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Impact of Environmental Regulation on Export Technological Complexity of High-Tech Industries in Chinese Manufacturing

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Abstract: Since the reform and opening-up, China has developed into the world's number one manufacturing country. Meanwhile, China's environmental protection efforts continue to strengthen. So, will changes in the intensity of environmental regulatory policies have an impact on the technological development level and international competitiveness of China's high-tech manufacturing industries? In response to this issue, we have reviewed relevant research in the field of environmental regulation and export technology complexity, and then selected appropriate indicators to quantify the environmental regulation and export technology complexity of high-tech manufacturing industries in different regions of China. Furthermore, the entropy method was used to calculate the intensity of environmental regulations in different regions of China. In the subsequent empirical analysis, based on relevant indicator data from 30 provinces in China, excluding Tibet, from 2006 to 2021, we quantitatively analyzed the impact of China's environmental regulations on the complex export technology of high-tech manufacturing industries. The degree of influence and the robustness of the benchmark regression results was proved through endogeneity testing and robustness testing. The main conclusions are as follows: (1) from 2006 to 2021, China's environmental regulation intensity and the technological complexity of high-tech industry exports have shown an upward trend. (2) The empirical analysis results show that the increase in intensity has a significant "U-shaped" impact on the technological complexity of exports of high-tech manufacturing industries. (3) The "U-shaped" impact of environmental regulation on the technological complexity of exports of high-tech manufacturing industries has regional differences. However, the high-tech manufacturing industry does not show obvious industry differences. (4) Environmental regulations will affect the level of export technology complexity of the high-tech manufacturing industry through foreign direct investment, human capital, and innovative R D investment, which cause indirect effects. Based on those conclusions, this paper has suggested corresponding policy measures and future research directions.

Keywords: environmental regulation; export technological complexity; high-tech manufacturing industry; technological innovation

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1. Introduction

China is currently the world's top-ranking manufacturing power, possessing strong advantages in terms of variety and scale of its manufacturing industry (Hering and Poncet 2014; Kee and Tang 2016; Wang et al. 2022, 2023). However, the technological level of China's manufacturing industry is not high, with low product added value, and it faces challenges such as insufficient innovation and Western developed countries holding a grip on core technologies (Ahn et al. 2011; Kee and Tang 2016; Yang et al. 2024; Yang et al. 2022c). In order to address this phenomenon, "Made in China 2025" explicitly proposes that China aims to construct itself as a "manufacturing powerhouse," converting the scale advantages of its manufacturing industry into technological and qualitative advantages, achieving a transformation and upgrade of the manufacturing industry. In the current landscape of China's manufacturing industry, high-tech industries within manufacturing exhibit a greater demand for technology, innovation, and research and development investment (Gao and Dong 2022). These industries are key to achieving breakthrough development in manufacturing, significantly enhancing the international competitiveness of the sector. Despite the gradual increase in the proportion of high-tech industry exports within the entire manufacturing industry, their technological level requires further improvement (Gnangnon 2022; Tsurumi et al. 2015).

According to the prevailing academic practice, the export technological complexity index is employed to characterize the technological level of a country or region's industrial exports (Bigerna et al. 2019; Saqib et al. 2023; Tarei et al. 2021). A higher value of the export technological complexity index indicates stronger international competitiveness for that industry. Therefore, to achieve a further leap in the overall level of China's manufacturing industry, efforts should be made to enhance the export technological complexity of high-tech industries within manufacturing (Barrieu and Sinclair-Desgagné 2006; Chen et al. 2023; Naime 2017).

Simultaneously, with the rapid development of China's manufacturing industry, environmental issues such as air and water pollution have become increasingly severe (Alexander and Schwandt 2022; Bardi and Hfaiedh 2021; Blundell et al. 2020; Duflo et al. 2018; Veretennikova and Selezneva 2023). Due to a lack of standardized management of corporate behaviors, untreated industrial wastewater and emissions directly threaten the ecological balance, posing a serious threat to the environment. To address these environmental issues, the country has introduced a series of environmental regulatory policies to balance economic development and environmental protection (Aversa and Guillotin 2018; Manatovna et al. 2023; Nõmmela and Kõrbe Kaare 2022; Novitasari and Tarigan 2022). These policies regulate and constrain various activities that pollute the natural environment, thereby propelling China's economy towards green, efficient, and high-quality development (Borenstein et al. 2019; Chen et al. 2023; Kvasha et al. 2023; Ullah et al. 2023). In response to escalating global issues such as climate change, China officially announced the "Strive to achieve carbon peak by 2030 and carbon neutrality by 2060" goal in 2020 (referred to as the "Dual Carbon" goal). To achieve this goal, China will further strengthen environmental regulations to reduce the emissions of pollutants such as carbon dioxide (Blundell et al. 2020; Kvasha et al. 2023; Saqib et al. 2023; Tarei et al. 2021; Wang et al. 2022). The intensification of environmental regulations implies higher green standards for the production activities of enterprises, especially those in the manufacturing industry. Therefore, in the context of global division of labor, high-tech industries within China's manufacturing sector should receive more attention and strive to increase their export technological complexity, thereby gaining stronger international competitiveness.

However, in the face of escalating environmental problems, effectively enhancing the export technological complexity of high-tech industries in China's manufacturing sector requires compliance with environmental regulatory requirements (Oginni and Omojowo 2016; Phuoc 2022; Yang et al. 2023b). To further promote the development of China's manufacturing industry and the entire national economy, it is essential to study the impact of environmental regulations on the export technological complexity of high-tech industries. While China is developing its economy, it is highly attentive to environmental protection issues (Barrieu and Sinclair-Desgagné 2006; Blundell et al. 2020; Yang et al. 2023c). The introduction of the "Dual Carbon" goal indicates a new level of importance attached to environmental issues in China. Strengthening environmental protection does not mean sacrificing economic development but requires accelerating the pace of economic transformation towards green and efficient development, striving for a "win-win" situation between economic development and ecological protection. However, the intensified environmental regulations imply higher environmental protection conditions, such as stricter emission control requirements, which will impose certain restrictions and impacts on the production and operation of enterprises (Ren et al. 2023; Yang et al. 2022d). Although heavy-polluting industries like steel, chemicals, petroleum, and coal are greatly affected by environmental regulations (Yang et al. 2023a), the environmental regulatory pressure faced by high-tech industries within the manufacturing sector should not be underestimated. The strengthening of environmental regulations will pose greater pressure on China's high-tech industries within the manufacturing sector, leading to increased production costs (Jin et al. 2019; Mbanyele and Wang 2022; Song et al. 2023; Xu 2023). In this context, to maximize profits, enterprises will intensify innovation and research and development efforts to further improve production efficiency and product added value. Therefore, the export technological complexity of high-tech industries within manufacturing will be affected accordingly.

Given these considerations, the main objective of this paper is to explore whether the export technological complexity of high-tech industries within China's manufacturing sector will change correspondingly when the intensity of environmental regulatory policies changes, and to identify the specific mechanisms behind such changes. Additionally, this paper will conduct heterogeneous analysis on the relationship between the intensity of environmental regulations and the export technological complexity of high-tech industries within manufacturing in different regions, exploring whether regional differences exist. Finally, based on the conclusions drawn from this research, the paper aims to propose relevant policy recommendations to promote the development of high-tech industries within China's manufacturing sector.

Based on the existing literature (please also refer to Section 2), it can be seen that research on environmental regulation mainly focuses on the impact of the implementation of environmental regulation policies on economic development, such as the scale of export trade. Although some scholars have explored the relationship between environmental regulations and export technology complexity, these studies have focused on high-pollution and high-emission industries that use a large amount of fossil energy, and research involving high-tech manufacturing industries is relatively rare. In addition, when studying the relationship between environmental regulation and high-tech manufacturing industries, existing research is often based on the perspective of export scale. It can be seen that there is still a lack of specific research on the relationship between environmental regulation and the technological complexity of exports in high-tech manufacturing industries and its impact mechanisms. Therefore, this article attempts to build on the existing literature and add research content to existing research to explore the possible causal relationships and impact mechanisms between the implementation intensity of China's environmental regulatory policies and the technological complexity of high-tech industry exports.

The subsequent sections of this paper are arranged as follows: Section 2 reviews relevant literature; Section 3 gives the methods and specific steps of indicator calculation; Section 4 conducts empirical analysis, obtaining baseline regression results by constructing an econometric model, and also conducting related tests and mechanism analysis; and Section 5 summarizes the paper, proposes corresponding policy recommendations, and looks forward to future research directions.

2. Literature Review

As China's national economy undergoes rapid development and transformation, environmental regulation has evolved from initial simple policy constraints to a mature regulatory policy system. In the early years of the People's Republic, the initiation and development of heavy industry led to the emergence of environmental pollution issues. Since the era of reform and opening-up, with the rapid development of China's national economy, environmental pollution problems have become increasingly prominent. During this period, China's environmental regulation gradually moved onto the right track, with governments at all levels successively issuing laws and regulations on environmental protection and strengthening the construction of environmental protection institutions, laying the foundation for the initial formation of the environmental regulation policy system. In the 21st century, there have been new developments and breakthroughs in the construction of the environmental regulation policy system, gradually realizing diversified development through the integration of economic, legal, and technological means, and forming the basic framework of the environmental protection regulation system.

In 2012, the 18th National Congress of the Communist Party of China clearly defined the overall layout of the "Five-Sphere Integrated Plan," including the construction of an ecological civilization, emphasizing the strategies of prioritizing conservation, prioritizing protection, and giving priority to natural restoration. The nation's attention to environmental issues has further increased, and the environmental regulation policy system has been further improved. Meanwhile, China regards respecting, adapting to, and protecting nature as a prerequisite for high-quality development, striving to build a Chinese-style modernization that promotes harmonious coexistence between humans and nature.

The continuous improvement of the environmental regulation policy system imposes increasingly higher requirements on enterprises, especially with regard to the increasingly stringent emission standards for pollutants. Through persistent efforts, China's ecological environment quality has seen significant improvement in recent years. As of 2022, the national ambient air quality has continued to improve, with the concentration of fine particulate matter (PM2.5) in 339 cities that are prefecture-level and above decreasing by 3.3% compared to 2021, reaching 29 micrograms per cubic meter. Throughout the year, air quality in these cities reached an excellent level for 86.5% of the time, surpassing the annual target by 0.9 percentage points. The aforementioned environmental indicators indicate that China's overall ecological environment is gradually improving, and the implementation of environmental regulation policies has yielded positive results.

2.1. Impact of Environmental Regulation on the Economy

The term "regulation" refers to the government's establishment or enactment of rules to constrain the behavior of certain entities to achieve specific goals (Fuadah et al. 2022; Gnangnon 2022; Huang et al. 2022). From an economic perspective, regulation, as a concrete institutional arrangement, represents the management or constraint imposed by the government on economic activities. To address inherent issues in market mechanisms and promote better economic development, the government employs various policy regulations to intervene in the behavior of entities such as enterprises (Oginni and Omojowo 2016; Phuoc 2022; Santos 2023). Governments enact laws and regulations to regulate and intervene in microeconomic activities based on legal foundations, all aimed at achieving economic growth (Manatovna et al. 2023; Oginni and Omojowo 2016). Environmental regulation is a category of policies enacted by the government with the goal of environmental protection.

Scholars have different interpretations of environmental regulation. Some scholars argue that environmental regulation is a force aimed at constraining entities responsible for pollution through tangible institutional arrangements or intangible pressure, driven by the goal of environmental protection (Nõmmela and Kõrbe Kaare 2022; Novitasari and Tarigan 2022; Sapta et al. 2021). Others see that environmental regulation effectively controls the generation of new pollution (Blundell et al. 2020; Jin et al. 2019; Naime 2017). Despite these different perspectives, environmental regulation, in general, can be understood as the formulation of corresponding rules and measures to restrain activities that may threaten ecological environmental safety. Implementing environmental regulation policies helps to establish sustainable long-term development models, fostering a "win-win" situation for economic development and environmental protection.

Environmental regulation can be broken down into three key components: subjects, objects, and tools. Firstly, the main subject of implementing environmental regulation policies in China is the government. The government is responsible for formulating the specific implementation details of environmental regulation policies and ensuring their effective implementation (Novitasari and Tarigan 2022; Oginni and Omojowo 2016). Secondly, enterprises and residents, as producers of environmental pollutants, are the main objects of environmental regulation policies. Compared to the normal discharge of pollutants from residents' daily lives, the significant amount of waste pollutants emitted by enterprises is a major cause of environmental damage, making enterprises a key focus of environmental regulation. Finally, the tools of environmental regulation primarily include command control tools, market incentive tools, and public participation tools. Command control tools involve the government directly setting explicit standards for pollution emissions and related technologies to control corporate pollution. Examples include pollution control investment, emission permits, and environmental administrative penalties. Market incentive tools leverage market mechanisms to influence corporate decision-making, providing enterprises with more autonomy in controlling environmental pollutants while promoting innovation. Well-known examples include emission fees and environmental protection taxes. Public participation tools involve voluntary public or non-governmental organization participation in environmental protection activities to constrain environmentally harmful behavior. When studying these tools, it is essential to focus on information sources such as environmental-related complaints, environmental petitions, and relevant pollution news reports.

The implementation of environmental regulation policies is closely linked to economic development, and many scholars have conducted research on this policy. Through a review of the existing literature, it is evident that scholars hold different opinions on the implementation of environmental regulation policies and their impact on economic development. Some scholars argue that the implementation of environmental regulation will have a negative impact on economic development. Strengthening environmental constraints would increase the cost of pollution control for enterprises, imposing a greater burden on production (Blundell et al. 2020; Borenstein et al. 2019). Under environmental constraints, higher-intensity environmental regulation hinders the development of export trade under certain conditions. Moreover, through an analysis of export trade in EU countries, researchers found that the implementation of environmental regulation inhibits export trade (Bigerna et al. 2019; Kee and Tang 2016; Reynaert 2021). Hering et al., based on an analysis of export data at the city level in China, concluded that the implementation of environmental regulation negatively impacts export trade (Hering and Poncet 2014). There are also studies that use China's export data with 37 trading partner countries, dividing them into developed and developing countries, to investigate the relationship between environmental regulation and (Graham and Wada 2002; Malecki 2003; Yang et al. 2022b). The results indicate that the impact on developing countries is not significant, but the increase in the intensity of environmental regulation policies in developed countries will have a negative impact on China's export trade (Ren and Huang 2015).

However, other studies indicate that the implementation of environmental regulation policies has a positive impact on economic development (Alexander and Schwandt 2022; Assunção et al. 2023; Barrage 2020; Iverson and Karp 2021; Reynaert 2021). On the one hand, the implementation of environmental regulation policies can promote technological innovation (Aversa and Guillotin 2018; Mbanyele and Wang 2022; Saqib et al. 2023; Ullah et al. 2023; Xu 2023), with the representative view being the "Porter Hypothesis". This hypothesis suggests that conducting moderate environmental regulation activities can stimulate technological innovation activities by enterprises, resulting in efficiency gains. Thus, these regulated enterprises have a greater competitive advantage compared to those not subject to environmental constraints. Tsurumi et al. stated that the implementation of environmental regulation policies would increase the level of technology, leading to an increase in the total amount of exports (Tsurumi et al. 2015). Ramzy et al. in their study on the impact of environmental regulation on agricultural trade, also suggested that the implementation of environmental regulation policies could reduce production costs by stimulating technological innovation, thereby benefiting agricultural exports (Ramzy and Zaki 2018).

In conclusion, the summarization of the main literature related to the impact of environmental regulation on the economy is listed in Table 1.

Table 1. Main Literature Related to the Impact of Environmental Regulation on the Economy.

Main Literature	Major Findings
(Fuadah et al. 2022; Gnangnon 2022; Huang et al. 2022)	Explanations of the term "regulation"
(Oginni and Omojowo 2016; Phuoc 2022; Santos 2023)	Regulation as a concrete institutional arrangement from an economic perspective
(Manatovna et al. 2023; Oginni and Omojowo 2016)	Government regulations aimed at achieving economic growth
(Nõmmela and Kõrbe Kaare 2022; Novitasari and Tarigan 2022; Sapta et al. 2021)	Environmental regulation is a force aimed at constraining entities responsible for pollution
(Blundell et al. 2020; Jin et al. 2019; Naime 2017)	Environmental regulation effectively controls the generation of new pollution
(Novitasari and Tarigan 2022; Oginni and Omojowo 2016)	The government is responsible for formulating the specific implementation details of environmental regulation policies and ensuring their effective implementation
(Blundell et al. 2020; Borenstein et al. 2019)	Strengthening environmental constraints would increase the cost of pollution control for enterprises, imposing a greater burden on production
(Bigerna et al. 2019; Kee and Tang 2016; Reynaert 2021)	The implementation of environmental regulation inhibits export trade in EU countries
(Graham and Wada 2002; Malecki 2003; Yang et al. 2022a)	Investigating the relationship between environmental regulation and China's export trade
(Alexander and Schwandt 2022; Assunção et al. 2023; Barrage 2020; Iverson and Karp 2021; Reynaert 2021)	The implementation of environmental regulation policies has a positive impact on economic development
(Aversa and Guillotin 2018; Mbanyele and Wang 2022; Saqib et al. 2023; Ullah et al. 2023; Xu 2023)	The implementation of environmental regulation policies can promote technological innovation

2.2. Environmental Regulation Indicators

In the initial stages of implementing environmental regulation policies, the impact on enterprise production is mostly unfavorable. Environmental regulation policies impose additional pollution control costs on enterprises, adding to the burden of production (Ramzy and Zaki 2018; Song et al. 2023; Tarei et al. 2021; Xu 2023). The greater the intensity of regulation in the region where the enterprise is located, the higher the pollution emission standards. To meet these standards, enterprises producing high-tech products need to spend more funds and time on purchasing pollution control equipment and paying emission fees, increasing the production cost of high-tech products and affecting profitability. The further complexity of the original production processes of enterprises also leads to a decrease in production efficiency. Therefore, the output scale of high-tech enterprises and the scale of funds invested in production and innovation will be affected under the background of environmental regulation. The implementation of environmental regulation policies increases the production costs of high-tech enterprises, reducing the funds available for technological innovation research. The crowding out of innovation funds hinders technological progress and the increase in the technological complexity of high-tech industries in manufacturing (Aversa and Guillotin 2018; Song et al. 2023; Wang et al. 2022). Furthermore, with the increasing intensity of environmental regulation, the additional increase in production costs of high-tech products directly reduces enterprise profits, thereby reducing the profitability of enterprises. In order to minimize profit losses, enterprises may attempt to offset the increased costs of environmental regulation by expanding production scale ("cost offsetting effect"). However, this approach may not only further increase the scale of pollutant emissions but also lead to sustained imbalances in production planning, further reducing enterprise profits. Ultimately, this continuous compression of innovation investment scale poses a serious obstacle to the increase in technological complexity of high-tech industries in manufacturing.

As environmental regulation policies evolve, the unfavorable impacts on enterprise production caused by increased policy intensity gradually diminish (Duflo et al. 2018; Yang et al. 2020a, 2020b). The accompanying "innovation compensation effect" will to some extent promote the increase in technological complexity of high-tech industries in manufacturing. With the increase in the intensity of environmental regulation policies in various regions, environmental regulation gradually stimulates technological innovation and reform within enterprises from both external pressure and internal incentives. This helps enterprises obtain higher profit returns and a larger market share, compensating for the additional costs of environmental regulation. This is manifested in two aspects: on the one hand, the increased enforcement of environmental policy regulations puts pressure on high-tech enterprises, compelling them to further increase scientific and technological innovation investment to improve production efficiency. This helps to offset some of the profit losses resulting from increased production costs and promotes the adjustment and optimization of management systems, enabling enterprises to develop better under environmental regulation. On the other hand, after the intensity of environmental regulation policies increases, high-tech enterprises strive to achieve green innovation in production technology, reducing the pollution produced by products while maximizing profits. This further enhances the competitiveness of high-tech products, forming a green competitive advantage in high-tech products (Mbanyele and Wang 2022; Song et al. 2023; Xu 2023). Under the dual influence of external environmental protection pressure and internal profit stimulation, the increase in the intensity of environmental regulation promotes the development of green technological innovation in high-tech enterprises, contributing to the increase in technological complexity of high-tech industries in manufacturing.

Regarding how to measure the size of environmental regulation indicators, scholars have proposed different views. Through analysis and summarization of relevant research, the methods for measuring environmental regulation can be broadly categorized into two types: single-indicator methods and composite-indicator methods. The single-indicator method involves selecting indicators related to the environment, such as sulfur dioxide removal rates or pollutant emissions, to represent the intensity of environmental regulation. The composite-indicator method involves constructing a comprehensive-indicator system composed of multiple indicators to measure the implementation intensity of environmental regulation policies in different regions (Bigerna et al. 2019; Yang et al. 2022a). This includes using entropy methods to construct a comprehensive index of environmental regulation from the perspectives of intensity and efficiency. It also involves constructing a comprehensive index measuring environmental constraints using the emission compliance rate of "three industrial wastes" and employing principal component analysis to calculate a comprehensive index from different perspectives, ultimately integrating into a comprehensive environmental regulation index (Zhang et al. 2022).

In the existing literature related to export technological complexity, scholars generally focus on how to measure export technological complexity and which factors influence changes in export technological complexity. The following key research points have emerged: regarding the measurement of export technological complexity, it could be calculated by summing up the amount of R&D investment in exported products (Mbanyele and Wang 2022; Wang et al. 2023). However, this method is challenging because data on R&D investment at the product level is difficult to obtain. Therefore, income level data of exporting countries can be used as a substitute for the original R&D investment amount to measure the technical content of exported products. Based on previous research, Hausmann et al. improved the calculation method for export technological complexity, proposing to calculate product-level export technological complexity and then use product-level data to calculate the export technological complexity at the national level, a method widely recognized by many scholars (Hausmann et al. 2007). On this basis, Wu et al. further adjusted the calculation method for export technological complexity (Wu et al. 2022), replacing data from different countries with provincial-level data, making the method more applicable at the regional level, and they conducted research on whether the impact of foreign investment and domestic investment in processing trade on China's export technological complexity is consistent. The results showed a positive promotion effect of foreign investment on China's export product technological complexity, while domestic investment in processing trade exhibited a negative impact relationship. Regarding the factors influencing export technological complexity, scholars generally agree that increases in foreign direct investment (Hausmann et al. 2007) and improvements in human capital and R&D investment will drive the growth of export technological complexity through spillover effects (Mbanyele and Wang 2022; Wang et al. 2023).

In conclusion, the summarization of the main literature related to environmental regulation indicators is listed in Table 2.

Table 2. Main Literature Related to Environmental Regulation Indicators.

Main Literature	Major Findings
(Ramzy and Zaki 2018; Song et al. 2023; Tarei et al. 2021; Xu 2023)	Environmental regulation policies impose additional pollution control costs on enterprises
(Aversa and Guillotin 2018; Song et al. 2023; Wang et al. 2022)	The crowding out of innovation funds hinders technological progress and the increase in the technological complexity of high-tech industries in manufacturing
(Duflo et al. 2018; Yang et al. 2020a, 2020b)	As environmental regulation policies evolve, the unfavorable impacts on enterprise production caused by increased policy intensity gradually diminish
(Mbanyele and Wang 2022; Song et al. 2023; Xu 2023)	The environmental regulation policies further enhances the competitiveness of high-tech products, forming a green competitive advantage in high-tech products
(Bigerna et al. 2019; Yang et al. 2022a)	Constructing a comprehensive-indicator system composed of multiple indicators to measure the implementation intensity of environmental regulation policies in different regions;
(Wu et al. 2022)	Explore the impact of industrial intelligence on export technology complexity from different dimensions
(Hausmann et al. 2007; Mbanyele and Wang 2022; Wang et al. 2023)	Increasing foreign direct investment and improvements in human capital and R&D investment will drive the growth of export technological complexity through spillover effects

2.3. Environmental Regulation and Export Technological Complexity

In order to accurately measure the competitiveness of a country or region's exported products for adjustment purposes, scholars suggest assessing the technological content of products from the perspective of technological structure. Export technological complexity serves as a comprehensive indicator to measure technological content, combining characteristics such as the quality and productivity of exported products (Hausmann et al. 2007). When a country possesses higher export technological complexity, it implies that the products it exports have higher technological content. Some scholars also view export technological complexity as the proportion of high-value-added and high-tech products among all exported products (Gao and Dong 2022; Saqib et al. 2023; Wu et al. 2022). Generally, a higher export technological complexity index is believed to represent a higher level of technological structure in a country or region and its position in the global value chain. Higher export complexity suggests products with higher added value, providing stronger competitiveness in the international market. Conversely, products with lower export technological complexity are considered to have weaker competitiveness. The increase in export technological complexity not only represents a numerical change but also signifies a dynamic process of products transitioning from low-end to high-end.

Although there is not a universally agreed-upon definition of export technological complexity, analyzing different scholars' perspectives reveals its core concept (Hausmann et al. 2007; Ramzy and Zaki 2018; Tsurumi et al. 2015; Yang et al. 2022b). The export technological complexity of a country is closely related to the technological level of its products, serving as an indicator of international competitiveness. Countries or regions with higher export technological complexity tend to export products with higher technological content, indicating stronger competitiveness and a more advantageous position in international division of labor. The introduction of the export technological complexity indicator has facilitated research on product quality, suggesting that higher export technological complexity corresponds to better product quality.

We believe that the core connotation of export technological complexity is that a country's export technological complexity is closely related to the technical level of the country's products and is a benchmark for international competitiveness. Countries or regions with higher export technology complexity will have higher technical content in their exported products, which means that they can show stronger competitiveness in international competition and be in a more advantageous position in the international division of labor.

In existing literature, many scholars argue for a positive promotion relationship between environmental regulation and export technological complexity. Research results indicate that China's export technological complexity tends to increase with the strengthening of regional environmental regulation intensity. However, there are differences in the promoting effects of environmental regulation policies on export technological complexity among different regions. The implementation of environmental regulation policies can significantly promote the quality of export products. Some studies suggest a positive promotion relationship between environmental regulation and export technological complexity, as command-and-control environmental regulation forces companies to accelerate technological innovation and process improvement, facilitating further improvement in export technological complexity (Jin et al. 2019; Xu 2023). Nevertheless, some scholars hold a different view, arguing that the implementation of environmental regulation policies is not conducive to the improvement of export technological complexity. The relationship between environmental regulation and the upgrading of export product quality exhibits a "U-shaped" pattern, with China currently in a declining stage. Continuous strengthening of the implementation of environmental regulation policies is not conducive to upgrading the technological content of exported products. A study focusing on six provinces and one city in East China found that the increase in the intensity of environmental regulation policies has a negative impact on the improvement of export technological complexity (Hering and Poncet 2014; Yang et al. 2022b).

Furthermore, some scholars believe that the relationship between environmental regulation and export technological complexity is not necessarily linear and may involve more complex non-linear relationships (Bigerna et al. 2019; Kee and Tang 2016; Wang et al. 2022). The intensity of China's environmental regulation and technological production techniques in both the Eastern and Central regions exhibits a "U-shaped" relationship with a decline followed by an increase. Focusing on China's industrial sectors, the magnitude of environmental constraints exhibits a "U-shaped" impact relationship with export technological complexity. Within a certain range, environmental regulation shows a significant positive impact on export technological complexity. However, if the intensity of environmental regulation policies is too high or too low, beyond this range, it is not conducive to the improvement of export technological complexity. Some studies have classified environmental regulation into different types and empirically analyzed the relationship between different types of environmental regulation and technological innovation in enterprises. The results suggest that cost-based environmental regulation hinders the progress of technological innovation, while investment-based environmental regulation has the opposite effect. Further research on the relationship between "pre-control" and "post hoc" environmental regulation and exports showed an inverted U-shaped impact relationship in the former and a negative impact in the latter on export upgrading.

In summary, the literature indicates that research on environmental regulation focuses on its impact on economic development, such as the scale of export trade. The results of many studies show that the implementation of environmental regulation policies has both advantages and disadvantages for the economy. Environmental regulation can promote the development of technological innovation to some extent. In order to more intuitively reflect the size of environmental regulation intensity, researchers have proposed various methods to measure environmental regulation, continually refining them. Regarding factors influencing export technological complexity, widely accepted factors include foreign direct investment, the level of digital economic development, and human capital, among others. Although some scholars have explored the relationship between environmental regulation and export technological complexity, these studies primarily focus on high-pollution and high-emission industries that heavily use fossil energy, with limited research on high-tech industries in manufacturing. Additionally, current research on the relationship between environmental regulation and high-tech manufacturing industries often adopts an export-scale perspective. Therefore, there is still a lack of specific research on the relationship and influencing mechanisms between environmental regulation and the export technological complexity of high-tech manufacturing industries.

In conclusion, the summarization of the main literature related to environmental regulation and export technological complexity is listed in Table 3.

Table 3. Main Literature Related to Environmental Regulation and Export Technological Complexity.

Main Literature	Major Findings
(Gao and Dong 2022; Saqib et al. 2023; Wu et al. 2022)	Viewing export technological complexity as the proportion of high value-added and high-tech products among all exported products
(Hausmann et al. 2007; Ramzy and Zaki 2018; Tsurumi et al. 2015; Yang et al. 2022b)	Analyzing the core concept of export technological complexity from different perspectives and construct corresponding calculation methods
(Jin et al. 2019; Xu 2023)	Suggesting a positive promotion relationship between environmental regulation and export technological complexity
(Hering and Poncet 2014; Yang et al. 2022b)	The increase in the intensity of environmental regulation policies has a negative impact on the improvement of export technological complexity
(Bigerna et al. 2019; Kee and Tang 2016; Wang et al. 2022)	The environmental regulation and export technological complexity may involve more complex non-linear relationships

3. Indicator Calculation Methods

3.1. Explanation of Specific Steps

Based on the above content, we can summarize the specific research questions in this study as follows:

1. How to calculate environmental regulation intensity?
2. How to calculate export technology complexity index?
3. In practice, what impact does environmental regulation intensity have on export technology complexity index?

The methodology of this research proceeds according to the following steps:

Step 1: Calculating environmental regulation intensity.
Step 2: Calculating the export technology complexity index.
Step 3: Conducting empirical analysis and corresponding test.

Please see Table 4 for a detailed explanation of the above steps:

Table 4. Explanation of Methodology Steps.

Step	Explanation	Method
1. Calculating environmental regulation intensity	Three indicators—industrial sulfur dioxide removal rate, industrial wastewater treatment rate, and comprehensive utilization rate of industrial solid waste—are selected to calculate environmental regulation intensity	Entropy method (Please refer to Section 3.2), which has been used in this area
2. Calculating the export technology complexity index	The export value of high-tech manufacturing industries' sub-sectors are calculated first; then the export technological complexity of high-tech sub-sectors is calculated; and finally, the export technological complexity of high-tech manufacturing industries in different regions of China are gained	Calculating the export technological complexity for China's 30 provinces (excluding Tibet, Hong Kong, Macao, and Taiwan) from 2006 to 2021 (Please refer to Section 3.3), which has been used in this area
3: Empirical analysis and corresponding test	Establishing econometric model	Econometric Modeling, which has been used in this area
	Summarizing and revealing the distributional properties of the data	Descriptive Statistics, which has been used in this area
	Studying the causal relationship between the environmental regulatory intensity and the export technological complexity of high-tech industries	Regression Analysis, which has been used in this area
	Eliminating possible endogeneity issues in baseline regression results	Endogeneity Test, which has been used in this area
	Testing the robustness of baseline regression results	Robustness Test, which has been used in this area
	Examining whether the impact of environmental regulation on the technological complexity of high-tech industrial exports is consistent across different regions	Heterogeneity Analysis, which has been used in this area
	Analyzing the specific mechanism by which environmental regulatory intensity affects the export technological complexity of high-tech industries	Mechanism Analysis, which has been used in this area

3.2. Environmental Regulation Intensity

In order to intuitively reflect the intensity of environmental regulation policy implementation in various regions, scholars at home and abroad have constructed relevant indicator systems for calculation. However, there is currently no unified indicator system for measuring environmental regulation intensity in academia. Among the existing indicator systems, the single-indicator method and the comprehensive-indicator method are two commonly used approaches. The former measures the intensity of environmental regulation based on single indicators directly related to environmental regulation policies, such as the number of environmental protection laws and regulations, pollutant emissions, or treatment rates. Data used in such calculations can be obtained from government environmental protection departments, testing agencies, authoritative third-party organizations, and non-profit statistical organizations, making the data relatively objective and easily accessible. However, this single-indicator calculation method has limitations. On one hand, the scope of environmental regulation policies is extensive, and using a single indicator is challenging when comprehensively depicting the intensity of environmental regulation. On the other hand, when using certain single quantity indicators to calculate environmental regulation intensity, factors such as regional or industrial-scale effects on regulation intensity may be overlooked.

The comprehensive-indicator method, compared to the single-indicator method, provides a more comprehensive calculation. This method involves incorporating multiple dimensions of environmentally related indicators into the same framework and constructing a unified comprehensive-indicator system using standardization methods such as entropy method and principal component analysis. The environmental regulation indicator calculated through the comprehensive-indicator method can more scientifically and systematically reflect the constraining force of environmental regulation in a region and has been favored by many scholars both domestically and internationally. However, the limitations of this calculation method lie in the difficulty of collecting indicator data and the significant time investment required for data processing and computation.

Considering the limitations of single indicators, this paper chooses the comprehensive-indicator method to calculate environmental regulation intensity. Taking into account data availability, three indicators—industrial sulfur dioxide removal rate, industrial wastewater treatment rate, and comprehensive utilization rate of industrial solid waste—are selected. The environmental regulation comprehensive indicator is calculated using the entropy method. The specific calculation method is as follows.

Firstly, normalize the data using Equation (1), where a_{ij} and X_{ij} represent the i region's j indicator before and after normalization, respectively.

$$X_{ij} = \frac{a_{ij} - min\ a_{ij}}{max\ a_{ij} - min\ a_{ij}} \tag{1}$$

Secondly, calculate the weight P_{ij} of each indicator using Equation (2).

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}} \tag{2}$$

Next, calculate the entropy value e_j for each indicator using Equation (3).

$$e_j = -\frac{1}{\ln m}\left(\sum_{i=1}^{m} P_{ij} lnP_{ij}\right) \tag{3}$$

Then, determine the entropy weight W_j for each indicator using Equation (4).

$$W_j = \frac{(1 - e_j)}{\sum_{j=1}^{n}(1 - e_j)} \tag{4}$$

Finally, multiply the normalized value X_{ij} by the corresponding entropy weight W_j, and sum the results to obtain the environmental regulation intensity indicator ER using Equation (5).

$$ER = \sum_{j=1}^{n} W_j X_{ij} \tag{5}$$

Using the above method, Table A1 provides the data for the calculated environmental regulation comprehensive indicator for some years from 2006 to 2021 for 30 provinces, autonomous regions, and municipalities directly under the central government in China (excluding Tibet). From the data results in the table, it can be observed that China's environmental regulation indicator has generally shown an upward trend since 2006, indicating a continuous strengthening of environmental protection efforts in the country. Due to the vast geographical expanse of China and the varying natural conditions and economic development statuses across different regions, there exist disparities in the environmental regulatory intensity among these regions. Consequently, this paper further distinguishes the 30 provinces based on the calculated environmental regulatory indicators. Following the classification standards published by the National Bureau of Statistics in 2011, these provinces are categorized into four major regions: East, Central, West, and Northeast. The specific criteria for this classification are detailed in Table A2.

3.3. Calculation of Technical Complexity

To scientifically reflect the level of a country or region's export technological proficiency, it is essential to calculate the export technological complexity indicator. In this regard, Hausmann et al. proposed a method for calculating national-level export technological complexity, based on the comparative advantages of various products, which has gained widespread recognition among domestic and international scholars (Hausmann et al. 2007). Wu et al., building upon Hausmann et al.'s calculations, substituted national data with regional data to measure the export technological complexity of products at the national and regional levels (Wu et al. 2022). This paper focuses on the export technological complexity of high-tech manufacturing industries in various provinces of China, adopting a method similar to Wu et al. to calculate the export technological complexity for 30 provinces (excluding Tibet, Hong Kong, Macao, and Taiwan) from 2006 to 2021. The specific calculation steps are as follows.

This paper refers to the calculation method and first calculates the export value of high-tech manufacturing industries' sub-sectors. The specific steps are as follows: the five major sub-sectors of high-tech manufacturing industries are coded corresponding to SITC Rev.3 codes (see Table A3), and then, the corresponding HS 6-digit codes are obtained through the conversion relationship between HS and SITC. Finally, industry export data is obtained from the customs database.

Calculation of the export technological complexity of high-tech sub-sectors is then performed. According to the high-tech manufacturing industry, due to a lack of relevant statistical data for the manufacture of information chemicals, this paper excludes it from the study. Equation (6) is used to calculate the export technological complexity of a specific industry in a given year, denoted as $industry_{mt}$

$$industry_{mt} = \sum_{i=1}^{n} \frac{x_{imt}/X_{it}}{\sum_i x_{imt}/X_{it}} Y_{it} \quad (6)$$

where m represents the industry, t represents the year, i represents the region, x_{imt} represents the export value of the high-tech manufacturing industry sub-sector, X_{it} represents the total export value, and Y_{it} is the per capita regional gross domestic product (GDP).

Calculation of the export technological complexity of high-tech manufacturing industries in different regions of China is then performed. Based on the calculated export technological complexity of each industry using Equation (6), multiply it by the ratio of the industry's export value to the total export value in each region, and finally, obtain the export technological complexity of high-tech manufacturing industries in region i at time t, denoted as $expy_{it}$

$$expy_{it} = \sum_m (x_{imt}/X_{it}) industry_{mt} \quad (7)$$

where x_{imt} represents the export value of the industry and X_{it} represents the total export value.

Tables A4–A7 report the calculated export technological complexity data for some years in various provinces of China, including the Eastern, Central, Western, and Northeastern regions. Due to the substantial differences in numerical values between the results and environmental regulation indicators, the export technological complexity indicators for each province in high-tech manufacturing industries are logarithmically transformed for ease of empirical analysis. From the tables, it can be observed that, over time, the export technological complexity of high-tech industries in various provinces has generally shown an upward trend. In 2021, for most regions, the export technological complexity is generally around 10, indicating a significant improvement compared to 2006. Furthermore, the Eastern and Central regions exhibit higher export technological complexity in high-tech manufacturing industries compared to the Western and Northeastern regions. This discrepancy may be attributed to the more developed infrastructure and higher economic development level in the Eastern and Central regions, better meeting the needs of the development of high-tech manufacturing industries. Additionally, high-tech manufacturing industry-related enterprises are more densely distributed in the Eastern and Central regions than in the Western regions.

4. Empirical Analysis

4.1. Econometric Model Construction and Variables Selection

4.1.1. Econometric Model Construction

We are conducting an empirical analysis and corresponding examination on the impact of environmental regulations in China on the export technological complexity of high-tech industries within the manufacturing sector. In this empirical analysis, the study utilizes panel data regression models based on environmental regulatory intensity and export technological complexity data of high-tech industries within manufacturing, aiming to empirically analyze the causal relationship between the two variables. Considering the potential existence of "cost offset effects" and "innovation compensation effects" following the increase in environmental regulatory intensity, it is acknowledged that the relationship between environmental regulations and the export technological complexity of high-tech industries within manufacturing may not necessarily exhibit a simple linear pattern. Therefore, when constructing the baseline regression model, we incorporate the quadratic term of the environmental regulatory intensity indicator for a more comprehensive analysis. The final regression model is represented as Equation (8)

$$EXPY_{it} = \alpha + \beta_0 ER_{it} + \beta_1 ER_{it}^2 + \beta_2 Z_{it} + \varepsilon_{it} \quad (8)$$

where: i denotes the region, t denotes the year, the dependent variable $EXPY_{it}$ represents the export technological complexity of high-tech industries within manufacturing, the explanatory variable ER_{it} represents the environmental regulatory intensity in region i at time t, and ER_{it}^2 is the quadratic term of the environmental regulatory intensity variable for region i at time t. Additionally, Z_{it} represents the vector of control variables, α is the constant term, and ε_{it} is the error term.

4.1.2. Variable Selection

This study primarily investigates the impact of environmental regulations on the export technological complexity of high-tech industries within the manufacturing sector. Therefore, the core explanatory variable is environmental regulatory intensity, and the dependent variable is the export technological complexity indicator of high-tech industries within manufacturing. The model also includes control variables such as the degree of openness to foreign trade, economic development level, financial development level, urbanization level, and the degree of government intervention.

The dependent variable is the export technological complexity of high-tech industries within manufacturing ($EXPY$), calculated as outlined in Equation (8). The explanatory variable is environmental regulatory intensity (ER), calculated as previously described in Equation (5).

Degree of Openness to Foreign Trade ($OPEN$): The improvement in the trade environment due to an increase in openness to foreign trade can both promote the enhancement of export technological complexity in high-tech industries within manufacturing and pose new challenges. The degree of trade openness is represented by the ratio of the value of goods import and export to the regional gross domestic product (GDP).

Economic Development Level (ECO): The economic strength of a country or region determines the starting point of development. The advancement of export technological complexity in high-tech industries within manufacturing requires a solid economic foundation. The economic development level is measured using per capita regional GDP, and logarithmic transformation is applied in the empirical analysis.

Financial Development (FIN): A well-developed financial system can save production costs for high-tech industries within manufacturing, enhance the circulation speed of funds, and facilitate the rational allocation of resources. Additionally, robust financial development provides strong financial support for the development of export technological complexity in high-tech industries within manufacturing. The ratio of year-end financial institution loans to deposits to regional GDP is calculated as an indicator of financial development.

Urbanization Level ($CITY$): The scale economy and technological innovation effects brought about by urbanization can impact the efficiency of production factors in high-tech industries within manufacturing. The urbanization level is represented by the ratio of urban population to total population in different regions.

Degree of Government Intervention (GOV): Theoretical considerations suggest that government assistance and support for some high-tech enterprises can influence the fluctuation of export technological complexity. This variable is measured by the ratio of local government fiscal expenditure to regional GDP.

Table 5 reports all variables used in the empirical analysis, providing explanations for each variable. The original data for the dependent variable, explanatory variable, and control variables are mainly sourced from the "China High-tech Industry Statistics Yearbook," provincial statistical yearbooks, and customs databases, as well as the "China Environmental Statistics Yearbook".

Table 5. Variables and Their Explanations.

Variable Type	Variable Symbol	Variable Name	Variable Definition
Dependent Variable	$EXPY$	Export Technological Complexity of High-tech Industries within Manufacturing	Logarithmically transformed export technological complexity of high-tech industries within manufacturing
Explanatory Variable	ER	Environmental Regulatory Intensity	Calculated using the entropy method based on removal rates of industrial sulfur dioxide, industrial wastewater treatment rates, and comprehensive utilization rates of industrial solid waste
	ER^2	Environmental Regulatory Intensity Quadratic Term	Square of the environmental regulatory intensity indicator
Control Variable	$OPEN$	Degree of Openness to Foreign Trade	Ratio of goods import and export amounts to regional gross domestic product (GDP)
	ECO	Economic Development Level	Per capita regional GDP (logarithmically transformed)
	FIN	Financial Development	Ratio of year-end financial institution loans to deposits to regional GDP
	$CITY$	Urbanization Level	Ratio of urban population to total population in the region
	GOV	Degree of Government Intervention	Ratio of government fiscal expenditure to regional GDP

Note: The variables are calculated based on data from the "China High-tech Industry Statistics Yearbook," provincial statistical yearbooks, customs databases, and the "China Environmental Statistics Yearbook."

4.1.3. Descriptive Statistics of Variables

Based on the aforementioned entropy method, this study first calculates the weights of various indicators as shown in Table 6:

In the above Table, the original data for $EXPY$ come from the calculation results of Section 3.3, and those for ER come from the calculation results of Section 3.2. The original data for $OPEN$, ECO, FIN, $CITY$, and GOV are all from the statistical yearbook of the corresponding year officially released by the National Bureau of Statistics of China.

To prevent potential biases in regression results caused by extreme outliers in panel data, this study conducted further data cleaning after variable calculations. Trimming was performed at the upper and lower 1% of the data. The reported descriptive statistics in the table reflect the sample data after this trimming process.

Table 6. Descriptive Statistics of Variables.

Variable	Mean	Median	Minimum	Maximum
$EXPY$	7.913	1.691	3.674	10.81
ER	0.629	0.115	0.400	0.810
ER^2	0.409	0.141	0.160	0.656
$OPEN$	0.307	0.357	0.0502	1.293
ECO	9.162	0.498	8.440	10.39
FIN	2.783	0.835	1.695	4.841
$CITY$	0.488	0.145	0.249	0.829
GOV	0.194	0.0761	0.0912	0.363

4.2. Empirical Results and Analysis

4.2.1. Baseline Regression Analysis

In this analysis conducted using Stata 16 software, two models, OLS and panel data regression, were employed to examine the relationship between environmental regulatory intensity and the variability in export technological complexity of high-tech industries within the manufacturing sector. Random effects and fixed-effects models were utilized in panel regression, with the Hausman test indicating the superiority of the fixed-effects model at a 1% significance level. The baseline regression results are presented in Table 7, with column (1) representing the OLS regression results, and columns (2) to (6) presenting the fixed-effects model results with the gradual inclusion of control variables.

Table 7. Baseline Regression Analysis Results.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
	OLS	**FE**					
	EXPY	***EXPY***	***EXPY***	***EXPY***	***EXPY***	***EXPY***	***EXPY***
ER	1.412 ***	−0.865 **	−1.836 ***	−1.886 ***	−1.851 ***	−1.885 ***	−1.447 ***
	(3.14)	(−2.33)	(−5.43)	(−5.82)	(−5.62)	(−5.74)	(−4.17)
ER^2	−0.521	1.474 ***	1.746 ***	1.675 ***	1.633 ***	1.637 ***	1.229 ***
	(−1.42)	(4.83)	(6.47)	(6.46)	(6.09)	(6.13)	(4.24)
$OPEN$	0.084 ***	0.196 ***	0.154 ***	0.197 ***	0.196 ***	0.197 ***	0.233 ***
	(2.95)	(4.99)	(4.41)	(5.78)	(5.75)	(5.79)	(6.33)
ECO	−0.045 *		0.370 ***	0.350 ***	0.347 ***	0.324 ***	0.246 ***
	(−1.75)		(11.35)	(11.14)	(10.96)	(9.58)	(5.28)
FIN	0.025 **			0.057 ***	0.056 ***	0.049 ***	0.017
	(2.35)			(6.37)	(6.14)	(5.13)	(1.40)
$CITY$	0.160 **				0.028	0.021	−0.052
	(2.57)				(0.61)	(0.46)	(−1.03)
GOV	−0.322 ***					0.244 *	−0.072
	(−3.39)					(1.96)	(−0.47)
Constant	0.416 *	0.675 ***	−2.202 ***	−2.127 ***	−2.119 ***	−1.910 ***	−1.199 ***
	(1.71)	(6.16)	(−8.12)	(−8.17)	(−8.13)	(−6.80)	(−3.03)
Regional Effects		Yes	Yes	Yes	Yes	Yes	Yes
Temporal Effects		No	No	No	No	No	Yes
N	480	480	480	480	480	480	480
R^2	0.633	0.661	0.659	0.681	0.682	0.683	0.683

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. The values in parentheses represent t-values.

Firstly, from the regression results in column (6) of the table, it can be observed that the coefficient of the independent variable is −1.885 and significant. This indicates a negative impact of environmental regulations on the level of technological complexity in the export of high-tech industries. The regression coefficient of the quadratic term of environmental regulations is 1.637, signifying a significant positive relationship with the dependent variable at a 1% confidence level. Thus, it can be inferred that the impact of environmental regulations on the technological complexity of high-tech industry exports in China follows a "U-shaped" pattern, initially decreasing and then increasing.

Secondly, to further reduce the potential bias caused by factors that may not vary with individual changes in different years, in column (7), after controlling for regional effects, time effects are introduced, constructing a bidirectional fixed-effects model. The regression results indicate that, with the inclusion of time fixed effects, the coefficient of environmental regulation and its quadratic term on the technological complexity of high-tech industry exports have changed. The coefficient of the linear term changes from −1.885 to −1.447, and the coefficient of the quadratic term decreases from the original 1.637 to 1.229. However, the direction and significance of both coefficients remain unchanged, confirming the existence of the "U-shaped" relationship between environmental regulations and the technological complexity of high-tech industry exports. Therefore, based on the baseline regression results, it can be concluded that the strengthening of environmental regulations has a significant "U-shaped" impact on the technological complexity of high-tech industry exports, characterized by an initial suppression followed by promotion.

In addition to the core explanatory variable, the impact of environmental regulations, the regression results in the baseline model also show that the variables representing openness to foreign trade (OPEN) and the level of economic development (ECO) are both significant at a 1% confidence level. An increase of one percentage point in the level of regional openness to foreign trade is associated with a 0.233% increase in the technological complexity of high-tech industry exports, and a 1% fluctuation in economic development leads to a 0.246% directional change in the technological complexity of high-tech industry exports.

This baseline result is also supported by existing works. For example, Zhang et al. have found that the intensity of China's environmental regulation and process production technology showed a "U-shaped" relationship that first decreased and then increased in the Eastern and Central regions (Zhang et al. 2011); Yu focused the attention on China's industrial industry and believed that the size of environmental binding forces and the complexity of the industry's export technology also showed a "U-shaped" impact relationship (Yu 2015); and the research results of Peng et al. also show that the relationship between environmental regulations and export product quality upgrades shows a "U-shaped" impact relationship that first decreases and then increases, and China is still in a declining stage (Peng et al. 2016).

4.2.2. Endogeneity Test

The endogeneity issue in the regression model primarily stems from measurement errors, omitted variables, or bidirectional causality. In the construction of this model, these shortcomings are also present. For instance, there is a certain degree of error between the values of the environmental regulation indicator used in constructing the regression model and the actual data. Additionally, in reality, there are numerous factors that can influence the technological complexity of exports in high-tech industries, but not all potential influencing factors could be incorporated into the regression model during empirical analysis. Consequently, the regression model in this study unavoidably experiences the omission variable phenomenon. Furthermore, while this study primarily investigates the impact of environmental regulations on the technological complexity of exports in high-tech industries, the development of high-tech industries in manufacturing inevitably comes at the cost of sacrificing a certain degree of environmental resources. From an environmental protection perspective, the intensity of environmental regulations in a region is likely to change. Therefore, there may be bidirectional causality between environmental regulations and the technological complexity of exports in high-tech industries.

To address the endogeneity issues in the model, this study borrows methods from existing literature and introduces instrumental variables on top of the baseline regression for endogeneity testing. The instrumental variable constructed in this study is the air circulation coefficient (VC) for different provinces. This study uses the average wind speed and boundary layer height product in the four grid cells closest to each province's location in the ERA-Interim grid as a representation of the air circulation coefficient. Since the air circulation coefficient for a province is related to its natural environment, provinces with higher air circulation coefficients tend to have better environmental quality. Consequently, the intensity of environmental regulations implemented by the government is relatively lower. However, the air circulation coefficient's level is not strongly correlated with the technological complexity of exports in high-tech industries or other variables. Therefore, the air circulation coefficient satisfies the two conditions for being an instrumental variable.

To prevent excessively large regression coefficients, the air circulation coefficient is logarithmically transformed before conducting the regression analysis. The endogeneity test results are presented in Table 8. Column (1) shows the baseline regression results with bidirectional fixed effects. Columns (2) to (5) display the endogeneity test results after introducing instrumental variables through two-stage least squares regression. It can be observed from the table that, with the inclusion of instrumental variables, the regression coefficient between environmental regulations and the technological complexity of exports in high-tech industries has changed, but the significant "U-shaped" relationship between them still persists.

Table 8. Endogeneity Test Results.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**
	FE	**2SLS**	**2SLS**	**2SLS**	**2SLS**
	EXPY	***EXPY***	***EXPY***	***EXPY***	***EXPY***
			Second Stage		
ER	−1.447 ***	−8.803 ***	−6.725 ***	−6.209 ***	−5.439 ***
	(−4.17)	(−7.02)	(−6.77)	(−6.91)	(−4.77)
ER^2	1.229 ***	7.202 ***	5.504 ***	5.063 ***	4.476 ***
	(4.24)	(7.32)	(6.95)	(7.07)	(4.81)
$OPEN$	0.233 ***	0.228 ***	0.252 ***	0.246 ***	0.239 ***
	(6.33)	(4.55)	(5.89)	(6.02)	(6.00)
ECO	0.246 ***	0.540 ***	0.472 ***	0.426 ***	0.436 ***
	(5.28)	(10.10)	(10.50)	(9.69)	(6.07)
FIN	0.017		0.063 ***	0.054 ***	0.042 ***
	(1.40)		(5.69)	(4.76)	(2.87)
$CITY$	−0.052		−0.090	−0.086	−0.089
	(−1.03)		(−1.49)	(−1.50)	(−1.61)
GOV	−0.072			0.332 **	0.333 *
	(−0.47)			(2.26)	(1.67)
			First Stage		
VC		−0.006 ***	−0.008 ***	−0.008 ***	−0.008 ***
		(−8.55)	(−9.26)	(−9.96)	(−7.20)
Constant	−1.199 ***	−1.472 ***	−1.561 ***	−1.560 ***	−1.646 ***
	(−3.03)	(−4.18)	(−5.51)	(−5.33)	(−3.82)
Regional Effects	Yes	Yes	Yes	Yes	Yes
Temporal Effects	Yes	No	No	No	Yes
N	480	480	480	480	480
R^2	0.683	0.710	0.646	0.870	0.835

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. The values in parentheses represent t-values.

4.2.3. Robustness Test

1. Variable Replacement

To ensure the stability of results, the substitution of explanatory and dependent variables is a common approach in robustness testing. In this study, the number of environmental administrative penalty cases handled by each province is utilized as a substitute variable for the baseline regression's environmental regulatory intensity index constructed through the entropy method. The empirical analysis involves taking the logarithm of the variable, denoted as EF, representing the replaced explanatory variable. A higher number of environmental penalty cases implies a greater environmental regulatory intensity by regional governments. In Table 9, columns (1) and (2) present the baseline regression results with regional fixed effects and both regional- and time-bidirectional fixed effects, corresponding to columns six and seven in Table 7. Columns (3) and (4) display the results of the robustness test after replacing the explanatory variable with the number of environmental penalty cases (EF) by region, using the same fixed-effects model. The regression results from these two columns indicate that, even after replacing the explanatory variable, the intensity of environmental regulation policy implementation still exhibits a "U-shaped" impact on the technological complexity of high-tech industrial exports in the manufacturing sector. Therefore, the robustness test is successfully passed.

Table 9. Robustness Test Results.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
	Baseline Regression		**Replacement Variables**		**Exclusion of Direct-Controlled Municipalities**	
	EXPY	***EXPY***	***EXPY***	***EXPY***	***EXPY***	***EXPY***
ER	−1.885 ***	−1.447 ***			−1.865 ***	−1.321 ***
	(−5.74)	(−4.17)			(−5.14)	(−3.45)
ER^2	1.637 ***	1.229 ***			1.647 ***	1.152 ***
	(6.13)	(4.24)			(5.53)	(3.58)
EF			−0.095 ***	−0.079 ***		
			(−3.79)	(−3.13)		
EF^2			0.006 ***	0.005 ***		
			(3.52)	(2.64)		
$OPEN$	0.197 ***	0.233 ***	0.178 ***	0.239 ***	0.216 ***	0.252 ***
	(5.79)	(6.33)	(5.11)	(6.37)	(4.08)	(4.37)
ECO	0.324 ***	0.246 ***	0.325 ***	0.204***	0.317 ***	0.215 ***
	(9.58)	(5.28)	(11.12)	(4.66)	(8.18)	(3.98)
FIN	0.049 ***	0.017	0.057 ***	0.016	0.053 ***	0.010
	(5.13)	(1.40)	(5.52)	(1.26)	(4.99)	(0.74)
$CITY$	0.021	−0.052	0.086 **	−0.037	0.008	−0.118
	(0.46)	(−1.03)	(1.98)	(−0.75)	(0.12)	(−1.65)
GOV	0.244 *	−0.072	0.257 **	−0.204	0.158	−0.179
	(1.96)	(−0.47)	(2.04)	(−1.34)	(1.15)	(−1.05)
Constant	−1.910 ***	−1.199 ***	−2.129 ***	−0.899 **	−1.811 ***	−0.896 *
	(−6.80)	(−3.03)	(−8.20)	(−2.27)	(−5.67)	(−1.95)
Regional Effects	Yes	Yes	Yes	Yes	Yes	Yes
Temporal Effects	No	Yes	No	Yes	No	Yes
N	480	480	469	469	416	416
R^2	0.661	0.683	0.636	0.672	0.632	0.660

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. The values in parentheses represent t-values.

2. Exclusion of Direct-Controlled Municipalities

Additionally, considering that direct-controlled municipalities may enjoy policy advantages in economic development compared to other regions, they were excluded to ensure the robustness of the results. Beijing, Tianjin, Shanghai, and Chongqing were removed from the research sample. After this exclusion, an in-depth empirical analysis was conducted on the remaining sample to obtain more precise and robust research outcomes. In Table 9, columns (5) and (6) present the regression results after excluding the four direct-controlled municipalities. A comparison with the baseline regression in the first and second columns of the table indicates that the data analysis results, even after removing direct-controlled municipalities, continue to show a significant "U-shaped" relationship between environmental regulation and technological complexity of high-tech industrial exports. Thus, the analysis results obtained from the baseline regression are robust.

4.2.4. Heterogeneity Analysis

1. Regional Heterogeneity Analysis

As discussed in the previous section, there exist variations in the calculated environmental regulatory intensity among different regions in China. The execution strength of environmental regulations is generally higher in the Eastern region, while relatively weaker in the Western and Northeastern regions. Differences in factors such as infrastructure construction, degree of openness to the outside world, and economic development among regions can lead to variations in the technological complexity of high-tech manufacturing exports in China. To examine whether the "U-shaped" impact of environmental regulation on the technological complexity of high-tech industrial exports is consistent across different regions, the 30 sample regions are divided into four groups: Eastern, Central, Western, and Northeastern, for a regional heterogeneity test. The division method for the four regions is the same as mentioned earlier.

The results in Table 10 present the heterogeneous effects of environmental regulatory intensity on the technological complexity of high-tech industrial exports across different regions. In particular, columns (2) and (3) demonstrate a "U-shaped" impact of environmental regulation on the technological complexity of high-tech manufacturing exports in both the Eastern and Central regions, aligning with the regression results of the full sample comprising all 30 regions. Moreover, the significance level is higher in the Eastern region. However, for the Western and Northeast regions, the influence of environmental regulation on the technological complexity of high-tech industrial exports is not statistically significant.

Table 10. Regional Heterogeneity Analysis Results.

	(1)	(2)	(3)	(4)	(5)
	Total	**Eastern Region**	**Central Region**	**Western Region**	**Northeastern Region**
	EXPY	***EXPY***	***EXPY***	***EXPY***	***EXPY***
ER	−1.447 ***	−0.748 ***	−3.018 **	−0.571	−1.318
	(−4.17)	(−3.09)	(−2.51)	(−0.91)	(−0.45)
ER^2	1.229 ***	0.619 ***	1.952 *	0.427	1.760
	(4.24)	(3.23)	(1.90)	(0.79)	(0.67)
OPEN	0.233 ***	0.020	0.225	0.469 ***	0.429
	(6.33)	(1.26)	(0.41)	(3.76)	(1.17)
ECO	0.246 ***	0.068 **	0.684 ***	−0.013	0.342
	(5.28)	(2.06)	(3.97)	(−0.16)	(1.60)
FIN	0.017	−0.033 ***	0.182 ***	0.042 **	0.069
	(1.40)	(−4.68)	(2.85)	(2.43)	(0.82)
CITY	−0.052	0.008	−3.671 ***	1.424 ***	−0.728
	(−1.03)	(0.34)	(−3.83)	(3.84)	(−1.54)
GOV	−0.072	−0.156 *	0.455	−0.101	1.012
	(−0.47)	(−1.66)	(0.47)	(−0.42)	(1.40)
Constant	−1.199 ***	0.431	−3.383 **	0.362	−2.312
	(−3.03)	(1.41)	(−2.51)	(0.56)	(−1.14)
Regional Effects	Yes	Yes	Yes	Yes	Yes
Temporal Effects	Yes	Yes	Yes	Yes	Yes
N	480	160	96	176	48
R^2	0.683	0.919	0.841	0.748	0.807

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. The values in parentheses represent t-values.

The observed regional differences in the regression results may be attributed to the more solid financial foundation and higher technological proficiency of provinces in the Eastern and Central regions. These regions also serve as significant hubs for high-tech talent. Consequently, the Eastern and Central regions possess richer endowments of resources required for the development of high-tech manufacturing industries compared to other regions. Faced with increased environmental regulatory policies, these regions can allocate more resources, such as research and development funds and human capital, to innovate green production technologies, thereby enhancing resource utilization efficiency and production efficiency. The positive gains from technological innovation gradually offset the negative impacts, such as increased costs due to heightened environmental regulations, ultimately leading to an improvement in the technological complexity of high-tech industrial exports.

In contrast, the Western region, with its relatively lagging natural environment, infrastructure, and economic conditions, exhibits a lower overall level of development in high-tech manufacturing industries, coupled with a shortage of high-quality talent. The Northeast region, although advanced in heavy industries, still faces challenges in mastering core technologies. Therefore, the difficulty of technological breakthroughs in the Western and Northeast regions is greater, and the unilateral increase in environmental regulatory intensity may not necessarily directly impact the technological complexity of high-tech industrial exports significantly.

2. Industry Heterogeneity Analysis

Building upon the analysis of the full sample, further disaggregation of high-tech manufacturing industries was conducted. Using the export technological complexity indicators for the five sub-sectors within high-tech manufacturing as the basis, panel data fixed-effects regression was employed to analyze whether the impacts of environmental regulation on high-tech industrial exports are consistent across different sub-industries. The results of the industry heterogeneity analysis are presented in Table 11.

Table 11. Industry Heterogeneity Analysis Results.

	(1)	(2)	(3)	(4)	(5)
	Pharmaceutical Manufacturing	**Aerospace and Aircraft Equipment Manufacturing**	**Electronics and Telecommunications Equipment Manufacturing**	**Computer and Office Equipment Manufacturing**	**Medical Instruments and Apparatus Manufacturing**
	***EXPY*1**	***EXPY*2**	***EXPY*3**	***EXPY*4**	***EXPY*5**
ER	−0.552 ***	−0.550 ***	−0.272 ***	−0.712 ***	−0.230 **
	(−6.01)	(−6.28)	(−3.06)	(−6.55)	(−2.44)
ER^2	0.537 ***	0.542 ***	0.272 ***	0.705 ***	0.242 ***
	(7.19)	(7.60)	(3.77)	(7.97)	(3.17)
$OPEN$	−0.013	−0.012	0.015 *	−0.029 **	0.022 **
	(−1.34)	(−1.27)	(1.67)	(−2.53)	(2.23)
ECO	0.174 ***	0.168 ***	0.142 ***	0.205 ***	0.130 ***
	(18.46)	(18.62)	(15.58)	(18.37)	(13.47)
FIN	0.017 ***	0.018 ***	0.003	0.023 ***	0.005 *
	(6.22)	(7.01)	(1.07)	(7.26)	(1.89)
$CITY$	0.114 ***	0.100 ***	0.109 ***	0.125 ***	0.098 ***
	(8.88)	(8.16)	(8.81)	(8.24)	(7.47)
GOV	0.353 ***	0.355 ***	0.177 ***	0.488 ***	0.158 ***
	(10.13)	(10.70)	(5.26)	(11.83)	(4.44)
Constant	−0.606 ***	−0.577 ***	−0.299 ***	−0.955 ***	−0.200 **
	(−7.72)	(−7.71)	(−3.94)	(−10.27)	(−2.50)
N	480	480	480	480	480
R^2	0.929	0.933	0.869	0.937	0.840

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. The values in parentheses represent t-values.

The data results from Table 11 indicate that variations in the core explanatory variable, environmental regulation, exert a significant negative impact on the export technological complexity across all five sub-sectors within high-tech manufacturing. Simultaneously, the coefficients of the quadratic term of environmental regulation are positive and significant for each sub-sector. This suggests a "U-shaped" relationship between the stringency of regional environmental policy constraints and the technological complexity of each sub-sector. Consequently, the size of the regional environmental policy constraints exhibits a "U-shaped" impact on the technological complexity of different sub-sectors.

This implies that the results of the industry heterogeneity analysis align with the overall research conclusions for China's high-tech manufacturing industries. Therefore, the baseline regression results of this study do not demonstrate significant variation among different sub-industries within high-tech manufacturing.

4.3. Mechanism Analysis

By reviewing relevant studies on the technological complexity of high-tech industrial exports in the manufacturing sector, it is evident that variations in the levels of foreign direct investment (FDI), human capital, and innovation research and development (R&D) inputs have significant implications for the technological complexity of high-tech industrial exports. However, does the fluctuation in the intensity of environmental regulation policies further influence the magnitude of technological complexity in high-tech industrial exports by impacting the levels of FDI, human capital, and innovation R&D inputs at the regional level? To elucidate the indirect impact mechanisms of environmental regulation on the technological complexity of high-tech industrial exports, this study employs fixed-effects regression models to separately analyze the relationships between environmental regulation intensity and FDI, human capital, and innovation R&D inputs. The regression results are presented in Table 12.

Table 12. Mechanism Analysis Results.

	(1)	(2)	(3)
	Foreign Direct Investment	**Human Capital**	**Innovation Research and Development (R&D) Investment**
ER	−0.033 ***	0.006 ***	−0.009 ***
	(−2.64)	(2.93)	(−3.70)
OPEN	0.018 ***	0.004 ***	−0.003 **
	(3.00)	(3.58)	(−2.28)
ECO	0.028 ***	0.008 ***	−0.011 ***
	(3.90)	(6.35)	(−7.57)
FIN	−0.003	0.000	−0.000
	(−1.62)	(0.76)	(−0.44)
CITY	−0.022 ***	0.003 *	0.008 ***
	(−2.78)	(1.87)	(5.23)
GOV	0.119 ***	0.004	−0.028 ***
	(4.93)	(1.07)	(−5.86)
Constant	−0.209 ***	−0.070 ***	0.110 ***
	(−3.30)	(−6.39)	(8.87)
Regional Effects	Yes	Yes	Yes
Temporal Effects	Yes	Yes	Yes
N	480	480	480
R^2	0.286	0.872	0.706

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. The values in parentheses represent t-values.

The results in Table 12 present the mechanism analysis, examining the relationships between environmental regulation and foreign direct investment (FDI), human capital, and innovation research and development (R&D) investment.

In Column (1), the regression coefficient of environmental regulation on foreign direct investment is −0.017, and it is significant at the 1% level. This suggests that an increase in the environmental regulation intensity index negatively impacts foreign direct investment. Larger foreign direct investment scales in a region are associated with higher technological complexity in manufacturing exports. Therefore, a one-percentage-point increase in environmental regulation intensity would lead to a 0.017 percentage point decrease in the level of foreign direct investment in the region, subsequently reducing the technological complexity of high-tech industrial exports. Column (2) indicates that an increase in regional government environmental regulation intensity has a significant positive impact on human capital. Higher levels of regional human capital contribute to the advancement of technological complexity in high-tech manufacturing exports. Therefore, under the constraint of environmental regulation, an increase in regulatory intensity significantly promotes the improvement of human resources, further enhancing the technological complexity of high-tech industrial exports in the region. The results in Column (3) show that a 1% increase in the Chinese government's environmental regulation intensity leads to a significant 0.009% decrease in innovation R&D investment at the 1% significance level. An increase in innovation R&D investment in high-tech industries corresponds to an increase in export technological complexity. Hence, when environmental regulation policy becomes more stringent, the cost of environmental governance may squeeze the space for innovation R&D investment, causing a reduction in R&D investment in the short term and indirectly affecting the changes in the technological complexity of high-tech industrial exports.

In summary, after the government enhances environmental regulation intensity, the increase in costs will lead to a reduction in investment within the region, hindering the improvement of technological complexity in high-tech industrial exports. On the other hand, there is a positive correlation between environmental regulation intensity and the levels of human capital and innovation R&D investment. Therefore, increasing environmental regulation intensity not only facilitates the enhancement of human capital and innovation R&D investment but also indirectly elevates the export technological complexity of high-tech manufacturing industries.

5. Conclusions

This study primarily investigated the impact of China's environmental regulation intensity on the technological complexity of high-tech industrial exports in the manufacturing sector. By reviewing relevant research in the domains of environmental regulation and export technological complexity, this study defined the concepts of environmental regulation, high-tech manufacturing industries, and export technological complexity. Subsequently, suitable indicators were selected to quantify the environmental regulation and technological complexity of high-tech industrial exports in different regions of China. Based on this, this study discussed the current status and shortcomings of both aspects. Using entropy analysis, this study measured the environmental regulation intensity across different regions of China. Theoretical analysis explored the specific pathways through which environmental regulation influences the technological complexity of high-tech industrial exports. The empirical analysis, utilizing data from 30 provinces (excluding Tibet) between 2006 and 2021, quantitatively analyzed the impact of environmental regulation on the technological complexity of high-tech industrial exports. Robustness checks, including endogeneity tests, verified the resilience of the baseline regression results. Furthermore, this study delved into the heterogeneity of these effects across regions and industries.

The main research conclusions of this paper are as follows: (1) from 2006 to 2021, China's environmental regulation intensity and the technological complexity of manufacturing high-tech industry exports have shown an upward trend; (2) the empirical analysis results show that China's increase in environmental regulation intensity has a significant "U-shaped" impact on the technological complexity of exports of high-tech manufacturing industries; (3) the "U-shaped" impact of environmental regulation on the technological complexity of exports of high-tech manufacturing industries has regional differences, however, the manufacturing high-tech industry does not show obvious industry differences; and (4) environmental regulations will affect the level of export technology complexity of the manufacturing high-tech industry through foreign direct investment, human capital, and innovative R&D investment, which cause indirect effects. As a result, the three specific research questions raised in Section 3.1 of this paper have all been satisfactorily answered.

Based on the research conclusions above, we put forward the following policy recommendations:

(1) In determining the intensity of environmental regulation policies, the government should avoid blind choices and tailor them to the actual conditions of different regions, considering factors such as economic development levels, industrial pollution levels, and infrastructure conditions. The implementation of environmental regulation policies should be preceded by a comprehensive understanding of local industrial pollutant emissions and enterprise production efficiency, aiming to avoid one-size-fits-all approaches. Matching the environmental regulation intensity with the development level of high-tech industries prevents excessive impacts on local enterprises, ensuring their survival under environmental constraints. Simultaneously, reasonable external environmental pressure forces local enterprises to increase technological R&D and innovation efforts, encouraging innovation to improve enterprise output efficiency. This approach promotes the enhancement of the technological complexity of high-tech industrial exports, showcasing stronger international competitiveness in the global division of labor. Additionally, flexible and scientifically sound environmental regulation policies drive economic growth, facilitating the multifaceted development of ecological environments, technological innovation, and economic growth, thereby accelerating China's overall high-quality economic development.

(2) Technological innovation is the core driver for economic development and industrial transformation. Achieving high-quality development in China's high-tech industries and improving the international market competitiveness of its products require further improvements in the domestic environment for the development of high-tech industries. To promote R&D innovation in high-tech industries, concerted efforts are needed from both the government and enterprises due to the multifaceted influences on R&D innovation in regional high-tech industries.

(3) The degree of openness of a region to the outside world can affect the export technological complexity of high-tech manufacturing industries. As the process of economic globalization continues, economic connections between nations become increasingly intertwined, presenting more opportunities for the development of high-tech industries. Therefore, governments should adhere to an open-door policy, further enhance the level of openness, and seize new opportunities for the development of high-tech manufacturing industries. China's proposal of a new "dual circulation" development pattern in 2020 underscores the importance of the international market in development. The development of China's high-tech manufacturing industries should maintain an open stance, actively encourage the internationalization of high-tech manufacturing industries, fully utilize international market resources, and leverage the advantages of the international market to enhance the export technological complexity of high-tech manufacturing industries, demonstrating superior competitiveness in the international market.

(4) As the world's most populous country, China has a vast population and abundant labor resources. Labor advantages provide solid support for economic development, technological innovation, social progress, and other aspects. However, currently, most of the labor force is still concentrated outside the industries related to high-tech manufacturing, and there is still considerable room for the development of high-tech talents. To achieve a breakthrough in the development of high-tech manufacturing industries, China should further strengthen the cultivation of high-quality talents. This involves fully implementing the requirements for building a strong talent country, increasing investment in the education sector, updating higher education curricula, and cultivating more high-quality talents. These efforts provide strong talent support for improving the export technological complexity of high-tech manufacturing industries.

There are still some shortcomings in this paper that need further refinement in subsequent research. On the one hand, there may be regional variations in environmental regulation and the export technological complexity of high-tech industries, which could introduce uncertainties into the final research results. In future research, efforts can be made to conduct more detailed analyses by replacing variables and exploring at the municipal level to further improve this study. On the other hand, with the continuous development of environmental regulation policies, these policies can be broadly categorized into three types: command-and-control environmental regulation, market-based environmental regulation, and voluntary participation environmental regulation. However, in this study on the impact of environmental regulation policies on the export technological complexity of high-tech industries in manufacturing, and in the selection of environmental regulation indicators, there was no detailed categorization of environmental regulation. This study did not investigate whether the three types of environmental regulation policies would have different effects on the export technological complexity of high-tech industries. This is also an issue that the authors plan to explore in future research, aiming to further supplement and improve this study's results.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Environmental Regulatory Intensity Indicators by Province.

City/Year	2006	2009	2012	2015	2018	2021
Anhui	0.7212	0.7278	0.7753	0.8100	0.8100	0.8100
Beijing	0.6470	0.6715	0.7454	0.6918	0.7314	0.7403
Fujian	0.5544	0.5668	0.6113	0.6642	0.7578	0.7409
Gansu	0.4001	0.4565	0.5269	0.6307	0.6545	0.6236
Guangdong	0.4752	0.4887	0.6354	0.7340	0.7757	0.7986
Guangxi	0.5704	0.5515	0.6222	0.6352	0.7392	0.7153
Guizhou	0.4636	0.5087	0.5671	0.7031	0.7332	0.7624
Hainan	0.4461	0.4489	0.6391	0.7349	0.6644	0.6735
Hebei	0.4416	0.5290	0.6597	0.7078	0.6882	0.7799
Henan	0.5779	0.5680	0.6000	0.6489	0.6834	0.7283
Heilongjiang	0.5517	0.5634	0.5658	0.6394	0.5902	0.6152

Table A1. *Cont.*

City/Year	2006	2009	2012	2015	2018	2021
Hubei	0.6201	0.6419	0.6846	0.7687	0.7339	0.7463
Hunan	0.6014	0.6072	0.6341	0.7448	0.6990	0.7372
Jilin	0.4643	0.4576	0.5343	0.6016	0.6484	0.5836
Jiangsu	0.6427	0.6765	0.7249	0.7719	0.8100	0.8100
Jiangxi	0.4857	0.4868	0.5402	0.6198	0.6936	0.7258
Liaoning	0.5079	0.5120	0.5050	0.6394	0.6056	0.6023
Inner Mongolia	0.4001	0.4370	0.5980	0.6359	0.6598	0.6582
Ningxia	0.4510	0.5124	0.5529	0.5822	0.7096	0.6847
Qinghai	0.4001	0.4001	0.4001	0.4289	0.5766	0.6412
Shandong	0.6796	0.6762	0.7249	0.7829	0.8100	0.8100
Shanxi	0.5377	0.5365	0.6177	0.7239	0.7171	0.6965
Shaanxi	0.4001	0.4001	0.4738	0.5904	0.6834	0.7398
Shanghai	0.6519	0.6609	0.6653	0.8033	0.7914	0.8098
Sichuan	0.5111	0.4972	0.5330	0.5791	0.5974	0.6210
Tianjin	0.7333	0.7375	0.7994	0.8100	0.8100	0.8100
Xinjiang	0.4132	0.4001	0.4001	0.4233	0.5041	0.5605
Yunnan	0.5674	0.5699	0.6381	0.7061	0.7134	0.7062
Zhejiang	0.6023	0.6408	0.7058	0.7370	0.7985	0.8100
Chongqing	0.5493	0.5413	0.5867	0.6730	0.7061	0.7288

Table A2. The Criteria for Dividing the Four Major Regions.

Region	Provinces
Eastern	Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan
Central	Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan
Western	Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, (Excluding Tibet)
Northeastern	Liaoning, Jilin, and Heilongjiang

Table A3. The SITC Rev.3 Codes Corresponding to the Sub-Sectors of High-Tech Manufacturing Industries.

Industry	SITC Rev.3 Codes
Pharmaceutical Manufacturing	541, 542
Aerospace and Equipment Manufacturing	713, 792
Electronic and Communication Equipment Manufacturing	761, 762, 763, 764, 772, 773, 776, 778
Computer and Office Equipment Manufacturing	726, 751, 752, 759
Medical Instrument and Equipment Manufacturing	716, 718, 771, 774, 871, 872, 873, 874, 881

Table A4. Manufacturing High-tech Industry Export Technical Complexity (Eastern Region).

	2006	2009	2012	2015	2018	2021
Beijing	8.4988	9.1378	10.0355	10.1408	10.2156	9.9938
Fujian	7.9877	8.7944	9.2367	9.6039	9.6981	9.8737
Guangdong	8.2410	9.0565	9.5423	9.8685	9.7591	10.0288
Hainan	5.2937	6.1717	6.7870	6.5255	6.9370	9.8516
Hebei	6.4747	6.3956	6.8013	8.0116	7.9108	9.6076
Jiangsu	8.1845	9.2677	9.5641	10.0491	10.267	10.2672
Shandong	6.9023	7.5861	8.7068	9.1468	9.1181	9.3282
Shanghai	8.0282	9.0323	9.6001	9.8957	9.8242	9.9841
Tianjin	8.8057	9.3329	9.7965	9.8429	10.1375	10.1180
Zhejiang	6.8698	7.5334	8.42880	8.2941	8.3634	9. 4229

Table A5. Manufacturing High-tech Industry Export Technical Complexity (Central Region).

	2006	**2009**	**2012**	**2015**	**2018**	**2021**
Anhui	6.1568	6.4204	7.5441	7.7354	9.2525	10.1707
Henan	6.7995	7.0843	6.9648	7.9197	10.2672	10.2672
Hubei	6.9110	7.7064	8.9482	9.7398	9.6480	10.1228
Hunan	6.8549	7.6997	7.8195	7.7463	10.2176	10.2672
Jiangxi	6.2395	7.1733	8.5814	8.9361	9.0683	9.4548
Shanxi	4.8480	4.8480	7.1707	8.5057	10.2672	10.2672

Table A6. Manufacturing High-tech Industry Export Technical Complexity (Western Region).

	2006	**2009**	**2012**	**2015**	**2018**	**2021**
Inner Mongolia	4.8480	4.9020	6.1270	6.4747	7.2565	7.7804
Guangxi	4.8663	5.8774	7.4820	9.1730	9.8561	10.0686
Gansu	6.8754	6.1746	8.1289	7.1352	9.2203	10.6193
Guizhou	5.9127	7.7951	7.8102	7.7876	7.5383	10.6442
Ningxia	5.6424	6.4162	8.0300	7.8159	8.0883	9.1480
Qinghai	4.1489	5.0955	5.9527	5.1763	6.4547	8.6910
Shanxi	4.3571	3.9343	10.1870	8.5057	10.2671	9.0758
Shaanxi	7.6156	7.9535	9.0114	8.6899	8.9623	9.1667
Sichuan	7.6142	8.4481	10.5159	10.0201	10.2679	9.0574
Xinjiang	5.6743	5.0310	5.3674	5.2217	7.8480	9.5772
Yunnan	5.9780	5.8515	6.9165	6.4306	6.3606	10.1396

Table A7. Manufacturing High-tech Industry Export Technical Complexity (Northeast Region).

	2006	**2009**	**2012**	**2015**	**2018**	**2021**
Liaoning	7.8790	8.2531	8.5083	8.9368	10.3542	10.5244
Jilin	5.6720	7.1940	6.7631	6.6705	7.8770	8.4138
Heilongjiang	4.8837	5.3772	6.3068	6.6548	6.6840	6.9752

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