.23)	-0.722*** (0.24)				
<i>OERS</i>	0.191* (0.10)	0.230** (0.10)				
<i>MER</i>			0.740*** (0.23)	0.865*** (0.26)		
<i>MERS</i>			-0.247*** (0.09)	-0.284*** (0.10)		
<i>PER</i>					0.730*** (0.17)	0.863*** (0.20)
<i>PERS</i>					-0.226*** (0.06)	-0.260*** (0.08)
<i>AGE</i>	-0.315*** (0.02)	-0.286*** (0.02)	-0.319*** (0.02)	-0.291*** (0.02)	-0.326*** (0.02)	-0.299*** (0.02)
<i>MARKET</i>	-0.354* (0.20)	-0.610*** (0.18)	-0.221 (0.15)	-0.447*** (0.13)	-0.033 (0.14)	-0.222 (0.13)
<i>TFP</i>	-1.509*** (0.17)	-1.435*** (0.16)	-1.515*** (0.17)	-1.442*** (0.16)	-1.522*** (0.17)	-1.451*** (0.16)
<i>HHI</i>	0.258*** (0.07)	0.243*** (0.07)	0.254*** (0.07)	0.238*** (0.07)	0.263*** (0.07)	0.249*** (0.07)
<i>SALE</i>	0.010 (0.03)	-0.002 (0.03)	-0.000 (0.03)	-0.015 (0.03)	0.008 (0.03)	-0.005 (0.03)
<i>FS</i>	-0.226*** (0.07)	-0.283*** (0.07)	-0.335*** (0.08)	-0.415*** (0.09)	-0.210*** (0.06)	-0.263*** (0.06)
<i>SOE</i>	-0.310** (0.14)	-0.354*** (0.13)	-0.302** (0.15)	-0.345** (0.14)	-0.284** (0.14)	-0.324** (0.13)
<i>SUB</i>	-0.145 (0.55)	-0.290 (0.53)	-0.188 (0.54)	-0.342 (0.52)	-0.148 (0.55)	-0.293 (0.53)
Constant	14.550*** (1.06)	14.465*** (1.06)	13.975*** (1.16)	13.776*** (1.17)	13.427*** (1.07)	13.120*** (1.07)
U-shaped test	1.54*	1.80**	2.33***	2.30**	2.81***	2.42***
P value	0.062	0.037	0.010	0.011	0.003	0.008
Reflection point	1.573	1.570	1.498	1.523	1.615	1.660
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
F value	56.73	52.95	54.06	49.21	53.05	50.11
<i>R-squared</i>	0.682	0.680	0.682	0.680	0.682	0.681
observation	326079	326032	326079	326032	326079	326032

Note: the levels of \*\*\*, \*\* and \* were significant at 1%, 5% and 10%, respectively. The model controls the year and firm fixed effect, the standard error presented in parenthesis adopted at firm level clustering robustness

## 4.2 Heterogeneous results

In order to further investigate the heterogeneous characteristics of the impact of heterogeneous environmental regulations on the export technological sophistication of manufacturing enterprises, this paper refers to existing relevant literatures and conducts sample analysis on the total sample from three perspectives, including trade pattern, region and ownership. The heterogeneous regression results are shown in *Table 2*.

### 4.2.1 The heterogeneity on enterprises' trade pattern

According to the practice of Zhang et al. (2013), the samples of general trade, processing trade and mixed trade enterprises are divided. The coefficients of first and secondary term of environmental regulation in various trade firm samples were 0.010 and -0.019, -0.854 and 0.413, -0.738 and 0.275, met the 1% level of significance test, and U-shaped test value is 2.40 at 1% significance level, while the rest of variable coefficients and the corresponding U-shaped test values has not been through the 10% level of significance test, shows that the impact of control environmental regulation on the export technological sophistication of mixed trade enterprises is U-shaped nonlinearity. Coefficients of first and secondary term of incentive environmental regulation in various trade enterprises samples were 0.352 and -0.091, 1.799 and -0.714, 0.847 and -0.309, met at 1%-10% level of statistical significance test, but U-shaped test values of 0.86, 3.03 and 1.57, respectively, ordinary trade firm samples failed the 10% level of significance test, shows that the impact of incentive environment regulation merely on processing and mixed trade enterprises' export technological sophistication is inverted U-shaped nonlinearity. The coefficient of first and secondary variables of participative environmental regulation are 0.409 and -0.127, 1.100 and -0.404, 0.743 and -0.242 respectively in the sample of enterprises of various trade types. The coefficient of quadratic variables of processing trade enterprises is significant at the level of 5% except that the coefficient of quadratic variables of processing trade enterprises is significant at the level of 10%. The T-values of the U-test for the samples of the three types of trade mode enterprises are 2.47, 2.07 and 2.15 respectively, which all pass the significance test at the level of 1% to 5%, indicating that the influence of participatory environmental regulation on the technological sophistication of export of enterprises with different trade modes has an inverted U-shaped nonlinear characteristic.

Furthermore, the heterogeneity of the impact of environmental regulation on the export technological sophistication of sample enterprises is investigated from the perspective of inflection point. The inflection point of the impact of control environmental regulation on mixed trade enterprises' export technological sophistication is 1.342, and the intensity of mixed trade enterprises on the average regulation is 0.458, shows that the impact of control environmental regulation on

mixed trade enterprises' export technological sophistication is in negative interval, namely as the regulation intensity increases, the sophistication will be restrained. The inflection point of the impact of incentive environmental regulation on processing and mixed trade enterprises' export technological sophistication are 1.260 and 1.371, respectively, and mixed trade and processing trade enterprises on the average intensity of regulation are 0.653 and 0.689, respectively, shows that the impact of incentive environmental regulation on processing and mixed trade enterprises' export technological sophistication is in positive interval, namely as the regulation intensity increases, the sophistication will be promoted. The inflection point of the impact of participative environmental regulation on ordinary, processing and mixed trade enterprises' export technological sophistication are 1.610, 1.361 and 1.535, respectively, and enterprises with corresponding trade pattern on the average intensity of regulation are 0.903, 0.843 and 0.903, respectively, show that the impact of participative environmental regulation on ordinary, processing and mixed trade enterprises' export technological sophistication are in positive interval, namely as the regulation intensity increases, the corresponding sophistication will be promoted.

**Table 2 Empirical results of the heterogeneity on trade pattern**

Variable	(1) Ordinary	(2) Processing	(3) Mixed	(4) Ordinary	(5) Processing	(6) Mixed	(7) Ordinary	(8) Processing	(9) Mixed
<i>OER</i>	0.010 (0.18)	-0.854 (0.68)	-0.738*** (0.22)						
<i>OERS</i>	-0.019 (0.08)	0.413 (0.43)	0.275*** (0.10)						
<i>MER</i>				0.352*** (0.11)	1.799*** (0.40)	0.847** (0.38)			
<i>MERS</i>				-0.091* (0.05)	-0.714*** (0.19)	-0.309** (0.14)			
<i>PER</i>							0.409*** (0.11)	1.100** (0.56)	0.743*** (0.26)
<i>PERS</i>							-0.127*** (0.04)	-0.404* (0.23)	-0.242** (0.10)
<i>AGE</i>	-0.207*** (0.02)	-0.211*** (0.02)	-0.214*** (0.02)	-0.285*** (0.04)	-0.335*** (0.04)	-0.312*** (0.03)	-0.246*** (0.04)	-0.250*** (0.04)	-0.257*** (0.04)
<i>MARKET</i>	0.314* (0.16)	0.262** (0.12)	0.358*** (0.12)	-0.286 (0.32)	0.011 (0.18)	0.100 (0.18)	-0.306* (0.16)	-0.156 (0.15)	0.038 (0.17)
<i>TFP</i>	0.094 (0.11)	0.093 (0.11)	0.089 (0.11)	0.539 (0.33)	0.397 (0.34)	0.506 (0.34)	-1.217*** (0.18)	-1.226*** (0.18)	-1.229*** (0.18)
<i>HHI</i>	0.228*** (0.07)	0.225*** (0.08)	0.230*** (0.07)	0.043 (0.03)	0.035 (0.03)	0.056** (0.03)	0.236*** (0.08)	0.232*** (0.08)	0.240*** (0.08)
<i>SALE</i>	0.013 (0.03)	0.011 (0.03)	0.014 (0.03)	0.061 (0.05)	0.046 (0.05)	0.067 (0.05)	-0.001 (0.05)	-0.010 (0.05)	-0.001 (0.05)
<i>FS</i>	-0.264*** (0.09)	-0.256*** (0.07)	-0.207*** (0.06)	0.138 (0.14)	-0.277 (0.20)	0.180 (0.17)	-0.467*** (0.07)	-0.595*** (0.06)	-0.454*** (0.09)
<i>SOE</i>	-0.357* (0.21)	-0.344 (0.21)	-0.330 (0.21)	0.108 (2.10)	0.129 (2.12)	0.165 (2.09)	0.176 (0.31)	0.198 (0.32)	0.159 (0.31)
<i>SUB</i>	0.258 (0.25)	0.267 (0.24)	0.300 (0.24)	-0.861 (2.06)	-0.797 (2.05)	-0.825 (2.06)	-0.327 (1.09)	-0.401 (1.07)	-0.388 (1.07)
Constant	10.900*** (1.01)	10.990*** (1.16)	10.682*** (1.11)	13.259*** (1.39)	13.244*** (1.09)	12.024*** (1.08)	12.491*** (1.58)	11.796*** (1.69)	11.274*** (1.59)
U-shaped test	0.05	0.92	2.40***	0.86	3.03**	1.57*	2.47***	2.07**	2.15**
P value	0.478	0.18	0.009	0.194	0.001	0.059	0.007	0.020	0.017
Reflection point			1.342		1.260	1.371	1.610	1.361	1.535
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F value	24.68	25.57	28.14	11.77	33.78	24.92	30.62	31.97	25.54
<i>R-squared</i>	0.631	0.632	0.632	0.813	0.813	0.813	0.792	0.792	0.792
observation	173464	31579	78063	173464	31579	78063	173464	31579	78063

Note: the levels of \*\*\*, \*\* and \* were significant at 1%, 5% and 10%, respectively. The model controls the year and firm fixed effect, the standard error presented in parenthesis adopted at firm level clustering robustness.

#### 4.2.2 The heterogeneity on enterprises' located region

According to the division standards of the National Bureau of Statistics, the samples were divided into enterprises in the middle-western region and enterprises in the eastern region according to the regional divisions of enterprises. The relevant heterogeneous regression results are shown in *Table 3*<sup>3</sup>.

The coefficients of first and secondary term of environmental regulation in two region samples were -0.493 and 0.086, -0.804 and 0.286, met the 1% -5% level of significance test, and U-shaped test value is 2.15 at 5% significance level for eastern region subsample, while the rest of variable coefficients and the corresponding U-shaped test values has not been through the 10% level of significance test, shows that the impact of control environmental regulation on the export technological sophistication of eastern enterprises is U-shaped nonlinearity. The coefficients of first and secondary term of incentive environmental regulation in two region samples were 0.375 and -0.184, 0.912 and -0.252, the coefficient of secondary term for eastern enterprises is not significant at 10% level, and U-shaped test values for middle-western region subsample is 1.06, is not significant, shows that the impact of incentive environment regulation on middle-western and eastern enterprises' export technological sophistication is linear. The coefficient of first and secondary variables of participative environmental regulation on middle-western and eastern region subsamples are 0.162 and -0.103, 0.790 and -0.175, respectively. The coefficient of secondary term was statistically significant in all kinds of firm samples, but the U-shaped test values of each enterprises sample were 0.98 and 0.66, respectively, which were not statistically significant, indicating that the impact of participative environmental regulation on the export technological sophistication of enterprises in the middle-western regions and the eastern regions presented monotonicity.

Furthermore, the inflection point of the impact of control environmental regulation on eastern enterprises' export technological sophistication is 1.406, and the intensity of eastern enterprises on the average regulation is 0.457, shows that the impact of control environmental regulation on eastern enterprises' export technological sophistication is in negative interval, namely as the regulation intensity increases, the sophistication will be restrained. The incentive environmental regulation has only a monotonicity effect on the export technological sophistication of enterprises in the middle and western regions and the eastern regions. The first term coefficient for middle-western and eastern region subsample are 0.375 and 0.912 respectively, indicating that the incentive type has a more significant effect on the export technological sophistication of enterprises in the eastern

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<sup>3</sup> According to the National Bureau of Statistics, the eastern regions of China are: Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan, other provinces, municipalities and other autonomous regions are divided into middle-western regions.

regions than those in the middle and western regions. The coefficient of participative environmental regulation level is 0.162 and 0.790 respectively in the sample of enterprises in the middle- western regions and the eastern regions. Only the latter has statistical significance at the level of 1%, indicating that participative environmental regulation can significantly promote the technological sophistication of export of enterprises in the eastern region.

**Table 3 Empirical results of the heterogeneity on located region**

Variable	(1) Middle-western	(2) Eastern	(3) Middle-western	(4) Eastern	(5) Middle-western	(6) Eastern
<i>OER</i>	-0.493 (0.34)	-0.804*** (0.28)				
<i>OERS</i>	0.086 (0.11)	0.286** (0.12)				
<i>MER</i>			0.375** (0.17)	0.912** (0.37)		
<i>MERS</i>			-0.184*** (0.06)	-0.252 (0.15)		
<i>PER</i>					0.162 (0.15)	0.790*** (0.25)
<i>PERS</i>					-0.103** (0.05)	-0.175* (0.10)
<i>AGE</i>	-0.267*** (0.04)	-0.264*** (0.05)	-0.268*** (0.05)	-0.289*** (0.03)	-0.296*** (0.03)	-0.310*** (0.03)
<i>MARKET</i>	-0.658** (0.26)	-0.420** (0.20)	-0.359* (0.21)	-0.614*** (0.21)	-0.442*** (0.15)	-0.139 (0.14)
<i>TFP</i>	-1.291*** (0.20)	-1.288*** (0.20)	-1.292*** (0.20)	-1.456*** (0.18)	-1.470*** (0.18)	-1.486*** (0.18)
<i>HHI</i>	0.233*** (0.05)	0.233*** (0.05)	0.231*** (0.05)	0.245*** (0.08)	0.236*** (0.08)	0.250*** (0.08)
<i>SALE</i>	-0.027 (0.03)	-0.053* (0.03)	-0.049 (0.03)	0.006 (0.03)	-0.007 (0.03)	0.013 (0.03)
<i>FS</i>	-0.072 (0.12)	-0.184 (0.17)	-0.190 (0.16)	-0.301*** (0.08)	-0.454*** (0.10)	-0.255*** (0.07)
<i>SOE</i>	-0.309 (0.25)	-0.319 (0.25)	-0.276 (0.25)	-0.371** (0.15)	-0.351** (0.17)	-0.263* (0.15)
<i>SUB</i>	-0.442 (1.16)	-0.489 (1.13)	-0.503 (1.14)	-0.261 (0.58)	-0.323 (0.57)	-0.201 (0.59)
Constant	14.180*** (1.28)	13.580*** (1.25)	13.657*** (1.24)	14.486*** (1.20)	13.817*** (1.34)	13.002*** (1.18)
U-shaped test	0.23	2.15**	1.06	2.05***	0.98	0.66
P value	0.409	0.017	0.145	0.022	0.165	0.256
Reflection point		1.406				
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
F value	14.81	15.94	14.57	50.90	41.22	38.45
<i>R-squared</i>	0.772	0.772	0.772	0.753	0.753	0.753
observation	37759	37759	37759	287754	287754	287754

Note: the levels of \*\*\*, \*\* and \* were significant at 1%, 5% and 10%, respectively. The model controls the year and firm fixed effect, the standard error presented in parenthesis adopted at firm level clustering robustness.

#### 4.2.3 The heterogeneity on ownership

In this paper, the types of enterprises that belong to Sino-foreign cooperative enterprises, Sino-foreign joint ventures and wholly foreign-owned enterprises are divided into foreign-funded enterprises, and the other sample enterprises are domestic-funded enterprises. The relevant empirical results are shown in *Table 4*.

The coefficients of first and secondary term of environmental regulation in two ownership samples were -0.339 and 0.140, -0.998 and 0.291, the secondary term for domestic-funded enterprises is not significant at 10% level, while met the 5% level of significance test for foreign-funded enterprises, and U-shaped test value is 2.47 at 1% significance level for foreign-funded

enterprises subsample, shows that the impact of control environmental regulation on the export technological sophistication of foreign-funded enterprises is U-shaped nonlinearity. The coefficients of first and secondary term of incentive environmental regulation in two ownership samples were 0.416 and -0.154, 1.251 and -0.409, which are significant at 1% level, and U-shaped test values for domestic-funded and foreign-funded subsample are 3.02 and 1.87, met 1% significance test, shows that the impact of incentive environment regulation on domestic-funded and foreign-funded enterprises' export technological sophistication is inverted U-shaped nonlinear. The coefficient of first and secondary variables of participative environmental regulation on domestic-funded and foreign-funded firm subsamples are 0.580 and -0.197, 0.995 and -0.288, respectively, met 1% significance test, and corresponding U-shaped test values of each enterprises samples were 2.04 and 2.00, respectively, which were statistically significant at 5% level, indicating that the impact of participative environmental regulation on the export technological sophistication of enterprises in the domestic-funded and foreign-funded enterprises presented inverted nonlinearity.

Furthermore, control environmental regulation has a negative monotone effect on the export technological sophistication of domestic enterprises, but the effect is not statistically significant. The inflection point of the impact of control environmental regulation on foreign-funded enterprises' export technological sophistication is 1.710, and the regulation intensity of the corresponding subsample on the average 0.453, shows that the impact of control environmental regulation on foreign-funded enterprises' export technological sophistication is in negative interval, namely with the the regulation intensity increases, foreign-funded enterprises' export technological sophistication will be promoted. The inflection point of the impact of incentive environmental regulation on two ownership enterprises' export technological sophistication are 1.351 and 1.529, respectively, and the intensity of corresponding enterprises of average regulation 0.676 and 0.651, respectively, show that the impact of incentive environment regulation on the domestic-funded and foreign-funded enterprises' export technological sophistication are in positive interval, namely with the regulation intensity increases, export technological sophistication will be promoted. The inflection point of the impact of participative environmental regulation on two ownership enterprises' export technological sophistication are 1.472 and 1.727, respectively, and the intensity of corresponding enterprises of average regulation 0.907 and 0.878, respectively, show that the impact of participative environment regulation on the domestic-funded and foreign-funded enterprises' export technological sophistication are in positive interval, namely with the regulation intensity increases, export technological sophistication will be promoted.

**Table 4 Empirical results of the heterogeneity on ownership**

Variable	(1) Domestic	(2) Foreign	(3) Domestic	(4) Foreign	(5) Domestic	(6) Foreign
<i>OER</i>	-0.339* (0.20)	-0.998*** (0.26)				

<i>OERS</i>	0.140 (0.09)	0.291** (0.11)				
<i>MER</i>			0.416*** (0.15)	1.251*** (0.40)		
<i>MERS</i>			-0.154*** (0.06)	-0.409** (0.16)		
<i>PER</i>					0.580*** (0.12)	0.995*** (0.27)
<i>PERS</i>					-0.197*** (0.05)	-0.288*** (0.10)
<i>AGE</i>	-0.292*** (0.03)	-0.293*** (0.03)	-0.298*** (0.03)	-0.284*** (0.02)	-0.293*** (0.03)	-0.302*** (0.03)
<i>MARKET</i>	-0.161 (0.15)	-0.119 (0.12)	-0.020 (0.13)	-0.976*** (0.19)	-0.706*** (0.14)	-0.391** (0.16)
<i>TFP</i>	-1.098*** (0.16)	-1.101*** (0.16)	-1.104*** (0.16)	-1.787*** (0.18)	-1.800*** (0.19)	-1.800*** (0.18)
<i>HHI</i>	0.277*** (0.07)	0.275*** (0.07)	0.279*** (0.07)	0.222*** (0.07)	0.215*** (0.07)	0.230*** (0.07)
<i>SALE</i>	-0.033 (0.04)	-0.040 (0.04)	-0.037 (0.04)	0.020 (0.03)	0.006 (0.03)	0.021 (0.02)
<i>FS</i>	-0.179* (0.10)	-0.208** (0.09)	-0.154** (0.07)	-0.359*** (0.08)	-0.601*** (0.08)	-0.348*** (0.09)
<i>SOE</i>	-0.457*** (0.13)	-0.450*** (0.13)	-0.419*** (0.12)	-0.002 (0.01)	-0.256 (0.17)	-0.002 (0.04)
<i>SUB</i>	-1.017 (0.62)	-1.034* (0.61)	-0.986 (0.62)	0.424 (0.92)	0.367 (0.91)	0.433 (0.93)
Constant	13.977*** (1.19)	13.701*** (1.28)	13.373*** (1.24)	14.904*** (1.07)	13.881*** (1.21)	12.994*** (1.09)
U-shaped test	1.47*	2.47***	3.02***	1.87**	2.04**	2.00**
P value	0.071	0.007	0.001	0.032	0.021	0.024
Reflection point		1.710	1.351	1.529	1.472	1.727
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
F value	24.47	26.07	25.03	85.30	69.51	85.13
<i>R-squared</i>	0.755	0.755	0.755	0.748	0.748	0.748
observation	142289	142289	142289	183555	183555	183555

Note: the levels of \*\*\*, \*\* and \* were significant at 1%, 5% and 10%, respectively. The model controls the year and firm fixed effect, the standard error presented in parenthesis adopted at firm level clustering robustness.

### 4.3 Mediation effect analysis

Based on the analysis of the above theoretical part, it can be seen that the heterogeneous environment regulation affects the export technological sophistication of manufacturing enterprises through the mediation variable R&D innovation. This part focuses on examining the mediation mechanism of the heterogeneous environment regulation affecting the export technological sophistication. Existing literature there are a variety of ways to test the mediation effect, this paper refers to Baron & Kenny (1986), Wen et al. (2004) proposed by stepwise regression method to test the mediation effect, the test for the coefficient of interaction is the core. However, in practice often appear coefficient significantly, in turn, no significant test of product (Judd & Kenny, 1981; MacKinnon et al., 2002). Therefore, in the sequential test, either one independent variable or mediating variable is not significant, Sobel (1982) method should be further used to test the coefficient interaction to determine whether there is a mediating effect.

According to the above explanation on mediation effect test, the relevant econometric model paradigm is set as follows:

$$\begin{aligned}
TSI_{it} = & \alpha_0 + \beta_0 ER_{it} + \beta_1 ERS_{it} + \beta_2 AGE_{it} + \beta_3 SALE_{it} + \beta_4 FS_{it} + \beta_5 TFP_{it} \\
& + \beta_6 HHI_{it} + \beta_7 SOE_{it} + \beta_8 SUB_{it} + \beta_9 MARKET_{it} \\
& + \eta_i + \gamma_i + \varepsilon_{it}
\end{aligned} \tag{21}$$

$$RD_{it} = \alpha_0 + \beta_0 ER_{it} + \beta_1 ERS_{it} + \beta_2 AGE_{it} + \beta_3 SALE_{it} + \beta_4 FS_{it} + \beta_5 TFP_{it} + \beta_6 HHI_{it} + \beta_7 SOE_{it} + \beta_8 SUB_{it} + \beta_9 MARKET_{it} + \eta_i + \gamma_i + \varepsilon_{it} \quad (22)$$

$$TSI_{it} = \alpha_0 + \beta_0 ER_{it} + \beta_1 ERS_{it} + \beta_2 RD_{it} + \beta_3 AGE_{it} + \beta_4 SALE_{it} + \beta_5 FS_{it} + \beta_6 TFP_{it} + \beta_7 HHI_{it} + \beta_8 SOE_{it} + \beta_9 SUB_{it} + \beta_{10} MARKET_{it} + \eta_i + \gamma_i + \varepsilon_{it} \quad (23)$$

Where  $ER_{it}$  denotes the heterogeneous environmental regulation intensity, which is composed of control type, incentive type and participative type environmental regulation;  $RD_{it}$  represents the firm R&D innovation, composed of basic, practical and design innovation.

Table 5 shows the mediation mechanism regression results of the impact of control environmental regulation on the export technological sophistication of manufacturing enterprises. Column (1) is the regression result of the total effect of control environmental regulation on the export technological sophistication, and column (2)(3), column (4)(5) and column (6)(7) are the regression result of the mediation effect of basic, practical and design innovation, respectively. From the statistical significance of core independent variables and mediating variable coefficients, it is not difficult to find that the coefficients of the variables in columns (4) and (5) are statistically significant at 1% level, indicating that the practical innovation of enterprises is indeed an mediation channel for the impact of control environmental regulation on the export technological sophistication. The corresponding mediating variable coefficients in columns (2)(3) and (6)(7) are not significant. Sobel (1982) method is further used to conduct mediating effect test. The absolute value z statistics and p values are 2.87 and 0.004, 1.022 and 0.307, respectively.

**Table 5 The mediation effect of control environmental regulation**

Variable	(1) <i>TSI</i>	(2) <i>RD1</i>	(3) <i>TSI</i>	(4) <i>RD2</i>	(5) <i>TSI</i>	(6) <i>RD3</i>	(7) <i>TSI</i>
<i>OER</i>	-0.722*** (0.08)	-0.006*** (0.00)	-0.722*** (0.08)	-0.140*** (0.01)	-0.714*** (0.08)	-0.042*** (0.01)	-0.721*** (0.08)
<i>OERS</i>	0.230*** (0.05)	0.002* (0.00)	0.230*** (0.05)	0.033*** (0.01)	0.228*** (0.05)	0.015*** (0.01)	0.230*** (0.05)
<i>RD1</i>			0.032 (0.07)				
<i>RD2</i>					0.060*** (0.01)		
<i>RD3</i>							0.019 (0.02)
<i>AGE</i>	-0.286*** (0.00)	0.000 (0.00)	-0.286*** (0.00)	0.010*** (0.00)	-0.287*** (0.00)	0.002*** (0.00)	-0.286*** (0.00)
<i>MARKET</i>	-0.610*** (0.05)	-0.008*** (0.00)	-0.609*** (0.05)	-0.241*** (0.01)	-0.595*** (0.05)	-0.041*** (0.01)	-0.609*** (0.05)
<i>TFP</i>	-1.435*** (0.03)	-0.002** (0.00)	-1.435*** (0.03)	-0.056*** (0.00)	-1.431*** (0.03)	-0.014*** (0.00)	-1.434*** (0.03)
<i>HHI</i>	0.243*** (0.01)	-0.000 (0.00)	0.243*** (0.01)	0.005*** (0.00)	0.243*** (0.01)	0.002*** (0.00)	0.243*** (0.01)
<i>SALE</i>	-0.002 (0.01)	-0.000** (0.00)	-0.002 (0.01)	-0.006*** (0.00)	-0.002 (0.01)	0.001 (0.00)	-0.003 (0.01)
<i>FS</i>	-0.283*** (0.03)	-0.000 (0.00)	-0.283*** (0.03)	-0.050*** (0.00)	-0.280*** (0.03)	-0.000 (0.00)	-0.283*** (0.03)
<i>SOE</i>	-0.354*** (0.12)	-0.007** (0.00)	-0.354*** (0.12)	-0.096*** (0.02)	-0.348*** (0.12)	-0.040*** (0.01)	-0.353*** (0.12)
<i>SUB</i>	-0.290 (0.37)	-0.012 (0.01)	-0.290 (0.37)	-0.162*** (0.05)	-0.281 (0.37)	-0.056 (0.05)	-0.289 (0.37)
Constant	14.465*** (0.20)	0.024*** (0.01)	14.464*** (0.20)	0.470*** (0.03)	14.437*** (0.20)	0.054** (0.02)	14.464*** (0.20)



Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F value	669.3	7.494	608.5	288.8	610.2	14.33	608.6
R-squared	0.680	0.270	0.680	0.381	0.680	0.257	0.680
observation	326032	326620	326032	326620	326032	326620	326032

Note: the levels of \*\*\*, \*\* and \* were significant at 1%, 5% and 10%, respectively. The model controls the year and firm fixed effect, the standard error presented in parenthesis adopted at firm level clustering robustness.

Table 6 shows the mediation mechanism regression results of the impact of incentive environmental regulation on the export technological sophistication of manufacturing enterprises. Column (1) is the regression result of the total effect of incentive environmental regulation on the export technological sophistication, and column (2)(3), column (4)(5) and column (6)(7) are the regression result of the mediation effect of basic, practical and design innovation, respectively. From the statistical significance of core independent variables and mediating variable coefficients, it is not difficult to find that the variables of columns (4) and (5) are statistically significant at the 1% level, indicating that the practical innovation of enterprises is indeed an mediation channel through which the incentive environmental regulation affects the export technological sophistication. The corresponding mediating variables in columns (2)(3) and (6)(7) were not significant. Sobel (1982) method was further used to test the mediation effects. The absolute value of z statistics and p values were 2.443 and 0.015, 8.229 and 0.000, respectively.

**Table 6 The mediation effect of incentive environmental regulation**

Variable	(1) <i>TSII</i>	(2) <i>RD1</i>	(3) <i>TSII</i>	(4) <i>RD2</i>	(5) <i>TSII</i>	(6) <i>RD3</i>	(7) <i>TSII</i>
<i>MER</i>	0.8648*** (0.060)	0.0000 (0.002)	0.8648*** (0.060)	0.0563*** (0.009)	0.8613*** (0.060)	0.0067 (0.007)	0.8647*** (0.060)
<i>MERS</i>	-0.2840*** (0.028)	-0.0003 (0.001)	-0.2840*** (0.028)	-0.0178*** (0.004)	-0.2829*** (0.028)	-0.0006 (0.003)	-0.2840*** (0.028)
<i>RD1</i>			0.0397 (0.074)				
<i>RD2</i>					0.0623*** (0.014)		
<i>RD3</i>							0.0207 (0.016)
<i>AGE</i>	-0.2906*** (0.005)	0.0002* (0.000)	-0.2906*** (0.005)	0.0106*** (0.001)	-0.2913*** (0.005)	0.0026*** (0.001)	-0.2907*** (0.005)
<i>MARKET</i>	-0.4474*** (0.045)	-0.0057*** (0.001)	-0.4472*** (0.045)	-0.1848*** (0.006)	-0.4359*** (0.045)	-0.0267*** (0.006)	-0.4469*** (0.045)
<i>TFP</i>	-1.4419*** (0.034)	-0.0017* (0.001)	-1.4419*** (0.034)	-0.0551*** (0.005)	-1.4385*** (0.034)	-0.0135*** (0.004)	-1.4416*** (0.034)
<i>HHI</i>	0.2377*** (0.007)	-0.0000 (0.000)	0.2377*** (0.007)	0.0039*** (0.001)	0.2375*** (0.007)	0.0022** (0.001)	0.2377*** (0.007)
<i>SALE</i>	-0.0152** (0.008)	-0.0005** (0.000)	-0.0152** (0.008)	-0.0081*** (0.001)	-0.0147* (0.008)	0.0003 (0.001)	-0.0152** (0.008)
<i>FS</i>	-0.4145*** (0.031)	-0.0011 (0.001)	-0.4145*** (0.031)	-0.0805*** (0.004)	-0.4095*** (0.031)	-0.0077** (0.004)	-0.4144*** (0.031)
<i>SOE</i>	-0.3448*** (0.120)	-0.0068** (0.003)	-0.3445*** (0.120)	-0.0988*** (0.017)	-0.3386*** (0.120)	-0.0411*** (0.015)	-0.3439*** (0.120)
<i>SUB</i>	-0.3425 (0.371)	-0.0129 (0.10)	-0.3419 (0.371)	-0.1822*** (0.054)	-0.3312 (0.371)	-0.0613 (0.045)	-0.3412 (0.371)
Constant	13.7759*** (0.186)	0.0163*** (0.005)	13.7752*** (0.186)	0.2838*** (0.027)	13.7582*** (0.186)	0.0086 (0.023)	13.7757*** (0.186)
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F value	683.1	6.350	621.0	259.7	622.9	11.81	621.1
R-squared	0.680	0.270	0.680	0.380	0.681	0.256	0.680
observation	326032	326620	326032	326620	326032	326620	326032

Note: the levels of \*\*\*, \*\* and \* were significant at 1%, 5% and 10%, respectively. The model controls the year and firm fixed effect, the standard error presented in parenthesis adopted at firm level clustering robustness.

Table 7 shows the mediation mechanism regression results of the impact of participative environmental regulation on the export technological sophistication of manufacturing enterprises. Column (1) is the regression result of the total effect of participative environmental regulation on the export technological sophistication, and column (2)(3), column (4)(5) and column (6)(7) are the regression result of the mediation effect of basic, practical and design innovation, respectively. From the statistical significance of core independent variables and mediating variable coefficients, it is not difficult to find that the coefficients of variables in columns (4) and (5) are statistically significant at 1% level, indicating that practical innovation is indeed a mediation channel through which participative environmental regulation affects the export technological sophistication. The mediation effect of columns (2)(3) and (6)(7) was not significant. Sobel (1982) method was further used to test the mediation effect. Absolute value of z statistics and p values were 2.900 and 0.004, 1.211 and 0.226, respectively.

**Table 7 The mediation effect of participative environmental regulation**

Variable	(1) <i>TSII</i>	(2) <i>RD1</i>	(3) <i>TSII</i>	(5) <i>RD2</i>	(6) <i>TSII</i>	(8) <i>RD3</i>	(9) <i>TSII</i>
<i>PER</i>	0.8626*** (0.047)	0.0049*** (0.001)	0.8625*** (0.047)	0.8576*** (0.047)	-0.0059 (0.006)	0.8626*** (0.047)	0.0049*** (0.001)
<i>PERS</i>	-0.2601*** (0.020)	-0.0015*** (0.001)	-0.2600*** (0.020)	-0.2585*** (0.020)	0.0025 (0.002)	-0.2601*** (0.020)	-0.0015*** (0.001)
<i>RD1</i>			0.0208 (0.074)		0.0552*** (0.014)		
<i>RD2</i>							
<i>RD3</i>							0.0222 (0.016)
<i>AGE</i>	-0.2993*** (0.005)	0.0001 (0.000)	-0.2993*** (0.005)	-0.2998*** (0.005)	0.0028*** (0.001)	-0.2993*** (0.005)	0.0001 (0.000)
<i>MARKET</i>	-0.2224*** (0.045)	-0.0051*** (0.001)	-0.2222*** (0.045)	-0.2132*** (0.045)	-0.0259*** (0.005)	-0.2224*** (0.045)	-0.0051*** (0.001)
<i>TFP</i>	-1.4508*** (0.034)	-0.0018** (0.001)	-1.4507*** (0.034)	-1.4477*** (0.034)	-0.0132*** (0.004)	-1.4508*** (0.034)	-0.0018** (0.001)
<i>HHI</i>	0.2486*** (0.007)	0.0000 (0.000)	0.2486*** (0.007)	0.2484*** (0.007)	0.0023*** (0.001)	0.2486*** (0.007)	0.0000 (0.000)
<i>SALE</i>	-0.0053 (0.008)	-0.0005** (0.000)	-0.0053 (0.008)	-0.0049 (0.008)	0.0004 (0.001)	-0.0053 (0.008)	-0.0005** (0.000)
<i>FS</i>	-0.2634*** (0.032)	-0.0002 (0.001)	-0.2634*** (0.032)	-0.2598*** (0.032)	-0.0084** (0.004)	-0.2634*** (0.032)	-0.0002 (0.001)
<i>SOE</i>	-0.3236*** (0.120)	-0.0065** (0.003)	-0.3235*** (0.120)	-0.3184*** (0.120)	-0.0419*** (0.015)	-0.3236*** (0.120)	-0.0065** (0.003)
<i>SUB</i>	-0.2931 (0.371)	-0.0123 (0.010)	-0.2928 (0.371)	-0.2834 (0.371)	-0.0621 (0.045)	-0.2931 (0.371)	-0.0123 (0.010)
Constant	13.1200*** (0.187)	0.0143*** (0.005)	13.1197*** (0.187)	13.1077*** (0.187)	0.0070 (0.023)	13.1200*** (0.187)	0.0143*** (0.005)
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F value	713.1	8.741	648.3	649.7	11.52	713.1	8.741
R-squared	0.681	0.270	0.681	0.681	0.256	0.681	0.270
observation	326032	326620	326032	326620	326032	326620	326032

Note: the levels of \*\*\*, \*\* and \* were significant at 1%, 5% and 10%, respectively. The model controls the year and firm fixed effect, the standard error presented in parenthesis adopted at firm level clustering robustness.

#### 4.4 Discussion on endogeneity

The core independent variable of this paper is heterogeneous environmental regulation. As an environmental policy, it is exogenous to some extent, but the environmental regulation intensity is correlated with regional pollution levels and production activities. Therefore, it may be impossible

to avoid endogenous problems in the regression process. If the core explanatory variables are not strictly exogenous, the regression results will be biased and inconsistent. Generally speaking, there are mainly three forms of endogeneity: the first is the omission variable, that is, the endogeneity problem caused by the non-observable factors that may potentially affect the core explanatory variables included in the error term of the model, which is solved by controlling the year and firm fixed effect. The second is sample selection bias, that is, the observed values are only derived from the endogenous problems generated by non-random limited individuals, which is tested by the two-step method proposed by Heckman (1979). The third is reverse causality, namely endogeneity under the condition that dependent variables and independent variables influence each other, which is alleviated by the instrumental variable two-stage least square method 2SLS.

Prior to the application of Heckman two-step method and 2SLS method, it is necessary to determine the instrumental variables corresponding to the core variables. Due to the complex impact of environmental regulation on the export technological sophistication, no effective instrumental variables have been proposed in the existing literature. In relevant literature, most scholars choose the endogenous variable lag value of the first order and the average value of the variable as instrumental variables of the core independent variables (Li & Qi, 2011; Yu et al., 2014). Considering the possible inverse causality between environmental regulation and export technological sophistication, it is necessary to find appropriate instrumental variables. In terms of environmental regulation variables, referring to the practice of Shen et al. (2017), Chen & Chen (2018), the concept of air flow coefficient in meteorology is introduced as an instrumental variable of environmental regulation. To be specific, based on the grid data Era-Interim published by ECMWF, an air flow coefficient index describing air mobility at the prefectural-level city level in China was constructed. The relevant formula is similar to that of Broner et al. (2012), Hering & Poncet (2014):

$$AIRCUR_{ct} = WINDS_{ct} \bullet BOUNH_{ct} \quad (24)$$

Where  $AIRCUR_{ct}$  is the air flow coefficient,  $WINDS_{ct}$  is the wind speed of 10 meters, and  $BOUNH_{ct}$  is the height of atmospheric mixing layer (or boundary layer). ArcGIS software is used to analyze the latitude and longitude grid data into the data at the city level.  $c$  and  $t$  represent city and year, respectively. Theoretically, when the air pollutant discharge is the same, cities with low air flow coefficient tend to adopt more stringent environmental regulation tools, and the instrumental variables have a strong correlation with endogenous variables, and a weak correlation with error terms and dependent variables, which meet the conditions of instrumental variables. Therefore, it is reasonable to choose air flow coefficient as the instrumental variable of heterogeneous environmental regulation.

The relevant results are shown in *Table 8*. Columns (1)(2), (3)(4), and (5)(6) represent sample selection bias test results of the impact of control, incentive and participative environmental regulations on the export technological sophistication, respectively. Columns (1)(4)(7) and (2)(5)(8) are Heckman's regression results in the second stage. From the results, the inverse Mills ratio is statistically significant in all regression results, indicating that the model does have sample selection bias to a certain extent. Further analysis of various core model independent variable as a result, control, incentive and participative type environmental regulation and quadratic term coefficient are -0.391 and 0.293, 0.123 and -0.062, 0.293 and -0.086, both by 1%-5% level of significance test, the coefficient on the sign and statistical significance are consistent with the benchmark result, therefore this paper suggests that although there is a certain degree of sample selection bias, the regression results of core arguments did not cause obvious interference.

Columns (3), (6) and (9) show the results of the reverse causality endogeneity test of the influence of control, incentive and participative environmental regulations on the export technological sophistication of manufacturing enterprises, respectively. Based on the above selection and measure of instrumental variables, the coefficients in each column are -8.577 and 5.781, 2.294 and -0.037, 0.774 and -0.166, respectively, which are statistically significant at different levels. The coefficients are consistent with the benchmark results in terms of symbol and statistical significance. It is found that Kleibergen & Paap (2006) have LM test values of 105.59, 25.36 and 1066.41, respectively, which effectively rejects the null hypothesis that the instrument variable is not identifiable, indicating that the selected instrument variable is identifiable. The Wald rk F test values of Kleibergen & Paap (2006) are 36.85, 13.60 and 671.85, respectively, which effectively reject the weak recognition hypothesis, indicating that the selected instrument variable is highly identifiable. The Wald test values of Anderson & Rubin (1950) were 15.28, 23.67 and 97.78, respectively, effectively rejecting the null hypothesis of the weak instrumental variable. All the above test results show that there is no obvious problem in the validity of the instrumental variables in this paper.

**Table 8 Empirical results of endogeneity**

Variable	(1) Heckman Two-step	(2) Heckman Two-step	(3) 2SLS	(4) Heckman Two-step	(5) Heckman Two-step	(6) 2SLS	(7) Heckman Two-step	(8) Heckman Two-step	(9) 2SLS
<i>OER</i>	-0.391*** (0.05)		-8.577*** (2.92)						
<i>OERS</i>	0.293*** (0.03)		5.781** (2.38)						
<i>MER</i>				0.123*** (0.05)		2.294** (0.92)			
<i>MERS</i>				-0.062** (0.03)		-0.037* (0.020)			
<i>PER</i>							0.293*** (0.06)		0.774*** (0.19)
<i>PERS</i>							-0.086*** (0.02)		-0.166** (0.08)
<i>AGE</i>	-0.187*** (0.01)	-0.151*** (0.00)	-0.305*** (0.01)	-0.380*** (0.03)	-0.107*** (0.00)	-0.331*** (0.01)	-0.388*** (0.03)	-0.107*** (0.00)	-0.305*** (0.01)
<i>MARKET</i>	0.293*** (0.05)	0.306*** (0.02)	-1.236*** (0.21)	3.690*** (0.42)	1.238*** (0.02)	-0.535*** (0.13)	3.772*** (0.43)	1.238*** (0.02)	0.004 (0.05)
<i>TFP</i>	-0.043 (0.07)	-1.125*** (0.01)	-1.477*** (0.04)	-1.046*** (0.10)	0.276*** (0.01)	-1.220*** (0.06)	-1.025*** (0.10)	0.276*** (0.01)	-1.150*** (0.05)

<i>HHI</i>	0.215*** (0.01)	0.112*** (0.00)	0.247*** (0.01)	0.318*** (0.01)	-0.016*** (0.00)	0.141*** (0.02)	0.314*** (0.01)	-0.016*** (0.00)	0.186*** (0.01)
<i>SALE</i>	-0.030** (0.01)	-0.224*** (0.00)	0.017 (0.01)	-0.219*** (0.01)	0.022*** (0.00)	-0.028** (0.01)	-0.215*** (0.01)	0.022*** (0.00)	-0.001 (0.01)
<i>FS</i>	- 10.136*** (0.14)	-0.926*** (0.02)	0.066 (0.12)	- 11.220*** (0.16)	-0.223*** (0.02)	-0.389*** (0.06)	- 11.169*** (0.17)	-0.223*** (0.02)	-0.109** (0.05)
<i>SOE</i>	0.442*** (0.03)	0.169*** (0.02)	-0.326** (0.14)	1.057*** (0.08)	0.194*** (0.01)	-0.386* (0.21)	1.076*** (0.08)	0.194*** (0.01)	-0.561*** (0.20)
<i>SUB</i>	0.604 (0.41)	-0.884*** (0.16)	-0.177 (0.42)	1.540** (0.68)	1.567*** (0.22)	-0.356 (0.43)	1.630** (0.70)	1.567*** (0.22)	-0.377 (0.41)
<i>IMR</i>		2.056*** (0.21)			4.532*** (0.59)				4.679*** (0.61)
Constant	13.349*** (0.26)	6.468*** (0.10)	15.006*** (0.34)	9.060*** (0.55)	0.227*** (0.06)	14.454*** (0.29)	8.860*** (0.57)	0.227*** (0.06)	15.560*** (0.68)
U-shaped test			2.32***			3.14			0.58
P value			0.010			0.252			0.281
Reflection point									
rk LM test			105.59			25.36			1066.41
Wald rk F test			36.85			13.60			671.85
Wald test			15.28			23.67			96.78
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	354953	354953	326032	354953	354953	354953	354953	354953	354953

Note: the levels of \*\*\*, \*\* and \* were significant at 1%, 5% and 10%, respectively. The model controls the year and firm fixed effect, the standard error presented in parenthesis adopted at firm level clustering robustness.

## 5. Conclusions and Implications

This paper investigates the impact of environmental regulations on the export technological sophistication of manufacturing enterprises, tests the theoretical mechanism behind the impact, and makes an in-depth analysis of the impact on heterogeneity based on the perspective of trade pattern, location and ownership of enterprises. Relevant research conclusions are as follows:

(1) The impact of control type environmental regulation on export technological sophistication is U-shaped nonlinear, while the impact of incentive type and participative environmental regulation on export technological sophistication is inverted U-shaped nonlinear. The intensity of control, incentive and participative environmental regulation of the mean value are 0.465, 0.663 and 0.891, respectively, all kinds of environmental regulation affect the inflection point of the technological sophistication were 1.570-1.573, 1.498-1.523 and 1.615-1.660, shows that the impact of control environmental regulation on export technological sophistication is in negative interval, and the impact of incentive and participative environmental regulation on export technological sophistication is in positive range.

(2) In terms of heterogeneity of trade patterns, the impact of control environmental regulation on the export technological sophistication for mixed trade enterprises has a significant U-shaped nonlinear, which shows a specific negative effect; The impact of incentive environmental regulation on the export technological sophistication for processing trade and mixed trade enterprises has an inverted U-shaped nonlinear characteristic, which shows the positive effect; The impact of participative environmental regulation on the export technological sophistication for ordinary trade, processing trade and mixed trade enterprises has inverted U-shaped nonlinear characteristic, which

shows the positive effect.

In terms of heterogeneity of firm location, the impact of control environmental regulation on the export technological sophistication has a U-shaped nonlinear characteristic for eastern enterprises, which shows a negative effect; The incentive environmental regulation has only a monotonously positive impact on the export technological sophistication for enterprises in the east and the middle-west. Participative environmental regulation has a significant monotonic effect on the improvement for export technological sophistication of eastern enterprises.

In terms of the heterogeneity of firm ownership, the impact of control environmental regulation on the export technological sophistication has a U-shaped nonlinear characteristic for foreign-funded enterprises, which shows a negative effect. The impact of incentive environmental regulation on the export technological sophistication has an inverted U-shaped nonlinear characteristic for both domestic-funded and foreign-funded enterprises, which shows a positive effect. The impact of participative environmental regulation on the export technological sophistication for domestic-funded and foreign-funded enterprises has an inverted U-shaped nonlinear characteristic, which shows a positive effect.

(3) The results of mechanism analysis show that control environmental regulation has a significant impact on the export technological sophistication through mediation channels such as basic innovation and practical innovation. Incentive environmental regulation significantly affects the export technological sophistication through mediation channels such as basic innovation, practical innovation and design innovation. Participative environmental regulation significantly affects the export technological sophistication through mediation channels such as basic innovation and practical innovation.

The conclusion of this paper has obvious policy implications. In view of the differences in the types of tools of heterogeneous environmental regulation and the impact on the export technological sophistication of enterprises, the policy improvements brought by heterogeneous environmental regulation are also different. The effective implementation of control environmental regulation tools need to improve the environmental management system, and the competent department of our country current environmental authority is not clear, lack of market management, plan as a whole, such as problems to be solved, the government should further strengthen the relationship between their respective functions and powers, improve the efficiency of system operation and improve the efforts of environmental legal system construction; There is still much room for incentive environmental regulation to increase the export technological sophistication of enterprises. Relevant departments should continue to improve the environmental tax system, such as gradually expanding the range of environmental taxes and strictly controlling tax preferences. In addition, it is urgent to

improve China's pollution discharge rights mechanism. The government should improve the legal basis of emission trading, establish a fair and reasonable initial distribution and pricing mechanism, and accelerate the integration of emission trading and carbon trading. Participative environmental regulation plays an important role in improving the export technological sophistication. Therefore, China should further increase the enthusiasm of the public to participate in environmental construction. The government should clarify the public's environmental rights through laws, enhance the public's environmental awareness through publicity media and broaden and enrich the channels and forms for the public to participate in environmental management to improve participative environmental regulation.

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