How Effective is China's SO_2 Emissions Regulation?

Submitted in fulfilment of the requirements of the Degree of Doctor of Philosophy

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June 2025

Abstract

China's rapid industrialization has spurred severe environmental challenges, with sulfur dioxide (SO_2) emissions posing significant threats to public health and sustainable development. This thesis evaluates the effectiveness of China's SO_2 emissions regulations, focusing on the 2006 Eleventh Five-Year Plan (FYP) policy as a quasi-natural experiment. Leveraging difference-in-differences (DID) methods and comprehensive firm-level data, the study examines the policy's causal impacts on firm pollution emissions, total factor productivity (TFP), two-way foreign direct investment (FDI), and export performance.

The analysis reveals that the SO_2 emissions regulation achieved measurable success in reducing firm SO_2 emissions, particularly among state-owned and large-scale firms, though with heterogeneous effects across regions and industries. Strikingly, while stricter environmental mandates initially raised compliance costs, they stimulated total factor productivity gains by incentivizing technological innovation. The policy also reshaped China firms' global engagement: stricter regulation reduced inward FDI in but encouraged outward FDI (OFDI) as firms sought cleaner technologies abroad. Meanwhile, export performance exhibited nuanced outcomes. Export value and export product quality improved as firms upgraded production processes to meet environmental standards.

Mechanism tests underscore the role of innovation offsets, reduction cost, and market reallocation in driving these outcomes. Heterogeneity analyses highlight divergent responses based on firm ownership, firm size, and industry intensity, offering insights into the uneven distribution of regulatory costs and benefits. By integrating environmental economics with firm-level dynamics, this research contributes empirical evidence on the trade-offs and synergies between environmental governance and economic performance in emerging economies.

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Declaration

I declare that, except where explicit reference is made to the contribution of others, this dissertation is the result of my own work and has not been submitted for any other degree at the University of Glasgow or any other institution.

Printed name:

Signature:

1 Introduction

1.1 Research Background

Over the past 40 years since the reform and opening-up, China's economic development has made remarkable achievements. According to World Bank statistics, from 1978 to 2021, China's GDP climbed from 10th to 2nd globally, while GDP per capita rose from 131st to 64th in the global ranking. Total factor productivity, which reflects the quality level of economic development, has continuously grown at a rate of about 4% per year. However, behind this rapid economic growth, the huge amount of energy consumption has raised an increasingly serious problem of pollution and emissions (Liu et al., 2012), threatened the human living environment and devoured the fruits of human economic development (Zhang and We, 2008). According to the Global Environmental Competitiveness Report, China is perennially ranked at the bottom of the global air quality rankings. China's industrial sulfur dioxide (SO_2) emissions reached 25.888 million tons in 2006, topping the global charts, with 84% stemming from industrial sources (Shan et al., 2018).

SO_2 is a major air pollutant with significant adverse effects on human health and the environment. It contributes to the formation of acid rain, which can damage forests, soil, and aquatic ecosystems (Kaminski, 2003). Additionally, SO_2 can exacerbate respiratory conditions such as asthma and bronchitis, and long-term exposure has been linked to increased mortality rates and decreased life expectancy. In China, where air pollution is a pressing issue, addressing SO_2 emissions is crucial for improving public health and protecting the environment. Second, the economic and social costs associated with SO_2 emissions are also substantial. Acid rain, for instance, can damage crops and infrastructure, leading to significant economic losses. Furthermore, health impacts of SO_2 exposure result in increased healthcare costs and lost productivity due to illness and early mortality. By focusing on SO_2 emissions regulation, China can mitigate these costs and promote sustainable economic development. Third, SO_2 has been a primary target of China's air pollution control efforts since the early 2000s (Shi et al., 2023). It was one of the first pollutants to be seriously addressed in China's environmental policy, making it an excellent case study for evaluating the long-term effectiveness of emissions regulations. Success or failure in regulating SO_2 emissions can be indicative of China's overall capacity for environmental governance and its ability to address other pollutants and environmental challenges. By focusing on SO_2 emissions, my study aims to provide a comprehensive assessment of a key aspect of China's environmental regulation. This focus allows us to draw meaningful conclusions about the effectiveness of China's approach to emissions control, which can inform both the understanding of past policies and the development of future environmental strategies in China and potentially other developing countries facing similar challenges. Finally, from a methodological perspective, focusing on SO2 emissions allows for a robust analysis using available data. China has extensive monitoring networks for SO2 emissions, and there is a wealth of information on regulatory measures and their implementation. This data availability enables a detailed and nuanced examination of the effectiveness of SO2 emissions regulation in China.

In 2005, the Chinese government proposed quantitative emission reduction targets for the major air pollutant (SO_2) in the Eleventh Five-Year Plan (2006-2010) (Liu and Diamond, 2008). Five-year plans clarify and specify the task of emission reduction, facilitating all levels of government and relevant enterprises in defining their responsibility for emission reduction and devising effective measures to reduce emissions. Meanwhile, the Chinese government also used the achievement of emission reduction targets by local officials as an essential promotion indicator (Wu et al., 2017). For political incentives, almost all provinces and municipalities completed their emission reduction targets on schedule by 2010, and the policy achieved significant reductions in the total amount of major pollutants. As can be seen in Figure 1.1, from 2006 to 2010, China's SO_2 emissions decreased by 14.3% compared with the year 2005. I find that the turning point occurred in 2006, the starting year of China's Eleventh Five-Year Plan, demonstrating a close link between environmental improvements and environmental regulations. So, I propose to use the implementation of the Eleventh Five-Year Plan sulfur dioxide reduction policy in 2006 as a quasi-natural experiment to discuss the effectiveness of SO_2 emissions regulation, including desirable outcomes such as reducing pollution and improving economic performance, as measured by total factor productivity, two-way foreign direct investment, and export performance, using the difference-in-difference method.

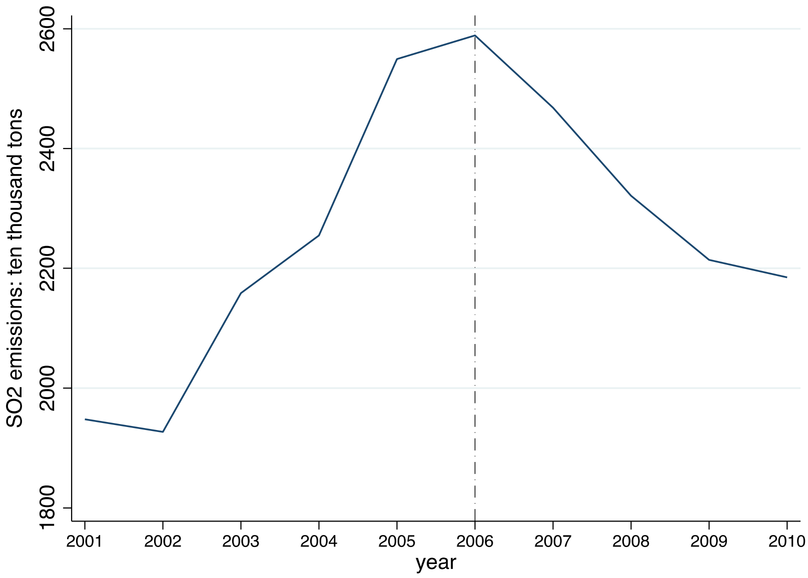

Figure 1.1: Sulfur Dioxide Emissions in China

Source: Analysis reported in this thesis.

The 11th Five-Year Plan (2006-2010) represents a pivotal period in China's environmental policy history, marking a significant shift towards more stringent and quantitative emission reduction targets (Liu and Diamond, 2008). Prior to this plan, China's environmental policies were largely focused on qualitative goals and less specific quantitative targets. The 11th Five-Year Plan introduced a quantitative emission reduction target for SO_2, one of the major air pollutants in China, which was a pioneering step in the country's efforts to combat air pollution (He et al., 2020). The quantitative emission reduction targets introduced in the 11th Five-Year Plan were unprecedented in China's environmental policy landscape. This policy innovation allowed for more precise measurement and accountability, and clarified and specified the task of emission reduction, facilitating all levels of government and relevant enterprises in defining their responsibilities for emission reduction (Xu, 2011; Liu et al., 2012). This detailed implementation mechanism provides a unique opportunity to analyse how different stakeholders interacted and responded to the policy, which is essential for understanding the broader implications of such policies. The SO_2 emission reduction policy in the 11th Five-Year Plan was implemented during a period of rapid economic growth in China. The introduction of quantitative targets provides a clear before-and-after scenario, allowing for a natural experiment setup to evaluate policy effectiveness. Studying this policy allows me to assess its impact on international investment, trade and environmental quality, providing insights into the potential trade-offs and synergies between these objectives.

1.2 Research Contents

In order to capture a comprehensive range of economic and environmental impacts of China's SO_2 Emissions Regulation. I choose SO_2 emissions, total factor productivity (TFP), foreign direct investment (FDI), outward direct investment (OFDI), and trade.

First, SO_2 emissions are a significant source of air pollution and have been a primary focus of China's environmental regulatory efforts (Li et al., 2015; Schreifels et al., 2012). By examining SO_2 emissions, I can directly assess the effectiveness of regulatory policies in reducing pollutants and improving air quality. This outcome is crucial for evaluating the environmental dimension of regulatory impact.

Second, TFP measures the efficiency of production, reflecting technological progress, managerial efficiency, and other factors that contribute to productivity growth (Lipsey and Carlaw, 2004; Limam and Miller, 2004). Environmental regulations can potentially affect TFP through several channels, such as encouraging technological innovation to reduce pollution or imposing costs that lead firms to reallocate resources more efficiently (Zhao et al., 2018; Yang et al., 2012). By analyzing TFP, I aim to understand the broader economic implications of environmental regulation on productivity and growth.

Third, FDI is an important driver of economic growth and technological transfer in China (Wu et al., 2020; Buckley et al., 2004). Environmental regulations may influence FDI inflows by affecting the cost structure of foreign investors, the attractiveness of the regulatory environment, and the overall business climate (List and Co, 2000; Hanna, 2010). By studying the relationship between environmental regulation and FDI, I can assess whether stricter regulations deter foreign investment or whether investors are willing to comply with higher standards in pursuit of market access and other benefits. And OFDI represents China's growing economic presence on the global stage (Huang and Wang, 2011). Environmental regulations may influence OFDI decisions by affecting the competitiveness of Chinese firms in international markets, their ability to meet foreign environmental standards, and their strategic responses to domestic regulatory pressures (Liu et al., 2022). Analyzing OFDI allows me to explore the international spillover effects of China's environmental policies.

Finally, Trade is another critical aspect of China's economic integration with the world (Romano, 2011).

Environmental regulations can affect trade flows through changes in production costs, export competitiveness, and trade barriers related to environmental standards (Chen et al., 2022). By examining trade, I can assess the potential trade-offs between environmental protection and trade liberalization, as well as the potential for export product quality to promote stable development.

In summary, these five outcomes “SO_2 emissions, TFP, FDI, OFDI, and trade” provide a multifaceted perspective on the impacts of China’s environmental regulatory policies. They allow me to evaluate not only the direct environmental effects but also the broader economic consequences, including productivity, investment, and trade dynamics. By focusing on these outcomes, I aim to contribute to a more nuanced understanding of the complex interplay between environmental regulation and economic performance in China.

1.3 Research Contributions

1.3.1 Theoretical Contributions

First, I contribute to the existing literature by providing a comprehensive framework that analyzes the multifaceted impacts of China’s SO_2 emissions regulation on various economic outcomes. By integrating insights from environmental economics and international trade, I offer a unified perspective that captures the intricate relationships between environmental regulation, enterprise behavior, and broader economic outcomes. I conduct research on the relationship between environmental regulations and environmental performance (SO_2 emission intensity) as well as economic performance (TFP, two-way FDI, exports) within a unified background.

Secondly, the Pollution Haven Hypothesis (PHH) posits that disparities in environmental regulations drive the relocation of pollution-intensive industries to jurisdictions with less stringent regulatory regimes (Copeland and Taylor, 1994). This study demonstrates that environmental regulations inhibit FDI while stimulating OFDI through increased pollution abatement and compliance costs. These findings substantiate the industrial relocation logic underlying PHH. Consequently, my results not only validate the core proposition of PHH but also provide empirical evidence elucidating how environmental regulations influence cross-border capital flows.

Finally, according to the Porter Hypothesis, stringent environmental regulations can stimulate technological and managerial innovations within firms. These innovations may partially or fully offset the costs incurred from regulatory compliance, and potentially create new competitive advantages. The Strong Porter Hypothesis further posits that well-designed environmental regulations not only compensate for compliance costs but also enhance corporate competitiveness, enabling firms to secure advantages in international markets, thus emphasizing the positive impact of environmental regulations on firm competitiveness. Referring to Melitz (2003), this thesis constructed a heterogeneous firm theoretical model of how environmental regulations affect firm TFP. It reveals that environmental regulation influences firms' TFP through two channels: On one hand, it directly increases production costs, primarily through the increased use of clean energy and emission reduction equipment. On the other hand, it can stimulate corporate innovation, improving TFP, OFDI, and export performance, mainly through increased R&D investment and patent generation. Since the technological innovation effect induced by environmental regulations can compensate for the increased compliance costs, environmental regulations ultimately enhance TFP. This conclusion validates the Strong Porter Hypothesis. This model extends the application boundaries of heterogeneous firm models and deepens the theoretical understanding of the relationship between environmental regulations and firm productivity.

1.3.2 Empirical Contributions

The research utilizes the continuous DID method to examine the relationship between environmental regulation and firm emissions, two-way FDI, export volume and export product quality, leveraging the strengthening of the mandatory SO_2 emissions target scheme in the 11th Five-Year Plan as a natural experiment.

Specifically, the chapter 4 contributes to the field of environmental policy and firm emissions by demonstrating that policies directly decrease firm emissions intensity using Chinese industrial enterprise data, investigating heterogeneous regulatory effects across ownership structure, sectoral, and firm size dimensions. Unlike previous studies, my study elucidates the mechanisms driving reduced emissions through resource reallocation and cleaner production processes. Specifically, environmental regulation may impact firm SO_2 emissions through two aspects: First, environmental regulation reduces the emission intensity of enterprises by reducing traditional energy use from the front-end control and increasing pollutant discharge equipment from the end-treatment. Second, environmental regulation can reduce the firm pollution emission intensity through the reallocation of resources among firms. This analysis helps to understand the channels through which environmental regulations affect pollution reduction.

Chapter 5 introduces environmental regulation into the heterogeneous firm model, discussing its theoretical impact on firm TFP, finding that while regulations initially increase costs, they ultimately enhance TFP through technological innovation. Unlike previous studies, my research uses the SO_2 emission reduction target in the Eleventh Five Year Plan as a proxy variable for environmental regulation to analyze its impact on TFP. This research supports the Porter Hypothesis framework, offering insights for developing countries.

Previous studies have only examined the impact of environmental regulations on FDI or OFDI, without examining the relationship between SO_2 emission reduction target and two-way FDI using DID model. Chapter 6 examines the relationship between environmental regulation and firm two-way FDI using DID model as a natural experiment. Departing from prior research that primarily relied on macroeconomic data, our study achieves a significant breakthrough in data utilization. I employ firm-level data from the China Industrial Enterprise Database and the Cathay Pacific CSMAR Database. The extensive sample of enterprises substantially reduces estimation bias. Additionally, this chapter explored the impact mechanism through cost, innovation, and financing effects. Heterogeneity analysis conducted considering firm ownership, size, factor densities, industries, and country differences. The findings indicate that the implementation of the 11th Five-Year Plan enhances environmental regulation, resulting in a negative impact on firm FDI and a positive impact on firm OFDI.

Chapter 7 analyses the impact of environmental regulation on the export of enterprises. The innovative points include: (1) combining environmental regulations with enterprise export volume and export product quality within a single framework, enriching research on export influencing factors and providing new ideas for developing countries to balance development and environmental relations; (2) exploring the heterogeneity of environmental regulations affecting enterprise export volume and export product quality at both enterprise and regional levels, finding that the promotional effect varies based on ownership type, region location, and enterprise size, which offers a reference for formulating supporting policies; and (3) delving into the channels through which environmental regulations affect enterprise export volume and export product quality, refining the understanding of this relationship and concluding that environmental regulations can promote product exports through technology effects, providing reference information for policymakers to design systems that continuously improve air pollution.

1.3.3 Policy-Making Contributions

My analysis demonstrates that SO_2 regulation policies can effectively reduce pollution emissions while promoting enterprise total factor productivity, foreign direct investment, outward foreign direct investment, and trade. This provides strong empirical support for the continuation and strengthening of such policies. Policymakers can use these findings to design more stringent and effective SO_2 regulation policies, setting reasonable emission reduction targets and standards to achieve environmental protection and economic development goals more efficiently.

The results indicate that environmental regulations do not necessarily hinder economic growth but can instead stimulate technological innovation and improve productivity, thereby positively impacting TFP. This suggests that policymakers can strike a better balance between environmental and economic objectives. They can introduce a mix of environmental regulation policies, including SO_2 regulation, to achieve sustainable development without significantly sacrificing economic growth. Additionally, policymakers can develop targeted support measures to help enterprises transition and adapt to stricter environmental regulations, minimizing potential negative impacts on specific industries or sectors.

The results of my study can assist policymakers in refining the design of SO2 regulation policies. For instance, policymakers can consider introducing complementary measures to mitigate the adverse effects of these policies on foreign direct investment. These measures could include offering tax incentives or subsidies to attract foreign investors who adopt environmentally friendly technologies and practices, or establishing specialized industrial parks with advanced pollution control infrastructure to reduce the environmental compliance costs for incoming foreign enterprises. By doing so, policymakers can strike a better balance between attracting foreign investment and achieving environmental objectives, thereby enhancing the overall effectiveness of environmental policies. The impact of SO_2 regulation policies on foreign direct investment highlights the importance of incorporating environmental considerations into investment policies. Policymakers can use my research findings to develop more sustainable investment policies that attract foreign direct investment with high environmental and economic value. For example, governments can establish green investment evaluation criteria to screen and guide foreign direct investment projects, prioritizing the approval and support of projects that feature advanced environmental technologies and practices, low pollutant emissions, and high added value. Conversely, projects with high SO_2 emissions and significant environmental risks can be subject to stricter scrutiny and regulation. This approach helps optimize the structure of foreign direct investment, improves the quality and efficiency of investment utilization, and promotes the coordinated development of the economy and the environment.

My finding that SO_2 regulation policies enhance export volume and export product quality suggests that environmental regulations can serve as a catalyst for industrial upgrading. Policymakers can leverage this insight to formulate targeted industrial policies that encourage enterprises to innovate and improve product quality in response to environmental regulations. For example, governments can increase funding support for research and development in high-quality production technologies and establish relevant technology innovation institutions to assist enterprises in overcoming technological barriers to achieving both environmental compliance and product quality upgrades. Additionally, policymakers can promote the industries development and the optimization of trade structures by supporting the export of high-quality products. This can be achieved through measures such as providing export credit insurance for high-quality products and organizing specialized exhibitions for product exports, thereby enhancing the international competitiveness of domestic industries and driving sustainable economic growth.

1.4 Research Framework

Chapter 1 is the introduction. This chapter introduces the research background.

Chapter 2 discusses the relationship between the environment and the economy in China. First, I introduce China's environmental situation. I analyze annual SO_2 emissions in China and compare them across different industries and regions. Second, I describe China's economic situation from China's TFP, two-way FDI and export. Specifically, in section 2.2, I define total factor productivity and analyse its changing trends across various industries and regions. In section 2.3, I introduce the definition of China's two-way

FDI and analyze its history and situation. Then, I compare export changes across different industries and regions. Third, I summarize the development history of China's environmental policies and the classification and characteristics of environmental regulatory tools. Lastly, I introduce the Five-Year Plan's background and analyse the plan's enforcement and outcomes.

Chapter 3 describes the research methods and the data used in this research. In section 3.2, I introduce the theory of difference-in-difference (DID) methods. In section 3.3, I analyse the core explanatory variable, sulfur dioxide emissions regulation. I use the implementation of the Eleventh Five-Year Plan sulfur dioxide reduction policy in 2006 as a quasi-natural experiment. In section 3.4, I describe the database; then I introduce the data processing and data merging that I will use in the thesis.

Chapter 4 concerns the influence of China's domestic environmental regulation on firm pollution emissions. In section 4.2, I review the literature. I introduce the research on environmental regulation, command-based environmental regulations and pollution, market-oriented environmental regulations and pollution, and public supervision-based environmental regulations and pollution. In section 4.3, I present my theoretical analysis. In section 4.4, I introduce the methodology and data description. In section 4.5, I first provide a basic regression and test the basic regression by using the parallel trend test and a series of robustness tests. Then, I examine the micro-impact mechanism of environmental regulation on firm pollution. Finally, I do the heterogeneity analysis.

Chapter 5 concerns the influence of China's domestic environmental regulation on firm TFP. In section 5.2, I review the literature on the impact of environmental regulation on TFP. Section 5.3 presents the theoretical analysis of the relationship between environmental regulation and TFP. In section 5.4, I introduce the methodology and data description. In section 5.5, I first provide a basic regression and test the basic regression by using a parallel trend test and a series of robustness tests. Then I examine the micro-impact mechanism. Finally, I do the heterogeneity analysis.

Chapter 6 tests the influence of China's environmental regulation on firm two-way FDI. In section 6.2, I first review the literature on the impact of environmental regulation on two-way FDI. In section 6.3, I analyze the theoretical mechanism of the relationship between environmental regulation and two-way FDI. In section 6.4, I introduce the methodology and data description. In section 6.5, I first provide a basic regression. I use the parallel trend test and a series of robustness tests to test the basic regression. Then, I examine the micro-impact mechanism of environmental regulation on firm two-way FDI and do a series of heterogeneity analyses.

Chapter 7 concerns the influence of China's domestic environmental regulation on firm export performance. In section 7.2, I review the literature. I introduce the impact of environmental regulation on export competitiveness, export volume and export product quality. In section 7.3, I analyze the theoretical mechanism and in section 7.4, I introduce the methodology and data description. In section 7.5, I first provide a basic regression to research the relationship between environmental regulation and export volume and export product quality, and then I examine the micro-impact mechanism of environmental regulation on firm export. Last, I do a series of heterogeneity analyses.

Chapter 8 is the conclusion. I summarize the major contents of the study, theoretical and practical implications and research deficiencies and prospects.

2 SO_2 Emissions and Principal Indicators of Economic Performance in China

This chapter introduces the relationship between China's environment and economic situation. First, I introduce the environmental situation in China. I mainly analyze annual sulfur dioxide emissions in China and compare sulfur dioxide emissions across different industries and regions. Second, I introduce China's economic situation from China's total factor productivity, two-way foreign direct investment and export performance. Third, I summarize the development of China's environmental policy and the classification and characteristics of environmental regulations. Lastly, I analyze the background of the Eleventh Five-Year Plan and the policy's enforcement and outcomes.

2.1 SO_2 Emission Situation

2.1.1 SO_2 Emission's Change Trend

1. Annual SO_2 Emission Total Analysis

In recent years, frequent "smog" events with prolonged duration have become a growing concern regarding air quality and pollution in China. According to Chinese air quality standards, major air pollutants exceeding emission limits include SO_2 emission, particulate matter (PM), nitrogen oxides, and fluorides. Among industrial exhaust emissions, SO_2 emission accounts for a high proportion and its statistics by provinces are relatively systematic and comprehensive. Therefore, industrial SO_2 emissions can serve as a salient indicator of atmospheric pollution. As exhibited in Figure 2.1, China's SO_2 emissions demonstrated a trend of initial increase followed by a decrease during 2000-2020. Specifically, China's SO_2 emissions in 2000 were 16.12 million tons. The emissions grew year by year, culminating at 22.34 million tons in 2006. Afterwards, SO_2 emissions commenced a gradual decline to 2.53 million tons in 2020. This trend may have been influenced by various factors. On the one hand, China has achieved remarkable advancement in energy structure adjustment and energy efficiency improvement, which contributed to emission mitigation. On the other hand, amid economic growth and rising energy demand, China's reliance on energy remained substantial, leading to rebounds in emissions. Additionally, environmental regulations implemented during 2000-2020, including the Air Pollution Prevention and Control Action Plan, the Air Pollution Prevention and Control Law, and the Atmospheric Pollution Prevention Action Plan, have also exerted significant impacts on reducing enterprise SO_2 emissions. In 2015, China's new Environmental Protection Law was implemented, which increased penalties for illegal abatement of pollutants and strengthened the responsibility of enterprises for pollution control (Zhang et al., 2018). In addition, the "13th Five-Year Plan" was released in 2015, which stipulates that by 2020, the total amount of SO_2 emissions can be reduced by more than 15% compared to 2015 (Liu and Wang, 2017). As a result, sulfur dioxide emissions fell sharply in 2015.

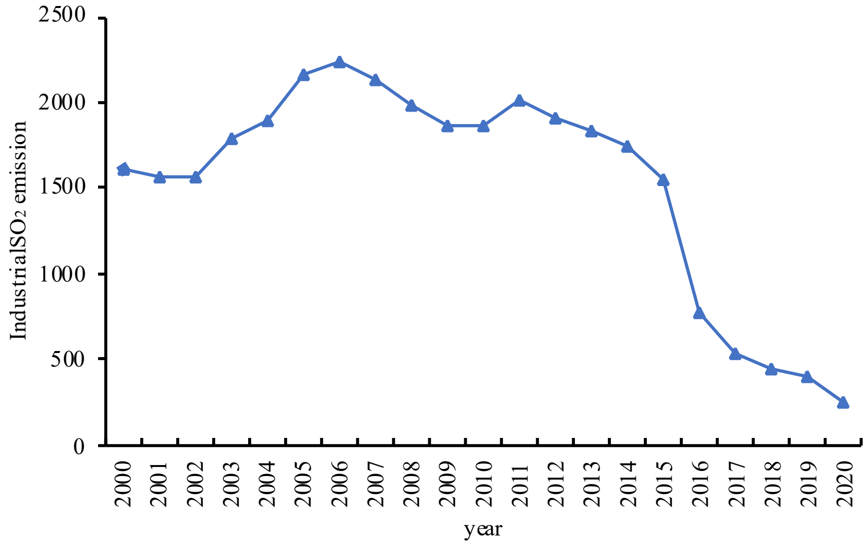

Figure 2.1: China's Industrial SO_2 Emissions from 2000 to 2020

Data source: The China Statistical Yearbook on Environment 2022, compiled by National Bureau of Statistics Ministry of Ecology and Environment. Unit: 10000 tons.

2. Comparative Analysis of SO_2 Emission in Different Industries

Table 2.1 indicates that SO_2 emissions from various industries in China exhibited an upward fluctuating trend during 1998-2014. In 2014, SO_2 emissions increased in most industries compared to 1998 levels. The industries with the highest emissions were petroleum processing, manufacturing of chemical raw materials and products, smelting and pressing of ferrous metals, smelting and pressing of non-ferrous metals, and manufacturing of non-metallic mineral products. These energy-intensive and highly-polluting heavy industries are also pillar industries in China, thus changes in their emissions directly impact air quality in the country. Some heavy industries saw noticeable increases in emissions, for example, SO_2 emissions from smelting and pressing of non-ferrous metals grew from 4.131 million tons in 1998 to 11.407 million tons in 2014, an increase of 176%. Emissions from petroleum processing increased from 0.622 million tons in 1998 to 4.512 million tons in 2014, up by 625%.

Table 2.1: SO_2 Emissions from Various Industries from 1998 to 2014

Industry category	1998	2000	2002	2004	2006	2008	2010	2012	2014
Agricultural and sideline food	11.10	11.03	9.11	8.97	11.33	11.99	11.63	15.68	14.03
Food manufacturing	3.17	4.05	3.54	5.01	7.19	7.44	9.09	11.50	11.15
Beverage manufacturing	7.06	7.07	6.07	5.56	6.33	7.22	7.30	8.73	6.24
Tobacco processing	1.51	1.58	1.02	1.03	0.50	0.49	0.38	0.40	0.35
Textile industry	13.79	13.84	14.43	22.36	21.62	17.32	17.87	19.71	16.99
Clothing fiber	0.43	0.69	0.84	0.95	1.39	1.13	0.85	1.20	1.25
Leather and fur	0.59	0.48	0.76	0.87	0.89	0.98	0.81	1.12	0.99
Wood processing	1.83	2.30	2.65	2.58	2.89	2.81	2.60	2.83	1.99
Furniture manufacturing	0.05	0.07	0.19	0.12	0.10	0.21	0.11	0.22	0.28
Paper products	14.38	20.92	23.88	26.13	30.31	31.91	35.07	37.59	27.63
Printing records	0.39	0.38	0.21	0.14	0.17	0.14	0.19	0.30	0.36
Culture, education, and sports	0.10	0.09	0.11	0.10	0.09	0.09	0.10	0.11	0.19
Petroleum processing	6.22	14.55	20.42	43.48	39.16	33.85	42.49	49.20	45.12
Chemical raw materials	53.07	54.22	53.12	75.75	82.72	73.86	74.15	91.03	90.40
Pharmaceutical manufacturing	4.81	4.48	4.68	4.67	5.31	4.94	6.10	8.46	8.35
Chemical fibers	10.56	8.88	5.53	5.96	5.87	4.35	5.57	8.11	5.73
Rubber plastic	3.42	3.60	2.80	2.89	3.74	2.60	3.32	3.45	2.98
Non gold minerals	1.16	1.72	0.91	0.91	2.27	1.97	2.68	4.44	3.19
Black metal	55.23	72.26	75.60	101.69	98.69	85.24	79.40	79.62	68.85
Nonferrous metals	41.31	53.34	62.35	90.02	123.68	97.04	124.49	150.47	114.07
Metal products	42.37	41.67	43.03	44.33	42.41	48.17	49.87	67.54	21.28
General equipment	1.36	1.35	1.62	1.92	1.82	1.64	1.88	2.49	14.05
Special equipment	2.03	2.33	1.90	2.11	2.18	2.45	2.93	3.97	5.03
Transportation	3.28	4.90	2.79	2.15	1.46	1.16	1.37	1.04	1.93
Electrical and mechanical	3.94	4.71	4.23	3.25	3.71	2.06	2.78	2.67	1.79
Computer	1.28	1.34	1.72	1.11	1.04	1.24	0.94	1.34	1.52
Instrumentation	0.97	0.80	0.85	1.45	0.62	0.61	0.43	0.54	1.65
Other Manufacturing	0.23	0.22	0.17	0.63	0.11	0.09	0.12	0.09	0.18
Waste Resources Comprehensive	0.17	0.70	0.14	0.20	0.24	0.27	0.26	0.48	2.00

Data source: Author calculated it through the China Annual Environmental Survey of Polluting Firms Database. Unit: million tons.

In contrast, some relatively clean industries like agricultural and sideline food and beverage manufacturing saw little change in emissions. A few industries experienced declining emissions, such as manufacture of metal products, which dropped by around 50% in 2014 compared to 1998 levels. In summary, China still needs to continue strengthening pollution control in heavy industries, promote industrial restructuring, and develop clean production, in order to effectively control SO_2 emissions across various industries.

3. Comparative Analysis of SO_2 Emission in Three Regions

From the distribution of emissions in the eastern, central, and western regions, SO_2 emissions in all three regions exhibited an inverted "U" trend from 2000 to 2020 (Figure 2.2 and Table A.1). The eastern region observed the steepest descent, with 2020 emissions constituting only around 11% of the 2000 levels. Between 2000-2012, SO_2 emissions in the three regions were relatively stable, with eastern region emissions approximating 68-75 million tons, central region 38-59 million tons, and western region 48-79 million tons. Throughout the period, eastern region emissions remained elevated compared to central and western regions. This can be attributed to its industrial-oriented economic structure and expeditious urbanization, eliciting surging energy consumption and considerable SO_2 emissions. In contrast, western provinces had relatively lower industrialization extent and slower urbanization advancement, resulting in lower emissions. Additionally, the affluent solar resources can mitigate western provinces' dependency on fossil fuels, thereby facilitating the reduction of SO_2 emissions. After 2012, as China intensified pollution control measures, emissions in the three regions commenced rapid decrease (Figure 2.2). By 2020, eastern region emissions had dwindled to 0.76 million tons, central region 0.63 million tons, and western region 1.13 million tons, plunging by 89%, 84% and 78% respectively. The precipitous emission declines across three regions post 2012 may arise from: 1) intensified emission control policies implemented by regional governments during this period; 2) China's economy entering a new phase with industrial restructuring and waning share of highly-polluting sectors; 3) expanded utilization of clean energy and decreased coal dependence. Despite the substantial curtailment, western region emissions in 2020 were still higher than eastern region, signifying the immense challenges central and western regions continue to confront in pollution control.

China's SO_2 emissions demonstrate heterogeneous spatial patterns, with pronounced variations across provinces. Overall, SO_2 emissions in Chinese provinces exhibited a declining trend year over year during

2000-2020. In 2000, emissions in over half of the provinces ranged from 0.5 to 1.46 million tons, whereas by 2020 emissions in most provinces had fallen below 0.1 million tons. This reflects the remarkable advancement that has been achieved in mitigating air pollution over the past two decades. Between 2000-2012, the emissions of provinces such as Hebei, Shandong, Henan, and Sichuan remained at the level of 1 million tons (Table 2.2). During 2000-2012, provinces such as Inner Mongolia, Liaoning, Ningxia and Xinjiang experienced sustained upsurge or fluctuating growth in emissions, which is associated with expanded coal mining and rapid industrialization in these areas. However, after 2012, as China intensified pollution control efforts, SO_2 emissions in these provinces plummeted perceptibly. By 2020, emissions in major provinces had declined over 50% relative to 2000. Regarding the spatial distribution of emissions between eastern, central and western regions, in 2000 emissions were primarily concentrated in eastern and central provinces including Shandong, Henan and Jiangsu. SO_2 emissions in eastern and central provinces were generally higher than in western regions. Nevertheless, by 2020, western provinces had relatively lower emissions. Emissions in eastern provinces had declined significantly, while central and western provinces remained major contributors. As economically advanced municipalities, Beijing and Shanghai witnessed substantial curtailment in SO_2 emissions during 2000-2020, with emissions constrained under 0.05 million tons. Collectively, different regions across China have accomplished remarkable progress in emission abatement, nonetheless central and western provinces still necessitate continuing enhancement of pollution control endeavors.

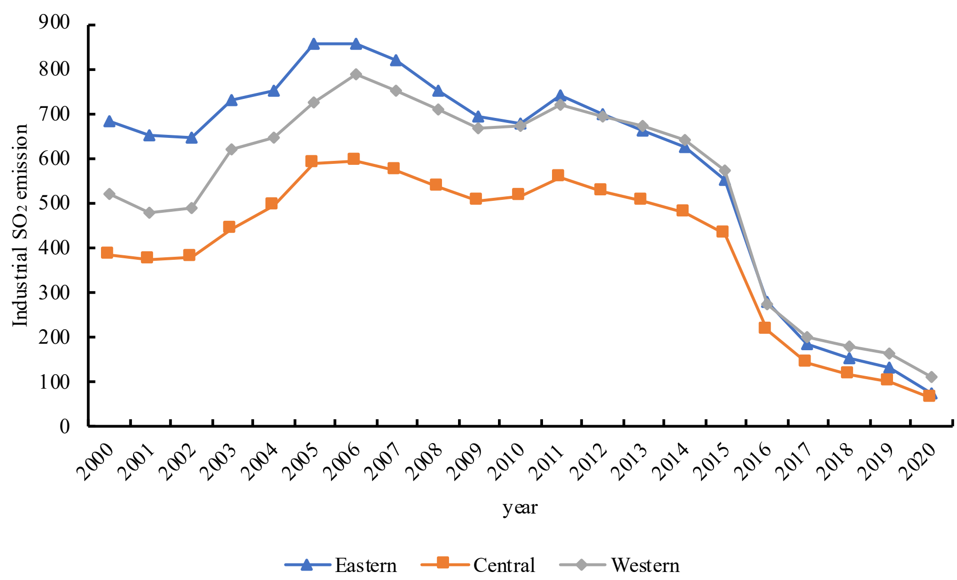

Figure 2.2: SO_2 Emissions in Three Major Regions of China from 2000 to 2020

Data source: Author calculated it through the China City Statistical Yearbook 2021. Unit: 10000 tons.

Table 2.2: SO_2 Emissions in 30 Provinces of China from 2000 to 2020

Province	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020
Beijing	14.64	12.06	12.50	9.40	5.78	5.68	5.93	4.03	0.76	0.10	0.10
Tianjin	24.18	20.08	20.10	23.20	20.98	21.76	21.55	19.54	2.20	1.66	0.98
Hebei	113.36	105.34	121.50	132.60	115.87	99.42	123.87	104.74	47.29	26.81	12.28
Shanxi	90.27	90.70	109.30	117.70	105.84	114.71	119.46	107.80	45.29	23.94	12.25
Inner Mongolia	50.63	55.90	103.40	138.40	125.86	119.30	124.15	116.71	51.64	30.94	22.39
Liaoning	70.57	57.30	64.90	103.70	100.08	85.94	97.90	92.60	38.18	29.35	14.44
Jilin	20.17	18.72	21.60	33.60	31.32	30.06	35.23	31.96	11.70	8.14	5.31
Heilongjiang	22.17	21.33	29.50	44.00	44.13	41.71	39.73	31.75	16.27	10.39	9.03
Shanghai	32.68	32.49	35.00	37.40	29.80	22.15	19.34	15.54	6.36	1.08	0.52
Jiangsu	114.10	105.51	118.30	124.10	107.36	100.24	95.92	87.02	56.48	30.42	10.83
Zhejiang	56.18	59.39	78.90	82.90	71.59	65.39	61.09	56.01	12.38	8.20	4.95
Anhui	35.06	34.91	43.90	51.90	50.26	48.39	46.98	44.06	25.51	15.56	10.47
Fujian	21.43	18.12	31.00	44.60	40.93	39.12	35.24	33.76	23.57	10.24	6.13
Jiangxi	28.81	24.81	46.90	57.00	51.12	47.10	55.15	51.74	44.14	23.11	8.64
Shandong	146.09	139.39	154.40	168.70	146.55	138.29	154.38	135.89	66.39	29.57	15.29
Henan	74.74	80.74	111.30	146.40	128.06	116.29	112.99	103.17	37.09	11.37	5.70
Hubei	50.82	47.28	60.80	65.40	56.23	51.60	54.86	50.62	15.51	9.71	5.51
Hunan	62.65	57.59	71.20	76.60	67.48	62.74	59.33	55.95	21.64	11.83	6.43
Guangdong	88.16	95.20	112.80	124.70	109.69	98.91	77.15	69.91	24.75	14.35	10.13
Guangxi	80.05	64.62	89.70	94.40	87.03	84.80	47.16	43.11	13.68	10.00	8.26
Hainan	2.02	2.20	2.20	2.30	2.12	2.82	3.30	3.19	1.34	0.81	0.59
Chongqing	66.42	55.18	64.10	71.20	62.72	57.27	50.98	47.48	11.14	8.58	4.70
Sichuan	99.41	93.02	109.90	112.10	96.89	93.76	79.40	72.57	29.24	17.90	12.50
Guizhou	64.25	57.71	60.00	104.00	74.13	63.78	83.71	70.24	28.76	27.55	14.36
Yunnan	32.39	29.31	40.00	45.60	41.99	43.96	62.26	58.26	41.48	21.33	14.62
Shaanxi	55.37	55.41	70.60	84.60	80.66	70.70	74.70	67.16	22.83	13.00	6.40
Gansu	31.19	37.38	43.80	46.30	41.24	45.25	47.99	47.70	12.69	9.94	6.60
Qinghai	2.02	2.21	6.40	12.10	12.61	13.31	12.91	11.80	5.20	4.27	3.87
Ningxia	17.42	18.72	26.00	35.00	31.92	28.04	38.44	34.10	19.28	12.69	6.79
Xinjiang	18.77	19.30	31.50	42.90	51.02	51.84	70.47	71.81	37.49	23.66	12.58

Data source: the China City Statistical Yearbook 2000-2020, compiled by Department of Urban Surveys, National Bureau of Statistics of China. Unit: million tons.

4. Challenges in Mitigating Sulfur Dioxide Emissions

China's economic expansion and urbanization have long been underpinned by voluminous consumption of conventional energy sources. This resource-depleting model of development predicated on compromising the environment is patently unsustainable in the long term. As the world's largest greenhouse gas emitter, China confronts unprecedented challenges regarding SO_2 emissions.

First, China's economy remains at a pivotal juncture of accelerated industrialization, while urban development continues to power on apace, both retaining enormous latent pressures on energy consumption and emissions. China's industrialization and urbanization have long depended on coal, accounting for nearly 60% of its energy mix. For decades, China has prioritized crude extensive exploitation of resources to propel economic augmentation. Enterprises were heavily incentivized to undertake energy- and pollution-intensive construction projects, heightening the interdependence between economic outputs and SO2 emissions. Concurrently, breakneck urban population expansion keeps upsurging energy demands (Zhang et al., 2019). Although cities occupy merely 3% of land area, their energy consumption represents 60-80% of the total, necessitating strategic realignment of urban industrial configuration and energy utilization patterns to transform the paradigm of economic and social advancement. Therefore, with intensifying trade-offs between economic progression, urban development and environmental stewardship, how to strike a balance between ecological civilization and expeditious growth and spearhead novel industrialization and urbanization assimilating lessons of excessive emissions during industrialization in developed nations, can pose formidable challenges for China to eventually explore sustainable, eco-friendly high-quality growth models in future emission mitigation undertakings.

Secondly, market failures further complicate SO_2 control. Pollution externalities - where firms avoid bearing the full environmental costs - lead to underinvestment in cleaner technologies (Stavins, 2010). China's emission trading schemes and pollution fees remain underdeveloped, with SO_2 emission costs often too low to deter polluters (Liu et al., 2022). Without robust pricing or stricter penalties, industries lack economic incentives to adopt cleaner practices.

Finally, as a responsible emerging power, China's government prioritizes SO_2 emissions. Yet the emission reduction goals can impose immense fiscal demands. The role of government is instrumental in environmental governance, albeit the influence of regulatory policies on ecological milieu and SO_2 emissions tends to be discounted. While central policies, such as the Air Pollution Prevention and Control Action Plan, set ambitious SO_2 targets, local governments often prioritize economic growth over enforcement (Kostka and Zhang, 2018). Fiscal decentralization means provincial authorities—dependent on industrial revenue -may relax environmental regulations, creating a "policy-implementation gap" (Van Rooij and Lo, 2010). Strengthening oversight and aligning local incentives with emission goals is critical.

Under the increasingly ominous global climate security landscape, whether the government can constitute a suite of fiscal safeguard mechanisms and fulfil proactive roles in SO_2 control as part of climate governance can directly affect the efficacy of transmuting government emission policies into firm market conduct. This also signifies building firm autonomous emission mitigation mechanisms to accomplish lasting emission goals. Therefore, under environmental exigencies, undertaking proactive and robust fiscal actions to ascertain optimal mechanisms between the government and the market for emission abatement and accomplish green low-emission growth represents an exigent quandary confronting China at present.

2.1.2 Environmental Governance Investment

Industrial pollution constitutes a principal source of environmental degradation in China. Curbing industrial pollution assists in alleviating the adverse repercussions of industrial "three wastes" (wastewater, waste gas and solid waste) on the ecosphere. Industrial pollution is dominated by wastewater contamination, waste gas emissions and solid waste. Investments in pollution abatement to a certain degree reflect the gravity government places on ecological governance. Outlays on industrial pollution control epitomize the "end-of-pipe" stage of governance and are instrumental in augmenting the efficacy of environmental pollution management. As exhibited in Figure 2.3, aggregate investment in the treatment of industrial pollution sources in China demonstrated an overall ascending trajectory during 2000-2014, surging from 23.94 billion RMB in 2000 to 99.66 billion RMB in 2014. During this period, on one hand, the enhancement of environmental awareness prompted governments to scale up environmental stewardship efforts. On the other hand, the 11th Five-Year Plan imposed stringent caps on pollutant discharges, and environmental authorities conducted targeted rectification in severely polluted areas, elucidating accountabilities for environmental governance. Therefore, the substantial expansion in pollution abatement investments signifies China's staunch determination and confidence in tackling environmental predicaments during this timeframe. After 2014, completed investments in industrial pollution control in China commenced descending. By 2020, the investment quantum declined to 45.4 billion RMB, approximately a 120% plunge, tracing an inverted U-shaped curve overall. The contraction in China's industrial pollution control investments during 2014-2020 may correlate with the revised "Environmental Protection Law". Investments in industrial pollution management can also boost the environmental industry. With ascending environmental consciousness and greater emphasis from the government on ecological safeguarding, the environmental industry is embracing increasingly promising prospects. Through outlays on industrial pollution control, the environmental protection sector can be invigorated to enable virtuous cycles between economic advancement and environmental stewardship.

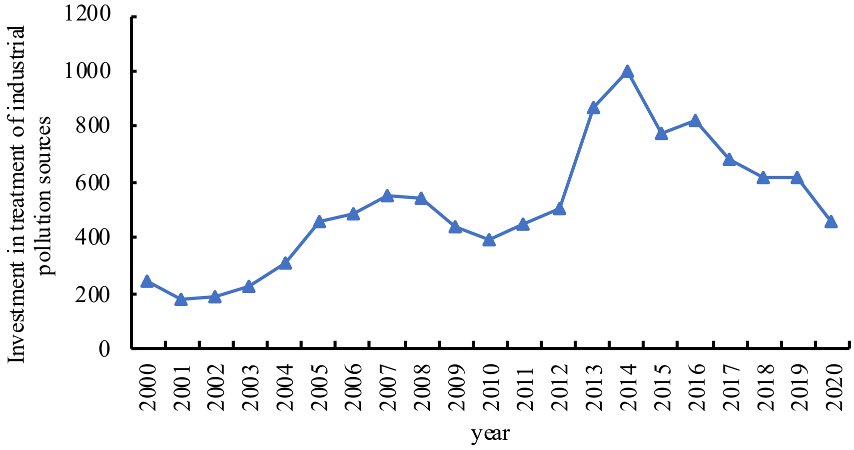

Figure 2.3: Investment in Treatment of Industrial Pollution Sources from 2000 to 2020

Data source: The China Statistical Yearbook on Environment 2021, compiled by National Bureau of Statistics Ministry of Ecology and Environment. Unit: 100 million yuan.

2.2 The Economic Situation

2.2.1 Total Factor Productivity (TFP)

1. What is TFP

The conception of TFP derives from productivity. Productivity refers to the ratio between inputs and outputs, calibrating the output level per unit input. From the input perspective, productivity can be categorized into single-factor productivity and total factor productivity. Single-factor productivity exclusively considers the ratio between inputs and outputs of one factor (such as labor or capital), whereas TFP accounts for the combined inputs and outputs across all factors (Tinbergen, 1942). TFP mirrors the efficiency and technological level of a production unit in harnessing various production factors. It encompasses pure technological advancement and productivity growth excluding all production factors (such as capital and labor), which are commonly termed “Solow residual” (Solow, 1957). TFP is customarily regarded as a composite indicator of the role of technological progress on economic expansion, as it embraces the impacts of technological innovation, production organization enhancements, management efficiency improvements and other factors on productivity (Denny et al., 1981).

TFP bears significant implications for economic augmentation and sustainable development. It can be leveraged to calibrate the contributions of technological advancement and efficiency improvement to economic growth, thereby assisting policymakers and entrepreneurs in identifying the wellsprings of economic enrichment. As global environmental quandaries progressively intensify, when gauging TFP, the emissions of environmental pollutants are incorporated into the production function as undesirable outputs to evaluate production efficiency under environmental constraints. In contrast, economic advancement steered by green TFP not only navigates economic proliferation, but also accounts for rational energy and resource exploitation and diminished environmental pollution. This reflects novel development philosophies. Moreover, TFP cares for not only enhancing economic performance, but also expediting environmentally benign development models to promote sustainable resource utilization.

2. TFP's Change Trend

(1) Annual TFP Total Analysis

Traditional DEA models mostly use angular and radial measures to calculate the efficiency of decision-making units (DMU). Therefore, the traditional DEA model can only start from the perspective of input or output, and it is difficult to fully consider the relaxation of input and output. The measurement of inefficiency only includes the proportion of all inputs (outputs) reduced (increased) in equal proportion. For invalid decision-making units, the relaxation improvement part except the equal proportion improvement part is not reflected in the efficiency measurement of the traditional DEA model, and the actual input-output is not equal proportion change. Based on this, Tone (2001) introduced relaxation variables directly into the objective function, and proposed non-radial and non-angular SBM models. The SBM model is widely used to measure TFP at the national, provincial and industry levels, mainly because of its ability to accurately identify and quantify unbalanced efficiency losses. Compared with the traditional radial DEA model, the core advantage of SBM is that it directly deals with the relaxation variables of input and output (such as excessive energy consumption or excessive emission of pollutants), so as to more truly reflect the heterogeneity and inefficiency of various regions or industries. For example, when analyzing China's provincial TFP, energy-intensive provinces (such as Shanxi) may exhibit significant energy input redundancy, while developed regions (such as Guangdong) may be closer to the efficiency frontier at the output end. The fact that SBM allows different variables to adjust the degree of relaxation independently (for example, emissions reductions require large cuts in emissions, while labor only needs to be fine-tuned) makes it particularly suitable for assessing multi-objective tradeoffs such as economic output and environmental constraints. In addition, the non-radial characteristics of SBM avoid the overestimation of efficiency caused by the assumption of proportional optimization in traditional methods. Although this method has limitations such as computational complexity and sensitivity to data quality, it has irreplaceable advantages in capturing complex and inefficient patterns in reality and is especially suitable for refined efficiency assessment under the background of unbalanced regional and industrial development in China. Therefore, in this chapter, I choose the SBM method to study the total factor productivity at the national, provincial and industrial levels.

Therefore, the SBM model assumes that each DMU has m input, there are S_1 desirable output, S_2 undesirable output. The vector form is $x \in R^m$, $y^g \in R^{S_1}$, $y^b \in R^{S_2}$; x, Y^g and Y^b are matrices; $X = [x_1, x_2 \cdots x_n] \in R^{m \times n}$, $Y^g = [y_1{}^g, y_2{}^g \cdots y_n{}^g] \in R^{S_1 \times n}$, $Y^b = [y_1{}^b, y_2{}^b \cdots y_n{}^b] \in R^{S_2 \times n}$. The slack of input, desired output and undesired output are respectively S^-, S^g, S^b indicates that λ is the weight vector and establishes the SBM-undesirable model:

$$\psi = \min \frac{1 - \frac{1}{m}\sum_{i=1}^{m} \frac{S_i^-}{x_{io}}}{1 + \frac{1}{S_1 + S_2}\left(\sum_{r=1}^{S_1} \frac{S_r^g}{y_{ro}^g} + \sum_{r=1}^{S_2} \frac{S_r^b}{y_{ro}^b}\right)} \tag{2.1}$$

$$s.t.\begin{cases} x_o = X\lambda + S^- \\ y_o^g = Y^g\lambda - S^g \\ y_o^b = Y^b\lambda + S^b \\ S^- \geq 0, S^g \geq 0, S^b \geq 0, \lambda \geq 0 \end{cases} \tag{2.2}$$

In the evaluation of model, there are usually cases where the efficiency value of multiple decision-making units is 1. It is impossible to further distinguish the efficiency of effective decision-making units. Tone and Sahoo (2004) propose a solution to the undesired output. The efficiency SBM-Undesirable model is used to evaluate the SMU-Undesirable effective DMU, which makes up for the shortcomings of not being able to compare the optimal efficiency DMU horizontally. The super-efficient SBM unexpected output model is established as follows:

$$\psi^* = \frac{\frac{1}{m}\sum_{i=1}^{m}\frac{\bar{x}}{x_{io}}}{1+\frac{1}{S_1+S_2}\left(\sum_{r=1}^{S_1}\frac{S_r^g}{y_{ro}^g}+\sum_{r=1}^{S_2}\frac{S_r^b}{y_{ro}^b}\right)} \tag{2.3}$$

$$s.t.\begin{cases} \bar{x} \geq X\lambda \\ \overline{y^g} \leq Y^g\lambda \\ \overline{y^b} \geq Y^b\lambda \\ \bar{x} \geq x_o, \overline{y^g} \leq y_o^g, \overline{y^b} \geq y_o^b, \lambda > 0 \end{cases} \tag{2.4}$$

This chapter establishes a super-efficient SBM model to measure China's TFP under environmental constraints. The model includes inputs, desirable outputs and undesirable production. Among them, input variables include three variables: capital stock (*K*), labor (*L*) and energy consumption (*EU*). Desirable outputs include a variable of GDP. Undesirable output variables include wastewater discharge, exhaust gas emission and solid waste generation.

The trend of TFP changes in China from 2000 to 2020 is shown in Figure 2.4. During the period from 2000 to 2020, China's overall TFP showed an upward trend, increasing from 0.537 in 2000 to 0.626 in 2020. This can be attributed to the fact that during the 11th and 12th Five-Year Plans, the government made limiting pollutant emissions a binding indicator, strengthening the government's environmental responsibility. Through the long-term transformation of economic development concepts and the implementation of various environmental measures, the effectiveness of environmental governance has been significantly improved.

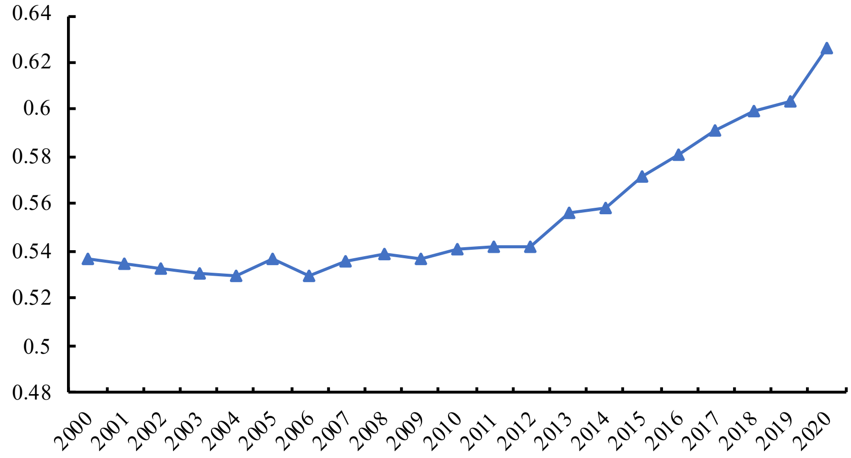

Figure 2.4: TFP Changes in China from 2000 to 2020

Data source: Author calculated it.

(2) Comparative Analysis of TFP in Three Regions

Based on the disparities in economic expansion and geographical locations across China, this study categorizes the 30 provinces into three regions: eastern region, central region, and western region. The TFP of these three regions is exhibited in Figure 2.5 and Table A.2. In terms of efficiency change trend, the TFP trend in western, central and eastern regions also conforms with the national level. Overall, China's TFP level progressively ascends from western to eastern regions. In 2020, the average TFP index was 0.834 for eastern region, 0.580 for central region, and 0.451 for western region, increasing by 0.187, 0.065 and 0.002 respectively compared to 2000. This signifies a greater magnitude of TFP enhancement in developed eastern provinces. Except for the eastern region surpassing national average, other regions have TFP levels below the national level. Thus, there exists robust coordination between economic advancement and environmental performance in the east, implying an imbalanced provincial distribution of China's total factor productivity. This is primarily attributable to the abundant scientific talents and relatively sophisticated technological innovation frameworks in the eastern region. This enables enterprises in this region to expeditiously introduce and develop novel technologies, elevating resource utilization efficiency and environmental stewardship. In the process of economic enrichment, the eastern region has progressively transformed from an industrial configuration predominated by heavy industry to services and technology-intensive sectors. This transformation curtails high-polluting, energy-intensive industries and amplifies the proportion of eco-friendly sectors, thereby enhancing total factor productivity. The central region, as a transitional zone between the eastern and western regions, benefits from the radiation and promotion of economic prosperity in the eastern region. In contrast, the western region is at a disadvantageous juncture compared to the east in geographical locations and natural conditions. Its relatively lagging economic maturation, inadequate environmental governance investments, heavy reliance on traditional energy-intensive heavy industries, and slightly deficient technological innovation capacity led to harsh environmental pollution and thus relatively inferior total factor productivity.

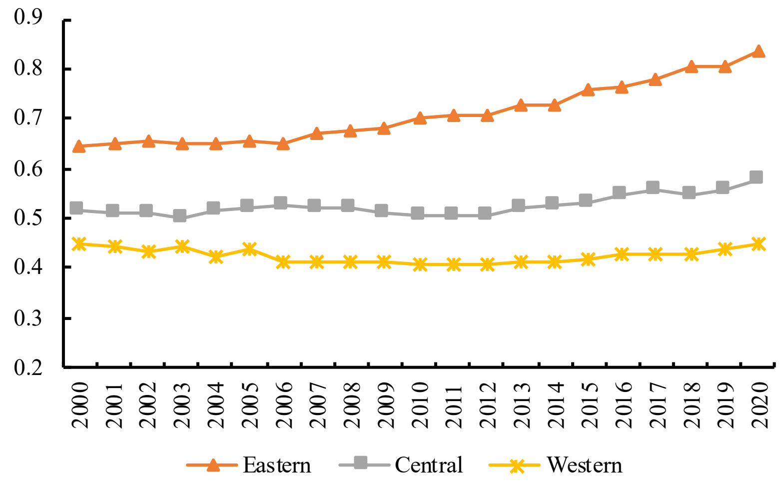

Figure 2.5: TFP of Three Regions in China from 2000 to 2020

Data source: Author calculated it.

Table 2.3 displays that in the eastern region, the top three total factor productivity in 2020 indices are Guangdong, Beijing, and Shanghai, with corresponding total factor productivity of 1.17, 1.14, and 1.13, respectively, representing an average increase of 0.17, 0.60, and 0.54 compared to 2000. Secondly, in the central region, the top three regions in total factor productivity in 2020 are Jiangxi, Jilin, and Heilongjiang, with corresponding mean values of 0.67, 0.64, and 0.63, respectively. Finally, in the western region, the top three areas of total factor productivity in 2020 are Chongqing, Sichuan, and Inner Mongolia, with corresponding average total factor productivity of 0.68, 0.59, and 0.54, respectively.

Table 2.3: TFP of 30 Provinces in China from 2000 to 2020

Province	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020
Beijing	0.54	0.50	0.46	0.64	0.82	1.00	0.97	0.98	1.01	1.00	1.11
Tianjin	0.51	0.56	0.61	0.63	0.65	0.67	0.69	0.75	0.80	0.84	0.89
Hebei	0.50	0.51	0.53	0.52	0.50	0.48	0.48	0.48	0.49	0.50	0.51
Shanxi	0.43	0.44	0.46	0.43	0.41	0.38	0.38	0.37	0.36	0.36	0.36
Inner Mongolia	0.56	0.51	0.45	0.45	0.44	0.44	0.44	0.44	0.46	0.48	0.52
Liaoning	0.57	0.59	0.61	0.60	0.59	0.58	0.59	0.61	0.63	0.63	0.64
Jilin	0.55	0.53	0.51	0.49	0.47	0.45	0.48	0.51	0.54	0.56	0.59
Heilongjiang	0.55	0.62	0.69	0.67	0.66	0.65	0.61	0.62	0.62	0.63	0.61

Shanghai	0.59	0.63	0.66	0.72	0.78	0.83	0.93	1.00	1.00	1.09	1.12
Jiangsu	0.65	0.64	0.62	0.64	0.65	0.67	0.70	0.75	0.79	0.81	0.82
Zhejiang	0.67	0.65	0.63	0.66	0.68	0.71	0.71	0.74	0.76	0.77	0.77
Anhui	0.50	0.52	0.54	0.54	0.54	0.54	0.55	0.56	0.57	0.58	0.57
Fujian	0.75	0.74	0.73	0.70	0.67	0.64	0.65	0.68	0.70	0.72	0.69
Jiangxi	0.61	0.56	0.52	0.52	0.53	0.53	0.55	0.58	0.59	0.60	0.62
Shandong	0.56	0.53	0.51	0.52	0.53	0.54	0.55	0.60	0.61	0.63	0.65
Henan	0.54	0.54	0.54	0.51	0.47	0.44	0.43	0.45	0.46	0.48	0.47
Hubei	0.48	0.47	0.45	0.47	0.48	0.49	0.49	0.53	0.54	0.55	0.56
Hunan	0.64	0.61	0.57	0.57	0.57	0.57	0.55	0.58	0.60	0.62	0.61
Guangdong	1.01	1.02	1.03	1.02	1.01	1.00	0.96	0.89	1.00	0.86	1.10
Guangxi	0.57	0.57	0.56	0.52	0.48	0.44	0.42	0.44	0.45	0.46	0.45
Hainan	0.49	0.51	0.53	0.55	0.56	0.58	0.55	0.53	0.54	0.55	0.55
Chongqing	0.57	0.50	0.43	0.46	0.49	0.51	0.55	0.61	0.63	0.67	0.67
Sichuan	0.52	0.51	0.49	0.50	0.50	0.51	0.53	0.56	0.57	0.59	0.59
Guizhou	0.34	0.33	0.32	0.33	0.34	0.34	0.34	0.34	0.34	0.34	0.35
Yunnan	0.47	0.46	0.45	0.45	0.44	0.43	0.40	0.40	0.40	0.41	0.39
Shaanxi	0.47	0.45	0.44	0.43	0.43	0.43	0.44	0.46	0.46	0.47	0.47
Gansu	0.44	0.44	0.44	0.43	0.43	0.42	0.42	0.42	0.42	0.42	0.42
Qinghai	0.33	0.31	0.29	0.30	0.31	0.31	0.29	0.28	0.27	0.27	0.28
Ningxia	0.32	0.30	0.27	0.26	0.26	0.25	0.25	0.24	0.24	0.24	0.24
Xinjiang	0.40	0.39	0.38	0.39	0.39	0.40	0.38	0.35	0.34	0.35	0.36

Data source: Author calculated it.

(3) Comparative Analysis of TFP in Different Industries

As exhibited in Table 2.4, the aggregate mean TFP of China’s 27 manufacturing industries demonstrated a steady upward trajectory, surging from 0.49 in 2000 to 0.72 in 2020, an escalation of 46.94%. The average TFP over the 20-year timeframe was 0.62. During 2000-2020, 12 out of the 27 manufacturing sub-industries had total factor productivity exceeding the national average, among which 5 maintained a mean of 1. They were computer and communications equipment manufacturing, furniture manufacturing, petroleum processing and coking, culture and sports goods manufacturing, and tobacco processing. The input and output variables of these industries in the model have reached the theoretical optimal ratio, and there is no room for improvement. For example, in the computer and communication equipment manufacturing industry, technological progress is rapid, production efficiency has been highly optimized, and the ratio of input to output has been stable for a long time. In petroleum processing and coking, because it is a highly capital-intensive industry, production technology and equipment may not have changed significantly for many years, and production efficiency has reached its limits. In the tobacco processing industry, as a relatively closed and tightly regulated industry, the production process is very fixed and there is less innovation, so the production efficiency is also stable at a high level.

Table 2.4: TFP of 27 Manufacturing Industries from 2000 to 2020

Industry category	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020
Agricultural and sideline food	0.32	0.34	0.36	0.44	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Food manufacturing	0.27	0.28	0.27	0.30	0.34	0.38	0.40	0.40	0.43	1.00	1.00
Beverage manufacturing	0.27	0.27	0.24	0.27	0.29	0.34	0.38	0.35	0.37	0.46	0.49
Tobacco processing	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.39	0.41
Textile industry	0.19	0.19	0.17	0.23	0.28	0.32	0.33	0.35	0.37	1.00	1.00
Clothing fiber	1.00	0.55	0.42	0.43	0.46	0.47	0.54	0.52	0.52	0.39	0.41
Leather and fur	0.62	0.63	0.57	0.53	0.52	0.51	0.53	0.55	1.00	0.52	0.52
Wood processing	0.38	0.37	0.37	0.41	0.38	0.39	0.39	0.38	0.55	1.00	1.00
Furniture manufacturing	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.72	0.89
Paper products	0.20	0.18	0.16	0.20	0.23	0.24	0.21	0.22	0.24	1.00	1.00
Printing records	1.00	0.47	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.26	0.28
Culture, education, and sports	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Petroleum processing	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Chemical raw materials	0.16	0.17	0.18	0.27	0.46	0.37	1.00	1.00	1.00	1.00	1.00
Pharmaceutical manufacturing	0.30	0.30	0.25	0.26	0.30	0.37	0.41	0.40	0.41	1.00	1.00
Chemical fibers	0.26	0.27	0.31	0.28	0.28	0.31	0.26	0.27	0.26	0.42	0.43
Rubber plastic	0.11	0.23	0.23	0.27	0.33	0.30	0.39	0.38	0.41	0.25	0.24
Non gold minerals	0.11	0.12	0.12	0.16	0.23	0.26	0.27	0.30	0.29	0.44	0.47
Black metal	0.16	0.17	0.24	1.00	1.00	1.00	1.00	100	0.34	0.28	0.27
Nonferrous metals	0.23	0.20	0.23	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Metal products	0.30	0.30	0.32	0.37	0.43	0.42	0.48	0.42	0.43	1.00	1.00
General equipment	0.22	0.25	0.27	0.37	0.48	0.49	0.51	0.53	0.49	0.44	0.45
Special equipment	0.24	0.27	0.27	0.36	0.49	0.51	0.59	0.57	0.61	0.45	0.41
Transportation	0.29	0.35	0.35	0.43	1.00	1.00	1.00	1.00	1.00	0.65	0.69
Electrical and mechanical	0.52	0.49	0.52	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Computer	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Instrumentation	1.00	1.00	1.00	1.00	1.00	0.76	1.00	1.00	1.00	1.00	1.00

Data source: Author calculated it.

There were 15 sub-industries with TFP below the manufacturing average, 12 of which demonstrated relatively low TFP (<0.62), specifically textile industry (0.29), wood processing and bamboo, rattan, palm and straw products (0.48), food manufacturing (0.37), papermaking and paper products (0.22), pharmaceutical manufacturing (0.35), rubber and plastic products (0.32), non-metallic mineral products (0.22), beverage manufacturing (0.33), chemical fiber manufacturing (0.27), metal products (0.40), general equipment manufacturing (0.41), and special equipment manufacturing (0.48). These industries are predominantly high resource-consuming and high-polluting chemical sectors. With over half of the sub-industries beneath the aggregate manufacturing TFP means, it signifies China's manufacturing sector overall is still situated in the lower echelon of industries, with substantial latitude for advancements in energy conservation, emission mitigation and green innovation maturation.

2.2.2 Two-Way Foreign Direct Investment (FDI)

2.2.2.1 Analysis of the History and Situation of China's FDI

1. Development History of FDI in China

With increasingly close political and economic ties between China and the world, FDI has become an important way for China to utilize foreign resources (Ali and Guo, 2005; Whalley and Xian, 2010; Zreik, 2023). Against the backdrop of China's continuous efforts to strengthen green high-quality development, it is necessary to comprehensively analyze the current situation of FDI in China.

Since the reform and opening up, China's FDI has maintained steady growth, playing a crucial role in promoting China's economic development (Chen et al., 1995; Liu et al., 2014; Jahanger, 2021). According to the Ministry of Commerce, by the end of 2021, the actual utilization of foreign investment in China had reached 173.483 billion USD (Figure 2.6). Currently, most scholars divide the development history of FDI in China into four stages, based on the growth of actual FDI utilization since the implementation of reform and opening up, using Deng Xiaoping's "Southern Tour Speech" in 1992, the tariff reform in 1996 and China's accession to the WTO in 2001 as the dividing points.

In 1979, China began to implement the reform and opening up strategy, achieving the breakthrough of zero actual FDI utilization. During this stage, the government established special economic zones, and promulgated a series of laws, regulations and preferential policies related to foreign investment, leading to rapid growth of actual FDI utilization in China to 11.55 billion USD in 1991. While expanding in scale, FDI also introduced advanced technologies and management expertise, laying a solid foundation for the steady growth of foreign investment attraction afterwards (Chen and Chen, 2009; Fu, 2012; Hao et al., 2020).

In 1992, Deng Xiaoping encouraged continued adherence to reform and opening up in his “Southern Tour Speech”, extending preferential policies on foreign investment from coastal areas to inland regions (Chatwin, 2024). Actual FDI utilization in 1992 reached USD 19.202 billion, a 66.25% increase over the previous year. With the government’s continued issuance of preferential policies, foreign exchange reform was implemented in 1994 to regulate the foreign exchange market (Drumm, 1994). In 1995, interim policies guiding foreign direct investment and an industrial catalogue for foreign investment were introduced to gradually form a multi-layered and multi-field opening up pattern, making China the largest FDI recipient among developing countries. The tariff reform in 1996 significantly reduced import tariffs, creating a sound environment for foreign investment in most industries and greatly enhancing China’s openness (Wang and Zhai, 1998). Driven by these preferential policies, China’s actual FDI utilization grew rapidly, reaching USD 54.804 billion in 1996, 2.85 times of that in 1992, facilitating China’s major economic achievements.

After 5 years of rapid growth, China’s actual FDI utilization entered an adjustment period during 1997-2001, with gradually slowing growth and even negative growth. This was due to the shock on foreign investment from the Asian financial crisis, leading to a temporary decline and the first negative growth in 1998. To cope with this shock, China relied on the Western Development Strategy to strengthen the guiding role of foreign capital introduction and promote foreign investment in central and western regions, balancing the regional distribution of FDI. Meanwhile, China adjusted FDI preferential policies, regulating the industries and regions for foreign capital introduction to improve FDI quality.

Since 2002, China’s FDI attraction has entered a stage of steady development. After joining the WTO in 2001, China’s actual FDI utilization continued to rise (Chen, 2011). To create a sound investment environment, China optimized the industrial distribution of foreign capital introduction. During this period, the government issued the “Special Management Measures for Foreign Investment Access” (Negative List) and revised the “Catalogue Guiding Foreign Investment”, while shifting the focus of foreign capital attraction towards the service industry. Despite a drop in 2009 due to the impact of the financial crisis, China maintained steady FDI growth owing to its strong risk resistance capabilities. In 2021, China’s actual FDI utilization grew by 20.16% to reach USD 173.483 billion.

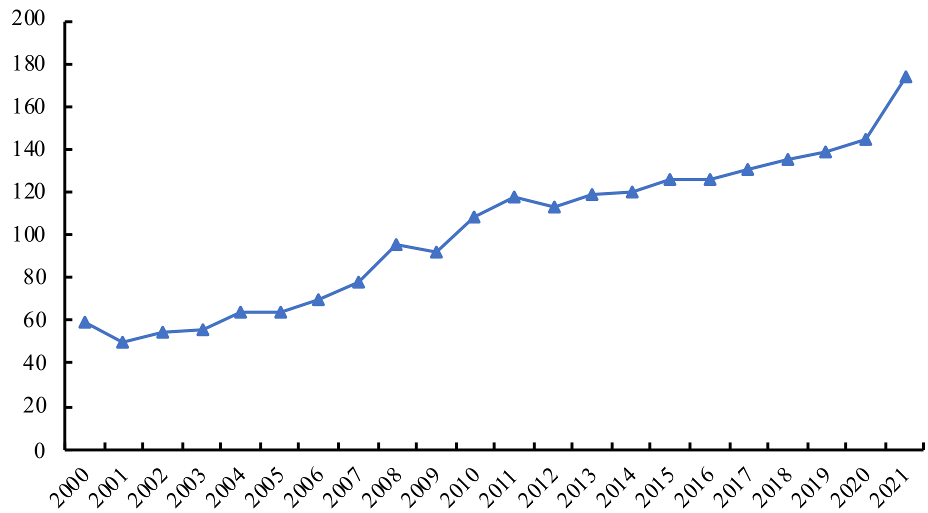

Figure 2.6: Development of Foreign Direct Investment in China from 2000 to 2021

Data source: Statistics Bureau of the People's Republic of China (https://data.stats.gov.cn/easyquery.htm?cn=C01). Unit: Billion USD.

2. Analysis of China's FDI Structure and Its Impacts

Table 2.5 shows the major source distribution of China's FDI during 2000-2021. Due to geographic proximity and economic ties, Asia accounted for the largest share of China's actual FDI, far exceeding the sum of other continents. Since 2013, FDI from Asia has exceeded 80% of China's total, reaching 88.56% in 2021. Meanwhile, the proportion from developed regions like Europe and America declined.

Table 2.5: Distribution of Major Sources of FDI in China from 2000 to 2021

Year	Asia	Africa	Europe	Latin America	North America	Oceania	Other
2000	62.59	0.71	11.70	11.34	11.75	1.70	0.20
2001	63.17	0.70	9.57	13.46	10.87	2.16	0.06
2002	61.75	1.07	7.68	14.32	12.31	2.69	0.19
2003	63.74	1.15	7.98	12.91	9.65	3.24	1.33
2004	62.05	1.28	7.91	14.92	8.21	3.26	2.38
2005	59.21	1.78	9.35	18.72	6.18	3.31	1.44
2006	55.67	1.93	9.06	22.47	5.85	3.59	1.42
2007	56.33	1.99	5.84	26.91	4.53	3.67	0.73
2008	60.98	1.81	5.91	22.62	4.28	3.43	0.97
2009	67.33	1.45	6.13	16.31	4.08	2.81	1.88
2010	73.39	1.21	5.60	12.79	3.80	2.20	1.01
2011	77.16	1.41	5.07	10.78	3.09	2.26	0.23
2012	77.60	1.24	5.63	9.12	3.42	2.03	0.95
2013	80.51	1.17	5.86	6.98	3.47	1.98	0.02

2014	82.51	0.85	5.60	6.45	2.72	1.58	0.28
2015	82.49	0.46	5.46	7.24	2.41	1.94	0.00
2016	78.44	0.89	7.49	9.70	2.46	1.01	0.02
2017	83.33	0.50	6.74	4.86	3.27	1.23	0.07
2018	79.29	0.45	8.29	6.69	3.81	1.41	0.05
2019	84.62	0.34	5.84	5.48	2.47	1.25	0.00
2020	85.91	0.49	5.17	5.58	1.86	0.87	0.13
2021	88.56	0.63	4.10	4.52	1.61	0.56	0.01

Data source: Statistics Bureau of the People's Republic of China and China Statistical Yearbook. Unit: %.

Figure 2.7 summarizes the top 10 source countries/territories of China's FDI in 2021, based on data from the National Bureau of Statistics and China Statistical Yearbook. Over the past decade, Hong Kong has remained the largest source of FDI in China. In 2021, FDI from Hong Kong reached 131.756 billion USD, representing 76% of China's total. The other nine countries/territories contributed 10.331, 5.281, 4.045, 3.913, 2.467, 2.462, 2.189, 1.68, 1.2 and 1.105 billion USD respectively, accounting for 5.96%, 3.04%, 2.33%, 2.26%, 1.42%, 1.42%, 1.26%, 0.97%, 0.69% and 0.64%. The top 10 source countries/territories contributed 95.99% of China's total FDI, indicating a high concentration of China's FDI sources.

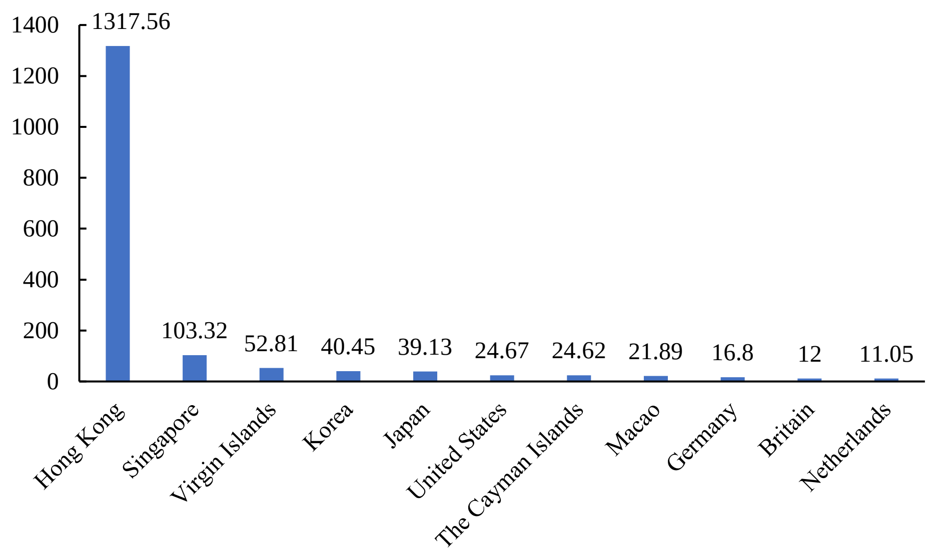

Figure 2.7: Top 10 Source Countries/Regions of FDI in China in 2021

Data source: Statistics Bureau of the People's Republic of China and China Statistical Yearbook. Unit: USD100mn.

3. Regional distribution of China's FDI

The eastern coastal region, serving as the vanguard of China's reform and opening-up, has emerged as the primary recipient of foreign investment owing to its inherent geographical and policy advantages. Over time, the influx of foreign capital has gradually expanded to encompass the central and western regions. As evidenced by Figures 2.8 and 2.9, substantial disparities exist in the actual utilization of foreign direct investment (FDI) among these regions, with the eastern region significantly surpassing the central and western regions in both magnitude and proportion. Prior to 2014, the actual utilization of FDI in the eastern region exhibited a gradual increase, followed by fluctuations and declines post-2014, indicative of an overall downward trend in its proportion. In 2000, the eastern region attracted USD 39.234 billion in actual FDI, accounting for 85.75% of the national total. By 2021, the actual FDI in the eastern region reached USD 156 billion, decreasing its share to 57.83%. Conversely, the central region witnessed stable increases in both the actual utilization of FDI and its proportion. In 2000, the central region attracted USD 4.377 billion in actual FDI, constituting 9.57% of the total, which surged to USD 91.9842 billion by 2021, representing 34.10% of the national total. The western region recorded the smallest actual utilization of FDI and proportion. Prior to 2014, it experienced an upward trend, stabilizing thereafter. The primary drivers of these changes include, on one hand, China’s supportive policies favouring the central and western regions, relaxation of conditions for establishing foreign-funded projects, encouragement of relocation of eastern region foreign enterprises to the central and western regions, promotion of regional cooperation and exchange, and guidance of foreign capital towards these regions. On the other hand, the gradual decline in the industrial scale advantage formed in the early stages in the eastern region, intensifying market competition and rising costs, has led to the gradual flow of foreign capital towards the central and western regions.

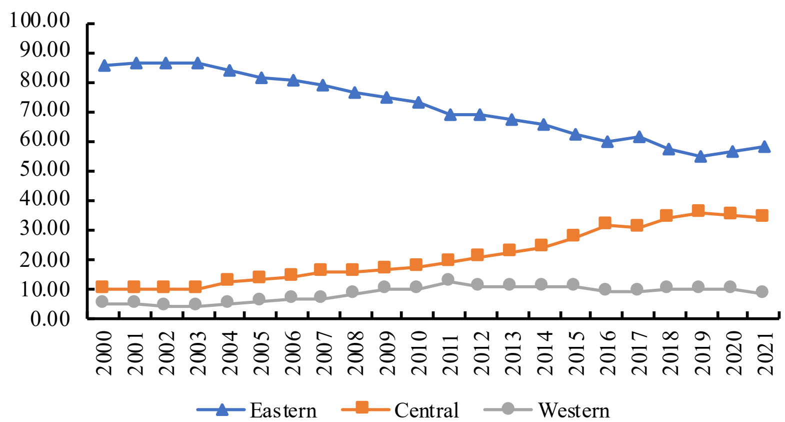

Figure 2.8: The Proportion of FDI in Three Regions of China from 2000 to 2021

Data source: Author calculated it using the data from Statistics Bureau of the People’s Republic of China and China Statistical Yearbook. Unit: %.

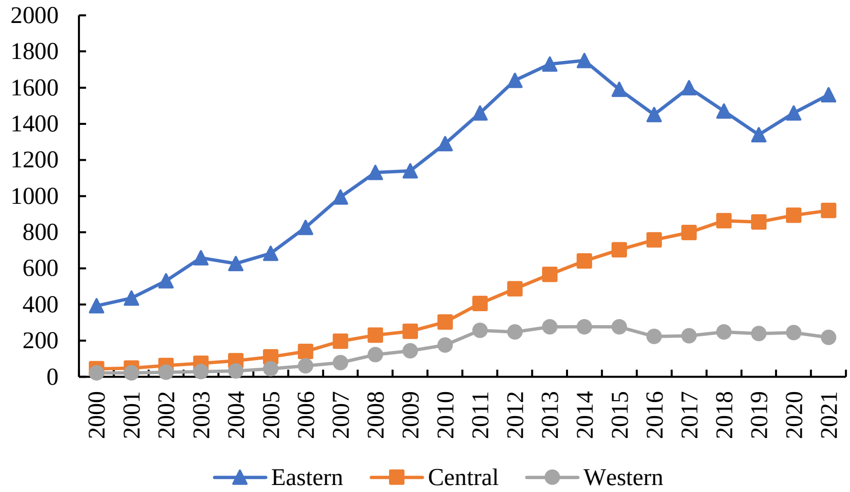

Figure 2.9: FDI Volume in Three Regions of China from 2000 to 2021

Data source: The author calculated it using data from the Statistics Bureau of the People's Republic of China and the China Statistical Yearbook. Unit: 100 million US dollars.

4. Industry Distribution of China's FDI

As depicted in Table 2.6, foreign direct investment (FDI) in China predominantly flows into the secondary and tertiary industries, particularly the manufacturing and service sectors.

Between 2004 and 2021, the average proportions of actual FDI in the secondary and tertiary industries were 45.72% and 52.84%, respectively. FDI inflows into the primary industry are negligible and have exhibited a downward trend annually, with its proportion declining to less than 1% after 2017. Foreign enterprises primarily operate in the secondary and tertiary sectors, with minimal presence in the primary sector. As China's domestic consumption levels continue to rise, the country has transitioned from being a "production and processing base" for foreign enterprises to a consumption market. To better understand China's consumption demands, foreign enterprises are increasingly entering the tertiary industry. Since 2008, the number of foreign enterprises in the tertiary industry has surpassed that of the secondary industry, becoming the industry with the highest number of foreign enterprises. Between 2004 and 2010, FDI inflows into the secondary industry were the highest, accounting for 74.98% in 2004 and gradually decreasing thereafter, although the actual scale continued to increase annually. With the increasing share of the service sector in the global economy and the need for China's domestic industrial restructuring, FDI in the tertiary industry has continuously increased. In 2008, there was a reversal in investment patterns, with the proportion of FDI in the tertiary industry surpassing that of the secondary industry for the first time, occupying a dominant position. As of 2021, FDI in the tertiary industry exceeds that in the secondary industry by more than threefold, with the number of foreign firms reaching 515,055, accounting for 77.81% of the total.

Table 2.6: Number of Foreign-Funded Enterprises in Various Industries from 2004 to 2021

Year	Primary industry	Secondary industry	Tertiary industry
2004	5310	177020	57062
2005	5752	186675	63617
2006	5821	194284	74223
2007	6005	195841	83835
2008	7399	208856	210654
2009	7157	201226	222980
2010	7103	197439	237703
2011	6993	190740	245790
2012	6827	183433	254043
2013	6661	176126	262295
2014	6784	171375	281482
2015	6937	168864	305116
2016	6866	165108	332870
2017	6832	159261	372873
2018	6962	154072	431785
2019	6910	148541	470920
2020	6848	141970	485520
2021	6913	139932	515055

Data source: Statistics Bureau of the People’s Republic of China.

Table 2.7: The Proportion of FDI in Various Industries from 2000 to 2020

Industry category	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020
Agriculture, forestry, animal husbandry and fishery	6.76	10.28	11.14	5.99	11.91	19.12	20.62	15.22	18.98	8.01	5.76
Mining	5.83	5.81	5.38	4.61	5.73	6.84	7.70	5.62	0.96	12.28	6.64
Manufacturing	258.44	368.00	430.17	400.77	498.95	495.91	488.66	399.39	354.92	411.74	309.97
Production and supply of electricity, gas, and water	22.42	13.75	11.36	12.81	16.96	21.25	16.39	22.03	21.47	44.23	31.14
Construction	9.05	7.09	7.72	6.88	10.93	14.61	11.82	12.30	24.77	14.88	18.19
Transportation/storage and postal services	10.12	9.13	12.73	19.85	28.51	22.44	34.74	44.56	50.89	47.27	49.99
Information transmission/computer services and software industry	-	-	9.16	10.70	27.75	24.87	33.58	27.55	84.42	116.61	164.31
Wholesale and retail	8.58	8.33	7.40	17.89	44.33	65.96	94.62	94.63	158.70	97.67	118.44
Accommodation and catering	-	-	8.41	8.28	9.39	9.35	7.02	6.50	3.65	9.01	8.24
Finance	-	1.07	2.52	2.94	5.73	11.23	21.19	41.82	102.89	87.04	6.48
Real estate	46.58	56.63	59.50	82.30	185.90	239.86	241.25	346.26	196.55	224.67	203.31
Leasing and business services	-	-	28.24	42.23	50.59	71.30	82.11	124.86	161.32	188.75	265.62
Scientific research/ technical services and geological exploration industry	0.57	1.98	2.93	5.04	15.06	19.67	30.96	32.55	65.20	68.13	179.40
Water conservancy/environment and public facilities management	-	-	2.29	1.95	3.40	9.09	8.50	5.73	4.22	4.74	5.68
Residential services and other service industries	2.19	2.94	1.58	5.04	5.70	20.53	11.65	7.18	4.91	5.62	3.08
Education	0.54	0.38	0.38	0.29	0.36	0.08	0.34	0.21	0.94	0.74	2.81
Health, social security, and social welfare industries	1.06	1.28	0.87	0.15	0.19	0.90	0.64	0.78	2.54	3.02	2.35
Culture, sports and entertainment	-	-	4.48	2.41	2.58	4.36	5.37	8.23	2.67	5.23	3.96

Data source: Author calculated it using the data from 2001-2021 China Statistical Yearbook[1]. Unit: 100 million US dollars.

[1] https://www.stats.gov.cn/sj/ndsj/2018/indexch.htm; https://www.stats.gov.cn/sj/ndsj/2019/indexch.htm; https://www.stats.gov.cn/sj/ndsj/2020/indexch.htm; https://www.stats.gov.cn/sj/ndsj/2021/indexch.htm;

According to Table 2.7, in specific industries, China's actual FDI is primarily concentrated in manufacturing, leasing and business services, and real estate, accounting for 20.8%, 17.8%, and 13.6% respectively in 2020, with their combined proportion reaching 52.2%. Although manufacturing is the industry with the highest FDI inflows, reaching USD 49.895 billion in 2008, its proportion has gradually declined in recent years. Due to the sluggish real estate market in recent years, the proportion of FDI in real estate has also declined, with its share decreasing to 13.6% in 2020. With the adjustment of China's economic structure, the service sector has become an important driver of economic development. Foreign investment inflows have expanded from manufacturing, which was predominantly processing-oriented, to various industries. The proportions of actual FDI in services such as information transmission, accommodation and catering, computer services and software, technical services and geological exploration, leasing and business services, water conservancy, scientific research, and environmental and public facility management have all shown a significant upward trend. Additionally, the proportion of agriculture, forestry, animal husbandry, and fishery industries has been consistently declining, with an annual decrease of less than 1%.

2.2.2.2 Analysis of the History and Situation of China's OFDI

OFDI refers to the economic behavior of a country's investors in exporting intangible assets such as capital, equipment, technology and management skills for the purpose of obtaining effective control over the operation and management of foreign enterprises (Wu et al., 2017; Peng et al., 2023). It is a way of international investment and one of the basic forms of international capital flows. The main bodies of OFDI are mainly multinational enterprises and other types of enterprises, and its investment modes include setting up new enterprises in foreign countries, acquiring or merging with existing enterprises, as well as obtaining the right to operate and manage foreign enterprises by means of equity participation, etc (Milelli and Sindzingre, 2013; Metallinou, 2022). OFDI can be classified into different types, such as greenfield investment (i.e., new construction investment), cross-border mergers and acquisitions, equity participation, etc (Lv et al., 2022; Ramasamy and Yeung, 2022). The choice of these investment modes depends on a variety of factors, such as the political and economic environment of the target market, the strategic objectives of the investing enterprise and its resource situation.

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https://www.stats.gov.cn/sj/ndsj/2022/indexch.htm

1. Development history of China's OFDI

The development and changes in China's outward foreign direct investment (OFDI) are closely related to the background of the era in which it is located. Therefore, starting from the internal and external environments and combining the characteristics of development in different periods, the development history is divided into five stages.

(1) Preliminary Exploration Stage (1979-1985)

In 1979, the development of Chinese OFDI began, driven by China's policy of "going global" (Wong and Chan, 2003). Since China's OFDI was still in the early stage of development during this period, the scope and scale of investment were relatively small, and state-owned enterprises (SOEs) were the mainstay of international investment. At the initial stage, China's outward FDI flow was less than 100 million US dollars. By 1984, the development of OFDI accelerated, with a year-on-year growth of 44 per cent, and in 1985 OFDI reached US$629 million, three times more than the previous year. During this period, China was at a difficult starting stage of OFDI, and the OFDI approval and management system was initially established.

(2) Accelerated Development Stage (1986-1992)

After going through the initial exploratory stage, the pace of government foreign investment quickened and related policies became increasingly standardized. During this period, China's foreign investment management was gradually standardized, and the state also introduced policies to support outward foreign direct investment, such as streamlining approval procedures and relaxing approval systems (Salidjanova, 2011). This promoted the orderly development of foreign investment. From 1986 to 1991, China's foreign investment maintained steady growth. By 1992, China's foreign investment outflows exceeded US$4 billion, while the stock exceeded US$9.3 billion. At the same time, the number of entities participating in foreign investment continued to increase, investment areas became more diverse, and began to gradually extend to manufacturing, transportation and other fields.

(3) Adjustment Development Stage (1993-2000)

Beginning in 1993, China began to adjust its economic structure and foreign investment approval conditions became stricter as policies on outward foreign direct investment began transitioning to an adjustment stage. In 1997, the 15th National Congress put forward supporting Chinese enterprises to leverage their own advantages to “go global”. In 1998, the 2nd Plenary Session of the 15th Central Committee further emphasized the need to fully utilize domestic and international markets and combine “bringing in” with “going out”. With the strong support of the Chinese government, foreign investment gradually rose to the strategic height of national development, and the scale and number of investments continued to increase.

(4) High-Speed Development Stage (2001-2016)

In 2001, China successfully joined the World Trade Organization, further integrating into the tide of globalization, also marking the official entry of China’s outward foreign direct investment into a high-speed development stage. The 10th Five-Year Plan also incorporated the “Go Global” strategy, creating a favorable domestic environment for enterprises to carry out foreign investment activities. As a result, the scale of China’s foreign investment began to expand rapidly, with increasingly widespread investment regions and industries, while foreign investment management continued to improve. Investment outflows increased from US$6.9 billion in 2001 to US$196.1 billion in 2016, while investment stock accumulated from US$27.2 billion to US$1.36 trillion. The investment stock ranking rose from 25th place in 2002 to 6th place in 2016. Investments covered all sectors of the national economy.

(5) Steady Development Stage (2017 to Present)

During this stage, China’s economy was in a period of relatively stable growth, entering a stage of high-quality economic development. The rapid development of foreign investment inevitably lead to some problems, such as blind investment, inefficient management, and irregular operations. In response to this situation, China has actively adopted relevant policy measures for adjustment and guidance, strengthening compliance reviews of enterprises’ foreign investment activities, and ensuring that foreign investment is on a healthy and rational development path. The decline in China’s outward foreign direct investment outflows in 2017 indicates that enterprises have started to invest cautiously and China's foreign investment has gradually returned to a rational development track.

2. Overall scale of China's OFDI

China's OFDI has witnessed exponential growth since it acceded to the World Trade Organization and adopted the "Go Global" strategy, positioning the country as a leading source of global OFDI flows. Specifically, Chinese OFDI has expanded dramatically in the post-2003 period, heralding a new era of high-paced development (Table 2.8). At the 2002 year-end, the stock of Chinese OFDI stood at USD 29.9 billion. By the close of 2021, Figure 2.10 had swelled to USD 2,785.15 billion - a 93.15-fold increase over the 2002 base. China's share of the global FDI trove mushroomed from a negligible 0.4% in 2002 to 6.7% by end-2021, with its global ranking vaulting from 25th to 3rd over the period, trailing only longstanding major investing countries - the United States and the Netherlands (Figure 2.10).

Moreover, among the top 10 OFDI source economies globally in terms of stock, China was the sole developing country on the leaderboard (Figure 2.11). Flows have risen in lockstep, with net annual OFDI leaving China multiplying from USD 2.7 billion at 2002-end to USD 178.82 billion by 2021, appreciating 66.23 times over the interval at a compound annual growth rate exceeding 25%. This powered China from 26th place in global OFDI flows at the end-2002 into the number two slot in 2020 for the first time on record, even seizing first position that year (Figure 2.12). Notably, while the 2008 Global Financial Crisis triggered a 21.6% contraction in worldwide OFDI volumes, Chinese OFDI more than doubled year-on-year against the trend. More recently in 2020, the global economy reeled from the COVID-19 outbreak, logging negative growth for the first time post-2009 as international merchandise trade plunged 5.3% and global FDI cratered 40%. Yet bucking the downturn, China singularly sustained positive economic expansion among major economies under the strain of this dire pandemic landscape. And Chinese OFDI again defied gravity, upholding 12.3% year-on-year advancement over 2019 levels. Thus in little over a decade, China has graduated from net capital importer to ranking among the foremost capital exporting nations worldwide.

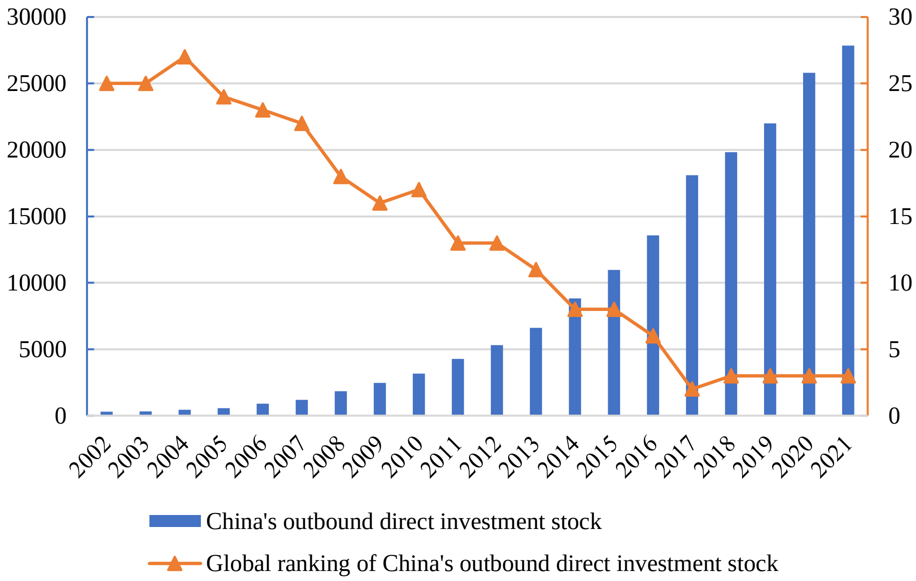

Figure 2.10: China's OFDI Stock and Global Ranking

Data source: 2021 Statistical Bulletin of China's Outward Foreign Direct Investment, compiled by Ministry of Commerce of the People's Republic of China[2]. Unit: Billion US dollars.

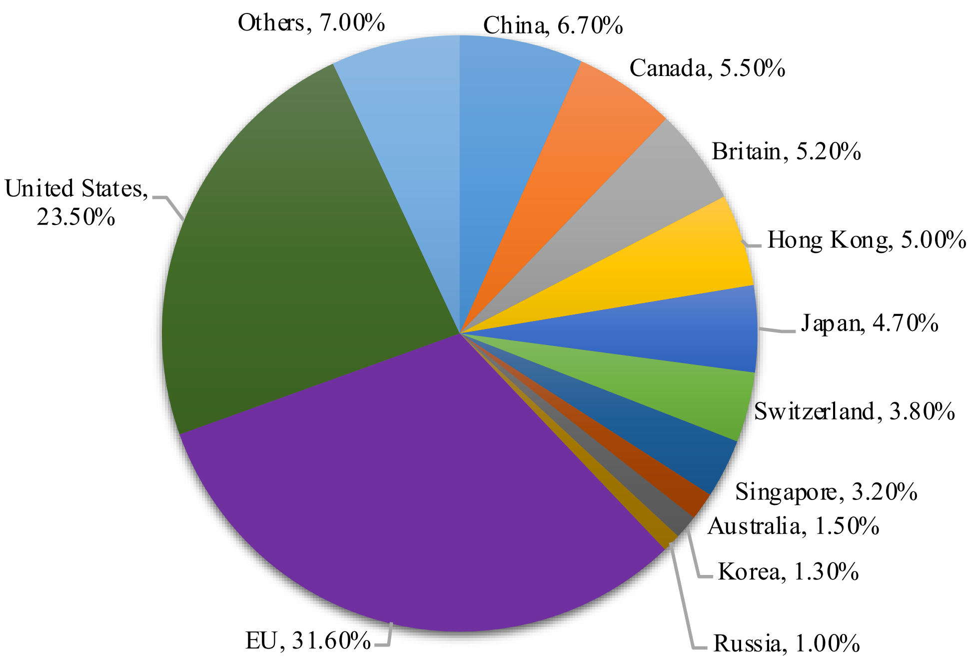

Figure 2.11: The Proportion of OFDI Stock of Major Global Economies in 2021

Data source: 2021 Statistical Bulletin of China's Outward Foreign Direct Investment.

[2] http://images.mofcom.gov.cn/fec/202211/20221118091910924.pdf

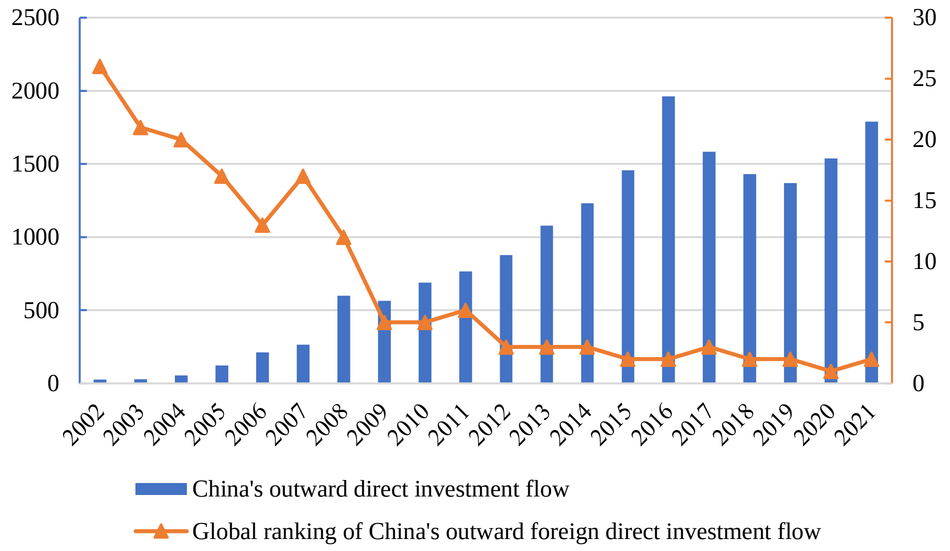

Figure 2.12: China's OFDI Flow and Global Ranking

Data source: 2021 Statistical Bulletin of China's Outward Foreign Direct Investment. Unit: Billion US dollars.

Table 2.8: China's OFDI Flow, Stock, and Global Ranking

	OFDI flow		OFDI stock	
Year	Amount	Global ranking	Amount	Global ranking
2002	2.70	26	29.90	25
2003	2.85	21	33.20	25
2004	5.50	20	44.80	27
2005	12.26	17	57.20	24
2006	21.16	13	90.63	23
2007	26.51	17	117.91	22
2008	59.91	12	183.97	18
2009	56.53	5	245.75	16
2010	68.81	5	317.21	17
2011	76.45	6	427.48	13
2012	87.80	3	531.94	13
2013	107.84	3	660.48	11
2014	123.12	3	882.64	8
2015	145.67	2	1097.86	8
2016	196.15	2	1357.39	6
2017	158.29	3	1809.04	2
2018	143.04	2	1982.27	3
2019	136.91	2	2198.88	3
2020	153.71	1	2580.66	3
2021	178.82	2	2785.15	3

Data source: 2021 Statistical Bulletin of China's Outward Foreign Direct Investment. Unit: Billion US dollars.

3. Industry Distribution of Chinese Enterprises' OFDI

Across industries, Chinese OFDI exhibits significant variability, concentrating heavily within select sectors like mining and manufacturing. Table 2.9 enumerates China's outward direct investment stock by industry from 2002-2020.

As of end-2020, China's OFDI landscape encompassed every domain of the national economy, with a relatively balanced distribution taking form. The 2020 Statistical Bulletin on China's Outward Foreign Direct Investment reveals six industries exceeding USD 100 billion in aggregate OFDI stock. While diversifying, pillar sectors including mining, wholesale/retail, leasing/business services, information transmission/software and information technology, manufacturing and finance contributed disproportionately to flows. The total stock of the above six industries is 219.868 billion US dollars, accounting for 85.2% of China's OFDI stock. Leasing/business services retained pole position at USD 831.642 billion in stock, constituting 32.2% of the total. Although expanding outright, mining's share of OFDI persisted in its descent - plunging from 15.12% (USD 8.652 billion) in 2005 to 6.8% of the USD 175.879 billion stock by 2020. As overseas mining investments frequently target foreign resource deposits like ores/fossil fuels to satisfy domestic energy appetite, often with environmental externalities, the contracting proportion indicates China's ongoing economic restructuring and improving growth quality.

Manufacturing commands a sizable OFDI presence as well, surging from around 10% (USD 5.770 billion) of the 2005 aggregate to USD 277.868 billion or 10.8% by 2020, harnessing overseas resources via industrial transfer to reduce labor costs and tapping advanced foreign technologies. Meanwhile transport/storage/post dwindled as a share of total Chinese OFDI over the period - from over 12% (USD 7.083 billion) in 2005 to 3.1% of the USD 80.776 billion stock by 2020 - marking it as a relatively dormant sphere. Finance has long occupied an integral role as firms make overseas financial investments to reasonably minimize costs and elevate capital utilization efficiency. Its share has mildly declined, however - from 0 in 2005 to 10.5% of the USD 270.062 billion stock in 2020. Notably, scientific research and technical services exhibited a steadily ascending profile - rocketing from just 1.06% (USD 0.604 billion) of total flows in 2005 to 1.62% on a stock of USD 60.580 billion in 2020 - reflecting escalating domestic commitment to scientific/technological advancement. Other sectors maintain relatively trivial shares without major fluctuations. Agriculture/forestry/husbandry /fisheries logged USD 0.512 billion

(27.4% CAGR) of OFDI in 2005 swelling to USD 19.435 billion by 2020; construction grew from USD 1.204 billion (28.34% CAGR) in 2005 to USD 50.796 billion in 2020. Both hovered stably around 1-2% of the total Chinese OFDI over the period.

Table 2.9: Industry Distribution of China's OFDI Stock

Industry category	2005	2010	2015	2020
Agriculture/Forestry/Animal husbandry/Fisheries	5.12	26.12	114.76	194.35
Mining	86.52	446.61	1423.81	1758.79
Manufacturing	57.70	178.02	785.28	2778.68
Production and supply of electricity/Heat/Gas and water	2.87	34.11	156.63	423.79
Construction	12.04	61.73	271.24	507.96
Wholesale and retail	114.18	420.06	1219.41	3453.16
Transportation/Warehousing and postal industry	70.83	231.88	399.06	807.76
Accommodation and catering	0.46	4.50	22.33	49.26
Information transmission/Software and information technology services industry	13.24	84.06	209.28	2979.14
Finance	-	552.53	1596.66	2700.62
Real estate	14.95	72.66	334.93	814.08
Leasing and business services	165.54	972.46	4095.68	8316.42
Scientific research and technology services	6.04	39.67	144.31	605.80
Water conservancy/Environmental and public facility management industry	9.10	11.33	25.42	35.71
Residential services/Repair and other service industries	13.23	32.30	142.77	135.41
Education	0.00	0.24	2.87	79.03
Health and social work	0.00	0.36	1.75	39.65
Culture, sports and entertainment	0.05	3.46	32.51	126.96

Data source: 2020 Statistical Bulletin on China's Outward Foreign Direct Investment. Unit: 100 million US dollars.

In terms of the industry distribution of Chinese firms' OFDI flows, OFDI covers 18 broad industry categories of the national economy (Table 2.10). In 2020, more than 80% of China's OFDI flows were directed to leasing and business services, wholesale and retail, manufacturing, finance, and transport/warehousing and postal services. The investment value of these industries exceeds US$10 billion, with leasing and business services accounting for 25.2 per cent of China's OFDI flows in 2020, the highest in the world. Manufacturing industry ranked second with US$25.838 billion accounting for 16.8 per cent. Wholesale and retail trade ranked third with an investment amount of 15 per cent of China's OFDI flows. The financial sector and the information transmission/software and information technology sector ranked fourth and fifth, accounting for 12.8 per cent and 6 per cent of China's OFDI flows, respectively.

Table 2.10: Industry Distribution of China's OFDI Flow

Industry category	2005	2010	2015	2020
Agriculture/Forestry/Animal husbandry/Fisheries	1.05	5.34	25.72	10.79
Mining	16.75	57.15	112.53	61.31
Manufacturing	22.80	46.64	199.86	258.38
Production and supply of electricity/Heat/Gas and water	0.08	10.06	21.35	57.70
Construction	0.82	16.28	37.35	80.95
Wholesale and retail	22.60	67.29	192.18	229.98
Transportation/Warehousing and postal industry	5.77	56.55	27.27	62.33
Accommodation and catering	0.08	2.18	7.23	1.18
Information transmission/Software and information technology services industry	0.15	5.06	68.20	91.87
Finance	-	86.27	242.46	196.63
Real estate	1.16	16.13	77.87	51.86
Leasing and business services	49.42	302.81	362.58	387.26
Scientific research and technology services	1.29	10.19	33.45	37.35
Water conservancy/Environmental and public facility management industry	0.00	0.72	2.19	13.68
Residential services/Repair and other service industries	0.63	3.21	15.99	21.61
Education	-	0.02	0.62	1.30
Health and social work	-	0.34	0.84	6.38
Culture, sports and entertainment	0.00	1.86	17.48	-21.34

Data source: 2020 Statistical Bulletin on China's Foreign Direct Investment. Unit: 100 million US dollars.

4. Enterprise Types of Chinese OFDI

From an ownership vantage, state-owned enterprises (SOEs) originally predominated China's outward foreign direct investment (OFDI), commanding substantial shares of both stock and flows in the initial stages of opening up. However, with economic development and evolving investment policies, non-state enterprises' OFDI activity began expanding rapidly, especially among private firms (Figure 2.13). From 2006, non-SOE OFDI accelerated markedly. By 2015, non-SOEs reached parity with SOEs in OFDI magnitude, underscoring the increasing openness and inclusiveness of China's OFDI policy regime as the state vigorously encouraged and steered non-state actors to jointly advance economic development. By 2017, non-SOEs overtook SOEs as China's primary OFDI source for the first time on record. This highlights the rising prominence of non-state players in China's "going global" process, as select SOEs transitioned into joint-stock companies while preferential state policies also incubated private enterprise OFDI.

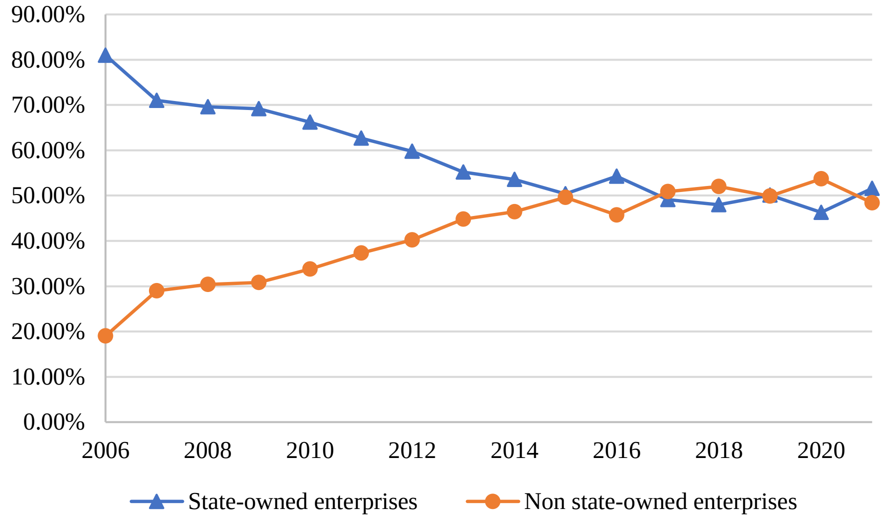

Figure 2.13: The Proportion of State-Owned and Non-State-Owned Enterprises from 2006 to 2021

Data source: 2021 Statistical Bulletin of China's Outward Foreign Direct Investment.

Table 2.11: Enterprise Types of Chinese OFDI in 2021

Enterprise type	Proportion
Limited liability company	32.7
Private enterprise	29.1
Limited liability company	13.8
State-owned enterprises	5.7
Foreign-invested enterprise	5.6
Investment enterprises from Hong Kong, Macao, and Taiwan	4.0
Individual operation	2.3
Cooperative stock enterprise	1.1
Collective enterprises	0.4
Joint venture	0.2
Others	5.1

Data source: 2021 Statistical Bulletin of China's Outward Foreign Direct Investment.

In terms of OFDI by investor type (Table 2.11), limited liability companies constituted the largest constituent at 32.7% of China's 28,000 OFDI firms as of end-2021, epitomizing the most active OFDI cohort. Private enterprises, joint-stock enterprises, SOEs and foreign-invested enterprises followed at 29.1%, 13.8%, 5.7% and 5.6%, respectively. Hong Kong, Macao and Taiwan investors along with self-employed households and cooperatives logged the smallest OFDI shares. From a central-local perspective, central SOEs accounted for a mere 0.6% of China's OFDI entities at 168 firms, with the remaining 99.4% originating from provincial-level local companies, clustered along the eastern seaboard in Beijing, Tianjin, Liaoning, Shanghai, Jiangsu, Shandong and southeastern coastal provinces like Guangdong, Fujian and

Zhejiang. Guangdong led with over 7,000 local multinationals conducting OFDI, constituting 25.2% of China's total.

5. Distribution characteristics of China's OFDI

(1) Province Distribution

Figure 2.14 illustrates OFDI by domestic region in China in 2021. The OFDI flow from the eastern region was US$71.81 billion, accounting for 81.9 per cent of the local investment flow, an increase of 0.6 per cent year-on-year. Among them, Guangdong, Zhejiang, Shanghai and Jiangsu all accounted for more than 10 per cent of OFDI flows. The OFDI flow from the central region was US$10.03 billion, accounting for 11.4 per cent, up 44.6 per cent year-on-year. The OFDI flow from the western region was US$4.51 billion, accounting for 5.1 per cent, a year-on-year decline of 23.8 per cent. The OFDI flow from the Northeast region was US$1.38 billion, accounting for 1.6 per cent, up 126.2 per cent year-on-year. In addition, from the perspective of OFDI stock in the eastern, central and western regions, OFDI from China's eastern region in 2021 was US$699.69 billion, accounting for 82.3 per cent of the total, far exceeding that of other regions.

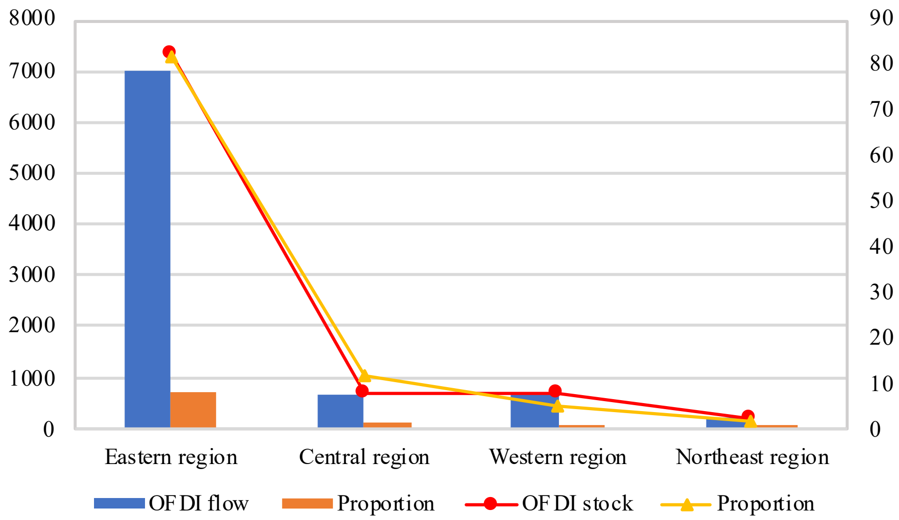

Figure 2.14: Regional Distribution of China's OFDI Stock and Flow in 2021

Data source: 2021 Statistical Bulletin of China's Outward Foreign Direct Investment. Unit: 100 million US dollars.

In terms of provincial OFDI stock, as of 2021 the top 10 provinces accounted for USD 705.63 billion, capturing 83% of the local aggregate. As exhibited in Table 2.12, Guangdong province ranked first with USD 165.72 billion, preserving considerable advantages in overseas investment. Further, Shanghai's markedly higher OFDI stock relative to other regions echoes more vigorous offshore momentum among developed coastal areas.

Analyzing features by province, Table 2.12 delineates China's top 10 by OFDI stock and flows. Firstly, by adopting the National Bureau of Statistics zoning, China's geography is demarcated into eastern, central and western regions. Regarding OFDI stock, 8 of the leading 10 provinces fell into the eastern bloc (barring Henan and Anhui), constituting 80% of this cohort. The stock commanded by these 10 provinces encapsulated 25.3% of the national total. Guangdong, Shanghai and Beijing alone represent 58.54%, occupying the top 3 positions. In OFDI flows, only Anhui hailed from the central area, with the balance situated out east. The collective share of front-running Guangdong, Shanghai and Zhejiang flows already claimed 46.5% of the aggregate. This substantiates a larger OFDI scale and heightened regional concentration in China's advanced eastern corridor. Pronounced disparities in eastern versus western provincial OFDI stock and flows remain intact.

Table 2.12: Distribution of OFDI Flow in Chinese Provinces in 2021

Rank	Province	OFDI stock	Rank	Province	OFDI flow	Proportion
1	Guangdong	1657.2	1	Guangdong	141.7	16.2
2	Shanghai	1515.0	2	Zhejiang	133.7	15.2
3	Beijing	958.8	3	Shanghai	132.2	15.1
4	Zhejiang	823.1	4	Jiangsu	90.6	10.3
5	Jiangsu	685.4	5	Beijing	70.5	8.1
6	Shandong	578.8	6	Shandong	50.2	5.7
7	Fujian	255.4	7	Fujian	40.4	4.6
8	Tianjin	240.6	8	Anhui	28.4	3.2
9	Anhui	176.4	9	Hebei	27.5	3.1
10	Henan	165.6	10	Tianjin	23.2	2.7

Data source: 2021 Statistical Bulletin of China's Outward Foreign Direct Investment. Unit: 100 million US dollars.

(2) Country Distribution

As of end-2021, China's direct cross-border investments extended to 190 countries and regions globally, blanketing six continents while representing 81.5% of the world's aggregate OFDI stock. As visualized in Figure 2.15, Asia constituted the foremost destination region, harnessing US$1,772.01 billion or 63.6%

of China's stock in 2021. Latin America ranked second, drawing US$693.74 billion (25% share) last year. Europe occupied the third position with US$134.79 billion (4.8%) of Chinese OFDI stock in 2021. North America followed closely in fourth, absorbing US$100.23 billion (3.6%) of China's outbound reserves. Africa and Oceania rounded out the field, attracting US$44.19 billion (1.6%) and US$40.19 billion (1.4%) of flows, respectively, in 2021.

However, the dispersal of China's OFDI flows diverges somewhat from stock allocations. While again blanketing all six continents, flows to Europe reversed course on the year. As documented in Figure 2.15, Asia still garnered the largest share of flows in 2021 at US$128.1 billion. Latin America took the second position with US$26.16 billion in outbound flows. North America drew the third largest slice at US$10.87 billion, followed by Africa (US$6.58 billion), Oceania (US$4.99 billion) and finally Europe which saw the smallest segment of just US$2.12 billion inflows last year.

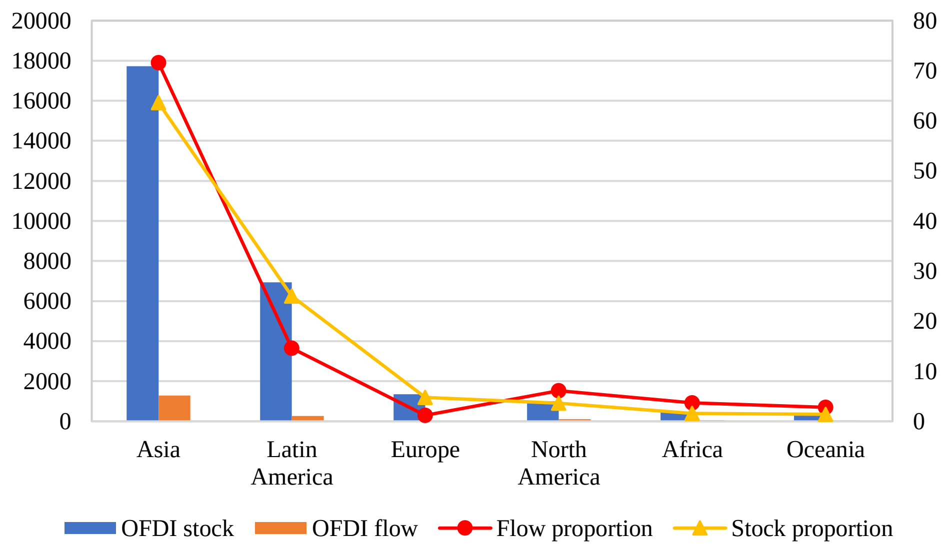

Figure 2.15: Distribution of China's OFDI Stock and Flow Across Continents

Data source: 2021 Statistical Bulletin of China's Outward Foreign Direct Investment. Unit: 100 million US dollars.

From a locational selection perspective (Table 2.13), Figures 2.16 and 2.17 delineate China's 2020 OFDI patterns. Regarding the stock, the top 15 destination countries and territories accounted for 91.95% of China's outbound reserves, verging on 90% concentration. Similarly by flows, 89.96% funneled to the same top 15 locales. This echoes high geographic concentration, with over half of both stock and flows consistently streaming to Hong Kong as the predominant OFDI hub, trailed by British Virgin and Cayman Islands - bespeaking Chinese investors' gravitation toward jurisdictions proffering favorable tax policies, largely to sidestep regulations and minimize tax liability. Thereafter, advanced economies like the United States, Singapore and Australia alongside emerging giants like the Netherlands have netted substantial Chinese OFDI in recent years as well.

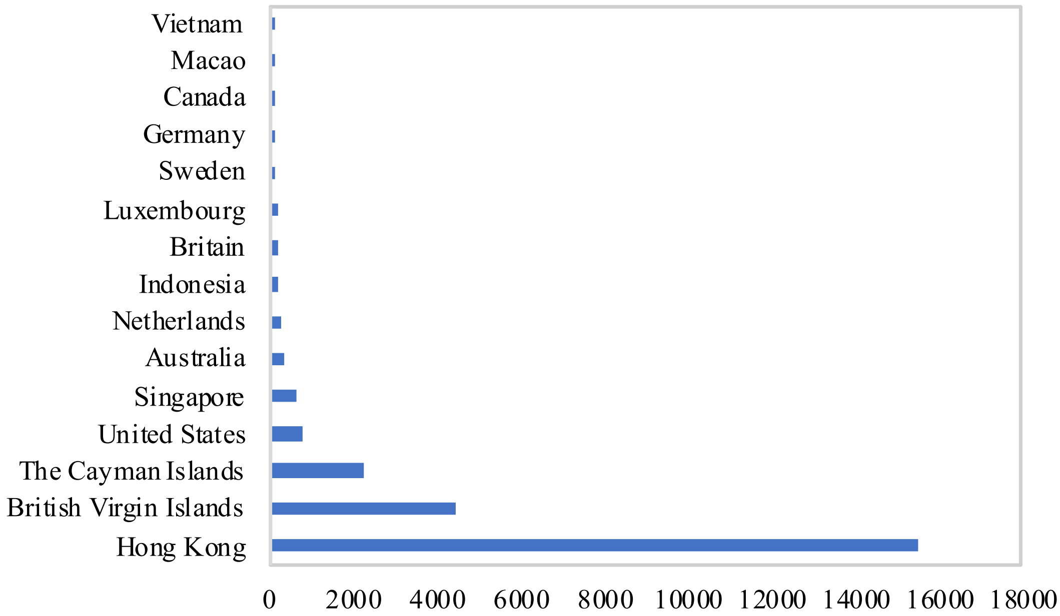

Figure 2.16: Top 15 Countries/Regions of OFDI Stock in 2021

Data source: 2021 Statistical Bulletin of China's Outward Foreign Direct Investment. Unit: 100 million US dollars.

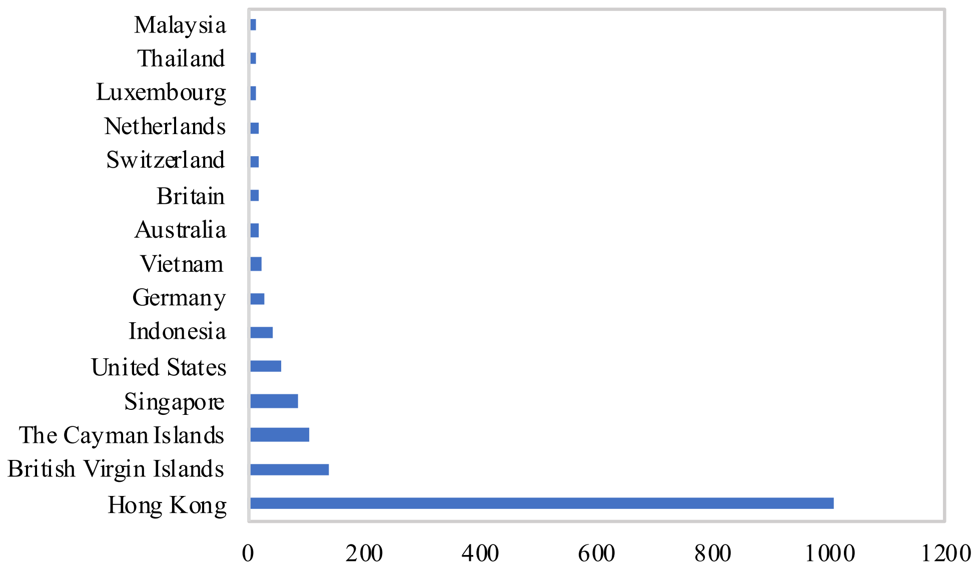

Figure 2.17: Top 15 Countries/Regions of Outward Foreign Direct Investment Flow in 2021

Data source: 2021 Statistical Bulletin of China's Outward Foreign Direct Investment. Unit: 100 million US dollars.

Table 2.13: Top 15 Countries/Regions of OFDI Flow in 2021

Rank	Country	OFDI flow	Proportion	Country	OFDI stock	Proportion
1	Hong Kong	1011.9	56.6	Hong Kong	15496.6	55.6
2	British Virgin Islands	139.7	7.8	British Virgin Islands	4474.8	16.1
3	The Cayman Islands	107.5	6.0	The Cayman Islands	2295.3	8.2
4	Singapore	84.1	4.7	United States	771.7	2.8
5	United States	55.8	3.1	Singapore	672.0	2.4
6	Indonesia	43.7	2.5	Australia	344.3	1.2
7	Germany	27.1	1.5	Netherlands	284.9	1.0
8	Vietnam	22.1	1.2	Indonesia	200.8	0.7
9	Australia	19.2	1.1	Britain	190.1	0.7
10	Britain	19.0	1.1	Luxembourg	181.3	0.6
11	Switzerland	18.2	1.0	Sweden	170.3	0.6
12	Netherlands	17.0	1.0	Germany	167.0	0.6
13	Luxembourg	15.0	0.8	Canada	137.9	0.5
14	Thailand	14.9	0.8	Macao	112.4	0.4
15	Malaysia	13.4	0.8	Vietnam	108.5	0.4

Data source: 2021 Statistical Bulletin of China's Outward Foreign Direct Investment. Unit: 100 million US dollars.

6. Problems in China's OFDI

While expanding briskly since opening up, China's OFDI has encountered the following snags over the past four decades:

(1) Scale Mismatched with Global Prominence

Firstly, China's OFDI flows significantly trail those of economic powerhouse the United States. As of end-2022, China's share of global OFDI flows languished at just 11.26%, dwarfing the 28.69% commanded by the US, despite China ranking second overall. Thus, wide gaps with the US remain. Moreover, China's OFDI flows as a proportion of total exports and GDP are exceedingly slim against its mammoth trade and economic statures. By end-2022, China's merchandise exports approached US$6.3 trillion, capturing 19.69% of world trade, while its US$17.96 trillion GDP constituted 17.86% of the global economy. However, OFDI flows represented a paltry 0.023% of China's export volumes and 0.0082% of its GDP tally. This undersized ratio mismatches China's preeminence as a trade and economic titan, signaling enormous potential for expanding OFDI commitments prospectively.

(2) Anemic Financial Investment

While climbing post-liberalization, financial investments have occupied relatively trivial portions of China's aggregate OFDI. Per statistical bulletin data, in 2020 financial slices constituted US$19.66 billion or 12.8% of China's US$153.71 billion OFDI outflows, while non-financial categories predominated at US$134.05 billion or 87.2%. In 2021, financial allocations edged up to US$26.8 billion but still only comprised 15% of the US$178.82 billion flows, with non-financial segments again supreme at US$152.02 billion or 85%. And in 2022, financial investments ticked higher to US$29.65 billion, though only claiming 20.2% of the US$146.5 billion OFDI total against US$116.85 billion (79.8%) in non-financial sectors. So while inching up, financial OFDI has lagged, warranting policy support.

(3) Inordinate Regional Concentration

For years, China's OFDI has remained heavily funneled to Asian destinations, while shares reaching sophisticated markets in Europe and North America or developing regions with growth runways like Latin America, Africa and Oceania have stayed deficient. In 2021 for instance, a towering US$128.1 billion or 71.6% of China's US$178.82 billion OFDI landed in Asia. Flows place second, to Latin America, totalled US$26.16 billion (14.6%), trailed by North America at US$10.87 billion (3.7%), Africa with US$4.99 billion (2.8%), Oceania at US$2.12 billion (1.2%) and lastly Europe at US$10.87 billion (6.1%). This imbalance requires resolution via enhanced diversification.

2.2.3 Export

1. What is Export

Export refers to the transportation of goods and services from one domestic jurisdiction to a foreign jurisdiction. In international commerce, exportation denotes a country's sale of goods or services to other nations in exchange for currency or other merchandise. Exportation can also signify the aggregate sales volume of products manufactured in a region or country in the global marketplace. The realization of exports depends on supportive import and export trade policies, and also necessitates that exporters possess certain market development capabilities and consciousness of international trade cooperation.

The scope of exports is extensive, encompassing not just traditional agricultural goods and manufactured products, but also trade activities in service industries, intellectual property rights, and other domains. The objectives of exporting include expanding production scales and prolonging product life cycles. Exports furnish enterprises with foreign exchange revenue, promote economic growth and employment, and additionally make available to the international market a wider selection of products at lower prices.

2. Export's Change Trend

(1) Annual Export Total Analysis

Figure 2.18 illustrates the variations in export volumes in China from 2000 to 2021. From the trend of export trade volume, apart from brief declines in 2008 and 2016 due to the impacts of the financial crisis and the anti-globalization trend, China's export scale has generally maintained rapid growth. Nationally, from 2000 to 2021, China's export volume surged from USD 249.2 billion to USD 3.316 trillion, marking a 13.31-fold increase, with an average annual growth rate of 58.6%. From 2000 to 2008, China's export volume exhibited a steady annual increase. The export volume in 2008 soared by USD 1.1814 trillion compared to 2000, maintaining a high growth rate with an average annual growth rate of 52.68%. However, the global financial crisis in 2009 led to a reduction in China's export volume by USD 229.081 billion.

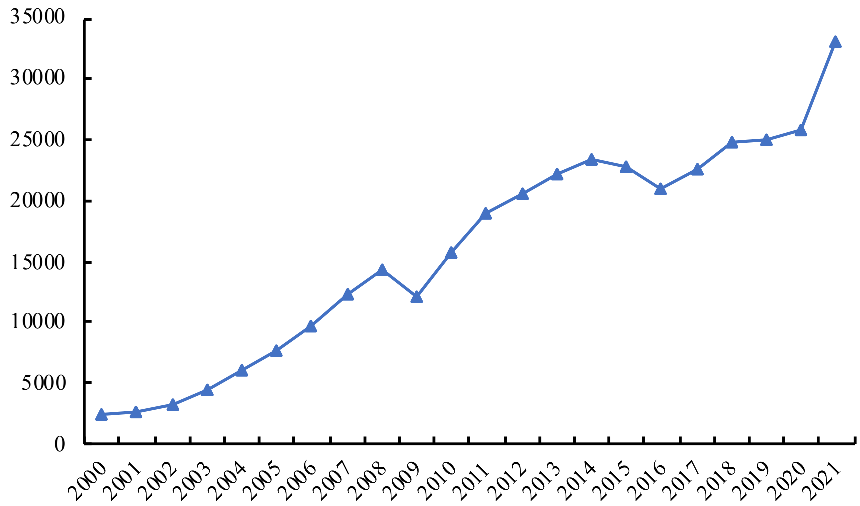

Figure 2.18: China's Total Export Value from 2000 to 2021

Data source: Statistics Bureau of the People's Republic of China[3]. Unit: 100 million US dollars.

[3] https://data.stats.gov.cn/easyquery.htm?cn=C01

From 2010 to 2020, the export volume surged from USD 1.577754 trillion to USD 3.316 trillion, with the average annual growth rate dropping significantly to 10.02%. For the eastern region, the export trade volume escalated from USD 243.987 billion in 2001 to USD 1.781711 trillion in 2016, registering an average annual growth rate of 39.39%. The peak export volume was reached in 2014 at USD 1.943343 trillion, exhibiting a trend in export volume change that closely paralleled the national level.

(2) Comparative Analysis of Export in Different Industries

Figure 2.19 presents the export volumes of primary products and manufactured products from 2000 to 2021 in China. In 2000, the export volume of primary products amounted to USD 25.46 billion, escalating to USD 140.072 billion by 2021. Correspondingly, its share of total exports decreased from 10.22% in 2000 to 4.22% in 2021. Throughout the observation period, the export volume of manufactured goods surged from USD 223.743 billion in 2000 to USD 3.222951 trillion at the end of the period, with its proportion rising from 89.78% in 2000 to 97.19% in 2021. From 2000 to 2021, the proportion of primary product exports continued to decline, maintaining between 5% and 10%. In contrast, the proportion of manufactured goods exports continued to rise, remaining between 90% and 95%. The dominance of manufactured goods exports over primary products exports signifies an ongoing optimization trend in China's export product structure since 2000. This optimisation is primarily attributable to the adjustment of China's industrial structure and the continuous improvement in manufacturing technology levels, which enhances export competitiveness and propels export trade development.

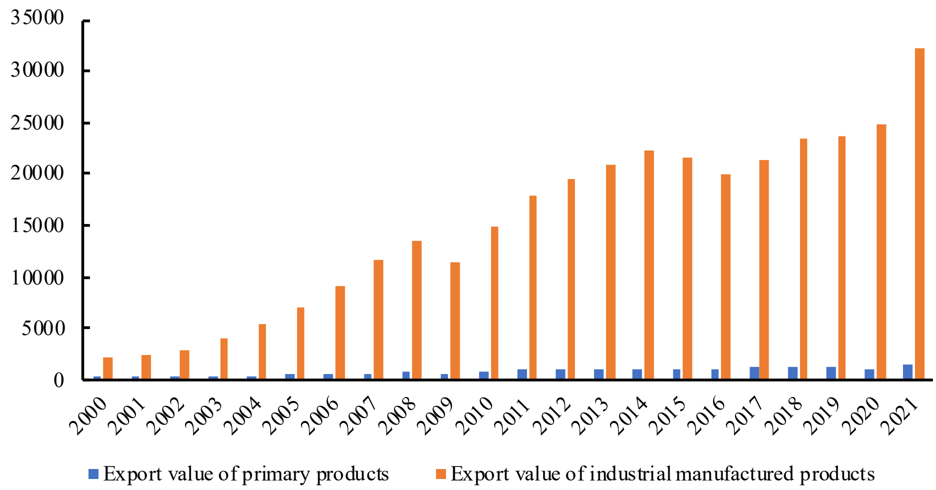

Figure 2.19: Export Volumes of Primary Products and Manufactured Products from 2000 to 2021

Data source: Statistics Bureau of the People's Republic of China. Unit: 100 million US dollars.

(3) Comparative Analysis of Export in Three Regions

There is a significant disparity in export volumes between the central and western regions compared to the eastern region. In 2000, the export volumes of the central and western regions were USD 12.39831 billion and USD 9.9266 billion, respectively, accounting for only 5.46% and 4.38% of the eastern region's export volume (Figure 2.20 and Table A.3). By 2021, the export volumes of the central and western regions surged to USD 350.96 billion and USD 320.35 billion, respectively, with average annual growth rates of 130.01% and 148.89%. Although the export volumes of the central and western regions are relatively lower, their average annual growth rates far exceed that of the eastern region.

Considering multiple factors such as geographical location, resource endowment, and economic environment, there are significant differences in economic development among regions. Consequently, the total export volumes vary greatly among different regions. By categorizing the regions into eastern, central, and western parts and analyzing their respective export volumes, it can be observed from Figure 2.20 that the export volumes of all three regions generally exhibit an upward trend, with minor declines in 2009 due to the impact of the international financial crisis. Moreover, the international trade development situation in the eastern region far surpasses that in the western and central regions, with the western region exhibiting the lowest total export volume.

The reasons behind these trends are as follows. First, the developed trade in the eastern region is mainly attributed to China's emphasis on international trade since the reform and opening-up, coupled with its coastal location that facilitates maritime transportation, leading to rapid economic growth in coastal areas. Furthermore, China's development strategy prioritizes the development of the eastern coastal region before extending to the central and western regions. The central region, lacking coastal access and with less abundant resources, relies mainly on its large labor force. However, labor from the central region often migrates to more developed areas in the eastern region, resulting in less development compared to the eastern region. Lastly, the western region, characterized by harsh environments, complex terrain, sparse population, and primarily focused on animal husbandry due to unfavorable conditions for agricultural development, exhibits a relatively lower standard of living. Moreover, transportation infrastructure is inadequate, dissuading most enterprises from establishing factories in the region, hence rendering the prospects for export trade in the western region less optimistic.

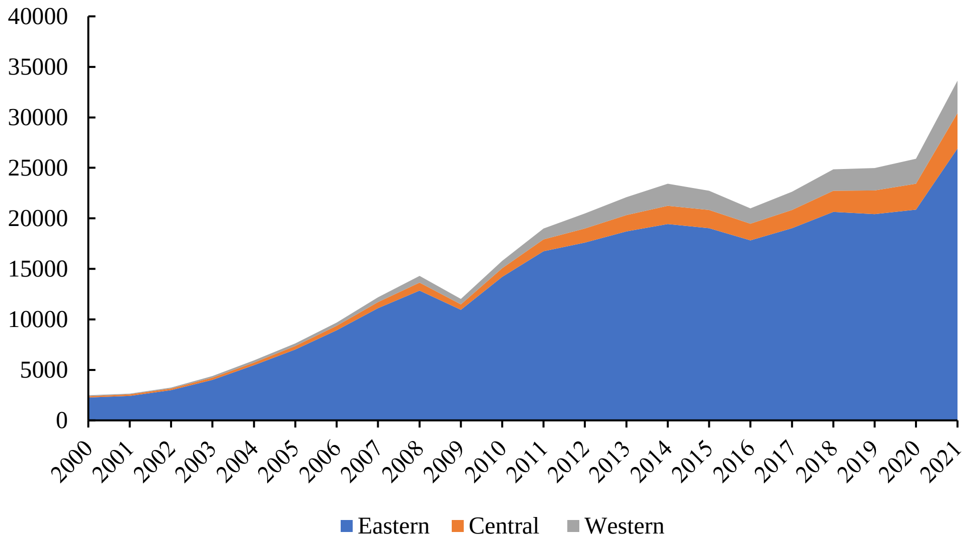

Figure 2.20: Export Volume of Three Regions in China from 2000 to 2021

Data source: Statistics Bureau of the People's Republic of China and China Statistical Yearbook. Unit: 100 million US dollars.

2.3 History of China's Environmental Regulation

2.3.1 The Development History of China's Environmental Policy

Environmental regulation, as a solution to the "tragedy of the commons" resulting from resource overexploitation (De Young and Kaplan, 1988; Paavola, 2011), has undergone multiple revisions and become increasingly diversified in China. Initially, environmental regulation was perceived to be confined to direct government intervention in resource and environmental matters through measures such as production bans, non-transferable permits, or the closure of non-compliant enterprises, devoid of market mechanisms. Subsequently, the introduction of the "Pigouvian tax" and the Coase theorem introduced novel perspectives to environmental regulation (Milne and Andersen, 2012; Heine, 2020). It became evident to the public that environmental taxes, subsidies, and tradable pollution permits could effectively address pollution externalities, thus gradually evolving into market-based incentives with regulatory functions aimed at norming polluting behaviors (Kallbekken et al., 2011). With the gradual enhancement of public environmental awareness, certain voluntary environmental behaviors by the public have also been incorporated into the realm of environmental regulation (Lyon and Maxwell, 2019). The developmental trajectory of environmental regulation in China can be roughly categorized into the following four stages.

(1) Formal Establishment Stage (1978-1991)

In 1978, China embarked on its policy of reform and opening up, gradually placing emphasis on environmental protection. In 1979, the “China Environmental Protection Law” was promulgated, marking China’s first environmental protection legislation (Beyer, 2006). In 1982, the provisions regarding environmental protection in the “Constitution of the People’s Republic of China” were further amended to include the protection and improvement of the ecological environment as a constitutional mandate (Shen, 2022). In 1983, the Second National Conference on Environmental Protection formally established environmental protection as a long-term fundamental national policy. In 1989, the Third National Conference on Environmental Protection issued the “Environmental Protection Goals and Tasks for 1989-1992”, emphasizing the importance of pollution prevention, the accountability of polluters for pollution control, and the efficiency of environmental management. Subsequently, a series of environmental protection laws and policies were introduced, such as the “Regulations on the Protection and Improvement of the Environment” and the “Trial Standards for the Discharge of Industrial ‘Three Wastes’”. The promulgation of these laws and policies marked the formal establishment of China’s environmental policy framework.

(2) Enhancement Stage (1992-2001)

In 1992, the Chinese government signed the “Rio Declaration on Environment and Development” and the “Agenda 21”, committing to implement a strategy of sustainable development. Subsequently, China intensified its environmental protection efforts and enhanced its environmental policy framework. For instance, in 1994, the Chinese government formulated the “China Agenda 21”, which delineated strategic goals and action plans for sustainable development (Lin, 1998). Moreover, a series of significant environmental protection laws and policies were enacted, such as the “Environmental Protection Law” and the “Law on the Prevention and Control of Atmospheric Pollution”.

(3) Strategic Transformation Stage (2002-2011)

With the onset of the 21st century, China's economy experienced rapid growth but also faced severe environmental challenges. To address these challenges, the Chinese government commenced a strategic transformation of environmental governance, shifting from end-of-pipe treatment to comprehensive pollution prevention and control. During this stage, the Chinese government introduced a series of important environmental policies and plans, such as the "National Environmental Protection 'Tenth Five-Year Plan'" and the "National Environmental Protection 'Eleventh Five-Year Plan'" (Wang, 2022). The implementation of these policies and plans effectively propelled China's environmental protection efforts.

(4) Comprehensive Improvement Stage (2012-Present)

Since 2012, the Chinese government has elevated the construction of an ecological civilization to a national strategy, advocating for green, circular, and low-emission development (Hanson, 2019). During this stage, the Chinese government further strengthened environmental protection efforts and promulgated a series of significant environmental policies and regulations, such as the amendment to the "Environmental Protection Law" and the "Action Plan for the Prevention and Control of Air Pollution". The implementation of these policies and regulations has vigorously promoted the development of China's environmental protection cause and facilitated sustainable economic and social development.

As China's economy and society continue to develop and environmental challenges become increasingly severe, the Chinese government continue to strengthen environmental protection efforts, enhance the environmental policy framework, and promote sustainable economic and social development.

2.3.2 Classification and Characteristics of Environmental Regulatory Tools

Based on practical experience, environmental regulatory tools can be broadly classified into command-and-control, market-based incentives, and voluntary agreements/public participation (Karp and Gaulding, 1995), with the former two being the primary environmental regulatory tools currently implemented in

China. Command-and-control environmental regulation, dominated by governmental administrative intervention, involves the explicit imposition of environmental protection requirements, pollution emission standards, and punitive measures through environmental protection legislation and regulations, thereby imposing mandatory constraints on the economic activities of polluting enterprises to achieve emission reduction and environmental pollution reduction goals (Markandya, 1998). Command-and-control environmental regulation, with its clear objectives of directly restricting the pollution emissions of enterprises, imposes severe penalties (such as fines, production reduction, relocation orders, or even forced closure of polluting enterprises) in the event of non-compliance, rendering it compulsory (Blackman et al., 2018). Consequently, command-and-control environmental regulation has demonstrated noticeable emission reduction effects, thus becoming one of the earliest and most widely utilized environmental regulatory tools worldwide. However, command-and-control environmental regulation also entails drawbacks such as high implementation costs, direct increases in production costs for enterprises, and reduced production efficiency (Zhao et al., 2015; Li et al., 2024).

Market-based incentives environmental regulation, primarily driven by market mechanisms, entails the marketization of pollution emissions by the government through rational institutional arrangements, actively guiding enterprises to achieve emission reduction objectives through market means (Stavins, 2010). Specific measures may include emissions trading systems, deposit-refund schemes, environmental taxes, pollution charges, and subsidies (Gunatilake and De Guzman, 2008). Market-based incentives environmental regulation not only internalizes pollution’s negative externalities but also effectively enhance the production initiative and efficiency of enterprises (Stavins and Whitehead, 1992). However, market-based incentives environmental regulation also has limitations. It does not directly reduce pollution emissions but rather induces polluting enterprises to change their production behavior to achieve emission reduction objectives through market trading mechanisms or tax measures (Brooks and Simon, 2024). As a result, the effectiveness of policies depends largely on the completeness of the specific market environment and the magnitude of transaction costs, and there may be time lags from policy implementation to effects.

Public participation environmental regulation. In recent years, as China’s economic development has surged to new heights and the material living standards of the public have improved, the demand for ecological environmental quality has been continuously elevated. Due to the frequent occurrence of extreme weather phenomena such as haze and the vigorous promotion of environmental protection concepts by the government, public awareness of ecological conservation has been steadily increasing. More diversified environmental governance measures, such as voluntary environmental regulation, have emerged.

This type of environmental regulation is often initiated by social groups and non-governmental organizations through spontaneous collective actions such as complaints, negotiations, or supervision, exerting pressure on governments and enterprises to achieve the public's environmental protection goals (Weinberg and Gould, 1993). Voluntary environmental regulation does not impose mandatory constraints on enterprises but rather indirectly compels them to adopt green and environmentally friendly production methods through social public opinion (Zhang et al., 2019). Public participation ensures that environmental policies are formulated and implemented with the involvement and supervision of the public, representing the will of the public (Stern and Dietz, 2008).

Although this type of environmental regulation emphasizes self-awareness and democratization, its constraint on polluting firms appears relatively weak, making it less feasible. Moreover, it requires a supportive system of environmental protection institutions to be perfected. As China's economy enters a stage of high-quality development, continuous adjustments to upgrade the green industrial structure are necessary. Environmental regulations need to be combined with information and intelligent technology to ensure the comprehensive and accurate governance effect of environmental regulations.

2.4 Background of the Eleventh Five-Year Plan

2.4.1 The History of Five-Year Plan

Since the 1980s, the Chinese government has identified environmental protection as a basic state policy. It emphasizes that the central government sets the overall environmental goals, while local governments are responsible for developing and implementing detailed environmental regulations (Van Rooij and Lo, 2010; Zheng and Kahn, 2013). The Chinese government first listed environmental protection as a separate chapter in the Sixth Five-Year Plan (1981-1985); then concentration controls regulatory tool for emission reductions was adopted in the Seventh Five-Year Plan (1986-1990) and the Eighth Five-Year Plan (1991-1995). Concentration control aims to reduce the concentration of pollutants to comply with national pollution control standards. Because of the ineffectiveness of concentration controls in limiting the total scale of pollutants, China's emission target controls have focused on "key pollutants", that is, the national emission reduction targets formulated by the central government are allocated to local governments. Thus, in September 1996, the Chinese government announced its Ninth Five-Year Plan (1996-2000), which called for total control of 12 major pollutants nationwide during the period 1996-2000. In December 2001, the Chinese government announced the Tenth Five-Year Plan (2001-2005), which proposed a 10% reduction in the total emissions of seven major pollutants (eg., SO_2) during the period 2001-2005. Unfortunately, due to the rapid expansion of energy-intensive industries such as steel and cement, the emission reduction targets in the Ninth Five-Year Plan and the Tenth Five-Year Plan were not achieved. In particular, SO_2 emissions rose from 19.95 million tons in 2000 to 25.49 million tons in 2005, an increase of 27.8%. The main reason for this result is that since the promotion opportunities of officials mainly depend on economic growth, local officials lack sufficient motivation to implement the environmental goals set by the central government (Kahn et al., 2015). Therefore, although the Chinese government pays more attention to environmental protection, environmental degradation is still increasing (Vennemo et al., 2009).

Facing the increasingly serious environmental situation, the Chinese government promulgated a new policy focusing on the "leadership responsibility system" to reduce pollutant emissions during the Eleventh Five-Year Plan. "The Eleventh Five-Year Plan" announced in 2006 proposed that the total emissions of sulfur dioxide (SO_2) and chemical oxygen demand (COD) should be reduced by 10% between 2006 and 2010. In addition, the Chinese government and local government leaders signed the "11th Five-Year Plan" to reduce the total amount of major pollutants, and the performance of government officials in implementing emission reduction tasks was included in the performance appraisal. Moreover, according to the "Measures on Accomplishment Evaluation of Critical Pollutants Emissions Control Target", the achievement of pollution targets is directly related to the promotion opportunities of local officials (Kahn et al., 2015). Importantly, in 2006, China promulgated supplementary regulations such as the "Statistical Measures for Key Pollutant Emission Control Targets" and the "Interim Inspection Measures for Key Pollutant Emission Control Targets". As a result, compared with 2005, China's total SO_2 emissions fell by 14.29% in 2010, exceeding the expected target.

The 11th Five-Year Plan (2006-2010) marked a paradigm shift in China's environmental regulation by replacing concentration control regulatory with total emission reduction targets. Under the concentration control regulatory, regulators set limits on pollutant levels per unit of exhaust, which allowed firms to comply simply by installing end-of-pipe technologies like flue gas desulfurization scrubbers. However, this system failed to constrain absolute pollution growth, as enterprises could increase total emissions by operating more production lines or running plants at higher capacity while maintaining compliant concentrations. Recognizing this flaw, the 2006 reforms introduced binding caps on aggregate emissions, forcing firms to either fundamentally restructure production or acquire costly emission permits. Therefore, total emission reduction target is more effective than concentration control regulatory.

2.4.2 The Policy's Enforcement and Outcomes

In 2005, the Chinese government proposed quantitative emission reduction targets for the major air pollutant (SO_2) in the Eleventh Five-Year Plan (2006-2010). This policy strengthens environmental regulation, which is reflected in the following two aspects: First, it proposes long-term goals and completion years for local government emission reductions. The central government requires a 10% reduction in SO_2 emissions during this period and makes this one of the "mandatory" goals of the national development strategy. Second, this policy links the completion of emission reductions with the performance evaluation of local government officials.

Since 2006, the central government has incorporated local environmental protection indicators into the indicator system for the promotion assessment of local officials, realizing a transition from purely economic efficiency indicator assessment to economic efficiency indicator assessment that takes environmental protection into account. Environmental protection has thus become an important part of the performance evaluation of local leading cadres and the main basis for selection, appointment, rewards and punishments. The linking of local officials' reputations with environmental protection performance has strengthened local environmental regulation to a certain extent.

As the core of the emissions control target, provinces were assigned different emissions reduction targets within the 11th Five-Year Plan. As can be seen in Table 2.14, Shandong province, which has the highest target, is obliged to reduce 0.401 million tons of SO_2 between 2006 and 2010, while Hainan, Xizang, Qinghai, Gansu and Xinjiang at the bottom of the list, have no target for SO_2 emissions control.

Table 2.14: SO_2 Emission Control Plan in China in the 11th Five-Year Plan

Province	Emissions for 2005	Control target for 2010	Emissions reduction target
Beijing	19.1	15.2	3.9
Tianjin	26.5	24.0	2.5
Hebei	149.6	127.1	22.5
Shanxi	151.6	130.4	11.1
Inner Mongolia	145.6	140.0	5.6
Liaoning	119.7	105.3	14.4
Jilin	38.2	36.4	1.8
Heilongjiang	50.8	49.8	1.0
Shanghai	51.3	38.0	13.3
Jiangsu	137.3	112.6	24.7
Zhejiang	86.0	73.1	12.9
Anhui	57.1	54.8	2.3
Fujian	46.1	42.4	3.7
Jiangxi	61.3	57.0	4.3
Shandong	200.3	160.2	40.1
Henan	162.5	139.7	22.8
Hubei	71.7	66.1	5.6
Hunan	91.9	83.6	8.3
Guangdong	129.4	110.0	19.4
Guangxi	102.3	92.2	10.1
Hainan	2.2	2.2	0.0
Chongqing	83.7	73.7	10.0
Sichuan	129.9	114.4	15.5
Guizhou	135.8	115.4	20.4
Yunnan	52.2	50.1	2.1
Xizang	0.2	0.2	0.0
Shaanxi	92.2	81.1	11.1
Gansu	56.3	56.3	0.0
Qinghai	12.4	12.4	0.0
Ningxia	34.3	31.1	3.2
Xinjiang	51.9	51.9	0.0

Data source: The Eleventh Five-Year Flan[4]. Unit: ten thousand tons.

With such different mandatory targets, there is generally a wide variation in the stringency of environmental regulation across provinces. Taking into account these regional differences in legal enforcement, I plotted the variation in SO_2 emissions across provinces to suggest whether the level of SO_2

[4] https://www.gov.cn/gongbao/content/2006/content_394866.htm

emissions is associated with the stringency of environmental regulations. Therefore, I divided the provinces into two groups - tightly regulated provinces and loosely regulated provinces - based on whether their SO_2 emission reduction targets were higher or lower than the median targets set out in the 11th Five-Year Plan. SO_2 emissions for each group are summed and shown in Figure 2.21. The blue line associated with the left Y-axis shows the overall SO_2 emissions for the tightly regulated provinces, while the red dashed line corresponding to the right Y-axis shows the SO_2 emissions for the loosely regulated group. It is worth noting that according to Figure 2.21, SO_2 emissions in the tightly regulated provinces have declined, with a sharp drop from 2006 onwards. On the contrary, SO_2 emissions in loosely regulated provinces decreased slightly between 2005 and 2010. It can be observed that in response to different levels of environmental regulation stringency, strictly regulated provinces reduce more pollutants than loosely regulated provinces.

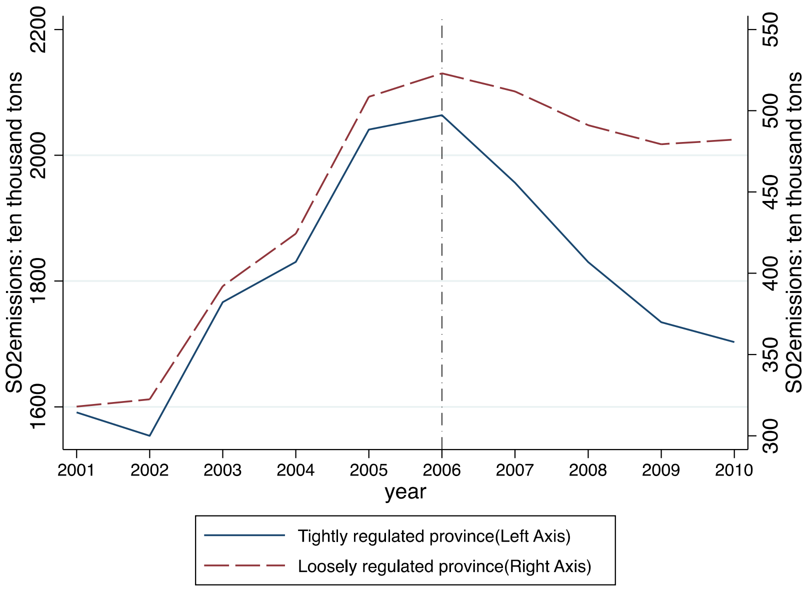

Figure 2.21: SO_2 Emissions in China in Tightly and Loosely Regulated Provinces

Source: Analysis reported in this thesis.

2.4.3 The Development of Environmental Regulation

Before the implementation of 11th Five-Year Flan, China's rapid economic growth was accompanied by significant environmental degradation. However, in recent years, the government has recognized the urgency of addressing environmental issues and has implemented a series of policies and regulations aimed at mitigating pollution and promoting sustainable development.

2.4.3.1 Framework of Environmental Regulation

First, about the legal basis, China's environmental regulation is rooted in a comprehensive legal framework, such as Law of the Soil Pollution Prevention and Control, Law of the People' Republic of China on Urban Real Estate Industry Regulation, Law of the People's Republic of China on Water Pollution Prevention and Control, Law of the People's Republic of China on Energy Saving, Law of the People' Republic of China on Renewable Energy, Law of the People's Republic of China on Solid Waste Prevention and Control and so on. These laws provide the foundational principles and standards for environmental protection. The environmental laws have been listed in Table 2.15.

Second, about the administrative structure, the environmental regulatory system in China is governed by multiple agencies at national, provincial, and local levels. The Ministry of Ecology and Environment (MEE) is the primary national-level agency responsible for overseeing environmental policy and enforcement. It coordinates with local environmental protection bureaus to ensure compliance with national standards.

Table 2.15: Major Chinese Environmental Laws

Environmental Protection Laws	Summary of Main Provisions
Law of the Soil Pollution Prevention and Control (20l8 revised) https://www.mee.gov.cn/ywgz/fgbz/fl/201809/t20180907_549845.shtml	Soil pollution risk control, remediation, monitoring
Law of the People' Republic of China on Urban Real Estate Industry Regulation (2011 revised) http://www.npc.gov.cn/zgrdw/npc/xinwen/lfgz/zxfl/2007-08/30/content_371220.htm	Land-use right, exploitation of real estate, real estate transaction (housing mortgage, transfer, and lease), real estate management
Law of the People's Republic of China on Water Pollution Prevention and Control (2008 revised) http://www.npc.gov.cn/c2937/c2942/201905/t20190522_50715.html	Control pollution of drinking-water sources, industrial pollution, agricultural non-point source pollution and ecological damage.
Law of the People's Republic of China on Energy Saving (2008) https://www.changzhou.gov.cn/gi_news/133983688257925	To reduce energy consumption in all aspects of production, to achieve effective and rational use energy.
Law of the People' Republic of China on Renewable Energy (2005) https://www.12371.cn/2020/06/22/ARTI1592756892780503.shtml	To deliver renewable energy industry instruction and technical support, including economic incentive and supervision measures
Law of the People's Republic of China on Solid Waste Prevention and	Reduce Solid-waste emission, fully

Control (2004) https://www.gov.cn/zhengce/2005-06/21/content_2602173.htm	utilize decontaminated solid waste, promote clean production and recycling economy
Law of the People's Republic of China on Promoting Clean Production (2002 revised) http://sthjj.ningbo.gov.cn/art/2004/1/1/art_1229062512_992798.html	Clean-production instruction and incentive measures
Law of the People's Republic of China on Environmental Impact Assessment (2002) http://www.bjchy.gov.cn/affair/zfyj/law/42879.htm	Planning and implementation of environmental impact analysis, forecasting and assessment of construction projects
Water Law of the People's Republic of China (2002) https://www.gov.cn/gongbao/content/2002/content_61737.htm	Development, use, conservation, protection, and management of water resources
Grassland Law of the People's Republic of China (2002) https://www.moa.gov.cn/gk/zcfg/fl/200601/t20060123_541189.htm	Protection, use, and development of grassland, conservation of biological diversity development of modern cattle husbandry
Law of the People's Republic of China on Air Pollution Prevention and Control (2000) https://www.gov.cn/gongbao/content/2000/content_60224.htm	Air-quality monitoring, combustion-pollutant control, motor vehicles and vessels emissions control

2.4.3.2 Policy Process and Implementation

Environmental policies in China are formulated through a top-down approach, with the central government setting national goals and standards. These policies are then translated into specific measures and targets at the provincial and local levels. Public participation and stakeholder consultations are increasingly being incorporated into the policy-making process to enhance transparency and accountability.

Over the past few decades, local governments in China have prioritized economic development over environmental protection (Mol and Carter, 2006; Yang et al., 2021). This preference stems from weak rule of law (Stern, 2010) and the frequent disregard of existing environmental regulations by local officials (Liu and Diamond, 2008). Although China's Environmental Protection Law obligates local governments to ensure environmental quality within their jurisdictions and mandates corrective measures, enforcement remains inconsistent. Local Environmental Protection Bureaus (EPBs), the primary agencies tasked with supervision and enforcement, face institutional constraints: their budgets and personnel are controlled by other local government departments. As a result, EPBs are predominantly accountable to local governments rather than to the central Ministry of Environmental Protection. Without strong local commitment to environmental goals, EPBs struggle to enforce regulations effectively. Compounding this issue, internal power dynamics within horizontal leadership structures often hinder EPBs' regulatory functions (Lo et al., 2006).

The key characteristics of Chinese Environmental Regulation and its evolution over time are as follows. During the initial phase of reform and opening-up (1973-1987), China began transitioning from a planned economy to a market economy. However, environmental governance awareness remained weak, and environmental protection efforts were still in their nascent stage. At this time, the environmental responsibilities of local governments were ill-defined, and environmental protection initiatives primarily relied on directives and policies from the central government.

As economic reforms deepened, the central government gradually devolved certain economic management authorities to local governments, leading to the preliminary formation of an environmental decentralization system (1988-2007). During this period, the central government progressively delegated some environmental regulatory powers to local governments, whose role in environmental governance became increasingly prominent.

With rapid socioeconomic development, environmental pollution problems intensified, prompting the central government to adjust and optimize the environmental decentralization framework (2008-2017) to address increasingly complex environmental challenges. In this phase, local governments gained greater autonomy in environmental governance but also faced heightened responsibilities and pressures.

Since 2018, China has imposed stricter requirements for ecological civilization construction. The central government has strengthened oversight and performance evaluation of local governments' environmental efforts through institutional mechanisms such as environmental inspection systems and ecological damage compensation schemes, ensuring more effective fulfillment of environmental responsibilities (Xu, 2022). While local governments now enjoy expanded autonomy and innovation capacity in environmental governance, they are also subject to more rigorous accountability and performance assessment mechanisms (Kostka and Nahm, 2017). To ensure effective implementation, China employs a combination of administrative, economic, and legal instruments (Schreifels and Wilson, 2012). Administrative measures include setting emission standards, issuing permits, and conducting inspections. Economic incentives, such as pollution taxes, subsidies for eco-friendly technologies, and carbon trading, are also used to encourage businesses to adopt cleaner production methods. Legal sanctions, including fines and criminal penalties, are imposed for violations of environmental regulations.

3 Methodology

3.1 Introduction

This chapter describes the research methods, and the data used in this study. Firstly, I discuss the research methods to test how effective is China's environmental regulation. I use difference-in-difference (DID) method to test the effectiveness of China's environmental regulation. In order to verify the robustness of DID results, I also use the parallel trend test, robustness tests, influence mechanism test, and heterogeneity analysis. Then, I describe the selection of variables, data selection, data processing and data merging. The chapter also discusses the specific methodology and data limitations that this study may face and potential remedies for these limitations.

3.2 Research Methods

This section explains the research design and explains why the chosen methodology is the most appropriate for this research. It discusses the general aspects of the methodology. I present the different techniques employed in this study. I adopt the quantitative analysis method. It comprises the DID method. Then, I use some robustness tests to examine whether the DID model is robust. The techniques have be illustrated as shown below.

3.2.1 Two-Way Fixed Effect (TWFF) Model

The Two-Way Fixed Effects (TWFE) model is a panel regression method that controls for unobserved heterogeneity across two dimensions, entity (e.g., firm)-level fixed effect and time (e.g., year)-level fixed effect. This model can account for time-invariant differences between entities and incorporate additional covariates to address time-varying confounders.

$$y_{it} = \beta X_{it} + \gamma_t + \gamma_i + \varepsilon_{it} \tag{3.1}$$

y_{it} is the dependent variable, X_{it} is the independent variable, γ_t is entity level fixed effect to control for time-invariant firm characteristics, γ_i is time level fixed effect to control for period-specific shocks, ε_{it} is the error term.

3.2.2 Tobit Model

The Tobit model, named after economist James Tobin (1958), is a regression model designed to analyze censored or truncated data where the dependent variable is only observed within a limited range. It is widely used in economics, finance, and social sciences. The Tobit model was a conventional estimation technique when the dependent variable was censored at zero (Sigelman and Zeng, 1999). The Tobit model has been applied to international trade (Carr et al., 2001) and FDI (Razin and Sadka, 2007) research. There are three features of the Tobit model.

First, censored data. The dependent variable y is only observed within a specific range, such as $y \geq 0$.

Second, latent variable. The model assumes an underlying (unobserved) latent variable y^* that follows a linear relationship:

$$y^* = x\beta + \varepsilon, \quad \varepsilon \sim N(0, \sigma^2) \tag{3.2}$$

Third, observed data. The observed y is a censored version of y^*:

$$y = \begin{cases} y^* & if\ y^* > L \\ L & if\ y^* \leq L \end{cases} \tag{3.3}$$

3.2.3 The Difference-in-Difference (DID) Method

As an important econometrics method, DID model has been widely used to evaluate the effects of various economic policies and health policies, and has achieved good results (Bertrand et al., 2004; Lechner, 2011; Dimick and Ryan, 2014). The principle is based on a counterfactual framework to assess changes in observed factors if policies occur and do not occur.

The classical DID model is an extension of the before-after design, which emphasizes the addition of a control group before and after differences, and the comparison of the differences between the treatment group and the control group before and after differences, forming a quasi-experimental design (Lee, 2016; Cook et al., 2002). The purpose of adding the control group is to eliminate the other influences in the treatment group before and after the experiment. In short, confounding variables operate in both the treatment and control groups, allowing their net effect to be eliminated by differences between the pre- and post-experimental and the pre- and post-control groups. Since it is a comparison of two differences, DID model is also called "double difference". Therefore, the classic DID model must include two time points before and after the experiment, as well as a treatment group and a control group, to form four observable outcomes. However, DID models have numerous extensions to this basic, simple parameterization, where three or more groups and/or multiple time periods can be included in the model (Imbens and Wooldridge, 2009).

The traditional DID model is as follows:

$$y_{it} = \beta_0 + \beta_1 treat_i \times post_t + \beta_2 treat_i + \beta_3 post_t + \eta X_{it} + \varepsilon_{it} \tag{3.4}$$

$$treat_i = \begin{cases} 1, & if \quad i \in treatment \quad group \\ 0, & if \quad i \in control \quad group \end{cases}$$

$$post_t = \begin{cases} 1, & if \quad t \in post \quad group \\ 0, & if \quad t \in before \quad group \end{cases}$$

$treat_i$ is the policy dummy variable; $post_t$ is the time dummy variable. $treat_i \times post_t$ is the interaction item of DID model. Let the change of *y* in the treatment group be D1 and that in the treatment group be D2, then the actual effect of policy impact is D = D1-D2.

$$
\begin{aligned}
D1 &= E(y \mid treat = 1, post = 1) - E(y \mid treat = 1, post = 0) \\
&= (\beta_0 + \beta_1 + \beta_2 + \beta_3) - (\beta_0 + \beta_2) \\
&= \beta_1 + \beta_3
\end{aligned} \tag{3.5}
$$

$$
\begin{aligned}
D2 &= E(y \mid treat = 0, post = 1) - E(y \mid treat = 0, post = 0) \\
&= (\beta_0 + \beta_3) - \beta_0 \\
&= \beta_3
\end{aligned} \tag{3.6}
$$

$$
D = D1 - D2 = (\beta_1 + \beta_3) - \beta_3 = \beta_1 \tag{3.7}
$$

Therefore, β_1 is the DID estimator.

Nanthan and Qian (2011) used the continuous DID model to conduct research. Continuous DID refers to replacing the policy grouping dummy variable in the regional (individual) dimension with a continuous variable to reflect changes in degree. In my thesis, the mandatory SO_2 emissions target scheme strengthened in the 11th Five-Year Plan is continuous. So drawing on Nanthan and Qian (2011) and under the TWFE model or Tobit model, I adopt the DID method and regard the mandatory SO_2 emissions target scheme strengthened in the 11th Five-Year Plan from 2006 as a natural experiment. I compare the change in cities with more stringent environmental regulations with equivalent changes in cities with less stringent environmental regulations before and after 2006 based on the following model:

$$
Y = \alpha + \beta_1 treat_c \times post_t + \beta_2 treat_c + \beta_3 post_t + \eta X_{it} + \gamma_t + \gamma_i + \varepsilon_{it} \tag{3.8}
$$

Where, *i* represents firm, *c* represents city, and *t* represents year. Y represents the explained variables (firms' pollution emissions intensity, total factor productivity, two-way foreign direct investment and firm export performance). $treat_c \times post_t$ represents environmental regulation. $treat_c$ is the continuous grouping index, and $post_t$ is a time dummy variable. X_{it} represents a set of control variables. γ_t is the year fixed effect, γ_i is the firm fixed effect, and ε_{it} is the random disturbance term. In order to eliminate possible autocorrelation and heteroscedasticity, all regressions are clustered at the firm level. Because I include year fixed effect, the $post_t$ indicator is collinear with the year dummies and drops out of the regression. So I can't report the coefficient of $post_t$.

The DID method, a widely adopted econometric approach in policy evaluation, is primarily employed to assess the differential impacts of interventions or events on treatment and control groups. To ensure the robustness and validity of the DID estimator, several key assumptions must be satisfied:

Parallel Trends Assumption: This critical assumption posits that, in the absence of treatment, the average outcomes for both treatment and control groups would have followed parallel trajectories over time. This assumption is fundamental to the causal interpretation of the DID estimator, as it ensures that post-intervention differences can be attributed to the treatment effect rather than pre-existing group-specific trends. So I use the event analysis to test parallel trends assumption.

3.2.4 Parallel Trends Assumption Test

The DID method does not require that the treatment group and the control group be completely identical. There may be some differences between the two groups, but the DID method requires that the difference does not change over time. That is to say, the premise of using the DID model is that the treatment group and the control group meet the same trend assumption before the implementation of the policy (Bertrand et al., 2004). To verify the parallel trends assumption, the study uses the event analysis method to test the common trend of the treatment group and the control group (Jacobson et al., 1993). Specifically, a series of dummy variables are added to establish the following measurement model:

$$y_{it} = \beta_0 + \sum_{1}^{j} \beta_j D_{ct}^{-j} + \sum_{1}^{j} \gamma_i D_{ct}^{+j} + \mu_i + \lambda_t + \eta X_{it} + \varepsilon_{it} \tag{3.9}$$

In the model, *D* (for writing purposes, $treat_c \times post_t$ is simply written *D*) is a series of dummy variables. When the treatment group is *j* years before the policy shock occurs, D_{ct}^{-j} is 1, otherwise, D_{ct}^{-j} is 0; D_{ct}^{+j} is 1 when the treatment group is *j* years after the policy shock occurred, otherwise, D_{ct}^{+j} is 0. In this study, dummy variables in the year when the policy shock occurred were excluded, which is equivalent to taking this year as the control group. The estimated coefficient of *D* in the regression results represents whether there is a significant difference in the changing trend of explained variables between the treatment group and the control group in *j* years before and after the policy takes place.

3.2.5 Advantages

1. The DID model can effectively overcome the interaction between independent variables and dependent variables, and control heterogeneity that does not change with time, so as to avoid the endogeneity problem (Kong and Liu, 2023; Yan et al., 2024).

2. It is simple and easy to use the DID model to introduce the intergroup dummy variable, time dummy variable, and their interaction term into the econometric model (Zhang et al., 2023).

3. The use of the DID model to measure through statistical significance the effect of policy implementation, compared with the method of comparing before and after the implementation of policies, can effectively overcome the "pseudo correlation" problem, which is mistaken for the existence of causal relationship due to the influence of the potential factors of the third party (Gu, 2024).

3.2.6 Limitations

Regarding the estimation of the error terms, this study may have a few limitations.

1. Three factors make serial correlation an important issue in the DID setting. First, the DID model relies on a long time series. Second, the dependent variable in the DID estimate is generally highly positively serially correlated (Daw and Hatfield, 2018). Third, the control group changes little over time within a city. These three factors reinforce each other, producing potentially large errors in the standard errors of the OLS estimates. This study will run a series of checks on the error terms to ensure that serial correlation and heteroscedasticity do not pose a substantive issue. In addition, I use the data from 2000 to 2010 which is a long time series. It can effectively avoid serial correlation issue.

2. This study suggests the inclusion of several independent variables, which may be contrary to multicollinearity and other traditional statistical principles. As a result, this study will examine the correlations between independent variables and will likely need to eliminate any variables with high correlations.

3. As in any quantitative study, measurement error and unobserved heterogeneity may cause biases in the findings, particularly with regard to the error terms, although the presence of classical measurement error tends to skew the findings in favor of zero (Wiley and Wiley, 1970). Given the use of the DID model, time-varying unobserved heterogeneity would be more concerning for the interpretation of the findings. To make sure there are no other time-varying shocks that could alter the results, all extra control variables will be examined to see if they change post-policy. In addition, I also use some heterogeneity tests to test the effectiveness in different regions and industries.

3.2.7 Improvement Measures

3.2.7.1 Robustness Test

Based on the original model, more models are invented by changing the research time interval and sample interval to test whether the research results obtained by DID method are robust.

1. Two-period double difference method. Based on Bertrand, Duflo and Mullainathan (2004), this part re-estimates the potential sequence-dependent problems by constructing a two-period double difference model. Specifically, firstly, I take the time when the policy occurred as the time node and divide the sample period into two stages: before and after the policy occurred. At each stage, arithmetic averages are calculated for each firm’s variables, and then regressions are performed. Through this method, I can effectively compare the long-term average effects of policies.

2. Winsorize. In statistics, it is common to encounter extreme values. In order to ensure the robustness of the estimated results, the winsorize treatment is usually used for robustness tests (Bu and Ren, 2023). Specifically, values greater than 99% quantile are replaced by a 99% quantile value; and values less than the 1% quantile with 1% quantile values. If the regression result is still significant, it indicates that the basic regression is robust.

3. Eliminate other policy distractions. In 2007, the government formally launched a pilot policy on the paid use and trading of sulfur dioxide emission rights and approved 11 pilot provinces for sulfur dioxide emission rights trading in Jiangsu, Tianjin, Zhejiang, Hebei, Shanxi, Chongqing, Hubei, Shaanxi, Inner

Mongolia, Hunan, and Henan, involving a wide range of industries such as iron and steel, cement, glass, chemical, and mining (Yang et al., 2024). Governments at all levels set the benchmark price for trading sulfur dioxide emission rights, and the actual trading price is mainly regulated by the market. According to the actual emission needs, emissions enterprises can buy or sell quotas at the regional emission trading centers, and in regions where trading centers have not yet been set up, emissions enterprises can also trade in other ways stipulated by the government. Sulfur dioxide trading adds a stringent sulfur dioxide constraint mechanism on enterprises. If a firm's actual emissions exceed the sulfur dioxide emission quotas allocated to it, it must purchase the missing quotas on the market or face fines or other penalties. This is equivalent to adding a sulfur dioxide cost to the firm, giving it an incentive to take energy-saving and emission reduction measures to reduce its own sulfur dioxide emissions. On the other hand, sulfur dioxide emissions trading gives enterprises the opportunity to obtain more sulfur dioxide emission allowances from the market. If a firm reduces its own sulfur dioxide emission intensity through technological innovation or structural adjustment, it can save sulfur dioxide costs and obtain additional benefits. Therefore, the implementation of the sulfur dioxide emissions trading policy has had a significant impact on the production decisions and technological innovation inputs of enterprises. Since it is a sulfur dioxide emissions trading system, my explanatory variable is also sulfur dioxide and the year 2007 is between the sample periods of my research, the emissions trading system may have interfered with my research. Therefore, the interaction terms of dummy variables of the emission trading policy treatment group and the policy time dummy variables are added to eliminate the interference of parallel policies on the estimated results of this research. If the estimated coefficient of $treat_c \times post_t$ is still significant, indicating the estimated results are robust, that is, environmental regulation policy is effective.

4. Using a relative target. I use the percentage of reduction to test whether the basic regression results are robust. If the estimated coefficients are still significant, indicating the estimated results are robust, that is, environmental regulation policy can effectively influence the SO_2 emission intensity, tfp, two-way FDI and export performance.

5. Placebo test. To ensure that the observed reduction in SO_2 intensity was indeed policy-induced rather than attributable to other confounding factors, I conducted a placebo test using smoke and dust emissions intensity as alternative outcome variables. If the regression results demonstrate statistically insignificant effects of SO_2 emission reduction target on both smoke and dust emissions, this finding means that the

documented decrease in SO_2 emission intensity was specifically driven by the policy intervention rather than other factors.

3.2.7.2 Influence Mechanism Test

In order to test the channels through which environmental regulations affect pollution emissions and China's economic indicators, I adopt the mechanism test for analysis. The mechanism test is widely used in social science research (Ren et al., 2021; Wu et al., 2021; Irfan et al., 2022).

The mechanism test is composed of mechanism variables, independent variables, and dependent variables. The relationship among the three is as follows: If independent variable X has a certain influence on dependent variable Y through a certain variable M, then M is called the mechanism variable of X and Y. The mechanism test can link existing studies on the same phenomenon together to find out the reason behind the phenomenon.

$$channel_{it} = \beta_0 + \beta_1 treat_c \times post_t + \beta_2 treat_c + \beta_3 post_t + \mu_i + \lambda_t + \eta X_{it} + \varepsilon_{it} \tag{3.10}$$

$$y_{it} = \beta_0 + \beta_1 treat_c \times post_t + \alpha channel_{it} + \beta_2 treat_c + \beta_3 post_t + \mu_i + \lambda_t + \eta X_{it} + \varepsilon_{it} \tag{3.11}$$

Formula (3.10) is the regression of independent variables to the mediation variable. If the estimation coefficient of $treat_c \times post_t$ is significant, it shows that environmental regulation has the impact on mechanism variables.

Formula (3.11) is the regression of independent variables and mediation variable to the explained variable. If the estimation coefficient of $channel_{it}$ is significant, it shows that mechanism variable has the impact on explained variable. And after controlling for the mediator variable, both the magnitude and statistical significance of the interaction term's coefficient estimate exhibited a notable change compared to the baseline regression estimates. This pattern of results provides empirical evidence supporting the existence of the hypothesized mediation effect.

3.2.7.3 Heterogeneity Analysis

Heterogeneity is the effect of one variable X on another variable Y that may vary from individual to individual. Heterogeneity analysis is a statistical analysis method used to study differences between different groups. I use sub-sample regression to test the impact of the implementation of environmental regulation policies on different groups. In order to compare the coefficient sizes, I have standardized the data using Z-score standardization method and conducted regression analysis again based on the standardized data. Z-score standardization (also called standardization or normalization) is a statistical technique that transforms a variable so that it has a mean of 0 and a standard deviation of 1 (Vaccario et al., 2017). This allows for comparing variables on the same scale, making regression coefficients and other statistical measures more interpretable. The Z-score of a value *x* is calculated as:

$$Z = \frac{x - mean}{std} \tag{3.12}$$

1. Firm ownership. Firms can be divided into state-owned enterprises and non-state-owned enterprises. State-owned enterprises, state-owned joint ventures, wholly state-owned companies or joint-stock cooperation and joint-stock limited liability companies with the absolute controlling status of state-owned economy are all state-owned enterprises (Parker and Pan, 1996; Hu et al., 2017). The other enterprises are non-state enterprises. State-owned enterprises are often closely related to the government, and their environmental governance activities are more driven by administrative directives and political assessments. They may find it easier to meet emission reduction requirements in the short term because they enjoy advantages such as financial subsidies and policy loans (Zhang, 2017； Zhang and Zhao, 2022). In contrast, non-state-owned enterprises are more sensitive to market signals and cost pressures. Strict environmental regulations may force them to reduce emissions intensity through technological upgrading or cleaner production, but they may also be forced to reduce production, relocate, or even exit the market due to financing constraints or high compliance costs. Therefore, the impact of environmental regulatory policies on the two types of enterprises may be very different (Wang et al., 2022). Therefore, I explore heterogeneity from the perspective of enterprise ownership.

2. Firm size. According to the firms’ median size, I divide firms into large scale firms and small scale

firms. If the firm size is greater than the median, it is a large scale firm; otherwise, it is a small scale firm. Examining the heterogeneous effects of the effective of SO_2 emission regulation by distinguishing between large-scale and small-scale enterprises is crucial for both theoretical and policy reasons. This classification reflects fundamental differences in how firms of varying sizes respond to regulatory pressures: large firms typically possess stronger financial capabilities and better access to financing, enabling them to absorb the high fixed costs of pollution control equipment and potentially achieve economies of scale in emission reduction. They are also more likely to pursue technological innovations for long-term environmental compliance, consistent with the Porter Hypothesis. In contrast, small enterprises often face severe financial constraints, where compliance costs may threaten their viability, leading to either passive compliance strategies or even regulatory evasion (Lei et al., 2017; Sun et al., 2020).

3. Factor density. According to the factor density, I can divide the industry into labor-intensive industry, capital-intensive industry and technology-intensive industry. Labor-intensive industry refers to the industry whose production mainly relies on the use of a large number of labor forces and relies less on technology and equipment (Chen and Li, 2019; Dai et al., 2022). Capital-intensive industry refers to the industry in which the capital cost accounts for a large proportion of the unit product cost and the fixed and working capital amount occupied by each worker is high (Wang, 2016). Technology-intensive industry refers to the industry that relies much more on technology and intelligence than on other production factors in the production process.

Labor-intensive industries include 15 industries such as processing of food from agricultural products, manufacture of foods, manufacture of beverages, manufacture of tobacco, manufacture of textile, manufacture of textile wearing apparel, footwear and caps, manufacture of leather, fur, feather and related products, processing of timber, manufacture of wood, bamboo, rattan, palm and straw products, manufacture of furniture, manufacture of paper and paper products, printing, reproduction of recording media, manufacture of articles for culture, education and sport activities, manufacture of rubber, manufacture of plastics and manufacture of artwork and other manufacturing. Capital-intensive industries include 8 industries such as processing of petroleum, coking, processing of nuclear fuel, manufacture of non-metallic mineral products, smelting and pressing of ferrous metals, smelting and pressing of non-ferrous metals, manufacture of metal products, manufacture of general purpose machinery, manufacture of special purpose machinery, and manufacture of measuring instruments and machinery for cultural activity and office work. Technology-intensive industries include 6 industries such as manufacture of raw chemical materials and chemical products, manufacture of medicines, manufacture of chemical fibers, manufacture of transport equipment, manufacture of electrical machinery and equipment, and manufacture of communication equipment, computers and other electronic equipment.

When examining the impact of environmental regulations on SO_2 emission intensity, conducting heterogeneity analysis across industries with different factor intensities (labor-intensive, capital-intensive, and technology-intensive) is critically important. This approach recognizes fundamental differences in pollution characteristics, technological capabilities, and policy responsiveness across these distinct industry types. Labor-intensive industries typically exhibit lower energy efficiency and weaker pollution control capacity. Capital-intensive industries generate substantial aggregate emissions. Technology-intensive sectors demonstrate greater capacity for proactive emission reduction through green innovation (Cao et al., 2019; Zhang and Chen, 2022). This classification not only reveals the heterogeneous mechanisms through which environmental regulations operate across industries but also informs the development of differentiated policies.

4. Regional heterogeneity. According to the division of the three regions of China by the Chinese Bureau of Statistics, enterprises located in Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan samples belong to the eastern region; enterprises located in Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan samples belong to the central region; enterprises located in Yunnan, Sichuan, Ningxia, Guangxi, Inner Mongolia, Xinjiang, Gansu, Xizang, Guizhou, Chongqing, Shaanxi and Qinghai samples belong to the western region.

5. Different industries. There are 29 manufacturing industry segments in China: processing of food from agricultural products (industry code: 13), manufacture of Foods (14), manufacture of beverages (15), manufacture of tobacco (16), manufacture of textile (17), manufacture of textile wearing apparel, footwear and caps (18), manufacture of leather, fur, feather and related products (19), processing of timber, manufacture of wood, bamboo, rattan, palm and straw products (20), manufacture of furniture (21), manufacture of paper and paper products (22), printing, reproduction of recording media (23), manufacture of articles for culture, education and sport activities (24), processing of petroleum, coking,

processing of nuclear fuel (25), manufacture of raw chemical materials and chemical products (26), manufacture of medicines (27), manufacture of chemical fibers (28), manufacture of rubber (29), manufacture of plastics (30), manufacture of non-metallic mineral Products (31), smelting and pressing of ferrous metals (32), smelting and pressing of non-ferrous metals (33), manufacture of metal products (34), manufacture of general purpose machinery (35), manufacture of special purpose machinery (36), manufacture of transport equipment (37), manufacture of electrical machinery and equipment (39), manufacture of communication equipment, computers and other electronic equipment (40), manufacture of measuring instruments and machinery for cultural activity and office work (41) and manufacture of artwork and other manufacturing (42).

I use sub-sample regression to test the impact of the implementation of environmental regulation policies on different individual.

3.3 Independent Variable

The independent variable used in this study is environmental regulation. Environmental regulation can be divided into formal environmental regulation and informal environmental regulation. Formal environmental regulation means that the government, through laws, regulations, or policies, makes provisions on the abatement standards of pollutants and the modes of production and operation of regions, industries, and enterprises. For example, the "two control zeros policy" in China in 1998. Informal environmental regulations generally refer to the supervision and reporting of pollution-intensive enterprises from the social level by relying on the public's awareness of environmental protection and the media's sense of social responsibility. Such environmental regulations largely depend on local people's education level, environmental awareness, per capita income, and other factors, which are difficult to accurately quantify.

At present, scholars have divided the measures of environmental policy intensity into five categories: first, the number of environmental regulation policies issued by the government; Second, the proportion of pollutant abatement fees in the output value; Third, the expenditure for the construction and operation of environmental pollution control infrastructure; Fourth, the emission of a single pollutant per unit of output; fifth, the number of tests conducted by the environmental protection departments on the pollutant abatement of enterprises (Lanoie et al., 1998). However, the above indicators may underestimate the intensity of environmental regulations or the endogeneity of the variables used in the study, which may lead to errors in the measurement of the intensity of environmental regulations and failure to effectively evaluate the effectiveness of environmental regulations. However, since the DID method is based on natural experiments, it can solve this problem well.

The 11th Five-Year Plan delineates two primary emission reduction objectives: a) an approximate 20% decrease in energy intensity per unit of GDP, and b) a 10% reduction in the aggregate emissions of key pollutants (Marquis et al., 2011). These targets can be elucidated as follows (State Council, 2007): First, energy intensity reduction: The reduction of energy consumption per unit of GDP by approximately 20%: This objective entails a 20% decrease in energy consumption per unit of GDP by 2010, relative to the 2005 baseline. Second, pollutant emission reduction: The plan mandates a 10% reduction in the total emissions of major pollutants. Specifically, it focuses on two key indicators: a) Chemical Oxygen Demand (COD): The target is to reduce COD emissions from 14.14 million metric tons in 2005 to 12.73 million metric tons by 2010. b) Sulfur Dioxide (SO_2): Emissions are to be curtailed from 25.49 million metric tons in 2005 to 22.94 million metric tons by 2010 (Liu et al., 2012; He et al., 2020).

The provincial level SO_2 emission reduction targets in this study were mandated by the central government, thereby establishing explicit reduction goals for each province (Xu, 2011; Liu et al., 2022). The emission control targets outlined in China's 11th Five-Year Plan exerted substantial impacts across provincial, municipal, and enterprise levels. At the municipal level, provincial governments disaggregated these targets into more specific city-level objectives, taking into account each city's economic structure, industrial base, and environmental conditions (Fan et al., 2025). Consequently, all enterprises within a given municipality were subject to the corresponding SO_2 reduction targets. In operationalizing these city-level emission targets, I followed the methodological approach established by Chen et al. (2018) and Fan et al. (2025), which aligns with current mainstream literature practices in this field.

The Five-Year Plan offers a quasi-natural experimental setting because the assignment of more stringent emission reduction targets was largely based on regional economic and environmental conditions, rather than provinces' voluntary choices. Provinces had limited discretion in negotiating their targets and that the final targets were largely determined by central government unified mandates (Xu, 2011). After establishing the national target of reducing SO_2 emissions by 10% in the 11th Five-Year Plan, each province and the central government negotiated their respective responsibilities. The pollution reduction contract with clear provincial targets is the result of negotiations and signed by the deputy governors of each province (State Environmental Protection Agency, 2006).

In conclusion, given the realities of environmental target setting and enforcement in China, the 11th Five-Year plan presents the best available opportunity to observe a "quasi-natural experiment". I believe that my empirical design, coupled with additional robustness checks and sensitivity analyses, provides a credible estimate of the effectiveness of China's SO_2 emissions regulation.

In the DID model, environmental regulation can be represented as $treat_c \times post_t$. This section describes the independent variables in greater detail. As emission control targets set by the central government and local governments vary, the stringency of regulation varies considerably from city to city, which helps to determine the causal relationship between environmental regulation and firm response. Therefore, I adopted the DID strategy facilitated by a mandatory SO_2 emissions reduction target scheme that was substantively strengthened by the 11th Five-Year Plan from 2006. I compared firm pollution in cities with more stringent environmental regulations around 2006 with equivalent changes in cities with less stringent environmental regulations.

$treat_c$ is the continuous grouping index of the treatment group and the control group, that is, the environmental regulation intensity of each city, which is measured by the SO_2 control target (ten thousand tons) of the city c. $post_t$ is a dummy variable equals to 0 for all years before 2006, and to 1 from 2006 and onward.

As the core of the emissions control target, provinces were assigned different emissions reduction targets within the 11th Five-Year Plan. Table 2.14 reports the provincial emissions reduction targets. From this table, Shandong province, which had the highest target, was obliged to reduce 0.401 million tons of SO_2 between 2006 and 2010, while Hainan, Xizang, Qinghai, Gansu and Xinjiang at the bottom of the list, had no targets for SO_2 emissions control.

An important question is how to measure the SO_2 control target of a city. Although the stringency of environmental regulation is intangible, it can reasonably be replaced by the different SO_2 reduction targets set out in the 11th Five-Year Plan. Considering that publicly available official documents only provide provincial emission reduction targets, I constructed municipal emission reduction targets following Chen et al. (2018) as follows:

$$\Delta SO_{2c,06-10} = \Delta SO_{2p,06-10} \times \sum_i u_i \frac{output \quad value \quad of \quad industry \quad i}{output \quad value \quad of \quad industry \quad i \quad in \quad province \quad p} \tag{3.13}$$

$\Delta SO_{2c,06-10}$ ($treat_c$) is SO_2 emissions reduction targets in the 11th Five-Year commitment period for city *c*. $\Delta SO_{2p,06-10}$ is SO_2 emission reduction target in the 11th Five-Year commitment period for province *p*, as shown in Table 2.14, which has been published. The second term on the right-hand side of the equation is a measure of a city's proportion to its province's total output value across all the two-digit industries, weighted by each industry's proportion of SO_2 emissions to total SO_2 emissions from manufacturers, u_i .

Figure 3.1 provides a map of China in which I depict the level of $treat_c$ of all 288 cities in my sample. The darker the color is, the higher the emissions reduction targets are and the stricter the environmental regulations and legal enforcement.

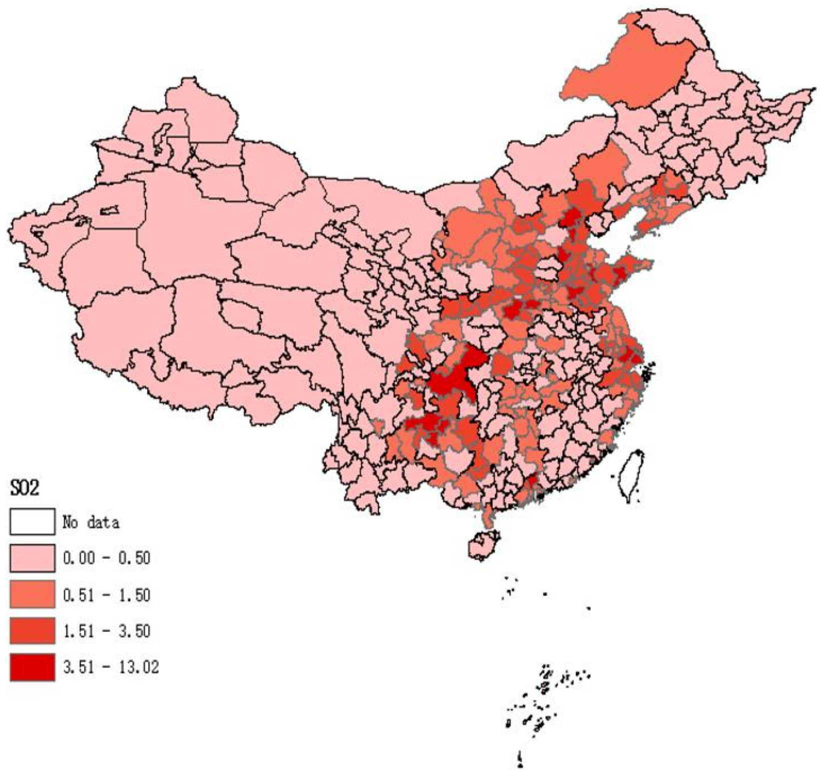

Figure 3.1: City-Level Regulation Stringency of SO_2

Source: Analysis reported in this thesis. Unit: 10 thousand tons.

These targets have not been implemented outside the province. Each province has its own emission reduction targets (Marquis et al., 2011; Liu et al., 2012). The emission reduction targets set forth in China's Eleventh Five-Year Plan had significant ramifications for cities, sectors, and firms (Liu and Wang, 2017; Fan et al., 2025). In response to the SO_2 reduction emissions target set by the central government, provincial governments design their own enforcement plans and allocate the regulatory burdens to different prefectural cities and counties in their jurisdictions. Lower levels of governments then identify all the main polluting sources and calculate how much emission each polluting source should abate in order to realize SO_2 reduction emissions target (Fan et al., 2025).

For cities, the targets were often translated into more specific, local-level goals, taking into account the economic structure, industrial base, and environmental conditions of each city (Chen et al., 2018). Cities with higher initial SO_2 emissions levels typically faced more stringent reduction targets. These cities often implemented more aggressive policies, such as shutting down older, more polluting factories or promoting the adoption of cleaner technologies (Cao et al., 2009).

For sectors, the targets were not uniformly applied across all industrial sectors. Heavily polluting industries, such as power generation, cement, and steel production, were subject to stricter controls. I found that these sectors were required to invest more in pollution control technologies and were often subject to more frequent inspections and monitoring (Shen et al., 2017). In contrast, sectors with lower SO_2 emissions, such as light manufacturing and services, faced less stringent regulations.

For firms, the targets meant the need for significant investments in pollution control equipment and operational changes to reduce emissions. Smaller firms, particularly those lacking the financial resources or technological capabilities to comply, faced the greatest challenges (Lei et al., 2017). Some firms chose to relocate to areas with less stringent regulations, while others merged with larger companies to pool resources for compliance.

The enforcement of the emission reduction targets was multifaceted. First, regulatory threats. The threat of factory closures for non-compliance was a significant motivator for firms to reduce emissions. To achieve the emission reduction targets set in the 11th Five-Year Plan, some local governments have taken major measures, such as significantly reducing the use of electricity or heating systems. The governments of provinces such as Hebei, Guangxi, Jiangsu and Zhejiang have shut down some factories in highly polluting industries such as steel. However, this was not the only enforcement mechanism (Marquis et al., 2011). Firms that failed to meet targets were also subject to fines, production quotas, and restrictions on new project approvals (Cao et al., 2009; Liu and Wang, 2017). Second, economic incentives. In addition to penalties, the government also provided economic incentives for firms that exceeded their reduction targets. These incentives included tax breaks, subsidies for pollution control technologies, and preferential access to government contracts (Marquis et al., 2011). Finally, monitoring and reporting. To ensure compliance, the government implemented a robust monitoring and reporting system. Firms were required to install continuous emission monitoring systems (CEMS) and submit regular reports to local environmental agencies. These agencies then verified the data and took enforcement actions as necessary (Chen et al., 2018). The combination of regulatory threats, economic incentives, and rigorous monitoring played a crucial role in achieving the emission reduction targets.

3.4 Data Selection

3.4.1 Data Source

This research uses data collected from numerous sources. The data in this research mainly come from the

China Annual Survey of Industrial Firms Database (ASIF), Annual Environmental Survey of Polluting Firms (AESPF) of China, China Customs Import and Export Data (CCD), the China Patent Database and the Financial Statements Database of Chinese Listed Companies.

1. The China Annual Survey of Industrial Firms Database (ASIF)

The database is established by the National Bureau of Statistics of the People's Republic of China, and its data is mainly collected from the quarterly and annual reports submitted by the sample enterprises to the local statistics bureau. The full name of the database is "Database of all state-owned and non-state-owned industrial enterprises above designated size". Its sample scope is all state-owned industrial enterprises and non-state-owned industrial enterprises above scale, and its statistical unit is enterprise legal person. The statistical standard of "industry" here includes three categories of "extractive industry", "manufacturing industry" and "production and supply industry of electricity, gas and water" in the "classification of industries of the National Economy", mainly manufacturing industry (accounting for more than 90%). The "above scale" here requires that the annual main business income (that is, sales) of the enterprise is 5 million yuan and above, and the standard was changed to 20 million yuan and above in 2011.

The China Annual Survey of Industrial Firms Database is the most comprehensive firm database. The database includes two kinds of information of the enterprise, one is the basic situation of the enterprise and the other is the financial data of the enterprise. The basic information of an enterprise includes legal person code, enterprise name, legal person representative, contact telephone number, postal code, specific address, industry, registration type (ownership), affiliation, year of operation and number of employees and other indicators. The financial data of the enterprise includes current assets, accounts receivable, long-term investment, fixed assets, accumulated depreciation, intangible assets, current liabilities, long-term liabilities, paid-in capital, main business income, main business costs, operating expenses, administrative expenses, financial expenses, operating profits, total profits and taxes, advertising expenses, research and development expenses, total wages, total welfare expenses, value-added tax, industrial intermediate inputs, and total industrial output value and export delivery value and other indicators. The total number of indicators is about 130.

2. The China Annual Environmental Survey of Polluting Firms Database (AESPF)

The database was established by the Ministry of Ecology and Environment (formerly known as the Ministry of Environmental Protection) in the 1980s in a bid to document the state of environmental pollution and abatement in China. AESPF covers rich information on firms' environmental performance, including emissions of main pollutants (industrial effluent, waste air, COD, NH_3, NOx, SO_2, smoke and dust, solid waste, noise, etc.), pollution abatement equipment, and energy consumption (usage of freshwater, recycle water, coal, fuel, clean gas, etc.), among others. It is currently the most comprehensive enterprise-level pollution emission data.

In the past 40 years, environmental surveys have gradually become normal, but since 2001, when the Tenth Five-Year Plan began, the scope, frequency, main indicators and reporting methods of environmental surveys have been basically stable. For example, a company is investigated when its emissions of a pollutant are in the top 85 percent of total emissions at the national level. These enterprises are included in the list of key environmental investigations. Once on the list, they are obliged to complete unified statistical statements sent by the environmental protection authorities, reporting various environmental information over the past year. The data will be confirmed and incorporated into the database after review and verification by the superior administrative department.

3. The China Customs Import and Export Data (CCD)

The China Customs Import and Export Data (CCD) from the General Administration of Customs of the People's Republic of China covers trade statistics of import and export goods, reflecting China's foreign trade situation. It contains monthly data on product-level transactions. It includes import and export, quantity, amount, unit price, customs code, commodity name, month, country of export destination (country of import origin), customs port, province or city (place of receipt or dispatch), mode of trade, mode of transportation, country of transit, nature of enterprise, economic zone of country, economic zone of enterprise, enterprise and its contact information (email, website, contact person, telephone, fax, address, etc.), revealing detailed international trade activities of Chinese import and export enterprises.

4. The China Patent Database

The China Patent Database is developed and provided by the State Intellectual Property Office of the People's Republic of China and the China Patent Information Center. It contains all patents since September 1985, including invention patents, utility model patents and design patents, and accurately reflects the latest patented inventions in China. The main data covers more than 20 indicators such as patent name, inventor, applicant, application date, public date, application number, public number, address, abstract, sovereign item, patent classification number, etc.

5. The Financial Statements Database of Chinese Listed Companies

The Financial Statements Database of Chinese Listed Companies comes from China Stock Market & Accounting Research Database (CSMAR) which is the largest, most accurate and comprehensive economic and financial research database in China. It is developed by Shenzhen Guotaian Education Technology Limited Company. The Financial Statements Database of Chinese Listed Companies collects quarterly, interim and annual reported financial data from A-share and B-share companies in the general and financial sectors listed on the Shanghai Stock Exchange, Shenzhen Stock Exchange and Beijing Stock Exchange since 1990. This database sets up five documents according to the types of statements published by listed companies: balance sheet document, income statement document, cash flow statement (direct method) document and cash flow statement (indirect method) document, and owner's equity statement document.

6. Directory data of Overseas Investment Firms (Institutions)

According to the "Overseas Investment Management Measures" (Order No. 3 of the Ministry of Commerce of the People's Republic of China in 2014), overseas investment refers to firms legally established in the People's Republic of China that own non-financial firms or firms overseas through new establishments, mergers and acquisitions, or other means. The act of acquiring ownership, control, management rights and other rights and interests of existing non-financial firms. The directory of overseas investment enterprises (institutions) records in detail information such as OFDI firms' names, locations of overseas institutions, transnational business scope, and approval dates.

7. The China City Statistical Yearbook 2021

The China City Statistical Yearbook is an annual information periodical that comprehensively reflects the social and economic development of Chinese cities. The China City Statistical Yearbook 2021 contains major statistical data on the social and economic development of cities at all levels across the country in 2020, with data from the relevant departments of each city. This yearbook is divided into four parts: the first part is the national urban administrative divisions, listing the distribution of different regions and different levels of cities; The second and third parts are the statistical data of prefecture-level cities and county-level cities respectively, including the data of population, resources and environment, economic development, scientific and technological innovation, people's livelihood, public services, infrastructure and other aspects; The fourth part is the appendix, which explains the main statistical indicators.

8. The China Statistical Yearbook on Environment

The China Statistical Yearbook on Environment is an annual comprehensive statistical data jointly compiled by the National Bureau of Statistics, the Ministry of Ecology and Environment and other relevant ministries and commissions, which reflects the basic situation of China's environment in various fields. It includes the basic environmental data of all provinces, autonomous regions and municipalities in the previous year and the main environmental statistics of major years.

3.4.2 Data Processing

1. The China Annual Survey of Industrial Firms Database (ASIF)

Step 1: Data cleaning and proofreading. Since the amount of data in the China Annual Survey of Industrial Firms Database is huge and is reported by firms every year, there will be issues with data accuracy. To this end, I checked the indicators on the obtained raw data and cleaned variables such as firm name, legal person code, and legal representative.

(1) Regarding the processing of firm names, first of all, there are punctuation marks such as "，", "。", "！" and "△", "▲", "（已注销）", "（破产）" and other fields, but according to China's firm naming standards, these fields should not appear in the firm name. So I delete those fields from the firm name. Secondly, the full-width and half-width status of the firm name will also have an impact on the computer's

recognition of the firm name. I have also unified them. Punctuation marks, English characters and numeric characters are all unified into half-width status, and Chinese characters are all unified into full-width status. Third, I screened out non-compliant fields through manual identification and then adjusted or eliminated them.

(2) Regarding the processing of legal person code, first of all, there are case inconsistencies in the legal person codes in some years. Through manual identification, I found that although the legal person codes are in different cases, they contain the same information and are the same firm. Therefore, I uniformly capitalize the letters of the legal person code. Second, the length of some legal person codes is less than the standard 9 characters. I found that the legal person code with only 8 characters was missing the last digit or the first digit, etc. The missing situation of legal person code information with other lengths (≤7 characters) was more complicated. Therefore, I replaced legal person code information that was less than 9 characters in length with null values.

(3) Regarding the processing of legal representative, first, for the legal person code samples that only appear in Chinese or English, I unified the English letters into a half-width display format. Secondly, for samples with more than two Chinese names filled in the legal representative information, I separated the multiple legal representative information in the sample. It indicates that the firm has multiple pieces of legal representative information in a specific year. Third, for samples where both Chinese and English appear in the legal representative, I manually identify and separate the Chinese name and English name, and divide them into two legal representative information.

(4) Regarding the processing of zip code, since the standard length of China's zip code is 6 characters, there are some zip codes with 5 characters, a small amount of zip code information with 4 characters or less, and zip code with non-numeric characters in the original data. I corrected the zip code through manual identification.

(5) Regarding the processing of industry code, the 4-digit industry codes in the China Annual Survey of Industrial Firms Database from 2000 to 2010 involve two sets of national economic industry classification standards: GB/T4754-1994 (1998-2002) and GB/T4754-2002 (2003-2012). I first compared the two versions of the 4-digit industry code with the official comparison table issued by the Bureau of Statistics

through manual identification, and then retained the 4-digit codes that corresponded to each other in the two sets of standards as a comparison table. For other industries that do not have one-to-one correspondence, I have unified them to the 2002 version of the industry code.

(6) Regarding the processing of province and city code, these codes in the China Annual Survey of Industrial Firms Database are obtained by intercepting the first 6 digits of the administrative division code. Among them, the first 2 digits represent provincial-level administrative divisions (provinces, autonomous regions, and municipalities directly under the Central Government), and the first 4 digits represent prefecture-level administrative divisions (prefecture-level cities, districts of municipalities directly under the Central Government, and districts of parts of provinces). However, in this database, there are cases where the last four digits of the province and city code are all 0 or the last two digits are both 0. For samples whose last four digits are all “0”, I manually corrected them based on the province and city codes of adjacent years.

Through the above cleaning process, I can ensure that in subsequent processing, samples with the same firm name, legal person code, legal representative and other firm information in the same year can be more accurately identified.

Step 2: Construct panel data with firm ID and year as two dimensions. It is difficult to find a unique characteristic to identify each sample firm for coding in this database. To this end, I identify whether different sample points come from the same firm based on basic information such as firm code, firm name, legal representative name, address, zip code, phone number, industry code, main product name, opening time, etc. The accuracy of firm code and firm name is relatively high and can be used as the main information on which I base my matching. Drawing on Brandt, Van Biesebroeck and Zhang (2012), I first identify the same firm based on the same firm code, and then identify it based on the same firm name, and finally refer to other basic information.

Step 3: Indicator exception handling. This database contains more than 130 indicators, but a considerable number of indicators have outliers. The existence of outliers makes many observations invalid, so they must be eliminated before performing econometric regression. Drawing on Cai and Liu (2009), I conduct the following processing on the China Industrial Enterprise Database. (1) I exclude firms with fewer than

8 employees to comply with China's official industrial enterprise definition and mitigate data quality issues. This ensures our sample represents economically meaningful entities with reliable reporting (Cai and Liu, 2009; Brandt et al., 2012); (2) delete firms with missing total industrial output value, net fixed assets and fixed assets; (3) delete firms with total industrial output value, net fixed assets and fixed assets are zero or negative (4) delete enterprises whose establishment age is less than zero; (5) reserve the two-digit industry code between 13 and 42; (6) Referring to Brandt et al. (2012), for the analysis in this thesis, I focus only on firms. The unit of analysis is the firm, and not the plant. Firm locations in my dataset reflect the actual operational addresses reported by the firms in the respective years.

The ASIF database processing situation is shown in Table 3.1.

Table 3.1: The China Annual Survey of Industrial Firms Database Processing

Data processing	Raw data	Construct panel data	Delete firms with less than 8 employees	Delete firms with missing data	Delete firms with 0/negative data	Delete age less than 0
2000	162,872	147,009	142,320	129,536	128,893	128,879
2001	171,254	155,453	151,991	140,113	139,352	139,344
2002	181,542	165,568	162,380	150,572	149,902	149,900
2003	196,206	180,825	178,701	169,230	168,362	168,328
2004	279,011	258,707	252,782	241,155	237,611	237,610
2005	270,023	249,377	248,374	238,159	237,651	237,651
2006	301,930	278,654	276,019	265,835	265,452	265,450
2007	336,732	312,707	310,913	300,490	300,012	300,012
2008	412,212	385,180	382,823	380,042	379,170	379,165
2009	366,130	340,756	338,787	317,023	314,760	314,755
2010	442,539	415,172	395,983	385,101	385,101	385,095
All	3,120,451	2,889,408	2,841,073	2,717,256	2,706,266	2,706,189

2. The China Customs Import and Export Data (CCD)

I conduct the following processing on the China Customs Import and Export Data: (1) Keep export data; (2) add up the monthly data to obtain the annual customs data; (3) delete enterprises whose company names include "economic and trade", "commerce", "trade", "logistics", etc., ; (4) delete enterprises whose trade value is less than \$50 and export quantity is less than 1; (5) delete the enterprise whose company name is blank; (6) delete enterprises whose export destination is China or unknown; (7) unify the HS6 bit code to the version of HS1996. The CCD database processing situation is shown in Table 3.2.

Table 3.2: The China Customs Import and Export Database Processing

Data processing	Raw data	Keep export data	Aggregate to firm level	Delete outlier firms
2000	10,598,247	1,857,622	80,231	61,479
2001	13,995,435	2,073,873	87,403	66,924
2002	13,843,463	2,472,089	97,166	72,835
2003	16,626,696	3,062,808	113,146	87,201
2004	19,703,008	3,736,429	134,894	106,283
2005	20,739,011	3,905,796	139,008	111,562
2006	25,661,754	5,756,679	198,498	158,136
2007	10,635,560	5,718,367	194,336	175,402
2008	11,230,600	6,663,346	210,672	179,865
2009	11,341,519	7,100,870	224,666	182,600
2010	13,356,580	8,747,604	247,633	200,047
All	167,731,873	51,095,483	1,727,653	1,393,334

3. The Financial Statements Database of Chinese Listed Companies

I conduct the following processing on the Financial Statements Database of Chinese Listed Companies: (1) Exclude Chinese listed companies that also issue B shares or H shares because these listed companies may be alienated due to multiple regulations. (2) Excluding ST and PT listed firms in a certain year or several years because their operating conditions are obviously abnormal. (3) The sample of listed firms in the financial sector is excluded because the financial conditions of financial firms differ significantly from those of ordinary firms. (4) Samples with missing key variables are excluded, for example, delete firms whose total assets are less than or equal to 0 or are missing or insolvent. The Financial Statements Database of Chinese Listed Companies Database processing situation is shown in Table 3.3.

Table 3.3: The Financial Statements Database of Chinese Listed Companies Processing

Data processing	Raw data	Excluding ST and PT listed firms	Delete financial firms	Delete firms with missing key variables
2000	1,176	911	876	797
2001	1,258	977	940	858
2002	1,319	1,042	1,004	902
2003	1,381	1,104	1,063	934
2004	1,469	1,197	1,156	1,005
2005	1,464	1,209	1,168	1,026
2006	1,547	1,264	1,221	1,052
2007	1,661	1,376	1,322	1,130
2008	1,715	1,445	1,391	1,203

2009	1,864	1,531	1,473	1,298
2010	2,218	1,856	1,791	1,570
All	17,072	13,912	13,405	11,775

3.4.3 Data Merging

1. The China Annual Survey of Industrial Firms Database merges with the China Annual Environmental Survey of Polluting Firms Database

Follow the following steps to merge the two databases: the first step is based on the firm name and year to match the firm database and the pollution emission database; the second step is based on the organization code and year to match the firm database and the pollution emission database; the third step is to merge the first and second steps, then delete duplicates data; finally, any firm that satisfies the first or second step of matching is obtained. The two databases merging situation is shown in Table 3.4.

Table 3.4: Matching Results between ASIF Database and AESPF Database

Year	Number of ASIF	Number of AESPF	Number of matching firms
2000	128,879	68,075	25,744
2001	139,344	68,313	25,923
2002	149,900	67,834	26,511
2003	168,328	66,938	27,272
2004	237,610	68,028	31,728
2005	237,651	65,783	31,975
2006	265,450	71,354	35,127
2007	300,012	99,561	45,608
2008	379,165	103,454	44,706
2009	314,755	103,901	40,459
2010	385,095	104,725	48,267
All	2,706,189	887,966	383,320

2. The China Annual Survey of Industrial Firms Database merges with the China Customs Import and Export Data

Since the code of the same firm in the China Annual Survey of Industrial Firms Database is not the same as that in the China Customs Import and Export Data, I used the matching method from Yu and Tian (2012) to conduct a two-step matching. The first step is to match the firm name and year. The year variable is necessary for matching because some firms may have different names in different years, and new entrants may adopt their original names. In the second step, I used another matching method to complement the first step. I used the firm's zip code and the last seven digits of the phone number to match. The assumption is that firms in the same zip code will use the same phone number.

Although the matching method seems simple, there are many small details that I need to deal with carefully. For example, the telephone numbers in the China Annual Survey of Industrial Firms Database include the area code and the small dash connecting the area code to the telephone number, which is not found in the China Customs Import and Export Data. Therefore, I use the last seven digits of a firm's phone number to identify the firm. There are two reasons: first, some big cities in China (such as Shantou in Guangdong) have added new digits to the original 7-digit phone number, but they are all added in the first place, so there will be no problem using the last 7-digit number; Second, the phone numbers in the original industrial firm database are saved as variables in string format with small dashes connecting the area codes. If the "destring" command is used, the information will be lost. But the last 7 digits of the phone number can be used very well to solve this problem.

Some firms may not report their names in the industrial firm database or customs database, and similarly, their zip code and telephone numbers may only appear in one database. To ensure that I get more firms in my matches, I retain all firms that can be matched by firm name, plus firms that can be matched by zip code and phone number.

The two databases merging situation is shown in Table 3.5.

Table 3.5: Matching Results between ASIF Database and CCD Database

Year	Number of ASIF	Number of CCD	Number of matching firms
2000	128,879	61,479	16,858
2001	139,344	66,924	19,864
2002	149,900	72,835	22,772
2003	168,328	87,201	27,395
2004	237,610	106,283	42,867
2005	237,651	111,562	44,292
2006	265,450	158,136	50,660
2007	300,012	175,402	61,883
2008	379,165	179,865	63,319

2009	314,755	182,600	55,112
2010	385,095	200,047	65,755
All	2,706,189	1,393,334	470,777

3.5 Chapter Summary

This chapter provides the methods used to examine the impact of environmental regulation on SO_2 emission, TFP, two-way FDI, and trade in China. The chapter starts with a brief introduction and the research methods, with a focus on the DID methods, parallel trend test, placebo test, robustness test, and influence mechanism test. I adopted the DID method and regarded the mandatory SO_2 emissions target scheme strengthened in the 11th Five-Year Plan from 2006 as a natural experiment to test the effectiveness of China's environmental regulation. After that, the data analysis follows. I introduce the independent variable use, the data source, data processing and data merging in this study. I mainly use the eight databases and I introduce in detail how to deal with the China Annual Survey of Industrial Firms Database, the China Annual Environmental Survey of Polluting Firms Database, the China Customs Import and Export Data and how to merge the China Annual Survey of Industrial Firms Database and other database. I also outline the limitations pertaining to this study and potential remedies employed by this study. In the next chapter, I provide empirical results and a discussion of the findings.

4 SO_2 Emissions Regulation and Firm SO_2 Emissions

4.1 Introduction

Reconciling economic development with environmental stewardship represents a challenging global undertaking critical to public welfare and sustainability (Chapin et al., 2010; Bennett et al., 2019; Falkner and Buzan, 2019). In China, rapid gross domestic product (GDP) expansion has improved living standards while exerting ecological pressures, as inefficient resource utilization and pollution place China at the bottom of environmental performance indices (Zhang and We, 2008; Huang et al., 2021). Since pioneering environmental governance systems in the 1970s, China has pursued proactive regulatory policies spanning institutions, legislation, and capital outlays to curb emissions (Wu et al., 2020). The 1987 Law on the Prevention and Control of Atmospheric Pollution employed concentration ceilings to mitigate acid rain and sulfur dioxide contamination. Beginning in 1998, China demarcated acid rain and sulfur dioxide zones to calibrate inter-regional variations, but failed to satisfy pollution abatement objectives. The 2006-2010 Five-Year Plan shifted from concentration to total emissions control, making officials' career appraisals contingent on the achievement of pollution targets. Such initiatives underscored the integral role of green development in China's economic sustainability, championing a paradigm leveraging technological eco-innovation to catalyze growth and social progress through improved resource and energy efficiency (Pan and Chen, 2021; Guo and Yuan, 2021). Despite regulatory advancements, China still contends with grave pollution and climate challenges.

As predominant economic constituents, firm emissions directly influence environmental quality (Du and Li, 2020; Shao et al., 2020). However, environmental conservation initiatives often entail substantial initial investments into upgraded equipment and processes without short-term returns, disincentivizing profit-driven enterprises. Thus, reconciling externalities relies heavily upon government intervention via environmental policies that both deter and stimulate firm behavior (Liu et al., 2023). Environmental regulations directly constrain emissions by imposing stringent criteria and output ceilings, while stimulus policies subsidize adoption of clean technologies and practices (Sun et al., 2020). Environmental regulations also indirectly affect emissions by propelling industrial upgrades and inciting innovations for heightened efficiency and less hazardous goods and processes. Clearly, regulations require multifaceted trade-offs, balancing policy formulation, roll-out, monitoring, and appraisal. Though supervision mandates expenditures on pollution control hardware, it may also raise operating expenses while curbing research and development (R&D) outlays. Thereby, environmental regulations could hamper productivity growth and production scale expansion in the short-term (Qiu et al., 2021). Given such intricate dynamics, investigating regulatory impacts on firm emissions is instrumental to balancing environmental and sustainability objectives.

Academic circles long ago began diagnosing regulations' repercussions on firm emissions, assembling extensive evidence that regulations promote abatement. Upon further examination, researchers have scrutinized these relationships through diverse lenses. Wang and Wheeler (2005), Chávez et al. (2009), and Langpap and Shimshack (2010) dissected the efficacy of economic instruments, public engagement, and other regulatory modalities. Liu et al. (2024) determined regulations circuitously affect emissions by reshaping industrial structures. Biswas et al. (2012) contended regulations' net effects remain ambiguous, as they dampen economic activity yet can also enable production expansions. Wu et al. (2023) proposed regulations may even prove counterproductive, exacerbating environmental problems at certain developmental phases. Such disjointed perspectives underscore the need for additional inquiry, incorporating factors like digital technologies (Sinclair et al., 2017; Martin and Rice, 2014), skill premia (Wang et al., 2021), and technological advancement. Studies concentrate on diffuse geographic contexts including Organization for Economic Cooperation and Development (OECD) economies (Ouyang et al., 2017), Romania (Arouri et al., 2012), and Group of 20 (G20) nations (Wang and Shao, 2019). However, scholars scarcely address environmental externalities linked to China's recent growth paradigm, galvanizing further research into this domain.

This chapter offers three primary contributions: First, it enriches academic exploring environmental policy and firm emissions. Extant literature concentrates largely on impacts mediated via finance and productivity. In contrast, this chapter harnesses Chinese industrial enterprise and emissions data to demonstrate that policies directly decrease firm emissions intensity. Second, it elucidates the mechanisms driving reduced emissions. Unlike previous studies, my study elucidates the mechanisms driving reduced emissions through resource reallocation and cleaner production processes. Specifically, environmental regulation may impact firm SO2 emissions through two aspects: First, environmental regulation reduces the emission intensity of enterprises by reducing traditional energy use from the front-end control and increasing pollutant discharge equipment from the end-treatment. Second, environmental regulation can reduce the firm pollution emission intensity through the reallocation of resources among firms. This analysis helps to understand the channels through which environmental regulations affect pollution reduction. Third, it investigates heterogeneous regulatory effects across ownership structure, sectoral, and firm size dimensions.

4.2 Literature Review

4.2.1 Research on Environmental Regulations

Weitzman (1974) was the first to examine the issue of environmental regulation instruments. He analysed and explained the difference between the price and quantity of environmental regulation instruments. When it is difficult or impossible to estimate pollution ex-ante cost, and the pollution control marginal benefit is higher than the marginal cost, quantitative instruments are preferable, conversely, price instruments are chosen. There are two main types of environmental regulation instruments: one is command-based environmental regulation; the other is market incentive-based environmental regulation. Command-based environmental regulation mainly includes government policies and laws and regulations such as regional pollutant emission standards, while market incentive-based environmental regulations refer to emission fees, environmental taxes and emission permits. Baumol and Klevorick (1970) argued that market incentive-based instruments are more efficient than command-based instruments and have better sustainability. In addition, command-based environmental regulation has the advantage of strict environmental standards but requires higher costs.

Through pioneering environmental legislation, governments have effectively stemmed and regulated pollutant discharges, reconciling the quandary between economic development and ecological deterioration (Callan and Thomas, 1996). Among policy mechanisms, command-and-control regulations utilize more direct tactics by codifying contaminant thresholds and capping emissions volumes to inhibit and govern pollution externalities (Blackman et al., 2018). Given conspicuous realization of anticipated outcomes, direct protocols have been extensively propagated by local decisionmakers. Market-oriented regulations chiefly employ economic tools to promote firm participation in conservation initiatives

(Blackman et al., 2018), encompassing effluent fees, subsidies, and tradable permits. Juxtaposed against command-based environmental regulations, market-based modalities minimize fiscal outlays while engendering efficacious policy repercussions (Copeland, 2013). Public supervision regulations mainly operate through eco-labeling and grievance platforms (Blackman, 2008). For example, public interest environmental litigation substantially supplements oversight efforts within the United States (Becker et al., 2013). Amid deteriorating contamination and evolving policy regimes, most academia concentrates on command and market-based controls while discounting the role of civic participation (Guo et al., 2021).

Formerly, the shortage of standardized gauges for diagnosing regulations has hindered indices of environmental policy stringency. Broadly speaking, quantification methodologies of environmental regulations include four categories: (1) cost indices, commonly harnessing abatement overheads and extensively applied in policy research. (2) input indices such as conservation budgetary appropriation and pollution control capitalization (Naso et al., 2017), signifying stringency according to governmental or firm capital outlay on contamination mitigation and green infrastructure (Zhang et al., 2020). (3) Performance indicators measure environmental regulation by the effectiveness of pollution control. Discharge trajectories directly determine regulatory aftermaths based on geographical or chronological emissions trends. (4) Some studies evaluate the strictness of environmental regulations in a region or country by counting the number of environmental regulations issued. Though straightforward, this tactic risks overlooking pivotal enforcement and efficacy considerations central to the realization of anticipated goals.

4.2.2 Command-Based Environmental Regulations and Pollution

The existing literature tests the effectiveness of command-based environmental regulation policies. Magat and Viscusi (1990) suggested that environmental regulations in the US can reduce emissions from pulp companies by approximately 20%. Laplante and Rilstone (1996) took the pulp and paper products industry in Canada as an example and found that environmental regulations reduced pollutant emissions of enterprises by about 28%. Nadeau (1997) found that strict environmental regulations can reduce the number of illegal enterprises. De Bruyn (1997) found that environmental regulation promoted the emission reduction of sulfur dioxide based on studies in the Netherlands and West Germany. Panayotou (1997) conducted an empirical analysis using data on environmental regulation indicators from 30 countries and regions and found that environmental regulatory policies had a curative effect on environmental pollution caused by SO_2. Marconi (2012) suggested environmental regulation can reduce pollution emissions using the data of China and the EU. However, Blackman and Kildegaard (2010) used environmental data from Mexico as a sample to explore the impact of environmental regulation on green technology innovation and pollution emissions. They found that environmental policies did not effectively incentivize green technology innovation, but rather increased pollution emissions. Zheng and Shi (2017) pointed out that China's environmental regulations had not achieved pollution reduction targets. The emission reduction effect of environmental regulation also depends on the intensity of the regulation (Cheng et al., 2017).

As conventional mechanisms, command-based environmental regulations depend on centralized formulation and enforcement of binding firm emissions parameters, legislation, and injunctions to regulate ecological externalities (Gao et al., 2022). Concerning realization of projected mitigation objectives, extant works have scrutinized the associated repercussions from multiple standpoints, crystallizing several fundamental premises. The total pollutant control policy implemented during the 11th Five-Year Plan period can quickly control pollution emissions. However, deficient monitoring alongside elevated administrative overheads and information asymmetries may expand illicit commerce, thus exacerbating contamination (Jin et al., 2019). Regarding technical advancement, appropriately designed schemes can promote R&D and integration of clean technologies to elevate productivity as postulated by the Porter hypothesis. Nonetheless, compliance expenditures may displace R&D budgets, forestalling productivity over the short-term. Through industrial reorganization dynamics, increasingly stringent requirements can phase out high-pollution sectors to optimize resource allocation, ultimately promoting energy conservation and emission reduction. Additionally, regulations likely influence ecological outcomes non-linearly given wage levels, subsectoral heterogeneity, governance integrity, and institutional factors (Zhou et al., 2019; Hou et al., 2023).

Several major Chinese ecological policies include total emissions control programs, dual-control zone demarcations, and interim initiatives. Research suggests geographically limited temporary environmental regulations face constraints regarding comprehensive, sustained pollution abatement. For example, total emissions caps during the Eleventh Five-Year Plan (2006-2010) rapidly controlled focal pollutants without effectively combating other categories (Jin and Lin, 2014) alongside considerable implementation costs (Xu et al., 2014). China's dual-control zones efficaciously lowered regional SO_2 levels while adversely affecting exports and economic expansion (Hering and Poncet, 2014). And while ephemeral actions such as emission control measures for the 2008 Beijing Olympics transiently ruptured smog accumulation, such outcomes have proven transient (Chen et al., 2013). Although command-based environmental regulations play a certain role in reducing pollution emissions, they also face some challenges in practical implementation. For example, the formulation and implementation of environmental standards may face issues of information asymmetry and regulatory failure. In addition, command-based environmental regulations often lack flexibility and are difficult to adapt to the actual situation of different industries and regions.

4.2.3 Market-Oriented Environmental Regulations and Pollution

As policy tools harnessing market dynamics to compel firm pollution abatement, market-based environmental regulations have attracted substantial research attention across environmental economics and policy makers in recent years. Compared to conventional command-and-control protocols, market-based regulations utilize pricing signals and economic incentives to recalibrate firm ecological conduct to optimize environmental resource allocation.

Extensive literature indicates that market-oriented approaches encompassing emissions trading platforms and environmental taxation can effectively promote contamination mitigation. For example, Cherry, Kallbekken and Kroll (2014) and Bel and Joseph (2015) revealed carbon trading schemes significantly reduced industrial carbon intensity trajectories. Analogous to carbon trading, pollution abatement ramifications of effluent allowance exchanges have faced extensive peer scrutiny. For example, Montgomery (1972) seminal emissions trading thesis proposed that by acquiring or divesting allotments, firms could cost-effectively recalibrate discharges to minimize expenses as predicted by microeconomic theory. Corroborating this prediction, Fowlie et al. (2012) revealed sulfur dioxide trading substantially curtailed power plant emissions across the United States. As Gan et al. (2024) accentuated, robustly designed trading infrastructures render pollution entitlements valuable assets, thus incentivizing abatement. Environmental taxation also discourages emissions by imposing levies on ecological damages, as pioneered by Pigou (1920) elucidation of effluent fees as tactics for reconciling negative externalities.

Subsequently, scholars have empirically gauged environmental tax impacts across jurisdictions. For example, Bovenberg and Mooij (1994) general equilibrium framework integrating eco-taxes revealed their projected efficacy in catalyzing mitigation and green innovation. Moreover, market-based environmental regulations may spark technological advancement and industrial upgrading, as the Porter hypothesis postulated that appropriately calibrated schemes can stimulate innovation to augment productivity and competitiveness (Porter and Van der Linde, 1995). Supporting this premise, Zhang et al. (2022) determined regulations substantially expand firm research and development outlays. Accordingly, research has evaluated market mechanism ecological efficacy, often through jurisdictionally delimited case studies. For instance, Cramton and Kerr (2002) appraisal of the United States Acid Rain Program uncovered successful sulfur dioxide abatement alongside clean energy transition promotion. However, other studies suggest that market-based regulations may fail to achieve anticipated objectives in certain contexts. For example, Wagner and de Preux (2016) found the European Union Emissions Trading System decreased air releases of certain pollutants while increasing water discharges of other contaminants.

In summary, while ecological efficacy remains contextually variable given issues surrounding design and enforcement, market-based environmental regulations constitute critical sustainability policymaking tools.

Some literature argues that market-based environmental regulation is not conducive to pollution abatement. Shibli and Markandya (1995) argued that sewage charging systems are only used as a means of local financing and are ineffective in controlling pollution. Bell (2003) and Kathuria (2006) found that although market-based environmental regulation can achieve regulatory objectives at a lower cost, due to the lack of a sound institutional basis in the early stages of environmental regulation in developing countries, the imposition of market-based incentives for environmental regulation is not effective in controlling pollutant emissions.

Environmental taxes are an important tool to promote pollution reduction (Bovenberg and Van der Ploeg, 1994). Due to the increasing prominence of environmental pollution problems, major developed countries have been implementing environmental tax policies and increasing environmental taxes (Barde and Owens, 1996). Most scholars argue that in response to the increasingly stringent environmental tax, firms in developed countries have an incentive to continuously increase pollution control investment to reduce pollution emissions. The lack of stringent environmental tax led to a lack of incentives for firms in developing countries, and then caused serious environmental pollution problems (Chen et al., 2013; Greenstone and Hanna, 2014). In addition, some scholars have studied market-based policies such as carbon emissions trading. Clarkson et al. (2015) and Brouwers et al. (2016), using EU countries' data concluded that market-based carbon trading policies reduce the value of firms.

In response to the effectiveness of market-based trading policies in the Chinese region, Wang et al. (2004) argued that China's emissions trading policy has failed to reduce SO_2 emissions. Cheng et al. (2016) used a computable general equilibrium model to predict the impact of an emissions trading system on carbon emissions in Guangdong Province, which is expected to reduce carbon dioxide emissions in 2020 to two-thirds of the 2010 level. Liao, Zhu and Shi (2015) used Shanghai's carbon emissions trading policy as a research object. They found that the implementation of the carbon emissions trading policy in Shanghai was beneficial to carbon emission reduction but not to economic output. In addition, Welsch (2003), Cole (2007) and Zhang, Liu and Feng (2015) suggested that corruption, rent-seeking and other implicit collaborative relationships between local governments and firms are closely linked to regional environmental pollution and regulatory policy failures.

4.2.4 Public Supervision-Based Environmental Regulations and Pollution

With mounting education, non-formal environmental regulations centered on civic participation have become pivotal research foci. Public involvement primarily encompasses four modalities: First, grievances and petitions feature uncertain pollution consequences, as certain analyses revealed their efficacy (Langpap and Shimshack, 2010; Dong et al., 2011) while others deemed impacts ambiguous (Zhang et al., 2019). Second, non-government organization disclosures also demonstrate mixed results, with Li et al. (2018) finding mobilization stimulated municipal ecological responses whereas Wu et al. (2018) determined negligible effects. Third, most scholars concur media coverage through platforms like newspapers and television discourages contamination, as Saha and Mohr (2013) concluded in their analysis. Fourth, web-based engagement via search engines, microblogs, and social media enables information dissemination, though associated pollution mitigation remains contingent on sample timeframe and methodological choices according to Bonsón et al. (2019) and Zhang et al. (2018). In summary, public participation pollution abatement ramifications appear contextually dependent given modalities, data samples, and empirical specifications.

Overall, several overarching limitations pervade the extant literature. First, existing academic focuses predominantly on developed country contexts, while research scrutinizing environmental regulatory efficacy in developing nations remains scarce, despite the heightened execution and evaluation challenges these jurisdictions face, necessitating additional study. Second, most current analyses utilize macroscopic techniques to assess aggregate regulatory repercussions rather than elucidating the micro-level conduits and mechanisms underlying emissions modulation pathways, thus impeding policy formulation. Methodologically, the field has also featured limited exploitation of quasi-experimental techniques capable of more rigorously establishing causality despite their merits. Lastly, minimal research has examined how regulations shape firm mitigation strategies and pathways, representing a promising avenue for more nuanced investigation.

4.2.5 China’s Environmental Regulations and Pollution

Cao et al. (2009) examined two primary policy measures implemented by the government to achieve SO_2 reduction targets: the shutdown of numerous small-scale, inefficient power plants and the installation of desulfurization equipment in both existing and new coal-fired power plants. The study revealed that the economic benefits derived from closing small power plants were sufficient to offset the costs associated with desulfurization facilities, even without accounting for the substantial environmental benefits of SO_2 emission reductions and the co-benefits of other pollutant reductions. Gao et al. (2021) evaluated the impact of pollution tax reforms on urban level SO_2 emissions. Their findings demonstrated that increased pollution levies exerted statistically significant positive effects on controlling industrial SO_2 emissions. Employing a DID approach with panel data from 285 Chinese cities between 2003 and 2018, Cui and Cao (2023) investigated the effects of China’s SO_2 emissions trading system on energy efficiency. The results indicated that the emissions trading system significantly enhanced green total-factor energy efficiency while reducing energy intensity. Wang and Lu (2023) utilized panel data from 30 Chinese provinces (2004-2020) and a spatial Durbin model to analyze strategic interactions among local governments in environmental regulation and their impacts on SO_2 emissions. The study identified a “race to the top” phenomenon in environmental regulation enforcement among local governments. Strengthening environmental regulations in either a specific region or its neighboring areas significantly reduced regional SO_2 emissions, suggesting that coordinated environmental governance could achieve considerable pollution control effectiveness. Several papers review environmental progress during the

11th Five-year Plan. These papers examine the development of emission targets (Xu, 2011), role of control technologies (Steinfeld et al., 2009; Xu, 2009), and energy efficiency measures including closure of small, inefficient boilers (Price et al., 2010; Price et al., 2011; Wang and Chen, 2010; Zhang et al., 2011).

4.3 Theoretical Analysis and Research Hypothesis

4.3.1 Governance Framework

Firm's environmental pollution has strong negative externalities. Firms produce environmental pollution during their production process, but firms do not bear compensation for the losses caused to society and the public. When the government fails to implement government environmental regulations, firm pollution emissions intensify. Under the concentration control regulatory, regulators set limits on pollutant levels per unit of exhaust, which allowed firms to comply simply by installing end-of-pipe technologies like flue gas desulfurization scrubbers. However, this system failed to constrain absolute pollution growth, as enterprises could increase total emissions by operating more production lines or running plants at higher capacity while maintaining compliant concentrations. Recognizing this flaw, the 2006 reforms introduced binding caps on aggregate emissions, forcing firms to either fundamentally restructure production or acquire costly emission permits. Therefore, total emission reduction target is more effective than concentration control regulatory. In 2005, China adopted the "Eleventh Five-Year Plan", which changed the regulation method from the previous concentration control to total emission reduction. This method linked the realization of the total target to the performance evaluation of officials which is likely to have a great effect on reducing the emission of pollutants. Local governments can influence the firm's pollution emissions according to the total pollutant emission control targets set by the central government. Firms can choose the amount of pollution emissions based on local government environmental regulations. Even if there is no way to fully understand all relevant information from local governments, firms still choose different environmental regulation intensities to adjust the firms' scale to achieve optimal results.

The central government is the maker of environmental regulatory policies, while local governments are the specific implementers of environmental regulations. Local governments have greater discretion in the implementation of environmental regulations. The government forces firms to improve production technology, improve resource allocation efficiency, and reduce pollution emissions through mandatory standards or economic means. Generally speaking, whether it is command-and-control environmental regulations such as environmental laws and regulations, technical standards, emission permit systems and product standards, or market incentive-based environmental regulations such as environmental taxes (fees) and emission rights trading, they both can force polluting firms to improve energy efficiency and reduce pollution emissions, so as to achieve the purpose of reducing emissions and pollution and improving environmental quality. Many studies show that environmental regulation has an obvious emission reduction effect (Laplante and Rilstone, 1996; De Bruyn, 1997; Marconi, 2012; Jin and Lin, 2014). Therefore, this study proposes the following hypothesis:

Proposition 1: Environmental regulation can reduce the pollution emission intensity of enterprises.

4.3.2 Pollution Control

The improvement of firm production mode affects the generation of pollutants, and the use of pollutant discharging equipment affects the treatment of pollutants. Therefore, the overall pollution emission of enterprises is affected by the production and treatment of pollutants in enterprises.

Restrictive policies such as environmental regulation can increase the environmental cost of production, forcing high-polluting companies to change their production methods, reducing the use of traditional energy sources, and reducing the burden of environmental costs (Pang and Shaw, 2011). The burning of sulfurous coal is the main source of sulfur dioxide. According to data provided by the National Development and Reform Commission, for every ton of standard coal burned in industrial boilers, 8.5 kilograms of sulfur dioxide and 7.4 kilograms of nitrogen oxides can be produced. Therefore, the exhaust gas from coal-fired boilers has become one of the main sources of atmospheric pollution. Coal is China’s main energy source in real production activities. Environmental regulation can reduce the firm’s pollution emission intensity through front-end control by reducing the use of traditional energy.

In order to achieve the goal of total emission reduction, firms not only reduce their pollution emissions through front-end control, but also need to improve the treatment efficiency of end-pollutants. Improving end-treatment ability is the most direct and efficient way for enterprises to quickly realize pollution reduction (Mizobuchi, 2008; Okushima and Tamura, 2010). It is not only quickly recognized by government departments, consumers and investors, but it can also generate more resources and financial support for improving recycling and purification technologies (Shu et al., 2016). Environmental regulation can encourage enterprises to speed up the elimination and upgrading of outdated pollutant abatement equipment. Enterprises can improve the pollution treatment capacity and then reduce pollution emissions of enterprises through the purchase of advanced sewage equipment. Therefore, this study proposes the following hypothesis:

Proposition 2: Environmental regulation reduces the emission intensity of enterprises by reducing traditional energy use from the front-end control and increasing pollutant abatement equipment from the end-treatment.

4.3.3 Resources Reallocation

The pollution emissions of enterprises are not only affected by the generation and treatment of pollutants, but also affected by the allocation of resources between enterprises, even the entry and exit behaviors of enterprises (Grossman and Krueger, 1991; Shapiro and Walker, 2018). The reallocation of resources between incumbent firms is mainly manifested by the flow of resources between firms and the change in market share. Moreover, it also affects the entry and exit decisions of firms with different pollution intensities (Deily and Gray, 1991). Environmental regulation policy restrictions on polluting products will guide the continuous flow of resources from high-pollution enterprises to low-pollution enterprises, promote the scale expansion and entry of low-pollution enterprises, and increase the market exit of high-pollution enterprises. The government implements stricter environmental regulations on new entrants, requiring them to have certain pollution treatment capabilities, which forms barriers to the entry of enterprises. Some highly polluting enterprises with backward technology and failing to meet environmental standards are unable to enter the market. At the same time, strict environmental regulation policies will also put forward higher requirements for incumbent enterprises. Environmental regulation will increase the cost of pollution control for existing enterprises, resulting in high-polluting enterprises having to withdraw from the market. On the contrary, those companies that meet environmental requirements and are technologically advanced are less likely to exit the market. Therefore, this study proposes the following hypothesis:

Proposition 3: Environmental regulation can reduce the pollution emission intensity of enterprises through the reallocation of resources among enterprises. Specifically, on the one hand, high-polluting enterprises continue to transfer resources to low-polluting enterprises. On the other hand, high-polluting enterprises increasingly withdraw and low-polluting enterprises continue to enter.

In summary, as can be seen in Figure 4.1, environmental regulation can reduce the firm emission intensity through three ways. First of all, from the front-end control perspective, reduce traditional energy usage. Second, from the end-treatment perspective, increase pollutant abatement equipment. Third, through the reallocation of resources among enterprises. High-polluting firms transfer resources to low-polluting firms, and high-polluting firms increasingly withdraw and low-polluting firms enter.

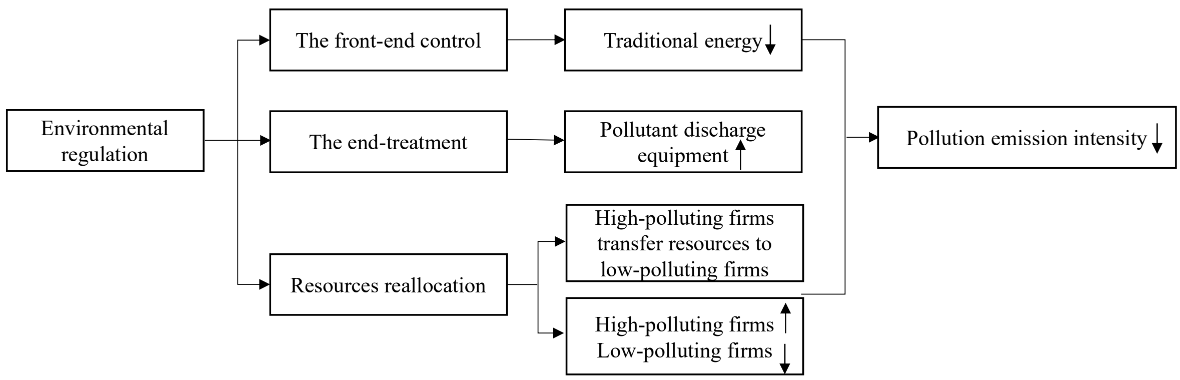

Figure 4.1: Theoretical Mechanism of Environmental Regulation on Firm Pollution Emission

4.4 Methodology and Data Description

4.4.1 Model Specification

As emission control targets set by the central government and local governments vary, the stringency of regulation varies considerably from city to city, which helps to determine the causal relationship between environmental regulation and firm response. Therefore, I adopted the TWFE model and continuous DID method and regarded the mandatory SO_2 emissions target scheme strengthened in the 11th Five-Year Plan from 2006 as the natural experiment. I compare the change in pollution emitted by firms in cities with more stringent environmental regulations with equivalent changes with less stringent environmental regulations before and after 2006 based on the following model:

$$SO_2inten_{it} = \alpha + \beta_1 treat_c \times post_t + \beta_2 treat_c + \beta_3 post_t + \eta X_{it} + \gamma_t + \gamma_i + \varepsilon_{it} \tag{4.1}$$

Where, *i* represents firm, *c* represents city, and *t* represents year. SO_2inten_{it} represents the sulfur dioxide emission intensity (kilograms per thousand yuan) of firm *i* in year *t*. $treat_c \times post_t$ is a dummy variable, representing environmental regulation. $treat_c$ is the continuous grouping index of the treatment group and the control group and $post_t$ is a time dummy variable. X_{it} represents a set of control variables. γ_t is the year fixed effect, γ_i is the firm fixed effect, and ε_{it} is the random disturbance term. In order to eliminate possible autocorrelation and heteroscedasticity, all regressions are clustered at the firm level. Because I include year fixed effect, the $post_t$ indicator is collinear with the year dummies and drops out of the regression. So I can't report the coefficient of $post_t$.

4.4.2 Explanation of Variables

(1) Environmental pollution (SO_2inten_{it}). Referring to Lin and Xu (2022), I take the logarithm of the ratio of sulfur oxide emissions to the current price of total output (log of kilograms per thousand yuan) is used to measure the firm pollution emissions intensity. Moreover, using the approach of Brandt et al. (2012), this chapter uses the output price index to deflate the nominal output level to measure the actual output level of the firm. *SO_2 emissions* is SO_2 emissions in firm *i* in year *t*. *total output* is the real output in firm *i* in year *t*.

SO_2 emission intensity of firm *i* in year *t* is determined as follows:

$$SO_2inten = \frac{SO_2 \quad emissions}{total \quad output} \tag{4.2}$$

The reason why SO_2 is chosen as the measurement index of pollution emission is mainly that SO_2 is still a big pollution problem in China, causing acid rain and other issues and there is good data on it. According to statistics, in 2018, nearly 30 million tons of SO_2 were released into the atmosphere by man-made SO_2 pollution hotspots around the world, equivalent to the amount released by more than 300 volcanic eruptions. This has brought great harm to human health and the environment. As China is the world's largest coal producer and consumer, coal-based air pollution is the main form of environmental pollution in China and sulfur dioxide is the main air pollutant produced by coal burning in China. Industrial sulfur dioxide emissions accounted for 80.82 percent of China's sulfur dioxide emissions in 2019. Therefore, I chose the sulfur dioxide emission intensity index to measure the pollution emission behavior of enterprises.

Table 4.1 reports the overall distribution of SO_2 emissions intensity in China from 2000 to 2010. It can be found that from 2000 to 2010, the mean, median, 25th percentile and 75th percentile of firm SO_2 emissions intensity first increases and then decreases. Skewness is less than 0, indicating that the data distribution is left skewed, and there are fewer data to the left of the mean than to the right of the mean. The kurtosis of the firm SO_2 emissions intensity is greater than 3, indicating that the data is steeper than the normal distribution. It can be found from Figure 4.2 that the intensity of SO_2 emissions follows a normal distribution.

Table 4.1: Total Distribution of SO_2 Emissions Intensity in China from 2000 to 2010

Year	Mean	Median	25% quantile	75% quantile	Std. Dev.	Skewness	Kurtosis	Obs
2000	-0.3552	-0.1894	-1.5514	1.0678	2.0737	-0.6765	4.4210	20,533
2001	-0.3041	-0.1536	-1.5339	1.1177	2.0953	-0.6046	4.3085	20,783
2002	-0.2087	-0.3931	-1.6015	1.0523	2.1207	-0.6443	4.3587	21,240
2003	-0.3923	-0.1872	-1.6204	1.0831	2.1586	-0.6604	4.3024	21,719
2004	-0.3365	-0.1247	-1.5764	1.1454	2.1935	-0.7023	4.5733	24,619
2005	-0.4062	-0.2003	-1.6470	1.1127	2.2134	-0.7060	4.4312	24,384
2006	-0.5315	-0.3280	-1.7631	1.0073	2.2640	-0.7755	4.7961	26,052
2007	-0.6180	-0.4135	-1.8073	0.8617	2.2339	-0.7754	4.9979	32,044
2008	-0.9199	-0.6961	-2.0881	0.5448	2.2270	-0.8508	5.1538	30,751
2009	-1.0344	-0.7845	-2.1887	0.4690	2.2651	-0.8992	4.9825	27,619
2010	-1.1467	-0.8866	-2.3042	0.3312	2.2914	-0.8482	5.0215	32,657
total	-0.6254	-0.4207	-1.8345	0.8727	2.2256	-0.7605	4.7740	282,401

Source: Analysis reported in this thesis.

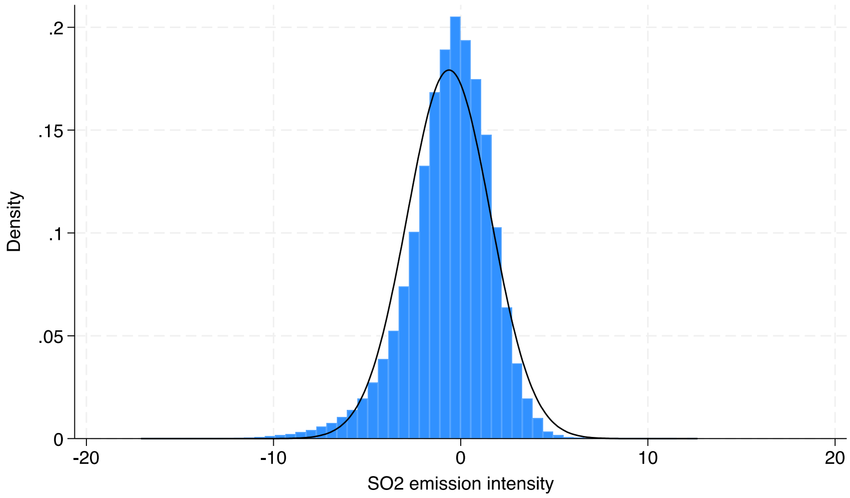

Figure 4.2: The Normal Distribution of SO_2 Emission Intensity

(2) $treat_c \times post_t$ is the core explanatory variable of the DID model. $treat_c$ is the continuous grouping index of the treatment group and the control group, that is, the environmental regulation intensity of each city, which is measured by the SO_2 control target (ten thousand tons) of the city *c*. $post_t$ is a dummy variable equals to 0 for all years before 2006, and to 1 from 2006 and onward.

(3) Control variables. To avoid the influence of omitted variables on the estimation results of this research, other variables that affect firm pollution emissions are added to the DID model. Drawing on Cai and Liu (2009) and Bu and Ren (2023), I adopted the following control variables. (1) The firm age is measured by adding 1 to the logarithm of the difference between the current year and the year of the establishment of the enterprise. (2) The firm size is measured by the total assets. Compared with small enterprises, large enterprises have more capital and technological advantages. (3) The firm capital labor ratio is measured by the logarithmic value of the ratio between the net value of fixed assets and the number of employed persons. (4) The dummy variables of enterprise ownership type. There are many types of ownership in China, including state-owned enterprises, private enterprises, foreign enterprises, mixed ownership enterprises, collective enterprises and so on. I only controlled the dummy variables of state-owned firms, foreign firms, and private firms. (5) The concentration ratio is measured by the Herfindahl-Hirschman Index of a four-digit industry. (6) Industry size is measured by the logarithm of the four-digit industry employment scale. It is the sum of the market share of the top N largest companies in the relevant market of an industry. It measures the degree of competition and monopoly in the market. (7) Regional economic growth is measured by the log of regional GDP per capita. It measures the level of economic development in a region. (8) Regional industrial structure is measured by the proportion of regional secondary industry

to tertiary industry. (9) Regional Internet development is measured by the log of regional Internet usage.

(4) Mechanism variable. First, coal. Coal is a mineral that can be used as fuel or industrial raw material. It is a black solid mineral composed of carbon, hydrogen, oxygen, nitrogen and other elements that changed the physical and chemical properties of ancient plants through biochemical and geological processes. I select the logarithmic value of coal to measure the scale of coal use. Secondly, clean gas. It is the energy that does not emit pollutants and can be directly used for production and life. I select the logarithmic value of clean gas (natural gas) consumption to measure the scale of clean gas use. Thirdly, SO_2 treatment rate. I use the logarithm of the ratio of SO_2 treatment to SO_2 production. Since some enterprises did not report the SO_2 treatment, in order to reduce the bias of the regression results, I only tested the enterprises that reported the SO_2 treatment. The value of 0 indicates that the SO_2 treatment capacity reported by the enterprise is 0. Last, treatment equipment. I use the logarithm of SO_2 treatment equipment to measure treatment equipment.

The data in this research mainly come from the China Annual Survey of Industrial Firms Database (ASIF) and the China Annual Environmental Survey of Polluting Firms Database (AESPF) from 2000 to 2010. The descriptive statistics of the variables are shown in Table 4.2. The reasons for the differences in the number of observations are: first, about SO_2 emission intensity. Some enterprises do not produce SO_2, or enterprises underreport SO_2 emissions, resulting in the absence of SO_2 values. Second, about the data on the city level (*average gdp* and *industrial structure*). The city level data are derived from the China Urban Statistical Yearbook. The enterprise level data are from the China Industrial Enterprise Database. Because of the different data sources, there are differences in data matching.

Table 4.2: Variables Description

	Variable	Abbreviation	Unit	Mean	Std. Dev	Min	Max	Obs
Dependent variable	*SO_2inten*	*SO_2inten*	log of kilograms/ 1000 yuan	-0.6254	2.2256	-17.0789	12.6466	282,401
Independent variable	$treat_c \times post_t$	$treat_c \times post_t$	-	1.1342	2.2306	0.0000	13.0190	383,320
Firm level control variables	*firm age*	*age*	year	2.3087	0.8600	0.0000	7.5000	383,320
	firm size	*size*	log of 1000 yuan	10.7680	1.5784	0.0000	19.4548	383,320
	capital labor ratio	*kl*	log of 1000 yuan/person	5.3456	1.0332	0.4570	12.4747	383,320
	state-owned firm	*soe*	-	0.1558	0.3626	0.0000	1.0000	383,320

	foreign firm	*foe*	-	0.1654	0.3716	0.0000	1.0000	383,320
	private firm	*pre*	-	0.4618	0.4985	0.0000	1.0000	383,320
Industry level control variables	*concentration ratio*	*hhi*	-	0.0122	0.0301	0.0003	1.0000	383,320
	industry size	*size_ind*	-	13.6829	0.7607	5.0239	14.7932	383,320
City level control variables	*average gdp*	*gdp*	log of 10000 yuan/person	11.1616	0.7183	8.6103	13.8312	382,919
	industrial structure	*ind*	-	1.3049	0.4876	0.0068	10.5529	382,889
	Internet development	*inter*	log of per household	11.9587	3.5702	0.0000	17.7617	383,320
Mechanism variables	*coal*	*coal*	log of ton	6.1480	3.5196	0.0000	16.5236	288,29
	clean gas	*gas*	log of ton million cubic meters	0.4080	1.5468	0.0000	17.6550	186,561
	SO_2 treatment rate	*rate*	-	-1.1949	0.9475	-14.7202	0.0000	81,493
	treatment equipment	*equip*	log of set	0.8932	0.7665	0.0000	8.8820	306,967

Source: Analysis reported in this thesis.

4.5 Empirical Results and Discussion

In this section, I analyze the empirical results of environmental regulation on firm pollution emission intensity. In section 4.5.1, I will analyze the basic regression results. In section 4.5.2, I will analyze the parallel trend test which verified the appropriateness of the DID model. In section 4.5.3, I will do a lot of robustness tests such as two-period double difference method, winsorize, eliminate other policy distractions, use pollution emission intensity under different output indicators, use a relative target and placebo test. In section 4.5.4, I will analyze the impact mechanism of environmental regulation on firm pollution emission intensity from the front-end control, the end-treatment and the reallocation of resources among firms. In section 4.5.5, I will analyze the heterogeneity analysis which will include the different firm ownership, the different firm sizes, the different factor densities, the different pollution intensity and the different industries.

4.5.1 Regression Analysis of the Basic Regression Model

Table 4.3 reports the benchmark regression results of the impact of environmental regulation policies on firm SO_2 emission intensity. Column (1) only controls for time fixed effects, and column (2) only controls for firm fixed effects. The estimated coefficients in columns (1) and (2) are significantly negative at the

1% statistical level. Column (3) controls both the year fixed effect and the firm fixed effect, and the conclusion has not changed. Column (4) adds enterprise-level control variables and Column (5) adds industry-level control variables. I find that the estimated coefficient of $treat_c \times post_t$ is still significantly negative, indicating that the environmental regulation policies can reduce environmental pollution. Column (6) adds city-level control variables and column (7) adds dummy variables of enterprise ownership type. The estimated coefficient of $treat_c \times post_t$ in column (6) is -0.0230 and it means that after 2006, for every 1 unit increase in the SO_2 emissions reduction target, the SO_2 emissions intensity decreases by 2.3%. The estimated coefficient of $treat_c \times post_t$ in column (7) is -0.0223 and it means that for every 1 unit increase in the SO_2 emissions reduction target, the SO_2 emissions intensity decreases by 2.23%. Before 2006, the average SO_2 emissions intensity of a firm is -0.3652, the average output of a firm is 157.5 million yuan and the average SO_2 emissions of a firm reached 109.3 tons in the sample. After 2006, for every 1 unit increase in the SO_2 emissions reduction target, a 2.23% reduction in SO_2 emissions intensity of a firm decreased the log-transformed intensity from -0.3652 to -0.3875, equivalent to a decline from 694.2 to 678.8 kg/million CNY. So the average SO_2 emissions of a firm decreased to 106.89 tons, achieving a 2.44 ton reduction. After 2006, the average SO_2 emissions reduction target of a firm is 2.03, so after the SO_2 emissions regulation, the average SO_2 emissions of a firm decreased to 104.35 tons, achieving a 4.95 ton reduction. There are 149123 SO_2 emissions firms from 2006-2010 in the sample, so the China's SO_2 emissions has a reduction of 0.74 million ton from 2006-2010. The estimated coefficients are still significantly negative. SO_2 emissions regulation policies reduce SO_2 emission intensity. This result is consistent with the findings of Qi et al. (2023).

Table 4.3: DID Model Regression Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	SO2inten	*SO2inten*	*SO2inten*	*SO2inten*	*SO2inten*	*SO2inten*	*SO2inten*
$treat_c \times post_t$	-0.0195***	-0.0227***	-0.0214***	-0.0228***	-0.0229***	-0.0230***	-0.0223***
	(-4.2084)	(-6.5082)	(-6.1631)	(-6.5675)	(-6.6061)	(-6.6601)	(-6.4530)
treat	-0.0970***	-0.1335	-0.1404	-0.1389	-0.1390	-0.1365	-0.1364
	(-23.3523)	(-1.2636)	(-1.3925)	(-1.3773)	(-1.3849)	(-1.3744)	(-1.3768)
age				0.0231***	0.0228***	0.0234***	0.0241***
				(3.1426)	(3.0963)	(3.1776)	(3.2578)
size				-0.1347***	-0.1354***	-0.1358***	-0.1358***
				(-12.7230)	(-12.7931)	(-12.8272)	(-12.8227)
kl				0.0382***	0.0389***	0.0393***	0.0385***
				(3.9136)	(3.9879)	(4.0303)	(3.9548)
hhi					-0.0831	-0.0675	-0.0686

					(-0.3590)	(-0.2918)	(-0.2968)
size_ind					0.0532***	0.0533***	0.0538***
					(3.2256)	(3.2335)	(3.2659)
gdp						-0.0457***	-0.0452***
						(-4.3849)	(-4.3396)
ind						0.0479***	0.0477***
						(3.6033)	(3.5849)
inter						-0.0070*	-0.0069*
						(-1.9085)	(-1.8975)
soe							0.0164
							(0.7705)
foe							-0.0282
							(-1.1484)
pre							0.0377***
							(3.2174)
Year FE	YES	NO	YES	YES	YES	YES	YES
Firm FE	NO	YES	YES	YES	YES	YES	YES
N	282,401	256,744	256,744	256,744	256,744	256,165	256,165
R-Square	0.0350	0.8129	0.8162	0.8166	0.8166	0.8168	0.8168

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

4.5.2 Parallel Trend Test

The premise of using the DID model is that the treatment group and the control group meet the same trend assumption before the implementation of the industrial policy (Bertrand et al., 2004). Specifically, this chapter examines whether there are differences in the distribution of SO_2 emission intensity between the treatment group and the control group before and after 2006. To verify the appropriateness of the DID model, this section uses the event analysis method to test the common trend of the treatment group and the control group (Jacobson et al., 1993). Specifically, a series of dummy variables are added to the benchmark model (4.1) to establish the following model:

$$SO_2inten_{it} = \alpha + \beta_1 D_{ct}^{-5} + \beta_2 D_{ct}^{-4} + \cdots + \beta_{10} D_{ct}^{+5} + \eta X_{it} + \gamma_t + \gamma_i + \varepsilon_{it} \tag{4.3}$$

In the model, *D* ($treat_c \times post_t$) is a series of dummy variables. In *j* years before the implementation of environmental regulation policy, D_{ct}^{-j} equals to 1, otherwise D_{ct}^{-j} equals to 0. In *j* years after the implementation of environmental regulation policy in the treatment group, D_{ct}^{+j} equals to 1, otherwise D_{ct}^{+j} equals to 0. I used the year (2005) before the environmental regulation policy was implemented as a control group (Bu and Ren, 2023). The estimated coefficient of *D* in the regression results represents whether there is a significant difference in the trend of environmental pollution between the treatment group and the control group in the *j* years before and after the implementation of environmental regulation policy. The regression estimation results and confidence intervals are shown in Figure 4.3. In the figure, the horizontal axis represents the year since the implementation of environmental regulation policy, the vertical axis represents the size of the estimate, the hollow point is the estimated coefficient, and the dashed line is the 95% confidence interval.

When $j<0$, 0 is within the dotted line. It means the estimated coefficient was not significant at the 5% level, indicating that before the implementation of environmental regulation policy, there was no significant difference in the changing trend of SO_2 emission intensity between the treatment group and the control group. It shows that there is a parallel trend before the implementation of environmental regulation policies, and the DID model can be used to test the impact of environmental regulation on firm pollution emissions. After the implementation of environmental regulation policy (when $j>0$), the estimated coefficient is less than 0 and is significant at the significance level of 5%. This indicates that environmental regulations reduce the intensity of sulfur dioxide emissions of enterprises.

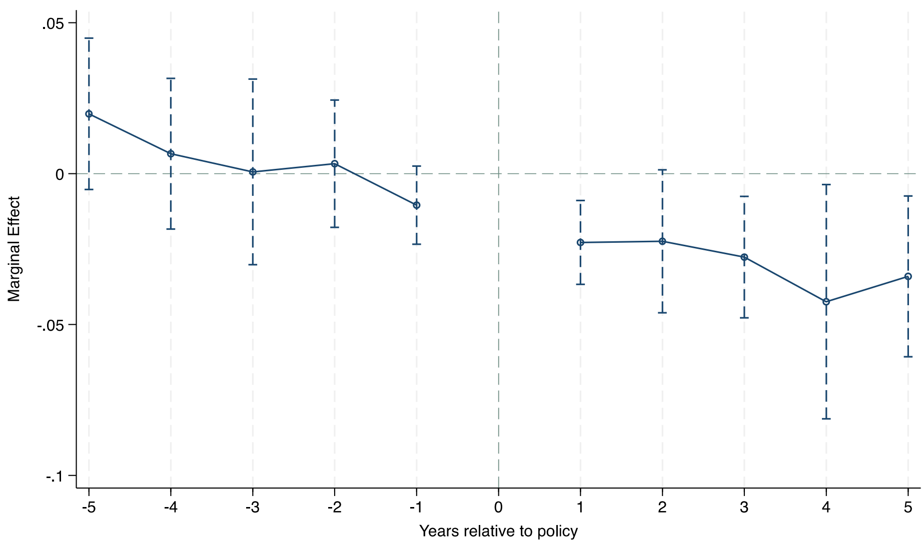

Figure 4.3: Parallel Trend Test on Firm SO_2 Emissions

4.5.3 Robustness Test

To verify that the baseline regression results are robust, I conduct a battery of additional tests, such as two-period double difference method, winsorize, eliminate other policy distractions, change the explained variable, use a relative target and placebo test to rule out alternative interpretations of my findings.

(1) Two-period DID method. Using two-period DID method serves as a robustness check for DID method by simplifying the estimation to only pre- and post-treatment periods, thereby reducing potential biases from dynamic treatment effects, time-varying confounders, or violations of parallel trends in multi-period settings. While DID leverages multiple pre- and post-treatment years for richer trend analysis, the two-period approach provides a more transparent and assumption-light alternative. If the estimated treatment effect remains consistent across both specifications, it strengthens causal claims by demonstrating insensitivity to model complexity. I refer to the method of Bertrand et al. (2004) to construct a two-period DID method to re-estimate the formula (4.1). The two-period double differential method divides the time dimension into two periods with policy shocks and without policy shocks. Specifically, I take the year 2006 as a new time node and divide the sample period into two stages: before the publication of the "Eleventh Five-Year Plan" (2000-2005) and after the publication of the "Eleventh Five-Year Plan" (2006-2010). At each stage, I calculate the arithmetic average of the variables of each company. The regression results are shown in columns (1) and (2) in Table 4.4. I found that the estimated coefficient is still significantly negative at the 1% statistical level, indicating environmental regulatory policy can effectively reduce the firm SO_2 emission intensity.

(2) Winsorize. To rule out the effect of extreme outliers, I narrowed the 1% and 99% quantiles of all continuous variables in the sample. The regression results are shown in columns (3) and (4) in Table 4.4. I found that the estimated coefficient is still significantly negative at the 1% statistical level, indicating environmental regulation policy can effectively reduce the firm SO_2 emission intensity.

(3) Eliminate other policy distractions. The environmental policies implemented during the sample period may have an impact on the environmental governance of enterprises, especially the typical emission trading policy. Therefore, the interaction terms of dummy variables of the emission trading policy treatment group and the policy time dummy variables are added to eliminate the interference of parallel

policies on the estimated results of this research. The regression results are shown in columns (5) and (6) in Table 4.4. The estimated coefficient is still significantly negative at the 1% statistical level, indicating the estimated results are robust, that is, environmental regulation policy can effectively reduce the SO_2 emission intensity. This result is consistent with the findings of Wang and Lu (2023).

Table 4.4: The Results of Robustness Test (1)

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	Two-period DID	Two-period DID	Winsorised	Winsorised	Eliminate other policy distractions	Eliminate other policy distractions
$treat_c \times post_t$	-0.0210***	-0.0219***	-0.0198***	-0.0205***	-0.0212***	-0.0221***
	(-5.7376)	(-6.0242)	(-6.0160)	(-6.2872)	(-6.1029)	(-6.3911)
trading policy					-0.0514***	-0.0484***
					(-3.1407)	(-2.9599)
treat	-0.1806	-0.1731	-0.1311	-0.1286	-0.1405	-0.1364
	(-1.6250)	(-1.6129)	(-1.4087)	(-1.4118)	(-1.3915)	(-1.3752)
age		0.0042		0.0242***		0.0238***
		(0.2755)		(3.3951)		(3.2116)
size		-0.1830***		-0.1287***		-0.1354***
		(-10.0912)		(-12.5054)		(-12.7914)
kl		0.0167		0.0321***		0.0394***
		(0.9539)		(3.4216)		(4.0406)
hhi		0.4150		-0.2536		-0.0692
		(0.5937)		(-0.6380)		(-0.2988)
size_ind		0.0646**		0.0573***		0.0528***
		(2.1295)		(3.6504)		(3.2050)
gdp		-0.0269**		-0.0491***		-0.0480***
		(-2.2280)		(-4.8512)		(-4.6028)
ind		0.0719***		0.0659***		0.0469***
		(5.0946)		(4.9100)		(3.5249)
inter		-0.0282***		-0.0054		-0.0066*
		(-6.9158)		(-1.5328)		(-1.8097)
soe		0.0804*		0.0189		0.0166
		(1.8719)		(0.9252)		(0.7769)
foe		-0.0727*		-0.0133		-0.0288
		(-1.8695)		(-0.5780)		(-1.1698)
pre		0.0175		0.0375***		0.0393***
		(0.8779)		(3.3117)		(3.3560)
Year FE	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
N	82,214	82,171	256,744	256,165	256,744	256,165
R-Square	0.8899	0.8910	0.8214	0.8219	0.8162	0.8168

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(4) Pollution emission intensity under different output indicators. The output index used in my calculation of the pollution emission intensity is the total industrial output value of enterprises in the China Annual Survey of Industrial Firms Database. In addition to the total industrial output value, the industrial sales output value is also an important indicator of enterprise output. Therefore, I choose the industrial sales output value to calculate the pollution emission intensity of an enterprise. Similarly, the output value of industrial sales is deflated by the output price index, and then a new sulfur dioxide emission intensity (SO_2inten_2) index is constructed. The regression results are reported in columns (1) and (2) in Table 4.5. I found that the estimated coefficient is still significantly negative at the 1% statistical level, indicating that the environmental regulation policy has significantly reduced the firm pollution emission intensity.

Since the industrial enterprise database and the pollution database are not the same, there are differences between them, which may lead to changes in the basic conclusions. To alleviate this concern, I choose the total industrial output value from the pollution database. The sulfur dioxide emission intensity (SO_2inten_3) was calculated after deflating with the output price index. The corresponding regression results are reported in columns (3) and (4) in Table 4.5. I found that the estimated coefficient is still significantly negative, which further indicates that environmental regulation policy has reduced the firm pollution emission intensity. The core conclusion in benchmark regression is robust.

(5) Using a relative target. I use the percentage of reduction to test whether the basic regression results are robust. The regression results are reported in columns (5) and (6) in Table 4.5. The estimated coefficients are still significantly negative at the 5% statistical level, indicating the estimated results are robust, that is, environmental regulation policy can effectively reduce the SO_2 emission intensity.

Table 4.5: The Results of Robustness Test (2)

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	SO_2inten_2	SO_2inten_2	SO_2inten_3	SO_2inten_3	SO_2inten	SO_2inten
$treat_c \times post_t$	-0.0069*	-0.0117***	-0.0073**	-0.0121***	-0.0078**	-0.0084**
	(-1.9476)	(-3.3464)	(-2.0683)	(-3.4642)	(-2.1583)	(-2.3567)
$treat$	-0.2237*	-0.2153*	-0.2206*	-0.2123*	-0.1023	-0.1002
	(-1.7652)	(-1.7579)	(-1.7265)	(-1.7185)	(-0.8504)	(-0.8545)
age		0.0142*		0.0181**		0.0247***
		(1.7444)		(2.2174)		(3.3331)
$size$		-0.4342***		-0.4363***		-0.1346***
		(-33.5910)		(-33.8276)		(-12.6966)

kl		0.1922***		0.1916***		0.0387***
		(16.7164)		(16.6951)		(3.9685)
hhi		0.0106		-0.0074		-0.0694
		(0.0445)		(-0.0313)		(-0.3008)
size_ind		0.0532***		0.0538***		0.0527***
		(2.9671)		(2.9927)		(3.1931)
gdp		-0.0371***		-0.0356***		-0.0445***
		(-3.5174)		(-3.3910)		(-4.2752)
ind		-0.0489***		-0.0493***		0.0523***
		(-3.6726)		(-3.7263)		(3.9241)
inter		-0.0076**		-0.0077**		-0.0070*
		(-2.0871)		(-2.1088)		(-1.9212)
soe		0.0500**		0.0537**		0.0132
		(2.1681)		(2.3217)		(0.6191)
foe		0.0095		0.0140		-0.0330
		(0.3863)		(0.5687)		(-1.3357)
pre		0.0185		0.0222*		0.0411***
		(1.4756)		(1.7710)		(3.5064)
Year FE	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
N	203,327	202,732	203,322	202,727	256,744	256,165
R-Square	0.8395	0.8426	0.8398	0.8429	0.8161	0.8167

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(6) Placebo test. To ensure that the observed reduction in SO_2 intensity was indeed policy-induced rather than attributable to other confounding factors, I conducted a placebo test using smoke and dust emissions intensity as alternative outcome variables. As presented in Table 4.6, the regression results demonstrate statistically insignificant effects of SO_2 emission reduction target on both smoke and dust emissions. This finding robustly confirms that the documented decrease in SO_2 emission intensity was specifically driven by the policy intervention rather than other factors.

Table 4.6: The Results of Placebo Test

Variable	(1)	(2)
	Smoke_inten	*Dust_inten*
$treat_c \times post_t$	0.0032	-0.0037
	(1.1494)	(-1.3857)
treat	-0.0430**	-0.0185
	(-2.1271)	(-1.1113)
age	-0.0019	-0.0019
	(-0.3642)	(-0.3985)

size	-0.2660***	-0.1369***
	(-18.5799)	(-14.6900)
kl	-0.0702***	-0.0902***
	(-8.3488)	(-12.9941)
hhi	-0.0118	-0.1455***
	(-0.1812)	(-3.0892)
size_ind	-0.0017	0.0218***
	(-0.1642)	(3.6199)
gdp	0.0002	-0.0263***
	(0.0130)	(-3.4072)
ind	-0.0292	-0.0302***
	(-1.4735)	(-2.8542)
inter	-0.0087	-0.0044*
	(-1.5576)	(-1.9473)
soe	-0.0215*	-0.0211*
	(-1.7883)	(-1.7450)
foe	-0.0085	0.0365***
	(-0.8196)	(3.6558)
pre	-0.0128	0.0143
	(-1.1671)	(1.5391)
Year FE	YES	YES
Firm FE	YES	YES
N	256,828	197,250
R-Square	0.7592	0.8647

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

4.5.4 Estimation Results of Influence Mechanism

The above empirical analysis shows that environmental regulation can reduce firm pollution. On this basis, this section further analyzes the specific impact mechanism of environmental regulation on firm pollution. According to the above theoretical analysis, environmental regulation may promote firm pollution control through two aspects: pollution abatement control and resource re-allocation. Polluting firms can adopt two pollution abatement control methods to reduce their pollution emission (He et al., 2020): front-end pollution control and end-of-pipe pollution treatment. Front-end pollution control mainly refers to clean production from the production end to reduce the generation of pollutants in the production process. For example, by reducing the use of traditional energy sources, increasing the use of clean energy sources, and adopting more efficient production facilities by improving research and innovation capabilities. End-of-pipe pollution treatment mainly refers to strengthening the treatment of pollutants to reduce the emission of pollutants. In addition, the resource reallocation effect also plays an important role in the pollution emissions of enterprises. The effect of resource reallocation mainly includes the entry and exit of incumbent enterprises, and the allocation of factors among enterprises. Therefore, this study analyzes the influence mechanism from the perspective of controlling firm pollution emissions and resource reallocation.

(1) Front-end pollution control. As the formula for calculating the sulfur dioxide emission intensity of the explained variable in this research is the total amount of enterprise sulfur dioxide emission divided by enterprise output, the change in enterprise pollution emission intensity can be caused by the change of the total amount of enterprise sulfur dioxide emission, or the change of enterprise output, or both. Therefore, I need to first analyze whether the change in enterprise pollution emission intensity is caused by the total amount of enterprise pollution emission or enterprise output. I use the SO_2 emissions (*SO_2volume*) as the dependent variable to test the emission reduction effects of environmental regulation. Column (1) of Table 4.7 reports the regression results of SO_2 emissions. The estimated coefficient of $treat_c \times post_t$ is significantly negative, indicating that environmental regulation significantly reduces the total SO_2 emissions of enterprises. Therefore, environmental regulation reduces SO_2 production and emissions of enterprises from the production side. Column (2) reports the regression results of the output. The estimated coefficient of $treat_c \times post_t$ is significantly positive, indicating that environmental regulation significantly improves the firm output.

Source of energy substitution is an important way for companies to control pollution emissions from the production side. SO_2 emissions are mainly caused by burning coal, which accounts for 60% of China's primary energy consumption. The reduction in the intensity of SO_2 emissions may be due to a decline in coal consumption. Furthermore, this research selects coal consumption (*coal*) to measure the scale of enterprise coal use, respectively. Column (3) of Table 4.7 reports the regression results of coal consumption. The estimated coefficient is significantly negative, indicating that environmental regulation significantly reduces the intensity of coal consumption in China. The estimated coefficient of $treat_c \times post_t$ in column (3) is -0.0091 and it means that after 2006, for every 1 unit increase in the SO_2 emissions reduction target, the coal consumption decreases by 0.91%. According to the above analysis, environmental regulation can reduce the pollution emission intensity of enterprises by reducing the use of traditional energy. Increased the use of cleaner energy. I select the logarithmic value of clean gas consumption to measure the scale of clean gas use. Column (5) of Table 4.7 report the regression results of clean gas consumption. The estimated coefficients are positive, indicating that environmental regulation policies significantly increased the intensity of clean gas usage in China. The estimated coefficient of $treat_c \times post_t$ in column (5) is 0.0534 and it means that after 2006, for every 1 unit increase in the SO_2 emissions reduction target, the clean gas consumption increases by 5.34%. Environmental regulation can reduce the pollution emission intensity of enterprises by increase the use of clean energy.

(2) End-pollution treatment. The dependent variable of SO_2 treatment rate (*rate*) is used to test whether the enterprise can reduce pollution emissions through end-treatment. Column (6) in Table 4.7 reports the regression results of the SO_2 treatment rate. I found that the estimated coefficient of the interaction term is significantly positive, showing that environmental regulation has a significant impact on the end-pollution treatment. The estimated coefficient of $treat_c \times post_t$ in column (6) is 0.0082 and it means that after 2006, for every 1 unit increase in the SO_2 emissions reduction target, the SO_2 treatment rate increases by 0.82%. Since the handling of pollutant abatement is the main method of end-pollution treatment, the number of waste gas treatment facilities is used to explore the impact of environmental regulation on the number of firm treatment equipment. Column (7) reports the regression results. The estimated coefficient is significantly positive, indicating that environmental regulation significantly increases the number of waste gas treatment facilities. The estimated coefficient of $treat_c \times post_t$ in column (7) is 0.0023 and it means that after 2006, for every 1 unit increase in the SO_2 emissions reduction target, the number of SO_2 treatment equipment increases by 0.23%. According to the above analysis, environmental regulation can reduce the pollution emission intensity of enterprises by increasing the number of discharging equipment and improving the pollution treatment rate.

This is consistent with the expectation of proposition 2 above. Environmental regulation reduces the emission intensity of enterprises by reducing traditional energy use from the front-end control and increasing pollutant abatement equipment from the end-of-pipe treatment.

Table 4.7: The Results of Front-End Pollution Control and End-Pollution Treatment (1)

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	SO_2volume	output	coal	clean gas	rate	equipment
$treat_c \times post_t$	-0.0257***	0.1294**	-0.0091**	0.0534***	0.0082**	0.0023*
	(-8.0004)	(2.3644)	(-2.0171)	(6.4722)	(2.0235)	(1.8643)
treat	-2.5358	-0.0826	-0.1409	-0.0043	0.2249	-0.0034
	(-1.1403)	(-1.2760)	(-1.2555)	(-0.1315)	(1.1839)	(-0.0565)
age	-0.4527***	0.0455***	0.0803***	0.7937***	-0.0102	0.0189***
	(-4.4415)	(6.6539)	(7.6046)	(18.8609)	(-1.2121)	(7.0228)
size	2.7851***	0.3347***	0.4063***	-0.0172**	0.0218	0.1149***
	(11.0469)	(32.4895)	(25.4044)	(-2.0595)	(1.6034)	(27.0618)
kl	-2.3837***	-0.2060***	-0.3232***	0.1651***	-0.0095	-0.0726***
	(-9.0359)	(-22.7357)	(-23.4774)	(9.6723)	(-0.7966)	(-20.0744)
hhi	-1.2003	-0.0811	-0.0574	-0.1252***	0.2868	-0.0327
	(-1.1745)	(-0.4104)	(-0.2707)	(-8.7990)	(1.4117)	(-0.6379)
size_ind	-0.0048	-0.0042	0.0296	-0.1429	-0.0133	0.0268***
	(-0.0312)	(-0.2927)	(1.3680)	(-0.9748)	(-0.6919)	(4.7178)
gdp	0.3876***	-0.0264***	-0.0714***	-0.0484***	-0.0073	-0.0135***
	(3.4179)	(-2.8301)	(-4.7689)	(-3.1267)	(-0.5172)	(-3.4094)
ind	-0.2206*	0.0374***	0.0642***	0.0275*	-0.0036	0.0092**
	(-1.7738)	(3.2132)	(3.9184)	(1.7157)	(-0.2442)	(1.9805)
inter	0.0183	-0.0008	-0.0012	0.0711***	0.0043	0.0018
	(0.3978)	(-0.2339)	(-0.2210)	(2.7634)	(0.8051)	(1.4604)
soe	-0.1687	-0.0048	-0.0296	-0.0023	-0.0028	0.0046
	(-0.2772)	(-0.2415)	(-1.0531)	(-0.3689)	(-0.1158)	(0.6243)
foe	0.4077	-0.0043	-0.0184	0.0439*	0.0294	-0.0023
	(1.5616)	(-0.2000)	(-0.5526)	(1.7238)	(1.1543)	(-0.2647)
pre	-0.4769***	0.0217**	-0.0153	0.1289***	-0.0252*	0.0050
	(-2.8801)	(2.0309)	(-0.9427)	(3.3951)	(-1.7027)	(1.1300)
Year FE	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
N	256,374	348,677	262,780	166,448	69,445	278,394
R-Square	0.8347	0.5847	0.8946	0.7779	0.6286	0.8246

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

The estimated coefficients of the mediating variables (coal consumption and bunker coal consumption) in columns (1)-(2) of Table 4.8 are statistically significant and positive, indicating that reduced consumption of coal and bunker coal leads to lower SO_2 emission intensity. Based on the estimation results presented in columns (3)-(4) of Table 4.7, it can be concluded that SO_2 emission reduction target can effectively reduce SO_2 emission intensity by curbing energy and fuel consumption. Notably, both the absolute magnitude and statistical significance of the interaction terms exhibit a discernible increase compared to the baseline regression results in columns (7) of Table 4.3 (-0.0223). When I control the front-end pollution control effect, the negative impact of environmental regulation on SO_2 emission intensity becomes greater, which provides empirical support for the existence of the front-end pollution control effect.

Furthermore, the estimated coefficients for the mediating variables (SO_2 treatment rate and the number of waste gas treatment facilities) in columns (3)-(4) of Table 4.8 are statistically significant and negative, suggesting that increased SO_2 treatment rates and additional waste gas treatment facilities contribute to reduced SO_2 emission intensity. As evidenced by the estimation results in columns (5)-(6) of Table 4.7, SO_2 emission reduction target can mitigate SO_2 emission intensity by enhancing both the SO_2 treatment rate and the quantity of waste gas treatment facilities. Notably, both the absolute magnitude and statistical significance of the interaction terms exhibit a discernible decrease compared to the baseline regression results in columns (7) of Table 4.3 (-0.0223). When I control the end-pollution treatment effect, the negative impact of environmental regulation on SO_2 emission intensity becomes less, which provides empirical support for the existence of the end-pollution treatment effect.

Table 4.8: The Results of Front-End Pollution Control and End-Pollution Treatment (2)

Variable	(1)	(2)	(3)	(4)
	SO₂inten	*SO₂inten*	*SO₂inten*	*SO₂inten*
$treat_c \times post_t$	-0.0312***	-0.0313***	-0.0166***	-0.0213***
	(-6.2772)	(-6.2160)	(-2.7123)	(-5.7147)
coal	0.2586***			
	(45.8245)			
bunker coal		0.1398***		
		(43.1509)		
rate			-0.4390***	
			(-37.4336)	
equipment				-0.0625***
				(-5.9551)
treat	-0.0570	-0.0971	-0.1553	-0.1612
	(-0.6161)	(-1.1019)	(-0.6827)	(-1.4343)
age	-0.0032	0.0121*	0.0098	0.0176**
	(-0.4264)	(1.7051)	(0.8333)	(2.3824)
size	-0.2129***	-0.1748***	-0.1125***	-0.1436***
	(-20.2412)	(-16.7622)	(-6.2407)	(-13.2701)
kl	0.1057***	0.0676***	0.0263	0.0397***
	(11.2305)	(7.1326)	(1.5973)	(3.9781)
hhi	0.1672	-0.0720	0.1871	-0.1157

	(0.8668)	(-0.3530)	(0.8049)	(-0.5407)
size_ind	0.0713***	0.0818***	0.0155	0.0527***
	(4.2794)	(5.0982)	(0.5313)	(3.0961)
gdp	-0.0382***	-0.0356***	-0.0287	-0.0440***
	(-3.6357)	(-3.3808)	(-1.5180)	(-3.9827)
ind	0.0488***	0.0622***	0.0528**	0.0470***
	(3.7145)	(4.7200)	(2.4194)	(3.3067)
inter	0.0089**	-0.0034	0.0126*	-0.0081**
	(2.1320)	(-0.9446)	(1.6914)	(-2.1558)
soe	0.0200	0.0180	0.0302	0.0206
	(0.9173)	(0.8760)	(0.9350)	(0.9600)
foe	0.0225	0.0298	0.0465	-0.0064
	(0.9171)	(1.2495)	(1.1990)	(-0.2518)
pre	0.0331***	0.0426***	0.0393**	0.0381***
	(2.8807)	(3.6827)	(1.9607)	(3.1913)
Year FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
N	224,303	232,617	69,311	227,739
R-Square	0.8219	0.8096	0.8359	0.8121

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(3) Resource transfer among incumbent firms. This part investigates the effect of resource allocation among firms. Referring to the practice of Olley and Pakes (1996) and Bartelsman, Haltiwanger and Scarpetta (2013), I add SO_2 emissions at the firm level to the annual urban industry level based on the company output share. Furthermore, I divide total emissions changes into weighted average emissions changes and allocation effects to set up the following equation:

$$totalSO_{2cft} = \overline{SO_{2cft}} + \sum (P_i - \overline{P_{cft}})(SO_{2i} - \overline{SO_{2cft}}) \tag{4.4}$$

i represents enterprise, *c* represents industry, *f* represents city, *t* represents year, P_i represents enterprise production share, $\overline{P_{cft}}$ represents average output share of all enterprises in the industry, SO_{2i} represents enterprise *i*'s sulfur dioxide emissions, $\overline{SO_{2cft}}$ represents average sulfur dioxide emissions of all enterprises in the industry. The first item on the right of formula (4.4) represents the change in the enterprise's internal technical efficiency, and the change of the second item represents the influence of the change in the enterprise's market share under different pollution emission levels.

Using the above methods, the effect of resource allocation can be separated well. In addition to controlling firm and year fixed effects, I also further control regional fixed effects. Then, the environmental regulation is respectively regressed on the total pollutant emission, average pollutant emission variation, and covariance. The regression results are shown in Table 4.9. Column (2) in Table 4.9 reports the impact of technology effects. The estimated coefficient of $treat_c \times post_t$ is significantly negative, indicating that technology effects reduce firms' SO_2 emissions. Column (3) reports the impact of resource allocation effects. It shows that environmental regulation promotes the continuous transfer of factor resources from high-pollution enterprises to low-pollution firms, thereby increasing the market share of cleaner production firms.

Table 4.9: The Results of Resource Allocation Effect

Variable	(1)	(2)	(3)
	Total SO_2 emissions	Technology effect	Resource allocation effect
$treat_c \times post_t$	-0.0410***	-0.0121***	-0.0269***
	(-14.5884)	(-4.4060)	(-9.0906)
treat	0.1995**	-0.0028	0.1946
	(2.2424)	(-0.0273)	(1.6123)
age	0.0136**	-0.0023	-0.0083
	(2.0632)	(-0.3463)	(-0.9102)
size	0.0917***	0.0600***	0.0734***
	(9.8374)	(6.5712)	(6.2288)
kl	-0.0327***	-0.0258***	-0.0397***
	(-3.8754)	(-3.1068)	(-3.6701)
hhi	-0.2896	0.2941	-0.1168
	(-0.9408)	(0.9730)	(-0.2676)
size_ind	0.5645***	0.0719***	0.6646***
	(21.4770)	(2.6699)	(19.3008)
gdp	-0.0907***	-0.1070***	-0.0489***
	(-9.0843)	(-10.7265)	(-3.7556)
ind	0.1854***	0.1634***	0.1759***
	(15.9848)	(14.3264)	(11.2874)
inter	0.0077***	0.0018	0.0303***
	(2.5963)	(0.6035)	(6.8604)
soe	0.0095	0.0257	-0.0105
	(0.4894)	(1.3463)	(-0.4182)
foe	-0.0785***	-0.0361*	-0.0096
	(-3.5305)	(-1.6650)	(-0.3468)
pre	0.0377***	-0.0059	0.0353**
	(3.5415)	(-0.5526)	(2.4756)
Year FE	YES	YES	YES
Firm FE	YES	YES	YES

Region FE	YES	YES	YES
N	341,517	341,517	254,670
R-Square	0.8308	0.8249	0.7757

Note: Using FE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect, *Region FE* is region fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(4) Enterprise entry and exit. The dummy variables of enterprise entry and enterprise exit are used as mechanism variables to test the impact mechanism of SO_2 emission regulation on enterprise pollution. Because enterprise entry and exit are dummy variables, I use Probit model and calculate the marginal effect of the coefficients to interpret the results. Because the Probit model cannot directly control the firm fixed effect, I control the year fixed effect and the region fixed effect. The regression results are reported in columns (1) and (2) in Table 4.10. The marginal effect of the coefficients are both significantly positive. It shows that environmental regulation promotes the probability of enterprises entry and enterprises exit. Furthermore, high-polluting companies and low-polluting companies are distinguished by the variable *pollut* based on the median of the SO_2 emission intensity. I incorporate the triple difference interaction term ($treat_c \times post_t \times pollut$) into the model. The regression results are shown in columns (3) and (4) in Table 4.8. In the regression using the dummy variable of enterprise entry as the explained variable, the coefficient of the triple-difference interaction term ($treat_c \times post_t \times pollut$) is significantly negative, indicating that compared with low-polluting enterprises, environmental regulation reduces the probability of entry of high-polluting enterprises. The coefficient of the triple-difference interaction term ($treat_c \times post_t \times pollut$) is significantly positive with the dummy variable of enterprise exit as the dependent variable, indicating that compared with low-polluting enterprises, environmental regulation increases the probability of exit of high-polluting enterprises. Therefore, environmental regulation can reduce the SO_2 emission intensity of enterprises by reducing the entry of high-polluting enterprises and increasing the exit of high-polluting enterprises.

Table 4.10: The Results of Firm Market Entry and Exit

Variable	(1)	(2)	(3)	(4)
	Entry	Exit	Entry	Exit
$treat_c \times post_t \times pollut$			-0.0160***	0.0022***
			(-5.3951)	(3.6017)
$treat_c \times post_t$	0.0275***	0.0063**	0.0328***	0.0072**

	(11.7603)	(2.3683)	(12.8586)	(2.3504)
treat	-0.0751***	0.0082	-0.0734***	0.0084
	(-12.6142)	(1.3317)	(-12.2926)	(1.3361)
pollu			-0.0697***	0.0208***
			(-9.9427)	(2.6786)
age	-0.4710***	0.0214***	-0.4717***	0.0215***
	(-1.2e+02)	(5.1306)	(-1.2e+02)	(5.2394)
size	-0.1385***	-0.1819***	-0.1439***	-0.1808***
	(-46.5045)	(-51.3559)	(-47.6627)	(-53.9670)
kl	0.0724***	0.0812***	0.0717***	0.0815***
	(16.9705)	(15.6005)	(16.8091)	(16.4954)
hhi	1.1951***	0.4121***	1.1184***	0.4340***
	(9.8270)	(3.3661)	(9.3186)	(3.5924)
size_ind	-0.0383***	-0.0410***	-0.0311***	-0.0427***
	(-9.0122)	(-8.4655)	(-7.2525)	(-8.9444)
gdp	-0.0259	0.0892***	-0.0316*	0.0891***
	(-1.4136)	(4.9688)	(-1.7232)	(4.8250)
ind	-0.0053	0.0448**	0.0003	0.0446**
	(-0.3539)	(2.3673)	(0.0182)	(2.3201)
inter	-0.0260***	-0.0014	-0.0257***	-0.0014
	(-4.1050)	(-0.2651)	(-4.0624)	(-0.2611)
soe	0.0536***	0.2277***	0.0538***	0.2276***
	(4.5902)	(20.8962)	(4.6059)	(21.2219)
foe	-0.0285**	-0.1152***	-0.0369***	-0.1136***
	(-2.5150)	(-8.3556)	(-3.2566)	(-8.2841)
pre	0.0653***	-0.0502***	0.0691***	-0.0510***
	(7.6827)	(-5.2088)	(8.1184)	(-5.3151)
Year FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
N	261304	221552	261304	221552
Pseudo R-Square	0.1216	0.0616	0.1224	0.0616

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

This is consistent with the expectation of proposition 3 above. Environmental regulations strengthen the market selection mechanism of survival of the fittest, and the resulting entry and exit behaviors improve the environmental performance of incumbents.

4.5.5 Heterogeneity Analysis

(1) Firm ownership. State-owned enterprises are often closely related to the government, and their

environmental governance activities are more driven by administrative directives and political assessments. They may find it easier to meet emission reduction requirements in the short term because they enjoy advantages such as financial subsidies and policy loans. In contrast, non-state-owned enterprises are more sensitive to market signals and cost pressures. Strict environmental regulations may force them to reduce emissions intensity through technological upgrading or cleaner production, but they may also be forced to reduce production, relocate, or even exit the market due to financing constraints or high compliance costs. Therefore, the impact of environmental regulatory policies on the two types of enterprises may be very different (Wang et al., 2022). Therefore, I explore heterogeneity from the perspective of enterprise ownership. I divide enterprises into state-owned enterprises and non-state-owned enterprises. State-owned enterprises, state-owned joint ventures, wholly state-owned companies or joint-stock cooperation and joint-stock limited liability companies with absolute controlling status of state-owned economy are all state-owned enterprises. I have standardized the data using Z-score standardization method (Vaccario et al., 2017). And then I use sub-sample regression to test the impact of the implementation of environmental regulation policies on enterprises of different ownership. Columns (1) and (2) in Table 4.11 report the regression results of enterprises with different ownership. I found that the estimated coefficients of $treat_c \times post_t$ are both significantly negative at the 1% statistical level. The estimated coefficient of $treat_c \times post_t$ in column (1) is -0.0159 and it means that after 2006, for every 1 unit increase in the SO_2 emissions reduction target, the state-owned enterprises' SO_2 emission decreases by 1.59%. The estimated coefficient of $treat_c \times post_t$ in column (2) is -0.0076 and it means that after 2006, for every 1 unit increase in the non-state-owned enterprises SO_2 emissions reduction target, the SO_2 emission decreases by 0.76%. The absolute value of the regression coefficient of state-owned enterprises is larger than that of non-state-owned enterprises. It can be concluded that environmental regulation policies have a greater impact on the emission reduction of state-owned enterprises. On the one hand, the natural political ties between state-owned enterprises and local governments make it easier for state-owned enterprises to obtain financial subsidies and tax incentives from the government. This has provided a sufficient financial guarantee for state-owned enterprises to reduce the use of traditional energy, increase waste abatement equipment and improve waste treatment capacity (Zhang, 2017； Zhang and Zhao, 2022). On the other hand, state-owned enterprises, as local leading enterprises, need to assume more social responsibilities and give full play to their leading demonstration role in reducing emissions (Wang et al., 2022). In terms of having mandatory targets, state-owned enterprises excel in environmental performance to meet the interests of their shareholders (Bai et al., 2006), Officials' political careers are closely linked to the degree to which they meet their assessment targets, including environmental mandatory targets (Liang and Langbein, 2021； Liang and Ma, 2020). Therefore, it shows that compared with non-state-owned enterprises, state-owned enterprises have a more prominent pollution reduction effect under environmental regulations.

(2) Firm size. Examining the heterogeneous effects of environmental regulations on SO_2 emission intensity by distinguishing between large-scale and small-scale enterprises is crucial for both theoretical and policy reasons. This classification reflects fundamental differences in how firms of varying sizes respond to regulatory pressures: large firms typically possess stronger financial capabilities and better access to financing, enabling them to absorb the high fixed costs of pollution control equipment and potentially achieve economies of scale in emission reduction. They are also more likely to pursue technological innovations for long-term environmental compliance, consistent with the Porter Hypothesis. In contrast, small enterprises often face severe financial constraints, where compliance costs may threaten their viability, leading to either passive compliance strategies or even regulatory evasion (Lei et al., 2017). Therefore, I explore heterogeneity from the perspective of firm size. According to the median enterprise size, the sample is divided into large-scale enterprises and small-scale enterprises for sub-sample regression. I have standardized the data using Z-score standardization method. Columns (3) and (4) in Table 4.11 report the regression results of enterprises with different enterprise sizes. The regression result of the estimated coefficient of large-scale enterprises is significantly negative, but that of small-scale enterprises is not significant. The estimated coefficient of $treat_c \times post_t$ in column (3) is -0.0123 and it means that after 2006, for every 1 unit increase in the SO_2 emissions reduction target, the large-scale firms' SO_2 emission decreases by 1.23%. It can be concluded that environmental regulation can reduce pollution emission intensity of large enterprises but has no effect on small-scale enterprises. Large-scale enterprises have strong financial strength and abundant factor resources. Environmental regulations can encourage large-scale enterprises to actively carry out green innovation, while small-scale enterprises are often faced with a high innovation cost burden due to limited resources, so they are not highly motivated to carry out emission reduction (Lei et al., 2017). Moreover, compared with small-scale enterprises, large-scale enterprises have more sound internal mechanisms and are often able to consider problems from the perspective of the long-term development of enterprises. Large-scale enterprises will fundamentally improve their environmental performance by increasing R&D investment and green innovation (Sun et

al., 2020).

Table 4.11: Heterogeneity Analysis (1)

Variable	(1)	(2)	(3)	(4)
	State-owned firms	Non-state-owned firms	Large-scale firms	Small-scale firms
$treat_c \times post_t$	-0.0159***	-0.0076***	-0.0123***	-0.0036
	(-4.2322)	(-4.3486)	(-5.5602)	(-1.6434)
treat	0.0007	-0.1617***	-0.0885	-0.0202
	(0.0279)	(-3.0753)	(-1.3606)	(-1.1667)
age	0.0191**	-0.0004	0.0107**	0.0004
	(2.1447)	(-0.0987)	(2.0928)	(0.0844)
size	-0.1119***	-0.0600***	-0.0858***	-0.0455***
	(-7.4653)	(-11.7903)	(-9.8716)	(-7.0213)
kl	0.0178	0.0204***	0.0103	0.0178***
	(1.3559)	(4.3562)	(1.4328)	(3.2606)
hhi	-0.1875	0.0549	-0.0038	-0.0549
	(-1.1280)	(0.3960)	(-0.0325)	(-0.2460)
size_ind	0.0217	0.0152*	0.0254**	0.0236**
	(0.9698)	(1.9274)	(2.2745)	(2.3862)
gdp	-0.0547***	-0.0145***	-0.0196***	-0.0134**
	(-2.8831)	(-3.0382)	(-2.6959)	(-2.1727)
ind	0.0578***	0.0192***	0.0236***	0.0043
	(3.5913)	(2.9643)	(2.7840)	(0.4917)
inter	-0.0113***	-0.0006	-0.0049**	-0.0015
	(-3.2255)	(-0.3133)	(-1.9763)	(-0.6730)
soe			0.0057	0.0116
			(0.4533)	(0.7456)
foe			-0.0064	0.0016
			(-0.4460)	(0.0949)
pre			0.0326***	0.0001
			(3.7087)	(0.0119)
Year FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
N	39,676	213,967	126,085	123,521
R-Square	0.8234	0.8203	0.8158	0.7979

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(3) Factor density. When examining the impact of environmental regulations on SO_2 emission intensity, conducting heterogeneity analysis across industries with different factor intensities (labor-intensive, capital-intensive, and technology-intensive) is critically important. This approach recognizes fundamental

differences in pollution characteristics, technological capabilities, and policy responsiveness across these distinct industry types. Labor-intensive industries typically exhibit lower energy efficiency and weaker pollution control capacity. Capital-intensive industries generate substantial aggregate emissions. Technology-intensive sectors demonstrate greater capacity for proactive emission reduction through green innovation (Cao et al., 2019; Zhang and Chen, 2022). I divided the industries involved into labor-intensive industries, capital-intensive industries, and technology-intensive industries, and analyzed the heterogeneity of different samples by using sub-sample regression. I have standardized the data using Z-score standardization method. The regression results are reported in columns (1), (2) and (3) in Table 4.12. I found that the estimated coefficient of $treat_c \times post_t$ is significantly negative in labor-intensive industries and technology-intensive industries but is not significantly negative in capital-intensive industries. The estimated coefficient of $treat_c \times post_t$ in column (1) is -0.0157 and it means that after 2006, for every 1 unit increase in the SO_2 emissions reduction target, the labor-intensive industries' firm SO_2 emission decreases by 1.57%. The estimated coefficient of $treat_c \times post_t$ in column (3) is -0.0188 and it means that after 2006, for every 1 unit increase in the SO_2 emissions reduction target, the technology-intensive industries' firms SO_2 emission decreases by 1.88%. This indicates that environmental regulation has a significant effect on reducing emissions in labor-intensive industries and technology-intensive industries, but not in capital-intensive industries. Technology-intensive industries have a higher level of technological innovation and higher green production efficiency. Environmental regulations are more conducive to reducing emissions in technology-intensive industries. At the same time, with the development of technology and the pressure of environmental regulation, many mechanized manual operations are gradually replaced by machines and equipment (Cao et al., 2019; Zhang and Chen, 2022). On the one hand, some labor-intensive industries are gradually becoming technology-intensive industries; on the other hand, labor-intensive industries continue to generate new technologies, thereby reducing corporate pollution emissions.

(4) Pollution intensity.

The classification of industries into high pollution intensive and low pollution intensive industries helps explain why environmental regulations significantly reduce SO_2 emission intensity. Drawing on Tang et al. (2020), I divided the industries involved into high pollution intensive industries and low pollution intensive industries. I analyzed the heterogeneity of different samples by using sub-sample regression. I have standardized the data using Z-score standardization method. The regression results are reported in columns (4) and (5) in Table 4.12. I found that the estimated coefficient of $treat_c \times post_t$ is significantly negative in high pollution intensive industries but is not significantly negative in low pollution intensive industries. The estimated coefficient of $treat_c \times post_t$ in column (4) is -0.0127 and it means that after 2006, for every 1 unit increase in the SO_2 emissions reduction target, the high pollution firms SO_2 emission decreases by 1.27%. This indicates that environmental regulation has a significant effect on reducing emissions in high pollution intensive industries. High-pollution industries typically feature concentrated emissions and outdated technologies, making them primary regulatory targets with greater potential for improvement through end-of-pipe treatment or process upgrades (Jiang and Lyu, 2021). Their large-scale operations also enable cost-sharing of pollution control investments, while heightened political scrutiny and social pressure create strong compliance incentives (He et al., 2022). Additionally, environmental regulations accelerate the exit of inefficient firms and spur technological innovation within these sectors, collectively driving more pronounced emission reductions compared to low pollution intensive industries where regulatory impacts may be marginal due to dispersed emissions and limited scale effects (Fu et al., 2021).

Table 4.12: Heterogeneity Analysis (2)

Variable	(1) Labor-intensive industries	(2) Capital-intensive industries	(3) Technology-intensive industries	(4) High pollution	(5) Low pollution
$treat_c \times post_t$	-0.0157***	-0.0020	-0.0188***	-0.0127***	0.0029
	(-5.0113)	(-0.9884)	(-5.1911)	(-6.9996)	(0.4200)
treat	-0.0219	-0.0544	-0.0779	-0.0694	-0.0131
	(-1.0005)	(-0.9842)	(-1.1756)	(-0.8853)	(-1.0216)
age	0.0055	0.0055	0.0134	0.0247***	0.0013
	(0.9399)	(1.2185)	(1.6051)	(5.4785)	(0.3487)
size	-0.0562***	-0.0488***	-0.1101***	-0.0493***	-0.0395***
	(-6.8939)	(-7.7338)	(-7.5978)	(-7.3343)	(-6.0723)
kl	0.0208***	0.0104*	0.0334**	0.0120**	0.0129**
	(2.9062)	(1.7776)	(2.4863)	(1.9657)	(2.2707)
hhi	-0.3941*	0.0153	0.1793	-0.0439	0.2154
	(-1.7765)	(0.0728)	(1.4622)	(-0.4638)	(1.5817)
size_ind	0.0554***	0.0109	0.0134	0.0271***	0.0037
	(3.7934)	(0.8164)	(0.4832)	(3.0054)	(0.3547)

gdp	-0.0275***	-0.0089	-0.0098	-0.0233***	-0.0113
	(-3.6115)	(-1.4182)	(-0.6234)	(-3.6246)	(-1.0906)
ind	0.0384***	0.0133	-0.0064	0.0121	0.0137
	(4.0494)	(1.5709)	(-0.3630)	(1.6142)	(1.4079)
inter	0.0043	-0.0042*	-0.0082*	-0.0040*	-0.0003
	(1.5076)	(-1.8544)	(-1.9046)	(-1.9461)	(-0.0750)
soe	0.0352**	-0.0012	0.0003	-0.0000	0.0068
	(2.0794)	(-0.0809)	(0.0171)	(-0.0033)	(0.6443)
foe	0.0102	-0.0069	-0.0374	-0.0026	-0.0167
	(0.6111)	(-0.4312)	(-1.2039)	(-0.2064)	(-1.2351)
pre	-0.0157***	-0.0020	-0.0188***	0.0208***	0.0001
	(-5.0113)	(-0.9884)	(-5.1911)	(2.9666)	(0.0183)
Year FE	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES
N	76,923	135,301	41,983	123,736	119,222
R-Square	0.7740	0.7986	0.8142	0.7746	0.7073

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(5) Different industries. According to manufacturing industry segmentation, I have standardized the data using Z-score standardization method and conducted subsample regression. The regression results are shown in Table B.1.1- B.1.5 in Appendix B. Among the 29 manufacturing segments, only 10 industries had a significantly negative estimated coefficient. The 10 industries are: manufacture of foods, manufacture of textiles, manufacture of textile wearing apparel, footwear and caps, manufacture of medicines, manufacture of rubber, smelting and pressing of ferrous metals, smelting and pressing of non-ferrous metals, manufacture of non-metallic mineral products, manufacture of general purpose machinery, manufacture of transport equipment and manufacture of electrical machinery and equipment. As can be seen, these industries are highly polluting. Environmental regulation has a greater emission reduction effect on high pollution industries. High pollution industry is the focus of the public and the government. The government often imposes stricter environmental regulations on high pollution industries, which can force the green transformation of high pollution industries, to achieve more pollution reduction.

4.6 Chapter Summary

In this chapter, I analyzed the effect of China's domestic environmental regulation on firms' SO_2 emissions reductions. I first theoretically analyzed the impact mechanism of environmental regulations on firm SO_2 emission intensity. Environmental regulation may impact firm SO_2 emissions through two aspects: First, environmental regulation reduces the emission intensity of enterprises by reducing traditional energy use from the front-end control and increasing pollutant abatement equipment from the end-treatment. Second, environmental regulation can reduce the firm pollution emission intensity through the reallocation of resources among firms. Specifically, on the one hand, high-polluting enterprises continue to transfer resources to low-polluting enterprises. On the other hand, high-polluting enterprises increasingly withdraw, and low-polluting enterprises continue to enter.

On this basis, using data from the China Annual Survey of Industrial Firms Database and the China Annual Environmental Survey of Polluting Firms Database from 2000 to 2010, I take the implementation of the Eleventh Five-Year Plan in 2006 as a quasi-natural experiment and employ the TWFE model and continuous DID method l to verify the conclusion of the theoretical analysis. I find that with the advent of stricter environmental regulations, represented by the differential emissions reduction targets set up in the Chinese Eleventh Five-Year Plan after 2006, manufacturers have emitted less SO_2. More stringent environmental regulation faced by firms is positively associated with a greater probability of reducing SO_2 emissions after 2006. I also conduct a series of robustness tests, including two-period double difference method, winsorize, eliminate other policy distractions, changing the dependent variable, and using a relative target, and the results remain significant. The analysis of the impact mechanism confirms that first environmental regulations can reduce firm pollution emissions through the front-end control and the end-treatment, and secondly environmental regulations can reduce firm pollution emissions through the reallocation of resources between firms. Furthermore, heterogeneity analysis showed that environmental regulation significantly reduces emissions of state-owned firms, large-scale firms, labor-intensive industries, technology-intensive industries and high pollution industries, eastern region’s firms.

In the next chapter, I will analyze the relationship between SO_2 emissions regulation and total factor productivity.

5 SO_2 Emissions Regulation and Firm Total Factor Productivity

5.1 Introduction

China has become the world's largest energy consumer and major emitter of greenhouse gases and air pollutants, bringing with it a range of severe environmental problems (Hao et al., 2020). Firms should undertake due responsibilities and play appropriate roles in pollution control and environmental protection (Zhang et al., 2008). However, Firms pursue profit maximization during development without proactively transforming their growth models to equally prioritize environmental protection and expansion. This underscores the need for governmental environmental regulations and measures to constrain economic entities, engender firm eco-awareness, and guide environmentally responsible firm conduct. To mitigate escalating environmental pollution, China has enacted environmental laws and policies to manage the negative externalities of firm pollution (Xu et al., 2010; Fan et al., 2021). Through ongoing reforms, China has gradually established environmental regulation system. Undeniably, the implementation of environmental regulations will impact economic growth and productivity (Haveman and Christainsen, 1981; Wang and Shen, 2016; Zhao et al., 2022). Past studies often employed innovation to gauge the technological impact of regulations. However, as innovation does not reflect efficiency changes, total factor productivity (TFP) provides a more accurate measure. Elevating TFP is integral to balancing environmental protection and economic development. This hinges on effective, rational implementation pathways and supportive regulations.

Theoretically, environmental regulations influence firm productivity by raising production costs and eliminating inefficient firms. Firstly, by mandating clean energy utilization and pollution control equipment installation, regulations raise firm costs and reduce revenue productivity – a negative impact widely validated (Gollop and Roberts, 1983; Gray and Shadbegian, 2002, 2003; Conrad and Wastl, 1995; Boyd and McClelland, 1999; Becker, 2011). However, the Porter Hypothesis holds that appropriate stringency can stimulate enterprises to enhance efficiency through new technologies and organizational approaches. Thus, although environmental policies may initially increase costs, long-term productivity and growth can improve. Monitoring could also drive innovation across related industries, continuously enhancing division of labor and TFP. Some empirical studies validate this hypothesis (Hamamoto, 2006;

Berman and Bui, 2001; Jaffe et al., 1995; Lanoie, Patry and Lajeunesse, 2008; Alpay, Kerkvliet and Buccola, 2002). Secondly, regulations eliminate less technologically advanced, highly polluting firms (Deily and Gray, 1991; Jefferson et al., 2013). Hering and Poncet (2014) and He, Wang and Zhang (2002) found regulations caused small, inefficient enterprises to exit polluting industries. Regulation also induces commercial retreat and alters locational choices (Greenstone, 2002; Shadbegian and Gray, 2005), while squeezing out productive investments and shifting them toward lenient regions (Gray and Shadbegian, 1998). Consequently, the productivity impact remains contested, necessitating further empirical analysis.

This chapter utilizes 2000-2010 Chinese industrial enterprise panel data and a DID model to analyze the direct TFP impact of environmental regulations, along with potential mechanisms and heterogeneities. The contributions of my work are reflected in the following aspects. Firstly, unlike previous studies, my research uses the SO_2 emission reduction target in the Eleventh Five Year Plan as a proxy variable for environmental regulation to analyze its impact on TFP. Secondly, I introduce environmental regulation into the heterogeneous firm model (Melitz, 2003) and discuss the theoretical mechanism of environmental regulation on enterprise total factor productivity. It reveals that environmental regulation influences firms' total factor productivity (TFP) through two channels: On one hand, it directly increases production costs, primarily through the increased use of clean energy and emission reduction equipment. On the other hand, it can stimulate corporate innovation, improving TFP, mainly through increased R&D investment and patent generation. Since the technological innovation effect induced by environmental regulations can compensate for the increased compliance costs, environmental regulations ultimately enhance TFP. This conclusion validates the Strong Porter Hypothesis. This model extends the application boundaries of heterogeneous firm models and deepens the theoretical understanding of the relationship between environmental regulations and firm productivity. Finally, the results indicate that environmental regulations do not necessarily hinder economic growth but can instead stimulate technological innovation and improve productivity, thereby positively impacting TFP. This suggests that policymakers can strike a better balance between environmental and economic objectives. They can introduce a mix of environmental regulation policies, including SO_2 regulation, to achieve sustainable development without significantly sacrificing economic growth. Additionally, policymakers can develop targeted support measures to help enterprises transition and adapt to stricter environmental regulations, minimizing potential negative impacts on specific industries or sectors.

5.2 Literature Review

The main purpose of environmental regulation is to reduce the pollutants emitted, clean up contaminated environments and improve social welfare (Kozluk and Zipperer, 2015). However, the policy implementation process has a complex impact on the economic activities of enterprises. TFP is often used as a proxy variable of economic development to study its relationship with environmental regulation. Currently, many papers have tried to reveal the influence of environmental regulations on TFP. Although these papers tried to show general and widespread results, the results were inconclusive.

5.2.1 Negative Impact of Environmental Regulations on TFP

Traditional economics argues that strict environmental regulation has negative effects. On the one hand, based on a static model, neoclassical economic theory suggests that environmental regulation causes firms to divert limited productive resources from productive inputs to pollution control its negative impact mainly comes from the "compliance cost" generated by environmental regulation. The environmental regulation policy increases the costs of pollution control and emissions by increasing the non-productive inputs (environmental production equipment), which reduces the productivity and market competitiveness of firms. Environmental regulation will reduce productivity and inhibit economic growth (Gray, 1987; Jorgenson and Wilcoxen, 1990; Palmer et al., 1995; Boyd and McClelland, 1999; Gray and Shadbegian, 2003).

On the other hand, the negative effect stems from the fact that environmental regulation increases the uncertainty faced by firms. Uncertainty about environmental regulation slows down firms' investment decisions (Viscusi, 1983), and affects the R&D processes of new products and production (Hoerger et al., 1983). The earlier empirical literature on developed countries such as the United States, Germany and Japan support these views. For example, Gray (1987) using data from 450 manufacturing industries between 1958 and 1978, found that environmental regulation hurt productivity growth. Other literature on sub-sectors of the US manufacturing industry has yielded similar findings. Gollop and Roberts (1983) used the data for the US electric power industry from 1973 to 1979 and found that sulfur dioxide emission restrictions reduced the rate of productivity growth in the sector. Christiansen and Haveman (1981) found that environmental regulation reduced the growth rate of labour productivity by 0.27% in the US manufacturing sector from 1958 to 1977. Barbera and McConnel (1990) analyzed the direct and indirect effects of environmental regulation on productivity. By examining the direct and indirect effects of environmental regulation in polluting industries in the US, they found a significant decrease in productivity in industries with strict environmental regulation.

At the same time, Ferjani (2011) and Kneller and Manderson (2012) support the "compliance cost" hypothesis, according to which firms' productivity and profitability are reduced by environmental regulation. In addition, several studies have confirmed that environmental regulations inevitably increase firms' production costs and undermine their competitiveness under conditions of continuous availability of technological resources (Wagner, 2007; Cole, Elliott and Okubo, 2010).

The same data and sample can vary greatly depending on the method (Berman and Bui, 2001; Lanoie et al., 2008). With the emergence of quasi-experimental methods and related technologies, the research focusses on this field has shifted from traditional regression analysis to the treatment of endogenous problems in order to obtain a more scientific and accurate causal relationship. Greenstone et al. (2012) used a quasi-experimental approach to assess the impact of the 1990 US Clean Air Act Amendments on firm productivity, which reduced firm productivity by around 2.6%. Further, the lagged effects have a greater negative impact than contemporaneous effects. Similarly, Hancevic (2016) studied the impact of the 1990 US Clean Air Act Amendments on firm productivity and found that productivity declined between 1% and 2.5%.

Some Chinese scholars have also found that environmental regulations have reduced the TFP of enterprises. Tang et al. (2020), analysing China's "two control zones" policy, found that environmental regulations severely impede the improvement of firms' total factor productivity, and that the negative impacts are lagging and persistent. Wang et al. (2018) and Li et al. (2019) support the "compliance cost" hypothesis, suggesting that firms' productivity and profitability are reduced by environmental regulation.

5.2.2 Positive Impact of Environmental Regulations on TFP

The above traditional view has been challenged. Some scholars argue that strict environmental regulation does not always have a negative effect on productivity. Porter and Van der Linde (1995) suggested that pollution emissions are related to the allocation of resources and are a manifestation of economic waste. Reducing pollution emissions and improving resource recycling will lead to increased firm productivity. Government environmental regulation policies may prompt companies to improve the way they use resources. At the same time, environmental regulation not only directs firms to care about inefficiencies in resource use and potential opportunities for innovation, but also puts pressure on firms to innovate technologically and organisationally. Thus, strict and appropriate environmental regulation increases the productivity of firms by providing them with incentives to develop new technologies or new ways of organising themselves, offsetting some or all of the environmental costs. This is also known as the "innovation compensation effect" of firms. The Porter hypothesis is the first to systematically address the possibility of a "win-win" outcome between environmental protection and economic growth through theoretical analysis and case studies. As a result, this hypothesis has received a great deal of attention since its inception.

Compared with theoretical research, some empirical literature supports Porter's hypothesis (Alpay et al., 2002; Hamamoto, 2006). Arimura et al. (2007) found a significant positive correlation between the stringency of environmental regulation and the probability of environmental R&D expenditure. Jaffe et al. (1995) argued that environmental regulation provides incentives for firms to update abatement measures. As a result, productivity is likely to increase. The Porter's Hypothesis is also supported by Berman and Bui (2001), who analysed how air quality regulation affects the productivity of petroleum refineries in Los Angeles and found that pollution control investment increases manufacturers' productivity. Alpay et al. (2002) found that productivity in the Mexican food processing industry increased with the increase in environmental regulation pressure.

Many studies have tested the weak Porter hypothesis. Brunnermeier and Cohen (2003) utilized panel data on U.S. manufacturing firms from 1983-1992 to investigate the impact of environmental regulations and emissions charges on firm innovation. Their research found that emissions taxes enhanced firms' innovative capabilities. Testa et al. (2011) empirically examined the EU construction industry, discovering that more stringent environmental monitoring policies can effectively motivate enterprises to invest in advanced equipment and innovative products. Moreover, environmental policy instruments can play a greater role than economic instruments. Galloway and Johnson (2016) investigated a new mechanism by which environmental regulations can improve technical efficiency, namely the intra-firm knowledge spillover effect induced by regulations. Governmental strengthening of environmental monitoring in non-compliant areas will increase the technical efficiency of that region, with these benefits materializing at least 3 years after the increase in regulatory stringency. Hamamoto (2006) found that environmental regulations led to increased innovation, which further promoted TFP growth in five Japanese manufacturing sectors over more than two decades. Fischer et al. (2003) argue that environmental regulations like emissions taxes and tradable permits can stimulate firms' technological innovation and performance improvement, with taxes and permits often providing greater innovation incentives than technology requirements and performance standards. André et al. (2009) provided new support for the Porter Hypothesis using a duopoly model. Additionally, Berman and Bui (2001) and Zhang et al. (2011) also empirically validated the Porter Hypothesis.

The existing literature also uses the quasi-natural experiment method to study environmental regulation and TFP in China. Employing China's "Two Control Zone" policy as a quasi-natural experiment, Tang et al. (2020) used a Chinese industrial enterprise panel dataset from 1998 to 2007 and found that environmental regulation had significantly hindered the growth of enterprise total factor productivity which mainly came from the increase in costs of enterprises and the negative impact on the enterprise resource allocation efficiency. Chen et al. (2022) used China's National Environmental Protection "Eleventh Five-Year Plan" as a quasi-natural experiment and found that environmental regulation promotes the TFP of enterprises. However, they don't have a good explanation of the mechanism by which environmental regulations affect the total factor productivity of enterprises. Using data from Chinese industrial firms from 2003 to 2012, Shi et al. (2022) utilized Chongqing's daily penalty policy (DPP) as a quasi-natural experiment to investigate the impact of stringent environmental regulations on firm productivity. They found that DPP can improve the TFP of firms by stimulating the innovation compensation effect of firms and crowding out high polluting and inefficient firms in the industry.

5.2.3 Uncertain Impact of Environmental Regulations on TFP

Some literature considers the impact of environmental regulation on TFP to be uncertain. On the one hand, this may be the result of the mechanisms of firm production costs and firm innovation cancelling each other out. On the other hand, because of the different environmental regulation policies chosen, objects and scopes, it is not possible to assume directly and absolutely that environmental regulation has a positive or negative impact on the productive performance of firms. For example, Jaffe and Palmer (1997) examined the effect of environmental regulation, as measured by emissions charges, on industry R&D expenditures and patent applications using data from US industrial sectors and found that environmental regulation significantly increased R&D expenditures in industrial sectors, but had no significant effect on patent applications. Shadbegian and Gray (2005) found no significant effect of pollution abatement expenditures on firm productivity in a study of US paper, gasoline refining and steel mill firms. Levinsohn and Petrin (2003) found that although pollution control costs in the US paper industry were high, productivity in the paper industry remained at a low level for a long time, implying that strict environmental regulation reduced productivity in the US paper industry.

However, Becker (2011) found that the effect of high environmental costs on productivity was not statistically significant for US manufacturing firms. Rubashkina et al. (2015) used industry-level data from 17 European countries from 1997 to 2009. They found that environmental regulation had a positive impact on the output of innovation activity, but no significant relationship was found between environmental regulation and productivity. Wang et al. (2018) evaluated the effects of environmental regulations on productivity in the 3Rs3Ls basins and found that they had no statistically significant effects on surviving firms' productivity. Albrizio et al. (2017) used a standard Neo-Schumpeterian model of multifactor productivity (MFP) growth. They studied the impact of changes in environmental policy stringency on the industry- and firm-level productivity growth in OECD countries. They found that at the firm level, environmental regulations had a negative effect on the productivity growth of high pollution-intensity and low-productivity firms. At the industry level, although the impact is smaller for low-productivity industries, the impact of environmental regulation is positive.

With the depth of research, some scholars gradually found that the impact of environmental regulation on total factor productivity is non-linear. Johnstone et al. (2017) found that the relationship between environmental regulation and total factor productivity of technological innovation is U-shaped, and that technological innovation further improves firms' total factor productivity. Wang and Shen (2016) used the Global Malmquist-Luenberger (GML) index to measure the TFP of Chinese industries and found an inverted U-shaped relationship between environmental regulation and TFP. Moreover, Dong et al. (2021) validate this finding using China as a study sample. Ge et al. (2023) found that the positive impact of environmental regulation on total factor productivity in the secondary sector is non-linear. The higher the level of digital economy development, the more significant the positive impact. More importantly, there are regional differences in the impact of environmental regulation on total factor productivity in primary and secondary industries. Overall, it can be found that most of the literature using micro-firm data finds that environmental regulation significantly reduces firm productivity (Jaffe et al., 1995; Greenstone, 2002; Rassier and Earnhart, 2010; Greenstone et al., 2012).

In addition, the impact of environmental policies also varies in short-term and long-term performance. Although environmental policies may increase costs in the short term, they may improve productivity and economic growth in the long term. Lanoie et al. (2008) analysed the impact of environmental regulation on total factor productivity in 17 Quebec manufacturing industries using data from 1985-1994 and tried to find the dynamic influence of environmental regulations on productivity. They found that the impact of environmental regulation on total factor productivity is negative in the same period, but if the lagging environmental regulation variable is adopted, the impact is positive, that is, environmental regulation can promote the improvement of productivity in the long run. At present, the mainstream theoretical research reached a consensus: from the long-term dynamic perspective, environmental regulation may promote enterprise R&D investment and technological innovation and realize the joint improvement of environmental performance and productivity through the innovation compensation effect (Porter and Van der Linde, 1995; Ambec et al., 2013). The debate on the relationship between environmental regulation and TFP in China has also been a popular topic of research in recent years. Using industrial data for Taiwan from 1997 to 2003, Yang et al. (2012) used a two-stage estimation approach and found that environmental regulation increased R&D expenditure, which in turn increased industrial productivity, supporting the Porter hypothesis. However, some literature supports the traditional economic theory. Zhang (2014) used Chinese provincial data from 2002 to 2012, Zhang et al. (2016) used similar data from 2011 to 2014, and Zhang et al. (2020) used Chinese data from 216 prefectural-level cities from 1998 to 2016 to estimate the effects of environmental regulation on TFP. They all found that the more stringent environmental regulations, the lower the TFP. Zhang and Du (2020), using a dynamic panel dataset of Chinese firms from the period from 1998 to 2012, found that there was a negative effect of environmental regulation on TFP. Lou et al. (2020) used firm-level data from 2010 to 2013 in China and found that environmental regulation has both positive and negative effects on firm productivity due to the presence of the treatment level of the policy, innovation, and government subsidies. Zhao et al. (2018) found that there was a significant inverted U-shape relationship between environmental regulation and the TFP of

China's carbon-intensive industries. There was no long-term Porter effect, and the impact of environmental regulation on carbon-intensive enterprises was gradually shifting from innovation compensation to compliance cost. However, Xu et al. (2003) examined the pollution control policies applied in China's paper industry during the period of economic reform from 1982 to 1992 and found that environmental regulation had an efficiency improving effect on most modern mills, but smaller mills were less efficient. Unlike these Chinese scholars' studies, I analyse the direct impact of environmental regulations on total factor productivity using panel data of Chinese industrial firms and the DID model from 2000-2010. For theoretical model construction, I introduce environmental regulations into the heterogeneous firm model (Melitz, 2003) and discuss the theoretical mechanisms of environmental regulations on firms' total factor productivity. In terms of research methodology, I use emission reduction targets as a natural experiment to empirically assess their impact on productivity. This approach effectively addresses the endogeneity concerns between variables. In addition, I discuss in detail the potential micro-influence mechanisms of environmental regulation on TFP and multidimensional heterogeneity.

By summarizing the above literature, it can be seen that existing literature has mainly focused on the impact of environmental regulation on TFP in developed countries, and the research in China is just beginning. At the same time, it is difficult to distinguish the specific mechanisms through which environmental regulation affects firm TFP. As a result, the impact of environmental regulations on the economy has been controversial, but studies vary by country, region and environmental regulations. The differences in the results of different studies may be mainly caused by the following factors. First, pollution and environmental regulations are rooted in factors such as the economic development approach, consumption structure, and resource endowment of each country or region, which determine the differences in policy effects between countries or regions (Greenstone et al., 2012; Gray et al., 2014). Second, measurements of environmental regulations in the current literature are usually based on pollution intensity (Ren et al., 2018), environmental taxation (Xu, 2016; Xie, Yuan and Huang, 2017), or pollution control costs (Wang and Shen, 2016), which are highly subjective and clearly endogenous (Lanoie et al., 2008). Third, the same sample data can even lead to different conclusions using different estimation methods (Berman and Bui, 2001; Lanoie et al., 2008). Traditional regression analysis is often criticised because endogeneity does not accurately identify the true policy impact (Greenstone et al., 2012). In addition, the selection of environmental regulation measures and the endogeneity between environmental regulation and TFP are also important reasons for the inconsistent findings of existing literature.

5.3 Theoretical Analysis and Research Hypothesis

In theory, environmental regulation affects firms total factor productivity through two channels. First, environmental regulations require firms to use more costly cleaner energy sources and increase pollution control equipment, which raises firms' production costs and reduces their total factor productivity (Gollop and Roberts, 1983; Gray and Shadbegian, 2002, 2003; Conrad and Wastl, 1995; Boyd and McClelland, 1999). However, Porter and Van der Linde (1995) proposed the Porter hypothesis. It refers to the idea that environmental regulation can increase firm productivity by providing incentives for firms to develop new technologies when the level of stringency of environmental regulation is more appropriate. The Porter hypothesis has been tested in several empirical studies (Jaffe et al., 1995; Berman and Bui, 2001; Alpay et al., 2002; Hamamoto,2006; Lanoie et al., 2008).

What impact China's environmental regulations have on firms' total factor productivity, and through what micro-channels they have an impact on firms' total factor productivity are the focus of my research in this chapter. Hence, I will analyze the mechanism of the impact of environmental regulation on firms' total factor productivity in terms of production costs and technological innovation. As can be seen in Figure 5-1, on the one hand, environmental regulation will increase firms' production cost and then reduce firms' total factor productivity; on the other hand, environmental regulation will encourage firms to increase technological innovation and then improve firms' total factor productivity. Therefore, the impact of environmental regulation on firms' total factor productivity is uncertain.

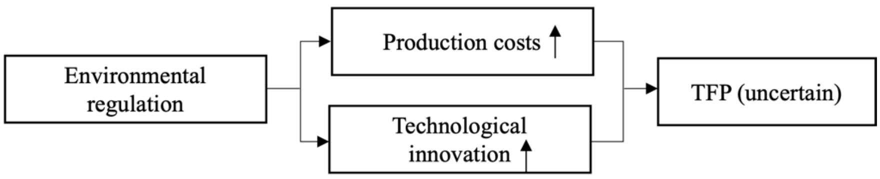

Figure 5.1: Theoretical Mechanism of Environmental Regulation on TFP

5.3.1 Model Settings

As a public supervision policy, environmental regulation interferes with the production of firms as an external factor, which is bound to have a direct impact on the production cost of firms and thus change the firms' production decisions (Conrad and Wastl, 1995; Gray and Shadbegian, 2002, 2003). The implementation of the sulfur dioxide emission restriction policy in China's 11th Five-Year Plan has put pressure on local governments to reduce emissions. In order to achieve the goals set by the central government, local governments will propose environmental regulatory measures to firms. For example, levy fees on emission reduction, increase investment in emission reduction, etc. To this end, firms will allocate part of the factors originally used for production into pollution control, thus increasing the input of factors per unit of output, raising production costs, and thus reducing firm productivity. This chapter is based on the heterogeneous enterprise model of Melitz (2003), embeds environmental regulation policies, constructs a partial equilibrium analysis framework, and analyzes the direct impact and mechanism of environmental regulations on enterprise productivity when firms are unable to carry out technological upgrades in the short term.

5.3.1.1 Consumer Decision

Based on the basic settings of Melitz (2003) heterogeneous firm model, I assume that the consumer's utility function is in the form of a constant elasticity of substitution (CES), and the utility maximization problem is:

$$U = \int_{i\in\Omega} q_i^{\frac{\sigma-1}{\sigma}} di - H(Z) \tag{5.1}$$

$$s.t. \int_{i\in\Omega} p_i q_i di \le E$$

i represents the continuously differentiated products consumed by consumers, and Ω is the set of differentiated products consumed continuously by consumers. q_i represents the consumption of commodity i, p_i is its price, σ represents the elasticity of substitution between products, and the elasticity of substitution is greater than 1. E represents consumer spending (income). Z represents the firm's total pollution emissions, $H(Z)$ is the negative effect of pollution on consumers, and $H(Z)$ is the increasing function of Z, indicating that it increases with the increase of pollutant emissions Z.

By solving the above utility maximization problem, the demand function for commodity i can be written as:

$$q_i = \frac{p_i^{-\sigma}}{P^{1-\sigma}} E \tag{5.2}$$

$$p_i = \left(\frac{P^{1-\sigma}}{E} q_i\right)^{-\frac{1}{\sigma}} \tag{5.3}$$

P is ideal price index:

$$P = \left(\int_{i\in\Omega} p_i^{1-\sigma} di\right)^{\frac{1}{1-\sigma}} \tag{5.4}$$

5.3.1.2 Producer Decision

Since I assume that the industry structure is monopolistic competition, firms take P as a given when making decisions. Each firm in the market can use different technological levels (φ) to produce differentiated products i. The products in each industry are horizontally differentiated and only use labor which is the single factor of production to produce products (Krugman, 1979). Drawing on Helpman et al. (2004), assume that φ obeys Pareto distribution and $G(\varphi) = 1 - \varphi^{-k}$, k is the shape parameter of the distribution, and the larger k is, the smaller the dispersion of productivity in the market. When environmental regulations do not exist, all labor is used to produce the product. Firm's production cost includes the initial fixed investment cost (f) and constant marginal cost ($1/\varphi$). Assume that for every q_i unit of output produced, firm needs to consume x_i units of intermediate input.

$$x_i = f + q_i/\varphi \tag{5.5}$$

Firm can produce intermediate products, and one unit of labor invested can obtain one unit of intermediate products. Firms will produce pollution during production activities. Assume that l_i is the firm's total labor input in producing commodity i, and m_i and $1\text{-}m_i$ are the share of labor invested in emission reduction and production activities respectively, then the labor required for unit x_i of intermediate products is $(1\text{-}m_i)l_i$.

When environmental regulations are implemented, firms will take emission reduction measures. Referring to Copeland and Taylor (2004), the relationship between pollution emissions (z_i) and the labor force invested in emission reduction activities is:

$$z_i = (1-m_i)^{\frac{1}{\alpha}} l_i \tag{5.6}$$

The more resources (m_i) devoted to reducing emissions, the less pollution (z_i) produced. Therefore, the labor required for x_i units of intermediate products is rewritten as:

$$(1-m_i)l_i = z_i^{\alpha} l_i^{1-\alpha} \tag{5.7}$$

Although pollution is a by-product produced in a firm's production process, in terms of mathematical derivation, I can equivalently regard a firm's production process as utilizing two inputs (i.e., labor and pollution). Assume that when environmental regulations are implemented, the government charges τ units for each unit of pollution. The larger τ, the stronger the environmental regulations. By solving the cost minimization problem, I can get the cost c of producing each unit of intermediate input product. The cost minimization problem is to choose z and l so that the cost of producing one unit of intermediate products is minimized:

$$min \tau z + l \tag{5.8}$$

$$s.t. z^{\alpha} l^{1-\alpha} = 1$$

The cost one unit of intermediate input product when the cost is minimum can be obtained:

$$c = \beta \tau^{\alpha} \tag{5.9}$$

β is a constant. $\beta = \alpha^{-\alpha}(1-\alpha)^{\alpha-1}$. Therefore, the total cost of intermediate input products x_i is:

$$TC(q,\tau,\varphi) = x_i \beta \tau^{\alpha} = (f + q_i/\varphi)\beta\tau^{\alpha} \tag{5.10}$$

$\beta\tau^{\alpha}$ is the firm's fixed cost and $\beta\tau^{\alpha}/\varphi$ is the firm's marginal cost.

The firm's profit maximization problem can be written as:

$$\max p_i q_i - TC(q,\tau,\varphi) \tag{5.11}$$

$p_i q_i$ is the firm's income. According to the principle of firm profit maximization, the optimal solution can be obtained:

$$p_i(\varphi) = \frac{\beta\tau^{\alpha}}{\varphi}\frac{\sigma}{\sigma-1} \tag{5.12}$$

$$r_i(\varphi) = P^{\sigma-1}\frac{\beta\tau^{\alpha}}{\varphi}\frac{\sigma}{\sigma-1}E \tag{5.13}$$

$$\pi_i(\varphi) = (\frac{\beta\tau^{\alpha}}{\varphi P})^{1-\sigma}\frac{\sigma^{-\sigma}}{(\sigma-1)^{1-\sigma}} - \beta\tau^{\alpha} f \tag{5.14}$$

Assuming that firm can exit freely in the market, then the firm's critical production technology level φ^* survival should meet the zero-profit condition $\pi(\varphi^*) = 0$. Then the zero-profit equilibrium condition is:

$$\varphi^* = (\sigma\beta\tau^\alpha)^{\frac{\sigma}{\sigma-1}} f^{\frac{1}{\sigma-1}} \frac{1}{P(\sigma-1)} \tag{5.15}$$

5.3.2 Cost Effect

Drawing on Melitz and Ottaviano (2008), it is assumed that the production technology of a single factor firm is determined by a linear production function, and marginal productivity is the inverse function of marginal production cost.

When there are no environmental regulations, the government does not charge for pollution, $\tau = 0$. So the firm does not need to allocate labor for pollution control, and all labor is invested in the production process. It can be seen from (5.5) that the marginal cost of producing q_i units of intermediate input products is:

$$MC = 1/\varphi \tag{5.16}$$

When there are environmental regulations, the firm's marginal cost is:

$$MC = \beta\tau^\alpha / \varphi \tag{5.17}$$

Therefore, when there are no environmental regulations, firm productivity is defined as:

$$\phi = \varphi \tag{5.18}$$

When there are environmental regulations, firm productivity is defined as:

$$\phi = \varphi / \beta\tau^\alpha \tag{5.19}$$

It can be seen from (5.18) that firm productivity (ϕ) decreases as the pollution charge (τ) increases.

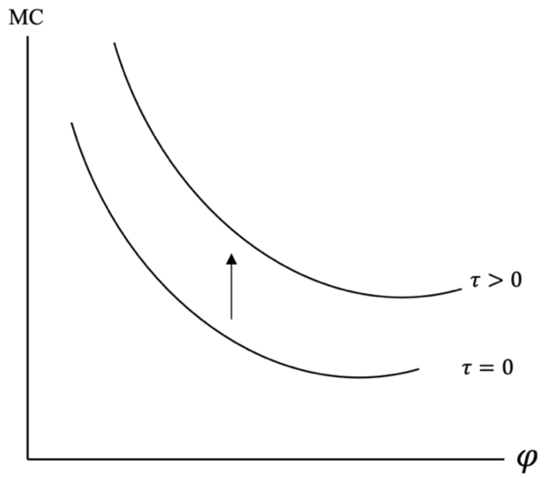

Figure 5.2: The Impact of Environmental Regulation on Marginal Cost

Figure source: Own creation.

According to (5.16) and (5.17), the horizontal axis of Figure 5.2 represents the firms' production technical parameters. The larger φ, the higher the productivity (ϕ). The vertical axis represents the firms' marginal cost. When environmental regulations are strengthened ($\tau > 0$), the firm's marginal cost moves upward and the firm's production costs increase.

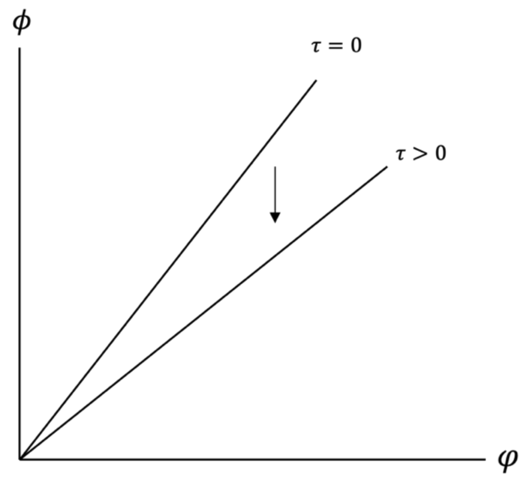

Figure 5.3: The Impact of Environmental Regulation on Productivity

Figure source: Own creation.

According to (5.18) and (5.19), the horizontal axis of Figure 5.3 represents the firms' production technical parameters. The vertical axis represents the firms' productivity. When environmental regulations are strengthened ($\tau > 0$), the firm's productivity curves downward and the firm's productivity decreases.

According to the "compliance cost theory", the implementation of environmental regulations restrains the production of enterprises and has a direct impact on the cost of enterprises, thus inhibiting the production efficiency and economic growth of the economy (Jorgenson and Wilcoxen, 1990; Conrad and Wastl, 1995). Through the construction of the theoretical model, it can be seen that the production cost of enterprises caused by environmental regulation is mainly the direct increase of enterprise cost caused by the increase of emission reduction investment caused by environmental regulation.

Environmental regulation will increase the firms' non-productive input. Firstly, in order to meet the standards set by the regulatory authorities, firms will reduce their inputs of non-renewable elements (coal, oil, etc.) that cause heavy emissions and increase the use of green, clean and renewable energy. The cost of clean energy is often higher than that of traditional factors of production and it takes a long time to make the switch from factor inputs. Therefore, an increase in emissions reduction inputs can increase the production costs of enterprises and thus inhibit the increase in total factor productivity (Barbera and McConnell, 1990). Secondly, in order to meet the requirements of environmental regulations, firms must use the appropriate pollution control equipment or environmental protection technology equipment to reduce pollution emissions. The adoption of new environmentally friendly production equipment also requires a certain amount of learning time, so the firms' total factor productivity will decline (Gray and Shadbegian, 2002). In addition, the introduction of such equipment and the improvement of production processes for the community is conducive to improving the living environment of the residents, but for the firms, it is bound to equal the increase in additional fixed costs. Therefore, this research proposes the following hypothesis:

Proposition 1: Environmental regulation can increase production costs through increasing the use of clean energy and the number of pieces of abatement equipment, then reduce firms' total factor productivity.

5.3.3 Innovation Effect

Firms can reduce the production cost pressure caused by environmental regulations through technological upgrading, but firms need to pay additional fixed costs for R&D investment to carry out technological research and development. Therefore, firms will face the choice of technological upgrading or not. There is a critical value for technological upgrading. At critical value, the firm's profit is the same if it chooses to upgrade technology as if it does not upgrade. If the productivity is higher than the critical value and the firm's profit from technological upgrading is greater than the profit from not carrying out technological upgrading, then the firm will choose technological upgrading. Referring to Helpman et al. (2004), assuming that the market for final products is monopolistically competitive, firms can use different technologies to produce differentiated products. Some firms under the constraints of environmental regulations consider technological innovation, and the production technical parameters (φ) are variable.

Referring to Bustos (2011), assuming that the firm pays the fixed cost of R&D investment (δf), and the firm's production technology improves to $\theta\varphi$, and $\theta > 0$. Then according to (5.11) and (5.14), the firm total cost and firm profit to produce q_i units of products after the technology upgrade are respectively:

$$TC'(q,\tau,\varphi) = (f + \frac{q_i}{\varphi})\beta\tau^{\alpha} + \delta f \quad (5.20)$$

$$\pi_i'(\varphi) = (\frac{\beta\tau^{\alpha}}{\theta\varphi P})^{1-\sigma} \frac{\sigma^{-\sigma}}{(\sigma-1)^{1-\sigma}} - \beta\tau^{\alpha} f - \delta f \quad (5.21)$$

At the critical value of productivity, firm's profit that chooses to upgrade technology is the same as that of not upgrading technology. According to (5.14), (5.15) and (5.21), $\pi_i(\varphi^*) = \pi_i'(\varphi)$. The solution is:

$$\varphi^{*\prime} = [\frac{\delta}{\beta\tau^{\alpha(\theta^{\sigma-1}-1)}}]^{\frac{1}{\sigma-1}} \varphi^* \quad (5.22)$$

$A = [\frac{\delta}{\beta\tau^{\alpha(\theta^{\sigma-1}-1)}}]^{\frac{1}{\sigma-1}} > 1$. The critical value of technological upgrading ($\varphi^{*\prime}$) is greater than the critical value of firm survival (φ^*). From (5.21), there is a positive correlation between firm's profit and firm technology (φ). When the firm's productivity is greater than the critical value, firms will choose technology upgrades after environmental regulations are implemented. And when the firm's productivity is small, the firm does not carry out technological upgrades. Environmental regulations will force high-productivity firms to carry out technological innovation, but there is no such force for low-productivity firms. That is, the innovation compensation effect of environmental regulations is positively related to firm's productivity.

Environmental regulation increases the firms' total factor productivity by promoting innovation. Arimura et al. (2007) found there is a significant positive correlation between the severity of environmental regulation and the probability of environmental R&D expenditure. From the perspective of innovation effects, appropriate environmental policies can encourage enterprises to engage in technological innovation. Environmental regulation will increase production costs and place a heavy financial burden on firms. This will force firms to innovate technologically or introduce advanced equipment to improve their technological level, thus generating innovation compensation for the rise in production costs and increasing firms' TFP (Acemoglu et al., 2016; Calel, 2020; Gutiérrez and Teshima, 2018). Therefore, this research proposes the following hypothesis:

Proposition 2: Environmental regulation can increase firm TFP through increasing technological innovation.

5.4 Empirical Specification and Data Description

5.4.1 Model Specification

It can be found from section 5.3 that the impact of environmental regulation on the firms' total factor productivity is uncertain, so I set up the following model for exploration. I adopt the TWFE model and continuous DID method and regard the mandatory SO_2 emissions target scheme strengthened in the 11th Five-Year Plan from 2006 as a natural experiment. I compare the change in firm level TFP before and after 2006, when more stringent environmental regulations were introduced, based on the following model:

$$tfp_{it} = \alpha + \beta_1 treat_c \times post_t + \beta_2 treat_c + \beta_3 post_t + \eta X_{it} + \gamma_t + \gamma_i + \varepsilon_{it} \tag{5.23}$$

Where, *i* represents firm, *c* represents city, and *t* represents year. tfp_{it} represents total factor productivity of firm *i* in year *t*. $treat_c \times post_t$ is a dummy variable, representing environmental regulation. $treat_c$ is the continuous grouping index of the treatment group and the control group and $post_t$ is a time dummy variable. X_{it} represents a set of control variables including firm level controls (firm age, firm size, firm capital labor ratio and firm ownership), industry level control variables (concentration ratio and industry size) and city level control variables (average GDP per capital, industrial structure and Internet development). γ_t is the year fixed effect, γ_i is the firm fixed effect, and ε_{it} is the random disturbance term. Because I include year fixed effect, the indicator is collinear with the year dummies and drops out of the regression. So I can't report the coefficient of $post_t$. In order to eliminate possible autocorrelation and heteroscedasticity, all regressions are clustered at the enterprise level. β_1 represents the impact of environmental regulation on firms' total factor productivity.

5.4.2 Explanation of Variables

1. The dependent variable is total factor productivity (TFP). The association between unobserved productivity shocks and input choices makes it challenging to estimate firm total factor productivity from the production function. As a result, estimation using ordinary least squares (OLS) produces inconsistent estimators. The literature has highlighted several drawbacks to the TFP calculation. Such drawbacks include simultaneity bias, selectivity, attrition bias, and unobserved (quasi-) permanent heterogeneity in productivity (correlated effects).

Traditional estimation methods (e.g., OLS) typically assume independence between input factors (e.g., capital, labor) and productivity. However, in practice, firms dynamically adjust their inputs based on productivity levels (e.g., higher-productivity firms tend to increase investment). The OP (Olley-Pakes) (Olley and Pakes, 1996) method addresses this by specifying a production function that treats firm productivity as an unobserved state variable, which is then indirectly estimated using firm-level input and output data. The methodological essence lies in controlling for firm-specific heterogeneity (e.g., firm size, technological capability) and temporal trends to isolate genuine productivity variations. This approach specifically resolves estimation biases arising from simultaneity (endogeneity between production decisions and productivity) and sample selection (exit of less efficient firms) in conventional productivity measurements, thereby enabling more accurate decomposition of firm-level total factor productivity (TFP). The OP method operates under the assumptions of weak factor substitutability and endogenous technological progress. In contrast to the OP approach, the LP (Levinsohn-Petrin) (Levinsohn and Petrin, 2003) method's theoretical foundation centers on constructing a linear programming model to identify optimal input-output relationships in firm production activities. Specifically, it measures production efficiency by comparing actual firm inputs and outputs against theoretically optimal combinations. The LP framework postulates the existence of a "production frontier" representing maximum attainable efficiency given current technology. This frontier comprises either the most efficient firms or decision-making units (DMUs) that either maximize output from given inputs or minimize inputs for given outputs. Through linear programming, firms are assigned efficiency scores (ranging from 0 to 1) relative to this frontier. The ACF (Ackerberg-Caves-Frazer) (Ackerberg et al., 2015) method represents an integrated approach combining production function estimation with Data Envelopment Analysis (DEA) for TFP measurement. Its conceptual innovation involves benchmarking relative efficiency differences among firms to identify the production frontier. Within the DEA framework, production efficiency is defined as the output-input ratio. Using linear programming techniques, each firm receives an efficiency score representing its performance relative to the frontier - which itself is constituted by the most efficient firms in the sample, indicating maximum feasible output for given inputs.

The OP method has a key limitation in its reliance on firm investment data, which is often subject to measurement errors or reporting lags. The ACF method, meanwhile, depends on stronger model assumptions and stricter identification conditions, making it prone to instability when applied to small samples or low-quality data. In contrast to the OP approach, the LP method uses intermediate inputs (such as raw materials or energy) rather than investment as proxy variables, thereby avoiding the sample attrition problem caused by zero or negative investment observations under the OP framework-a particularly common issue in industries with volatile investment patterns. Additionally, the LP method imposes less restrictive assumptions on capital adjustment, making it more suitable for sectors with high capital adjustment costs. Compared to the ACF method, the LP approach features lower computational complexity and weaker dependence on functional form specifications, circumventing potential identification challenges in ACF (due to high collinearity between labor and intermediate inputs). Consequently, the LP method demonstrates comprehensive advantages in terms of data availability, estimation robustness, and broader applicability across empirical settings.

Therefore, this research chooses LP method to measure total factor productivity of enterprises and the LP method uses a semi-parametric regression method to solve the problems of endogeneity and selectivity bias in OLS regression (Tang et al., 2020; Chen et al., 2021; Peng et al., 2021; Wu and Wang, 2022; Ren et al., 2022; He et al., 2022). This approach allows for firm-specific productivity differences, in other words, heterogeneous variations over time. The estimated equation is:

$$\forall i: \ln VA_{nit} = \beta_0 + \alpha \ln K_{nit} + \beta_1 \ln L_{nit} + \omega_{nit} + \eta_{nit} \tag{5.24}$$

i represents the firms. VA_{nit} represents the firms output, which is the operation revenue, L_{nit} is the free input variable: labor, which is the number of employees, k_{nit} is the state variable: capital, which equals the fixed assets . The error consists of two parts: ω_{nit} and η_{nit} . ω_{nit} is the unobservable productivity shock, η_{nit} is the error term independent of factor input selection. ω_{nit} and η_{nit} key difference is: ω_{nit} is a state variable, so will affect the firm's decision. And ω_{nit} is not obtained by calculation, but by firms adjusting their free variables accordingly. For simplicity, I use a lowercase model to represent the value of ln:

$$va_t = \beta_0 + \alpha k_t + \beta_1 l_t + \omega_t + \eta_t \tag{5.25}$$

According to the LP method, the input of intermediate product is m_t , which depends on the manufacturer's state variable k_t and the unobservable productivity shock ω_t . That is:

$$m_t = m_t(k_t, \omega_t) \tag{5.26}$$

Here, assuming that $m_t = m_t(k_t, \omega_t)$ increases monotonically with ω_t , this allows us to obtain the inverse function of the demand for intermediate products:

$$\omega_t = \omega_t(k_t, m_t) \tag{5.27}$$

Then the unobserved productivity shock can be an equation of two observable inputs. Thus, the final estimation equation is obtained:

$$va_t = \beta_0 + \alpha k_t + \beta_1 l_t + \omega_t + \eta_t = \beta_1 l_t + \phi_t(k_t, m_t) + \eta_t \tag{5.28}$$

Among them, $\phi_t(k_t, m_t) = \beta_0 + \alpha k_t + \omega_t(k_t, m_t)$. The use of the logarithm of capital, intermediates in the logarithm of third order polynomial can estimate $\phi_t(k_t, m_t)$, namely:

$$\phi_t(k_t, m_t) = \sum_{g=0}^{3} \sum_{h=0}^{3-h} \gamma_{gh} k_t^g m_t^h \tag{5.29}$$

The regression process is divided into two stages. In the first stage, equation (5.25) is estimated, and the estimated coefficient β_1 of *L* can be obtained. In the second stage, the estimation coefficient α of capital can be obtained under the given estimation coefficient β_1. Thus, I can get the total factor productivity of LP method:

$$tfp_t^{LP} = va_t - \beta_1 l_t - \alpha k_t \tag{5.30}$$

Table 5.1 reports total distribution of firm level TFP in China from 2000 to 2010. It can be seen that the median and mean of total factor productivity of industrial firms increased gradually from 2000 to 2010, indicating that the level of total factor productivity of firms was generally in the growth stage during the sample period. In terms of skewness, the skewness is almost always greater than zero in all the years, indicating that the distribution shape is positively skewed compared with the normal distribution, with more firms having total factor productivity levels higher than the average. Meanwhile, the skewness almost increases gradually with each year, which also indicates that the gap in total factor productivity levels between the firms is gradually getting wider and wider. In addition, the kurtosis of the total factor productivity of enterprises in each year changes from large to small, indicating that the distribution of total factor productivity in China's industry tends to converge gradually from dispersion. It can be found from Figure 5.4 that the intensity of TFP follows a normal distribution.

Table 5.1: Total Distribution of Firm Level TFP in China from 2000 to 2010

Year	Mean	Median	25% quantile	75% quantile	Std. Dev.	Skewness	Kurtosis	Obs
2000	8.1724	8.1578	7.5275	8.8840	1.2081	-0.3579	4.9606	126,566
2001	8.2306	8.1815	7.5711	8.9164	1.1652	-0.2260	5.0779	136,544
2002	8.3044	8.2438	7.6271	8.9767	1.1464	-0.1216	5.0972	147,556
2003	8.4253	8.3444	7.7227	9.0810	1.1166	0.0793	5.0004	166,159
2004	8.4170	8.2645	7.6998	9.0070	1.0394	0.5155	5.0262	235,161
2005	8.6076	8.4862	7.8598	9.2337	1.0670	0.5134	4.4558	234,566
2006	8.6945	8.5764	7.9230	9.3422	1.0776	0.5450	4.1475	262,672
2007	8.8234	8.7110	8.0329	9.4831	1.0787	0.6200	3.8425	293,666
2008	8.7794	8.6571	7.9564	9.4708	1.0940	0.6022	3.6909	379,149
2009	8.9736	8.8902	8.1542	9.6828	1.0985	0.4802	3.5217	311,957
2010	9.2697	9.2556	8.5498	9.9956	1.1734	-0.0218	4.1686	280,453
All	8.6949	8.5961	7.8972	9.4053	1.1489	0.2701	4.2891	2,574,449

Source: Analysis reported in this thesis.

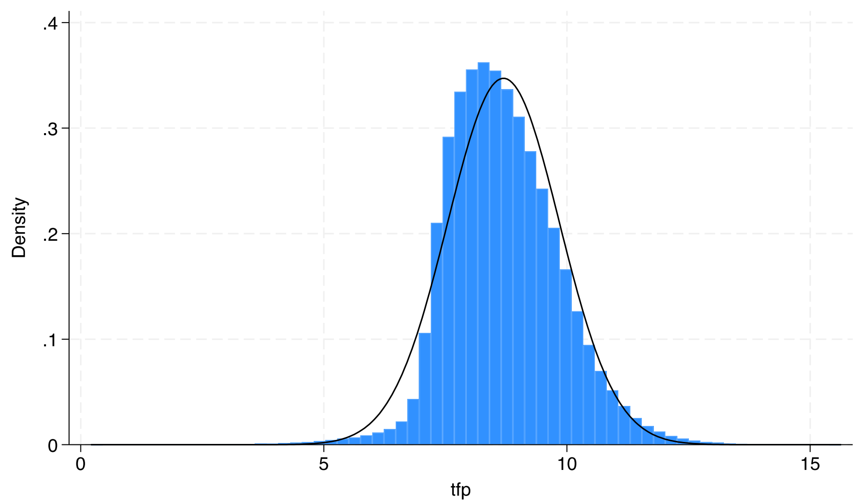

Figure 5.4: The Normal Distribution of TFP

2. Control variables. Drawing on Peng et al. (2021) and Bu and Ren (2023), to avoid the influence of omitted variables, some variables that affect firms' total factor productivity are added to the DID model. I added the firm level, industry level and city level control variables. (1) The firm age is measured by adding 1 to the logarithm of the difference between the current year and the year of the establishment of the enterprise (Peng et al., 2021). (2) The firm size is measured by the total assets. Compared with small enterprises, large enterprises have more capital and technological advantages. (3) The firm capital labor ratio is measured by the logarithmic value of the ratio between the net value of fixed assets and the number of employed persons. (4) The dummy variables of enterprise ownership type. There are many types of ownership in China, including state-owned enterprises, private enterprises, foreign enterprises, mixed

ownership enterprises, collective enterprises and so on. I only controlled the dummy variables of state-owned firms, foreign firms, and private firms. (5) The concentration ratio is measured by the Herfindahl-Hirschman Index of a four-digit industry. (6) Industry size is measured by the logarithm of the four-digit industry employment scale (Bu and Ren, 2023). It is the sum of the market share of the top N largest companies in the relevant market of an industry. It measures the degree of competition and monopoly in the market. (7) Regional economic growth is measured by the log of regional GDP per capita. It measures the level of economic development in a region (Li et al., 2023). (8) Regional industrial structure is measured by the proportion of regional secondary industry to tertiary industry. (9) Regional Internet development is measured by the log of regional Internet usage.

3. Mechanism variable. (1) Firm's production cost. The costs incurred by a firm to produce a product. I take the logarithm of the firm total cost as the firm's production cost variable. (2) Clean gas. It is the energy that does not emit pollutants and can be directly used for production and life. I select the logarithmic value of clean gas (natural gas) consumption to measure the scale of clean gas use. (3) Abatement equipment. The equipment can reduce the pollution emissions. I select the logarithmic value of the number of pieces of firm abatement equipment to measure firm abatement equipment use. (4) R&D. Research and development funds. I select the logarithmic value of R&D investment as the measure of R&D. (5) Patent. A patent is a set of exclusive rights granted by a sovereign state to an inventor or assignee for a limited period. I select the logarithmic value of the number of patents as the measure of technology innovation. (6) Invention patent. An invention patent is a solution to a specific technological problem and is a product or a process. I select the logarithmic value of the number of invention patents as the measure of technology innovation.

Table 5.2 reports the variables description.

Table 5.2: Variables Description

	Variable	Abbreviation	Unit	Mean	Std. Dev	Min	Max	Obs
Dependent variable	tfp	tfp	-	8.6949	1.1489	0.2103	15.6361	2,574,449
Independent variable	$treat_c \times post_t$	$treat_c \times post_t$	-	1.5742	2.6044	0.0000	13.0190	2,574,449
Firm level control	*firm age*	*age*	year	1.9736	0.8064	0.0000	6.0162	2,574,449
	firm size	*size*	log of ￥1000	9.7726	1.4123	0.0000	20.3208	2,574,449

variables	*capital labor ratio*	*kl*	log of ￥1000/person	5.1027	1.0514	0.1798	11.5083	2,574,449
	state-owned firm	*soe*	-	0.0732	0.2605	0.0000	1.0000	2,574,449
	foreign firm	*foe*	-	0.1682	0.3741	0.0000	1.0000	2,574,449
	private firm	*pre*	-	0.5807	0.4934	0.0000	1.0000	2,574,449
Industry level control variables	*concentration ratio*	*hhi*	-	0.0018	0.0038	0.0001	1.0000	2,574,449
	industry size	*size_ind*	-	14.7399	0.6419	11.9545	15.7804	2,574,449
City level control variables	*average GDP per capital*	*gdp*	log of ￥1000/person	11.3212	0.6740	8.6103	13.8312	2,574,449
	industrial structure	*ind*	-	1.3137	0.5028	0.0068	10.5529	2,574,449
	Internet development	*inter*	log of per household	12.5340	3.1849	0.0000	17.7617	2,574,449
Mechanism variables	*production cost*	*cost*	log of tens of millions yuan	9.9093	1.3597	0.0000	19.0307	2,293,991
	clean gas	*gas*	log of million cubic meters	0.4099	1.5516	0.0000	17.6550	183,061
	abatement equipment	*equip*	log of numbers of pieces	0.2382	0.4704	0.0000	4.8363	201,411
	R&D investment	*rd*	log of tens of millions yuan	0.9395	0.7598	0.0000	4.5638	2,565,405
	patent	*patent*	log of the number of pieces	0.0559	0.3343	0.0000	9.0985	2,574,449
	invention patent	*in_patent*	log of the number of pieces	0.0207	0.1847	0.0000	9.0493	2,574,449

Source: Analysis reported in this thesis.

The data in this chapter mainly comes from the China Annual Survey of Industrial Firms Database (ASIF) from 2000 to 2010. The patent data come from the China Patent Database (CPD) from 2000 to 2010. According to Section 3.4.2, I processed the China Annual Survey of Industrial Firms Database and finally got 2,574,449 samples. The reason for the differences in the number of mechanism variables is that some enterprises do not have the data on production cost, clean gas, abatement equipment and R&D investment. The absence of such data may be due to the firms' concealment, misreporting or forgetting to report.

5.5 Empirical Results and Analysis

In this section, I analyze the empirical results of environmental regulation on firm total factor productivity. In section 5.5.1, I will analyze the basic regression results. In section 5.5.2, I will analyze the parallel trend test which verified the appropriateness of the DID model. In section 5.5.3, I will do a lot of robustness tests such as two-period double difference method, winsorize, eliminate other policy distractions, changing the dependent variable and using a relative target. In section 5.5.4, I will analyze the impact mechanism of environmental regulation on firm total factor productivity from the perspective of production cost and technology innovation. In section 5.5.5, I will analyze the heterogeneity analysis which will include the different firm ownership, the different firm size, the different factor densities, the different regions and the different industries.

5.5.1 Regression Analysis of the Basic Regression Model

Table 5.3 reports the benchmark regression results of the impact of environmental regulation policies on firm level total factor productivity. Column (1) only controls the year fixed effect, column (2) only controls the firm fixed effect and column (3) controls both the year fixed effect and firm fixed effect. The estimated coefficients $treat_c \times post_t$ all are significantly positive at the 1% statistical level. In order to control for the firm-level and industry-level other variables to have an impact on the regression results, column (4) adds enterprise-level control variables and Column (5) adds industry-level control variables. I find that the estimated coefficient of $treat_c \times post_t$ is still significantly positive, indicating that the environmental regulation policies can increase firm level total factor productivity. The estimated coefficient of $treat_c \times post_t$ in column (5) is 0.1841 and it means that after 2006, for every 1 unit increase in the SO_2 emissions reduction target, the enterprise's TFP increases by 0.1841. Since my core explanatory variable is at the city level, it is also necessary to include city-level control variables. I add city-level control variables in column (6). I can see that the estimated coefficient $treat_c \times post_t$ is still significantly positive. The estimated coefficient of $treat_c \times post_t$ in column (6) is 0.1685 and it means that after 2006, for every 1 unit increase in the SO_2 emissions reduction target, the enterprise's TFP increases by 0.1685. Before 2006, the average TFP of a firm is 8.3912 in the sample. After 2006, for every 1 unit increase in the SO_2 emissions reduction target, a 0.1685 increase in average TFP of a firm increased from 8.3912 to 8.5597. After 2006, the average SO_2 emissions reduction target of a firm is 2.65 in my data, so after the SO_2 emissions regulation, the average TFP of a firm increased to 8.8377, achieving an increase of 0.4465. The results show that the implementation of environmental regulation increases the total factor productivity of firms, while reducing pollution emissions and improves the quality of the environment. This result is consistent with the findings of Zhang et al. (2020). This result is consistent with the findings of Peng et al. (2021).

The analysis of the impact mechanism shows that environmental regulation can have an impact on firms' total factor productivity through production costs (Conrad and Wastl, 1995; Gray and Shadbegian, 2002) and technological innovation (Porter, 1991; Hamamoto, 2006). The implementation of environmental regulations has prompted enterprises to shift from traditional energy sources to cleaner energy sources and to increase pollution-reducing equipment, which has increased their production costs. But environmental regulation can encourage enterprises to engage in technological innovation, thereby environmental regulation can increase their total factor productivity.

Table 5.3: DID Model Regression Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	tfp	*tfp*	*tfp*	*tfp*	*tfp*	*tfp*
$treat_c \times post_t$	0.1464***	0.7131***	0.2279***	0.1848***	0.1841***	0.1685***
	(26.6182)	(164.3240)	(52.7840)	(51.3228)	(51.1716)	(47.0268)
treat	-0.1907***	-0.6148***	-0.1591***	-0.1080***	-0.1082***	-0.1907***
	(-30.9540)	(-99.3992)	(-25.2199)	(-19.7695)	(-19.8055)	(-32.7658)
age				0.1316***	0.1318***	0.1322***
				(81.0032)	(81.1692)	(81.8957)
size				0.5856***	0.5861***	0.5843***
				(294.4885)	(294.7511)	(294.7751)
kl				0.3358***	0.3362***	0.3356***
				(201.0071)	(201.2911)	(201.5229)
soe				0.1013***	0.1005***	0.0989***
				(19.9347)	(19.7851)	(19.5155)
foe				0.0137***	0.0134***	0.0140***
				(3.7906)	(3.7056)	(3.9039)
pre				-0.0193***	-0.0189***	-0.0172***
				(-9.4103)	(-9.2028)	(-8.4368)
hhi					0.5909***	0.5663***
					(2.7150)	(2.6095)
size_ind					0.0513***	0.0493***
					(16.7611)	(16.1859)
gdp						0.0144***
						(8.2240)
ind						-0.1658***
						(-61.6745)
inter						-0.0074***
						(-11.5311)
Year FE	YES	NO	YES	YES	YES	YES
Firm FE	NO	YES	YES	YES	YES	YES
N	2,574,449	2,387,905	2,387,905	2,387,905	2,387,905	2,387,905
R-Square	0.0727	0.7761	0.8200	0.8503	0.8503	0.8512

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

5.5.2 Parallel Trend Test

This chapter examines whether there are differences in the distribution of TFP between the treatment group and the control group before and after 2006. To verify the appropriateness of the DID model, this part uses the event analysis method to test the common trend of the treatment group and the control group (Tang et al., 2020; Wu and Wang, 2022). Specifically, I add a series of dummy variables to the benchmark model (5.23) to establish the following model:

$$tfp_{it} = \alpha + \beta_1 D_{ct}^{-5} + \beta_2 D_{ct}^{-4} + \cdots + \beta_{10} D_{ct}^{+5} + \eta X_{it} + \gamma_t + \gamma_i + \varepsilon_{it} \tag{5.31}$$

The estimated coefficient of *D* in the regression results represents whether there is a significant difference in the trend of TFP between the treatment group and the control group in the *j* years before and after the implementation of environmental regulation policy. I used the year (2005) before the environmental regulation policy was implemented as a control group (Peng et al., 2021). The regression estimation results and confidence intervals are shown in Figure 5.5. In the figure, the horizontal axis represents the year since the implementation of environmental regulation policy, the vertical axis represents the size of the estimate, the hollow point is the estimated coefficient, and the dashed line is the 95% confidence interval.

When $j<0$, 0 is within the confidence interval. It means the estimated coefficient was not significant at the 5% level, indicating that before the implementation of environmental regulation policy, there was no significant difference in the changing trend of TFP between the treatment group and the control group. Therefore, the DID model can be used to test the impact of environmental regulation on TFP. After the implementation of environmental regulation policy (when $j>0$), the estimated coefficient is more than 0 and is significant at the significance level of 5%. This indicates that environmental regulations increase firm level TFP.

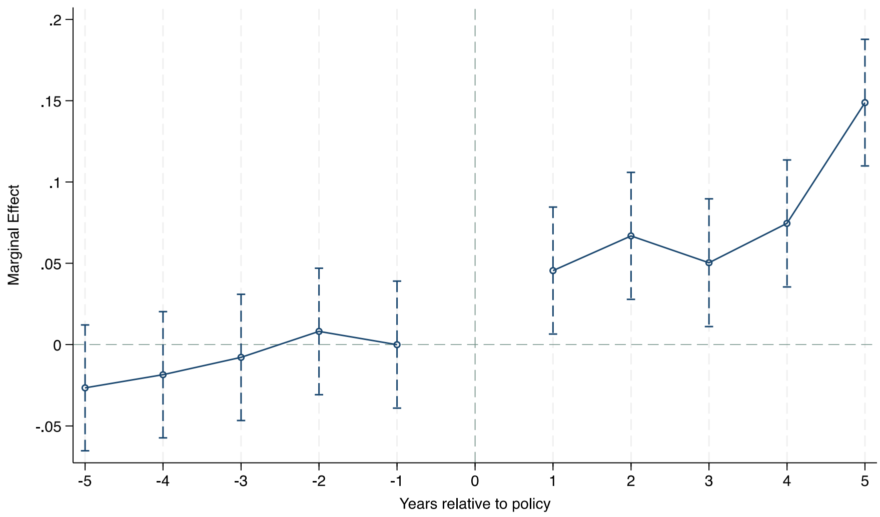

Figure 5.5: Parallel Trend Test on TFP

5.5.3 Robustness Test

(1) Two-period double difference method. To deal with potential sequence related problems, I refer to the method of Bertrand, Duflo and Mullainathan (2004) to construct a two-period DID method to re-estimate the formula (5.23). Specifically, I regard Year 2006 as a new time node and divide the sample period into two stages: 2000- 2005 and 2006- 2010. In each period, I calculate the arithmetic average of the variables of each firm. The regression results are shown in columns (1) and (2) in Table 5.4. I found that the estimated coefficient of $treat_c \times post_t$ is still significantly positive at the 1% statistical level, indicating environmental regulation policy can effectively increase TFP.

(2) Winsorize. To rule out the effect of extreme outliers, I narrow the 1% and 99% quantiles of all continuous variables in the sample. The regression results are shown in columns (3) and (4) in Table 5.4. I found that the estimated coefficient of $treat_c \times post_t$ is still significantly positive at the 1% statistical level, indicating environmental regulation policy can effectively increase TFP.

Table 5.4: The Results of Robustness Test (1)

Variable	(1)	(2)	(3)	(4)
	Two-period DID	Two-period DID	Winsorised	Winsorised
	tfp	*tfp*	*tfp*	*tfp*
$treat_c \times post_t$	0.3468***	0.3087***	0.2281***	0.1589***
	(53.9354)	(53.5410)	(53.6810)	(45.2199)

treat	-0.3673***	0.1750***	-0.1611***	-0.2272***
	(-10.9705)	(6.1225)	(-25.9700)	(-39.5569)
age		0.1658***		0.1300***
		(46.9157)		(82.9028)
size		0.7357***		0.5862***
		(226.2462)		(328.4391)
kl		0.4188***		0.3349***
		(120.6016)		(210.4726)
hhi		1.3265**		-0.2765
		(2.3027)		(-0.6162)
size_ind		0.0577***		0.0471***
		(9.3444)		(15.5768)
gdp		-0.1126***		0.0257***
		(-19.9922)		(14.9158)
ind		-0.1657***		-0.2410***
		(-25.2374)		(-98.9552)
inter		-0.0411***		-0.0111***
		(-31.6341)		(-17.8569)
soe		0.1089***		0.0961***
		(10.4856)		(19.7905)
foe		0.0317***		0.0189***
		(5.3801)		(5.3633)
pre		-0.0248***		-0.0156***
		(-6.7197)		(-7.8303)
Year FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
N	446,666	446,666	2,387,905	2,387,905
R-Square	0.8830	0.9157	0.8169	0.8496

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(3) Eliminating other policy distractions. The environmental policies implemented during the sample period may have an impact on firm TFP, especially the typical emission trading policy which has been introduced in Section 3.2.5. Therefore, the interaction terms of dummy variables of the emission trading policy treatment group and the policy time dummy variables (*trading policy*) are added to eliminate the interference of parallel policies on the estimated results of this research. Therefore, the regression results are shown in columns (1) and (2) in Table 5.5. The estimated coefficients of $treat_c \times post_t$ are still significantly positive at the 1% statistical level, indicating the estimated results are robust; that is, the environmental regulation policy can effectively increase TFP.

(4) Changing the dependent variable. In the benchmark model, I use the firm level TFP measured by LP method as the dependent variable. In order to increase the robustness of the empirical results, I use the firm level TFP measured by OP method instead of the LP method as the explained variable (Li et al., 2023). The LP method based on the production function calculates TFP by measuring the contribution of different factors of production to economic growth. The OP method based on the cost function calculates TFP by measuring the change in the cost of different factors of production. The OP method assumes weak substitutability between factors of production and that technological progress is endogenous. The regression results are shown in columns (3) and (4) in Table 5.5. The estimated coefficients are still significantly positive at the 1% statistical level. The results confirm that environmental regulation can increase TFP. The basic results are robust.

(5) Using a relative target. I use the percentage of reduction to test whether the basic regression results are robust. The regression results are reported in columns (5)-(6) in Table 5.5. The estimated coefficients are still significantly positive at the 1% statistical level, indicating the estimated results are robust, that is, environmental regulation policy can effectively increase the TFP.

Table 5.5: The Results of Robustness Test (2)

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	Eliminate other policy distractions	Eliminate other policy distractions	Change dependent variable	Change dependent variable	Relative target	Relative target
	tfp	*tfp*	*tfp_op*	*tfp_op*	*tfp*	*tfp*
$treat_c \times post_t$	0.2214***	0.1641***	0.1880***	0.1560***	0.2043***	0.1600***
	(51.4264)	(45.9238)	(47.4848)	(40.5997)	(50.3318)	(47.6773)
trading policy	-0.1559***	-0.1305***				
	(-37.1145)	(-36.2040)				
treat	-0.1683***	-0.1971***	-0.1023***	-0.1736***	0.0495***	-0.0374***
	(-26.7847)	(-34.0275)	(-17.3941)	(-28.4380)	(10.6220)	(-7.8880)
age		0.1335***		0.1391***		0.1324***
		(82.8647)		(81.9745)		(81.9285)
size		0.5842***		0.1164***		0.5843***
		(295.0177)		(60.8323)		(294.6267)
kl		0.3364***		-0.0522***		0.3356***
		(202.0980)		(-30.6535)		(201.3975)
hhi		0.5594***		1.3643***		0.5462**
		(2.5856)		(5.5455)		(2.5146)
size_ind		0.0478***		0.0899***		0.0492***
		(15.7204)		(26.6061)		(16.1624)

gdp		0.0180***		0.0152***		0.0147***
		(10.3658)		(8.3855)		(8.4216)
ind		-0.1545***		-0.1546***		-0.1702***
		(-58.1125)		(-57.3110)		(-62.6227)
inter		-0.0057***		-0.0079***		-0.0084***
		(-8.9099)		(-11.6907)		(-13.0014)
soe		0.0978***		-0.3505***		0.0996***
		(19.2933)		(-54.2065)		(19.6305)
foe		0.0133***		-0.0120***		0.0134***
		(3.7060)		(-3.2061)		(3.7364)
pre		-0.0155***		-0.0124***		-0.0185***
		(-7.6369)		(-5.8312)		(-9.0977)
Year FE	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
N	2,387,905	2,387,905	2,387,905	2,387,905	2,387,905	2,387,905
R-Square	0.8204	0.8514	0.7623	0.7724	0.8200	0.8512

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

5.5.4 Estimation Results of Influence Mechanism

The above results present the empirical analysis of the direct impact of environmental regulation policies on firm total factor productivity. On this basis, this section further analyzes the impact mechanism of environmental regulation on firm total factor productivity. According to the above theoretical analysis, on the one hand, environmental regulation may impact firms total factor productivity through production cost (Tang et al., 2020). Environmental regulation policies directly increase firms' costs and may reduce their total factor productivity in the short term (Lange and Bellas, 2005; Feng et al., 2017; Gollop and Roberts, 1983). On the other hand, environmental regulation can stimulate firms to innovate and increase their total factor productivity through the innovation compensation effect. Therefore, I analyze the impact mechanism from the perspective of production cost and technology innovation.

(1) Production cost. Table 5.6 reports the regression results of the production cost. I take the logarithm of the firm total cost as the firm's production cost variable, and then regress environmental regulation on the firm total cost. The regression results are shown in columns (1) in Table 5.6. I found that the estimated coefficients of the interaction term are significantly positive, showing that environmental regulation has a significant positive impact on the production cost. The estimated coefficient in column (1) is 0.0106 and

it means that after 2006, for every 1 unit increase in SO_2 emission reduction target, firm production costs increase by 1.06%. In addition, increased the use of cleaner energy and increased the use of pollution treatment equipment will lead to higher firm costs. I select the logarithmic value of clean gas consumption and the logarithmic value of the number of pieces of firm abatement equipment to measure the scale of clean gas use and firm abatement equipment use. Column (2) of Table 5.6 report the regression results of clean gas consumption. The estimated coefficients are positive, indicating that environmental regulation policies significantly increased the intensity of clean gas usage in China. The estimated coefficient in column (2) is 0.0210 and it means that after 2006, for every 1 unit increase in SO_2 emission reduction target, firm production costs increase by 2.10%. Column (3) of Table 5.6 report the regression results of abatement equipment. The estimated coefficients are positive, indicating that environmental regulation policies significantly increased the use of abatement equipment. The estimated coefficient in column (3) is 0.0457 and it means that after 2006, for every 1 unit increase in SO_2 emission reduction target, the number of abatement equipments increase by 4.57%. The increased use of clean energy and abatement equipment has increased firms' production costs. As a result, environmental regulation raises the firms' production costs, thereby reducing their total factor productivity. Hence, stricter environmental policies may imply additional costs for pollution abatement, alter investment decisions, and restrict the availability of inputs for the production process as well as the set of available technologies (Ambec et al., 2013, Ambec and Barla, 2002; Dechezleprêtre and Sato, 2017). So, at least in the short-run, higher compliance costs may negatively affect both international competitiveness and productivity growth. The estimated coefficient of the mediator variable (enterprise cost) in column (4) of Table 5.6 is significantly negative, indicating that the increase in enterprise cost reduces the TFP of the enterprise. Based on the estimation results in Table 5.6, it can be found that SO_2 emission reduction target can reduce TFP by lowering enterprise costs. Notably, both the magnitude and statistical significance of the interaction terms exhibit a discernible increase compared to the baseline regression results in columns (6) of Table 5.3 (0.1685). When I control the cost effect, the positive impact of environmental regulation on TFP becomes greater, which provides empirical support for the existence of the cost effect.

Table 5.6: The Results of Influence Mechanism on TFP (1)

Variable	(1)	(2)	(3)	(4)
	cost	*gas*	*equip*	*tfp*
$treat_c \times post_t$	0.0106***	0.0210***	0.0457***	0.1863***
	(10.8068)	(39.2784)	(42.0880)	(68.3659)

cost				-0.6945***
				(-71.2497)
treat	-0.0105***	-0.0775***	-0.0215***	-0.0631***
	(-6.7606)	(-20.1017)	(-17.7049)	(-7.6356)
age	0.0276***	0.0487***	0.0030*	0.0302***
	(8.3288)	(7.5596)	(1.6648)	(16.3833)
size	0.7901***	0.2707***	0.0964***	0.0590***
	(138.2385)	(29.8016)	(42.3279)	(7.3560)
kl	-0.4135***	-0.0787***	-0.0448***	0.0737***
	(-82.3875)	(-7.1476)	(-15.7273)	(15.9236)
hhi	-0.7886*	0.3023**	-0.0266	0.1594
	(-1.8626)	(2.2620)	(-0.5104)	(0.5739)
size_ind	-0.0518***	0.3004***	0.0842***	0.0027
	(-6.0286)	(8.9961)	(10.4759)	(0.4496)
gdp	0.0347***	0.1602***	0.0678***	-0.0024
	(7.4840)	(15.2203)	(23.2615)	(-0.9728)
ind	0.0998***	0.1046***	0.0000	-0.0232***
	(17.1467)	(5.4527)	(0.0114)	(-7.6838)
inter	0.0034**	0.0459***	0.0068***	-0.0013
	(1.9847)	(13.2665)	(5.7434)	(-1.2555)
soe	-0.0597***	0.1903***	0.0408***	0.0228***
	(-7.1483)	(10.5243)	(7.7731)	(4.7579)
foe	0.0086	0.2239***	-0.0176***	0.0102**
	(1.0424)	(12.6560)	(-3.6015)	(2.2356)
pre	0.0218***	0.0844***	0.0658***	0.0025
	(4.6565)	(7.5965)	(19.8466)	(1.0057)
preYear FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
N	2,293,991	182,754	200,997	2,293,991
R-Square	0.6116	0.2416	0.2604	0.8915

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(2) Technological innovation. Table 5.7 reports the regression results of the technological innovation. Regarding the measurement of technological innovation, the existing literature tends to use the firm's R&D investment and the number of patents to measure it. I select the logarithmic value of R&D investment, the number of patents and the number of invention patents as the measure of technology innovation (Wu and Wang, 2022). Column (1) report the regression results of R&D investment. The estimated coefficients are positive, indicating that environmental regulation policies significantly increased the R&D investment. The estimated coefficient in column (1) is 0.0351 and it means that after 2006, for every 1 unit increase in SO_2 emission reduction target, firm R&D increases by 3.51%. Column

(2) report the regression results of patent and column (3) report the regression results of invention patent. The estimated coefficients are all positive. It means that environmental regulation can increase the number of patents. The estimated coefficient in column (2)-(3) are 0.0185 and 0.0220 which mean that after 2006, for every 1 unit increase in SO_2 emission reduction target, firm patents and firm invention patents increase by 1.85% and 2.20%. From the results in Table 5.7, it seems environmental regulation can improve technological innovation. Ramanathan et al. (2017) and Fu and Jian (2021) also confirm the driving effect of environmental regulations on technological innovation in enterprises. The estimated coefficients of the mediating variables R&D investment, number of patents, and number of invention patents in column (4)-(6) of Table 5.7 are significantly positive, indicating that enterprise innovation has improved enterprise TFP. Based on the estimation results in columns (1) - (3) of Table 5.7, it can be found that SO_2 emission reduction target can improve TFP by enhancing corporate innovation (Wu and Wang, 2022). Notably, both the magnitude and statistical significance of the interaction terms exhibit a discernible decrease compared to the baseline regression results in columns (6) of Table 5.3 (0.1685). When I control the innovation effect, the positive impact of environmental regulation on TFP becomes smaller, which provides empirical support for the existence of the innovation effect.

In summary, environmental regulations can not only reduce the firms total factor productivity by increasing production costs, but also increase the firms total factor productivity by promoting technological innovation. A comparison of the magnitude of the estimated coefficients for the interaction terms in Tables 5.6 and 5.7 shows that the estimated coefficients for technological innovation are much larger than the estimated coefficients for production costs. It can be seen that environmental regulation has a much greater impact on technological innovation than production costs. It means the effect of environmental regulations in increasing total factor productivity by promoting technological re-engineering is greater than the effect of increasing the cost of production in reducing total factor productivity, and overall, environmental regulations increase the total factor productivity of enterprises. As can be seen from section 5.3.2, environmental regulation increases the total factor productivity in general.

Table 5.7: The Results of Influence Mechanism on TFP (2)

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	rd	*patent*	*in_patent*	*tfp*	*tfp*	*tfp*
$treat_c \times post_t$	0.0351***	0.0185***	0.0220***	0.0957***	0.1490***	0.1490***

	(28.5280)	(7.4407)	(14.3374)	(26.6811)	(47.2111)	(47.2016)
rd				0.2060***		
				(96.2155)		
patent					0.1022***	
					(43.2693)	
in_patent						0.1390***
						(30.8153)
treat	-0.2015***	-0.3413***	-0.2648***	-0.1464***	-0.1916***	-0.1914***
	(-63.1359)	(-9.1198)	(-12.0280)	(-25.2226)	(-32.9288)	(-32.8789)
age	0.0089***	0.1301***	0.0785***	0.1310***	0.1326***	0.1324***
	(16.2020)	(18.5552)	(18.3905)	(81.6107)	(82.1260)	(82.0049)
size	0.0096***	0.5084***	0.2431***	0.5821***	0.5830***	0.5838***
	(16.6267)	(53.5824)	(39.4644)	(293.8238)	(293.9351)	(294.2822)
kl	0.0039***	-0.2961***	-0.1581***	0.3349***	0.3349***	0.3353***
	(7.6185)	(-36.3376)	(-28.8556)	(201.5204)	(200.9837)	(201.1964)
hhi	-0.1623**	-6.0555***	-3.6552***	0.6799***	0.5506**	0.5576**
	(-1.9996)	(-4.9531)	(-4.8937)	(3.0673)	(2.5378)	(2.5698)
size_ind	0.0139***	0.0811***	0.0488***	0.0462***	0.0495***	0.0494***
	(12.9243)	(5.4998)	(5.5090)	(15.2123)	(16.2579)	(16.2246)
gdp	0.0275***	0.0123	0.0145***	0.0082***	0.0144***	0.0144***
	(26.6193)	(1.2894)	(2.6932)	(4.7234)	(8.2448)	(8.2444)
ind	-0.1223***	-0.0792***	-0.0497***	-0.1406***	-0.1660***	-0.1659***
	(-73.3786)	(-7.5431)	(-8.0850)	(-55.1071)	(-61.7276)	(-61.6988)
inter	0.0062***	-0.0056*	-0.0071***	-0.0097***	-0.0074***	-0.0074***
	(26.0579)	(-1.7505)	(-4.0406)	(-14.9365)	(-11.5548)	(-11.5573)
soe	0.0202***	0.0787***	0.0588***	0.0955***	0.0991***	0.0990***
	(11.1260)	(2.8706)	(3.2280)	(18.8052)	(19.5701)	(19.5467)
foe	0.0072***	0.1021***	0.0575***	0.0126***	0.0143***	0.0141***
	(5.1685)	(4.4689)	(4.0670)	(3.5286)	(3.9788)	(3.9423)
pre	-0.0112***	0.0844***	0.0399***	-0.0149***	-0.0170***	-0.0171***
	(-14.6062)	(8.4189)	(6.9625)	(-7.3333)	(-8.3309)	(-8.3900)
Year FE	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
N	2,379,602	2,387,905	2,387,905	2,379,602	2,387,905	2,387,905
R-Square	0.9409	0.5239	0.5016	0.8523	0.8512	0.8512

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

5.5.5 Heterogeneity Analysis

(1) Firm ownership. I use sub-sample regression to test the impact of the implementation of environmental regulation policies on firms' different ownership. I have standardized the data using Z-score

standardization method (Vaccario et al., 2017). Columns (1) and (2) in Table 5.8 report the regression results of enterprises with different ownership. The regression results of the estimated coefficients of state-owned firms and non-state-owned firms both are significantly positive, but the value and significance of the regression coefficient of state-owned firms are larger than that of non-state-owned firms. The estimated coefficient in column (1)-(2) are 0.1545 and 0.0764 which mean that after 2006, for every 1 unit increase in SO_2 emission reduction target, SOEs TFP increases by 0.1545 and non-SOEs TFP increases by 0.0764. It can be concluded that environmental regulation can increase TFP of state-owned firms and non-state-owned firms. But the impact of environmental regulation on state-owned firms is greater than that on non-state-owned firms (Chen et al., 2021). The possible reason for this is that one of the biggest differences between state-owned firms and non-state-owned firms is the difference in the degree of interference by administrative bodies. State-owned firms are naturally close to the government and have access to fiscal subsidies and financial support to ease the pressure of environmental regulations (Lin et al., 2023; Wang, Liu and Zhang, 2022). Increased production costs did not reduce firms' investment in technological innovation, and thus can increase state-owned firms' total factor productivity. As a result, environmental regulations have little impact on non-state-owned firms, but increase the total factor productivity of state-owned firms. Cai and Ye (2020) also reached a similar conclusion.

(2) Firm size. From the perspective of firm scale, there are differences in research and development capabilities, development models, and market competitive advantages among firms' different sizes. Firms with larger scales and better reputations are more likely to receive financial support. Therefore, environmental regulations have different impacts on companies of different sizes. I use sub-sample regression to test the impact of implementing environmental regulation policies on firms' different sizes. I have standardized the data using Z-score standardization method (Vaccario et al., 2017). The regression results are shown in columns (3) and (4) in Table 5.8. I found that the estimated coefficient is significantly positive at the 1% statistical level in large-scale firms but that of small-scale firms is not significant. The estimated coefficient in column (3) are 0.1762 which means that after 2006, for every 1 unit increase in SO_2 emission reduction target, large-scale firms TFP increases by 0.1762. It can be concluded that environmental regulation can increase TFP of large-scale firms. The possible reason for this is that large-scale firms can realize economies of scale (Scherer and Ross, 1990; Syverson, 2011). The larger the firm's size, the more it can reduce the cost per unit of product through bulk purchasing, production and sales activities, thus gaining the advantage of economies of scale (Hall and Mairesse, 1995). Firms can reduce

their production costs by scaling up production, so they develop a new advantage on equal terms. In addition, large-scale firms have a lot of funds (Titman and Wessels, 1988; Rajan and Zingales, 1998). They can carry out research and development innovation, which is conducive to improving firms' TFP. As a result, environmental regulations have an impact on large-scale firms.

Table 5.8: Heterogeneity Analysis of Firm Ownership and Firm Size

Variable	(1)	(2)	(3)	(4)
	State-owned firms	Non-state-owned firms	Large-scale firms	Small-scale firms
$treat_c \times post_t$	0.1545***	0.0764***	0.1762***	0.0025
	(48.0644)	(6.4054)	(38.6274)	(0.3114)
treat	-0.1774***	-0.0327	-0.1870***	-0.1588***
	(-34.2646)	(-1.1701)	(-23.8637)	(-23.9017)
age	0.1333***	0.0307***	0.1299***	0.0977***
	(90.2639)	(6.5008)	(64.7488)	(48.4191)
size	0.5108***	0.4724***	0.4140***	0.5868***
	(296.9031)	(47.3510)	(149.0158)	(237.3151)
kl	0.2928***	0.2797***	0.2585***	0.3034***
	(200.6297)	(39.4933)	(124.9052)	(144.0359)
hhi	0.1296	1.4993***	0.2714	0.4328*
	(0.5747)	(3.6979)	(0.9707)	(1.7232)
size_ind	0.0404***	0.0637***	0.0217***	0.0598***
	(14.9792)	(4.9097)	(5.7083)	(16.0433)
gdp	0.0155***	-0.0061	0.0274***	0.0013
	(10.0583)	(-0.6737)	(11.8824)	(0.6464)
ind	-0.1516***	-0.0410***	-0.1830***	-0.1054***
	(-62.7722)	(-5.4129)	(-50.7511)	(-36.3487)
inter	-0.0081***	0.0021	-0.0076***	-0.0054***
	(-13.6673)	(1.2494)	(-9.2013)	(-7.1676)
soe			0.1015***	0.0712***
			(11.1777)	(14.2546)
foe			0.0161***	0.0090**
			(2.9268)	(2.3734)
pre			-0.0105***	-0.0141***
			(-4.2378)	(-5.6225)
Year FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
N	168,662	2,210,282	1,179,886	1,127,587
R-Square	0.9335	0.8366	0.8674	0.7694

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(3) Factor density. As explained in Chapter 3, I divide the industries involved into labor-intensive

industries, capital-intensive industries, and technology-intensive industries, and use sub-sample regression to test the heterogeneity. I have standardized the data using Z-score standardization method. The regression results are reported in Table 5.9. I found that the estimated coefficient in labor-intensive industries is positive at the 1% statistical level and not significant in capital-intensive industries. And the estimated coefficient in technology-intensive industries is significantly positive at the 1% statistical level. The estimated coefficient in column (1) and (3) is 0.1610 and 0.2096 which mean that after 2006, for every 1 unit increase in SO_2 emission reduction target, labor-intensive industries' firm TFP increases by 0.1610, technology-intensive industries' firm TFP increases by 0.2096.

A possible reason for this is that labor-intensive industries are more dependent on the demand for labor resources and less dependent on resources such as capital, technology and knowledge. Examples include the textile and garment industries. This type of industry has higher pollution emissions and is easily affected by environmental regulation. Therefore, when environmental regulations are implemented, the cost of abatement rises. In order to meet the pollution emission standards, the production of the industry will be reduced, thus causing the total factor productivity of enterprises to decrease. Additionally, Ren et al. (2022) also found that climate policy reduces firm-level total factor productivity (TFP), and the negative effect is most pronounced for labor-intensive companies. Technology-intensive industries have more advanced technological equipment and more scientific and technical personnel, including mainly the emerging electronic computer industry, the robotics industry, the aerospace industry, the biotechnology industry, and the new materials industry. Compared with labor-intensive and capital-intensive industries, technology-industries have stronger research and development capabilities and innovation capabilities, so environmental regulations can increase TFP in technology-intensive industries.

Table 5.9: Heterogeneity Analysis of Factor Density

Variable	(1)	(2)	(3)
	Labor-intensive industries	Capital-intensive industries	Technology-intensive industries
$treat_c \times post_t$	0.1610***	0.0483	0.2096***
	(33.2838)	(0.1693)	(32.3459)
treat	-0.1565***	-0.1499***	-0.2348***
	(-19.7279)	(-17.5493)	(-22.7541)
age	0.1283***	0.0837***	0.1441***
	(56.7807)	(33.7345)	(53.0425)
size	0.4973***	0.5420***	0.4775***

	(173.1366)	(174.3930)	(153.9247)
kl	0.2841***	0.3052***	0.2847***
	(119.7175)	(114.7078)	(110.3269)
hhi	0.2449	0.6707***	2.0181***
	(0.6115)	(2.7466)	(2.8884)
size_ind	0.0079	0.1427***	-0.1222***
	(1.3353)	(24.2064)	(-15.5964)
gdp	0.0143***	0.0228***	0.0085***
	(5.8790)	(8.1707)	(3.0952)
ind	-0.1293***	-0.1558***	-0.1418***
	(-37.1253)	(-36.1927)	(-32.0337)
inter	-0.0050***	-0.0065***	-0.0049***
	(-5.7704)	(-6.2431)	(-4.7456)
soe	0.0750***	0.0846***	0.0956***
	(11.1624)	(11.8035)	(10.0828)
foe	0.0132**	0.0157***	0.0086
	(2.5437)	(2.8460)	(1.5370)
pre	-0.0199***	-0.0118***	-0.0099***
	(-7.3522)	(-3.7656)	(-2.7567)
Year FE	YES	YES	YES
Firm FE	YES	YES	YES
N	696,148	897,992	762,827
R-Square	0.8376	0.8564	0.8668

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(4) Regional heterogeneity. I divided the sample into eastern, central and western regions according to the division of the three regions of China by the Chinese Bureau of Statistics and analyzed the heterogeneity of different samples by using sub-sample regression. I have standardized the data using Z-score standardization method. The regression results are reported in Table 5.10. The estimated coefficients are significantly positive in the eastern region and the central region but are not significant in the western region. The estimated coefficient in column (1) and (2) is 0.1028 and 0.7297 which mean that after 2006, for every 1 unit increase in SO_2 emission reduction target, located in eastern firms' TFP increases by 0.1028, located in eastern firms' TFP increases by 0.7297.

The eastern region has been developed earlier and a large number of firms exist. Compared with the western regions, firms in the eastern and central regions are far more than those in the western regions in terms of technological innovation and financial support. Firms in the western region are at a stage of development where technology, capital and other elements are critical. Environmental regulations have increased production costs, which inevitably result in less investment in technological innovation, thus reducing the total factor productivity of firms in the western region. Yang et al. (2023) supports my conclusion and suggest that in the western region and highly competitive industries of China, environmental regulation significantly affects the total factor productivity of enterprises.

Table 5.10: Heterogeneity Analysis of Different Region

Variable	(1)	(2)	(3)
	Eastern region	Central region	Western region
$treat_c \times post_t$	0.1028***	0.7297***	0.0078
	(31.2033)	(25.9959)	(1.3129)
treat	-0.1187***	-0.0835**	0.0494
	(-22.0511)	(2.2200)	(1.0497)
age	0.1186***	0.1267***	0.0898***
	(71.0292)	(41.8755)	(19.7751)
size	0.5290***	0.4254***	0.4893***
	(285.6173)	(89.0601)	(77.6709)
kl	0.2979***	0.2669***	0.3078***
	(184.9765)	(69.2709)	(55.7401)
hhi	-0.0378	1.8510***	2.7030***
	(-0.1782)	(3.1612)	(3.4784)
size_ind	0.0422***	0.0066	0.0148
	(15.0028)	(0.7649)	(1.1217)
gdp	0.0223***	-0.0310***	0.0073
	(13.0149)	(-6.1151)	(0.8993)
ind	-0.1479***	-0.0745***	-0.0735***
	(-47.4339)	(-20.1172)	(-13.1401)
inter	-0.0095***	0.0051***	-0.0119***
	(-13.2182)	(4.4690)	(-5.3971)
soe	0.0665***	0.0874***	0.0734***
	(12.1185)	(9.4786)	(6.5987)
foe	0.0107***	0.0087	0.0162
	(3.2048)	(0.7600)	(1.1040)
pre	-0.0079***	-0.0175***	-0.0191***
	(-3.8750)	(-4.0705)	(-3.2696)
Year FE	YES	YES	YES
Firm FE	YES	YES	YES
N	1,810,889	377,623	199,379
R-Square	0.8502	0.8521	0.8715

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(5) Different industries. According to manufacturing industry segmentation, I conducted subsample

regression. The regression results are shown in Table C.1.1- C.1.5 in Appendix C. Among the 29 manufacturing segments, only 16 industries had a significantly positive estimated coefficient. The 16 industries are: Manufacture of Textile Wearing Apparel, Footwear and Caps, Manufacture of Leather, Fur, Feather and Related Products, Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm and Straw Products, Manufacture of Articles for Culture, Education and Sport Activities, Manufacture of Chemical Fibers, Manufacture of Plastics, Manufacture of General Purpose Machinery, Manufacture of Special Purpose Machinery, Manufacture of Transport Equipment, Manufacture of Electrical Machinery and Equipment, Smelting and Pressing of Non-ferrous Metals, Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work. It can be found that most of the industries whose total factor productivity is affected are those that emit more pollution. This research finding is consistent with Shen et al. (2019). In order to meet the requirements of environmental regulations, these industries will reduce their pollution emissions by increasing innovation, thus increasing their total factor productivity.

5.6 Chapter Summary

In this chapter, I analyzed whether China's domestic environmental regulation has a negative or positive influence on firms' total factor productivity in terms of manufacturing. For the aim of this study, I first analyzed the relationship between environmental regulation and firm total factor productivity. Environmental regulation may impact firm total factor productivity through two aspects: production cost and technology innovation. Environmental regulation can directly increase firms' costs which may reduce their TFP. Environmental regulation also can stimulate firms to innovate and increase their TFP.

On this basis, using data from the Chinese industrial enterprise database from 2000 to 2010, I take the implementation of the Eleventh Five-Year Plan in 2006 as a quasi-natural experiment and employ the TWFE model and continuous DID method to verify the conclusion of the theoretical analysis. The results show that environmental regulation can lead to a significantly positive impact on firm total factor productivity. My mechanism analysis reveals that environmental regulation impacts firm TFP through two channels: on the one hand, it directly increases firms' production costs which is mainly achieved by increasing the use of clean energy and the number of emission reduction equipment. On the other hand, it can stimulate firms to innovate to increase firm TFP. It is achieved mainly through increased investment in R&D and the number of patents. Because environmental regulation has a much greater impact on technological innovation than production costs, finally environmental regulations increase TFP. Furthermore, heterogeneity analysis shows that environmental regulation significantly increases TFP of state-owned firms, large-scale firms, technology-intensive industries, and eastern and central region firms. This chapter also conducts a series of robustness tests, including the two-period DID method, winsorize, eliminate other policy distractions, change the dependent variable and using a relative target, and the results remain significant.

In the next chapter, I will analyze the relationship between environmental regulation and firm two-way foreign direct investment.

6 SO_2 Emissions Regulation and Firm Two-Way Foreign Direct Investment

6.1 Introduction

Over four decades of reform and opening up, China has transformed from an economically backward country into the world's second largest economy, with its economic strength undergoing tremendous change. Two-way foreign direct investment in China has grown rapidly, and China has become a major destination for foreign direct investment (FDI) and outward foreign direct investment (OFDI) (Wang and Gao, 2019; Zhao and Wang, 2021). Adhering to paying equal attention to bringing in and going global, and improving the level of two-way investment is the only way to steadily promote the "coordinated development of two-way investment", and it is also an important part of building a new development pattern of the domestic and international dual circulation. Commensurate with the enhancement of economic power, China's FDI and OFDI activities, an important manifestation of China's "bring in" and "going global" strategy, have burgeoned in frequency and significantly impacted China's international trade, industrial upgrading, technological innovation, and employment (Tang et al., 2020; Chen et al., 2020; Jiang et al., 2020).

Since joining the WTO in 2001, China's momentum to attract FDI has become even stronger. In 2014, China attracted a total of US$119.56 billion in FDI, becoming the largest FDI inflow country, surpassing the United States. In 2022, China's actual use of FDI amounted to US$189.13 billion. OFDI flows ranked second globally in 2015 for the first time and has remained within the top three from 2016 to 2019. OFDI stock ballooned from US$317.21 billion in 2010 to US$2,198.88 billion in 2019, sustaining third place globally. Since 2020, the COVID-19 pandemic has severely impacted the global economy, engendering a deteriorating environment and recession (Naseer et al., 2023; Song and Zhou, 2020). Against this backdrop, China's government has underscored adherence to a domestic cycle as the primary and mutual promotion of domestic and international cycles in the new landscape of economic openness, with overseas investment cooperation emphasizing quality, efficiency, security and sustainability. By 2020, domestic investors had established 45,000 overseas enterprises across 189 countries and regions worldwide. As China persists in accelerating two-way FDI, its stock and flows have steadily expanded, with destinations continuously extending globally (Ma et al., 2023). The enduring two-way FDI growth warrants investigating its motivating factors. Beyond documented drivers like resource-seeking and market-seeking, could other overlooked factors be propelling China's burgeoning two-way FDI?

Concurrently, China's rapid economic ascent entailed an energy-intensive, high-emissions extensive growth model that imposed enormous resource and environmental costs (Tong et al., 2022; Wang et al., 2024). Per China Energy Statistics Yearbooks, coal constituted over 70% of energy consumption since 1980, though its share of primary energy consumption had fallen to 56.0% by 2021. This irrational energy mix has created serious environmental issues and gradual resource depletion. Upon recognizing the resultant problems, China's government regarded environmental issues as crucial nationally and established environmental protection as a fundamental and unwavering state policy in 1983. Moreover, China has continuously formulated and refined environmental laws and regulations, gradually intensifying oversight across dimensions. In 2015, China emphasized the relationship between humans and nature as well as resource and environmental issues in its new development concepts, while proposing a shift towards intensive growth. As the process of globalization continues to accelerate, firm investment has become an important force driving global economic development. However, firms often face a series of challenges and risks when carrying out investment activities, and one of the most prominent issues is environmental protection and sustainable development. Environmental regulation, as an important means of governmental environmental protection, has attracted increasing attention for its impact on firm investment (Fahad et al., 2022; Dong et al., 2021). A pertinent question is whether environmental regulations have induced Chinese investment as a "pollution haven" effect.

Therefore, using micro-data on Chinese firms' investments, this chapter analyzes the impact of China's environmental regulations on firm two-way FDI and potential mechanisms and heterogeneities. The contributions of this chapter are reflected in the following aspects. Firstly, this study demonstrates that environmental regulations inhibit FDI while stimulating OFDI through increased pollution abatement and compliance costs. These findings substantiate the industrial relocation logic underlying PHH. Consequently, my results not only validate the core proposition of PHH but also provide empirical evidence elucidating how environmental regulations influence cross-border capital flows. Secondly, previous studies have only examined the impact of environmental regulations on FDI or OFDI, without examining the relationship between SO_2 emission reduction target and two-way FDI using DID model. This chapter examines the relationship between environmental regulation and firm two-way FDI using DID model as a natural experiment. Departing from prior research that primarily relied on macroeconomic data, our study achieves a significant breakthrough in data utilization. I employ firm-level data from the China Industrial Enterprise Database and the Cathay Pacific CSMAR Database. The extensive sample of enterprises substantially reduces estimation bias. Thirdly, this chapter explored the impact mechanism through cost, innovation, and financing effects. Heterogeneity analysis conducted considering firm ownership, size, factor densities, industries, and country differences. The findings indicate that the implementation of the 11th Five-Year Plan enhances environmental regulation, resulting in a negative impact on firm FDI and a positive impact on firm OFDI. Finally, the results of my study can assist policymakers in refining the design of SO_2 regulation policies. Policymakers can consider introducing complementary measures such as tax incentives or subsidies to mitigate the adverse effects of these policies on foreign direct investment. Policymakers can use my research findings to develop more sustainable investment policies that attract foreign direct investment with high environmental and economic value.

6.2 Literature Review

6.2.1 Environmental Regulation and Foreign Direct Investment

A substantial literature has examined the impact of environmental regulation on foreign direct investment (FDI), with conclusions coalescing around three perspectives. The first view contends that environmental regulation deters inward FDI for several reasons. The pollution haven hypothesis, first proposed by Walter and Ugelow (1979), holds that environmental regulation increases production costs and crowds out R&D investment, which reduces the productivity, comparative advantage and relative competitiveness of enterprises, so as to prevent the inflow of FDI. Based on the pollution haven hypothesis, Taylor (2005) explained the theoretical logic of the impact of environmental regulation on FDI by dividing international industrial transfers into five segments. Firstly, the basic characteristics of a country determine the level of environmental regulation in a country. Secondly, the level of environmental regulation affects the firms' production costs. Thirdly, production costs affect FDI flow and trade. Fourthly, FDI flow affects variables such as prices, incomes and pollution. Finally, prices, incomes and pollution, in turn, affect the level of environmental regulation.

Van Long and Siebert (1991) developed a general equilibrium model with two countries, two factors of production and one production sector. The government imposes environmental regulations through the imposition of a tax on emissions. Under the assumption of free movement of capital between two countries, capital will flow to the country with a more relaxed level of environmental regulation. Venables (1996) introduced environmental regulation in an FDI model and concluded that stricter environmental regulation in a country drives firms toward cross-border production. Rauscher (1995) used a partial analysis framework and found that higher environmental taxes in host countries raise the barriers to FDI entry, and then reduce FDI entry. Levinson and Taylor (2008) also thought that influenced by environmental regulations, economic activities will move to countries with less stringent environmental regulations. Regulations compel firms to procure abatement equipment and technologies, imposing compliance costs (Tang, 2015; D'Agostino, 2016). Regulations also stipulate permissible treatment facilities and methods, precluding lax environmental conduct. Additionally, input-output constraints are imposed, limiting production approaches. To sustain competitive price advantages, multinational corporations often circumvent stringently regulated areas and invest where oversight is weaker, creating "pollution havens" (List and Co, 2000; Cole and Elliott, 2005; Dam and Scholtens, 2008; Wagner and Timmins, 2009; Chung, 2014; Millimet and Roy, 2016).

In addition, a large number of studies on developed countries such as the US and Japan support the pollution haven hypothesis, which falls into two main categories. One category is from the perspective of the host country, analysing whether FDI prefers regions with weak environmental regulations. For example, List and Co (2000) used a conditional logit model to analyse the impact of environmental regulations on FDI inflows in the US states from 1986 to 1993, arguing that states with more lenient environmental regulations are more likely to attract multinational companies and also increase FDI inflows. For example, for every 1% increase in government spending on environmental regulation in Arizona, the probability of attracting a foreign firm decreases by 0.262%. Xing and Kolstad (2002) also analysed data on outward investment in six US industries. It concluded that lax environmental regulations in host countries are an important factor in attracting pollution-intensive industries. The above literature confirms that the pollution haven hypothesis is valid in the US. Wagner and Timmins (2009) analysed panel data for six pollution-intensive industries in OECD and selected non-OECD countries for 1995-2002, confirming the existence of the pollution haven hypothesis in most pollution-intensive industries.

However, some empirical literature does not support the pollution haven hypothesis. Javorcik and Wei

(2003) identified four reasons for the non-existence of the pollution haven hypothesis: first, the host country's institutional barriers to FDI; second, the neglect of institutional factors in statistical analyses; third, the predominance of macro-level data in studies and the scarcity of micro-level analyses in the literature; and fourth, the environmental regulations of the host country and the pollution indicators of FDI firms are measured differently. Jaffe et al. (1995) concluded that there is no necessary link between environmental regulation and the relocation of pollution-intensive industries. This suggested that there is no significant correlation between the stringency of environmental regulations and the location decisions of FDI firms. De Melo and Grether (2004) researched five heavily polluting industries in 52 countries from 1981 to 1998 and found that polluting industries in countries with strict environmental regulations did not move to countries with less stringent regulations. Therefore, the pollution haven hypothesis did not exist.

Eskeland and Harrison (2003) studied French investment in Morocco and US investment in Venezuela and Mexico and found no necessary link between the strict environmental regulation and the movement of capital. Kirkpatrick and Shimamoto (2008) found that Japanese firms prefer to invest in countries with transparent and stable environmental regulations rather than in countries with lax environmental regulations, which rejected the pollution haven hypothesis. Kim and Rhee (2019) used a panel of 120 developing countries from 2000 to 2014 and found that strict environmental regulations drive host countries to attract more FDI, confirming the pollution halo hypothesis. Muhammad and Khan (2019) analyzed cross-country data for 34 host countries and 115 source countries in Asia over the period 2001 to 2012. Their results suggested that stronger environmental regulatory policies can drive the development of new energy and technology-intensive industries and attract FDI inflows from developed countries. The "Porter hypothesis" proposed by Porter and Van der Linder (1995) argues that appropriate environmental regulations will stimulate firms to innovate. Then it can increase productivity and competitiveness through the incentive effect of innovation. This is conducive to lower production costs and higher profit margins, which in turn is conducive to the inflow of FDI. Regulation incentivizes efficiency enhancements, curtailing production inefficiencies (Lee et al., 2014).

As China's coastal areas have implemented stricter environmental regulatory policies, FDI providers are more likely to choose China's coastal areas. Investment is also stimulated in environmental technology upgrades and management innovations, engendering "innovation offsets" that potentially counterbalance compliance costs. This enables concurrent economic and environmental performance gains, conferring first-mover advantages and competitive dominance in international markets, rendering jurisdictions with regulation more attractive for FDI (Rivera and Oh, 2013; Javorcik and Wei, 2005; Elliott and Shimamoto, 2008; Kirkpatrick and Shimamoto, 2008; Dijkstra et al., 2011; Ferrara et al., 2015).

The third view contends environmental regulation has negligible FDI impacts for several reasons. Given their technological sophistication, multinationals' location choices are insensitive to host country regulations, with market size, endowments, costs, and infrastructure outweighing environmental policy (Tole and Koop, 2011). Regulations affect FDI not only through compliance costs but also via other mechanisms like innovation offsets. Moreover, regulatory impacts depend on market efficiency, monitoring, penalties, industry technology, and pollution intensity. Thus, environmental regulation lacks a significant correlation with FDI (Eskeland and Harrison, 2003; Dean et al., 2009; Marconi, 2012; Manderson and Kneller, 2012; Poelhekke and Van der Ploeg, 2015). In summary, the literature provides conflicting perspectives on whether and how environmental regulation affects FDI inflows, warranting further research to provide clarification.

There is a paucity of research literature on the impact of environmental regulations on FDI flows in China. Ljungwall and Linde-Rahr (2005), using data for 28 Chinese provinces from 1987 to 1998, found that environmental regulations did not have a significant impact on FDI from a national perspective, and had a significant negative impact on FDI inflows in the western and central regions. Xu et al. (2016) found that environmental regulations can prevent FDI inflows in both the long and short term by using data from Shanghai. Cai et al. (2016) used a quasi-natural experiment of two control zones in 1998 and investigated the impact of environmental regulation on FDI. The results showed that strict environmental regulation led to a reduction in FDI inflows. Yang et al. (2018) used statistical data and a spatial Durbin model for 30 Chinese provinces from 2003 to 2014 to conclude that there is a significant spatial correlation between environmental regulation and FDI. Environmental regulation hurt the introduction of FDI, but this effect was not significant at the national level. It suggested that the evidence for the pollution haven hypothesis is not sufficient in China. Dean et al. (2009) examined pollution haven behavior by estimating the determinants of location choices of joint ventures in China. They derived and estimated a location choice model using the theoretical framework of firm production and emission reduction decisions. Then they concluded China's lax regulations only attracted high pollution Hong Kong, Macao, and Taiwan firms rather than broader foreign investment.

6.2.2 Environmental Regulation and Outward Foreign Direct investment

The relationship between environmental regulation and outward foreign direct investment (OFDI) is a classic issue that has garnered frequent scholarly attention. The literature delineates three principal conclusions regarding the impact of environmental regulation on outward foreign direct investment (OFDI).

First, environmental regulation promotes firm OFDI. Many scholars agree with the "pollution haven hypothesis" (Kellenberg, 2009). This hypothesis holds that under the openness and integration of the global economy, differences in the intensity of environmental regulations between different countries (regions) will lead to the transnational transfer of polluting industries, that is, pollution-intensive industries will shift from countries (regions) with strict environmental regulations to countries with loose environmental regulations (Walter and Ugelow, 1979).

Many literatures confirm the hypothesis. Analyzing US OFDI determinants across 22 industrializing countries, Xing and Kolstad (2002) uncovered significant effects of host country chemicals and metals sector regulations on US firms' investment decisions. However, the intensity of environmental regulations in other industries has no impact on firm investment decisions. Spatareanu (2007) studied the impact of the intensity of environmental regulations in 25 European countries on companies establishing overseas subsidiaries and found that the stricter the environmental regulations in home countries, the greater the likelihood that the country will make OFDI, and this phenomenon occurs at high levels. This is even more obvious for firms in polluting industries. Based on the OFDI data from the U.S., Cole and Elliott (2005) found that environmental regulation with speculative capital control can increase OFDI. Using micro firm-level data in the U.S. from 1966 to 1999, Hanna (2010) estimated the effect of environmental regulation on a multinational's foreign production decisions. Then, they found that the passage of the 1970 Clean Air Act Amendments caused an increase in overseas assets and output of regulated firms but did not disproportionately increase OFDI in developing countries. Using a DID approach, Chung (2014) evidenced a "pollution haven" effect of Korean environmental regulation on OFDI.

Examining Chinese firm data, Bu and Huo (2013) studied the impact of the intensity of the host country's environmental regulations on China's OFDI and found that the looser the host country's environmental regulations, the greater the probability that Chinese enterprises (especially resource-intensive enterprises) will invest overseas, indicating that China's OFDI has the characteristics of pollution haven. Employing a triple differences approach, Cai et al. (2016) showed that strengthened Chinese environmental regulation markedly deterred foreign firm entry. Manderson and Kneller (2012) posit that host country environmental regulation constitutes the primary determinant of OFDI in pollution-intensive enterprises, while merely comprising one of many drivers for other firm types.

Zheng and Shi (2017) used China's provincial panel data from 2004 to 2013 to study the impact of China's environmental regulations on the transfer of China's polluting industries. The study found that both market regulation tools represented by sewage charges and public regulation tools represented by environmental complaint letters have significantly promoted the production transfer of polluting industries. Based on the A-shared listed companies from 2000 to 2010, Liu et al. (2022) used the SO_2 emission reduction policy in the 11th Five-Year Plan as a policy shock to estimate the effect of environmental regulation on China's OFDI. They found that stricter environmental regulations in the host country have increased the probability of firms' OFDI, and environmental regulations increase OFDI by boosting firm innovation. Further research showed that this positive impact is stronger for small-scale firms, private firms and firms located in western region of China. However, their analysis of the influence mechanism is not comprehensive enough, only the innovation effect is analyzed, but the cost effect and financing constraint effect are not analyzed.

Second, the relationship between environmental regulation and OFDI is potentially nonlinear. Some literature indicates a U-shaped relationship between environmental regulation and OFDI. Accounting for home and host country regulations, Naughton (2014) identifies a "pollution haven effect" and "closed effect" of home country environmental regulation on FDI by using a panel of 28 OECD countries for 1990-2000. At low levels of increased stringency, the "pollution haven effect" stimulates OFDI, whereas at high levels, the "closed effect" dampens OFDI. Elliott and Zhou (2013) determined greater host country environmental stringency could counterintuitively increase foreign firm entry probability, conflicting with the "pollution haven" notion. Rezza (2013) analysed 256 Norwegian manufacturing firms investing abroad from 1999 to 2005 and found that while environmental regulations in the host country do not affect average investment, higher levels of environmental regulations in the host country do discourage efficiency-seeking subsidiaries from investing in the parent firm.

Third, environmental regulation does not necessarily stimulate firm OFDI. Eskeland and Harrison (2003) studied the foreign investment of the United States and France in four countries: Mexico, Morocco, Côte d'Ivoire, and Venezuela, and found that even if different environmental regulatory tools were considered, there was no obvious causal relationship between the intensity of environmental regulations and FDI inflows in these four countries. Examining German OFDI across 90 countries, Wagner and Timmins (2009) established host country regulation only deterred chemicals sector foreign investment, with no significant impact on other polluting industries. Assessing Indian state regulations, Kathuria (2018) used 21 Indian states from 2002 to 2010 to examine the relationship between environmental regulation and OFDI. They uncovered no unambiguous "pollution haven" effect on OFDI. Kellenberg (2009) found that environmental regulations have a significant negative effect on their location choice for overseas investment by using empirical analysis of US MNC data. Elliott and Shimamoto (2008) used industry data to study the impact of the increase in the intensity of Japan's domestic environmental regulations on OFDI. They found that with the strengthening of domestic environmental regulations, there was no obvious cross-border transfer of Japanese polluting industries.

This research differs significantly from previous studies. Previous studies have predominantly focused on either FDI or OFDI in isolation, failing to incorporate two-way direct investment into a unified analytical framework. This study makes a novel contribution by examining the comprehensive impact of environmental regulation on two-way direct investment, providing micro-level empirical evidence for the pollution haven hypothesis. Departing from prior research that primarily relied on macroeconomic data, our study achieves a significant breakthrough in data utilization. I employ firm-level data from the China Industrial Enterprise Database and the Cathay Pacific CSMAR Database. The extensive sample of enterprises substantially reduces estimation bias. Furthermore, I analyze the underlying mechanisms through three distinct pathways: the cost effect, innovation effect, and financing effect. This elucidates the transmission channels through which environmental regulation influences two-way direct investment.

6.3. Theoretical Analysis and Research Hypothesis

6.3.1 Cost Effect

A firm's basic goal is to maximize profit. However, environmental pollution cannot be avoided during the production process. Environmental pollution has a typical negative externality effect, that is, enterprises can transfer the pollution cost to society, resulting in negative externalities. At this time, relying solely on market mechanisms can no longer maximize the overall society welfare, so the government needs to regulate the environment, that is, the government needs to implement environmental regulatory policies to impose external costs on society from environmental polluters, which must be borne by themselves. This chapter takes a typical two-way FDI firm as the research object and analyzes the impact of environmental regulations on its investment through a cost-benefit analysis model that takes environmental regulatory factors into account. It is assumed that the model is established in an imperfectly competitive market, and the two-way FDI firm has increasing returns to scale.

In a market with imperfect competition, the long-term equilibrium of two-way FDI firm is shown in Figure 6.1. The firm's demand curve is *D*, and the marginal revenue curve is *MR*. The marginal revenue curve MR is below the demand curve *D*. Due to increasing returns to scale, the average cost curve *AC* slopes downward to the right. Marginal cost *MC* is lower than average cost *AC*, and the firm's marginal cost *MC* is constant. When marginal revenue equals marginal cost, output is Q_E, price is P_E, and the company maximizes profits.

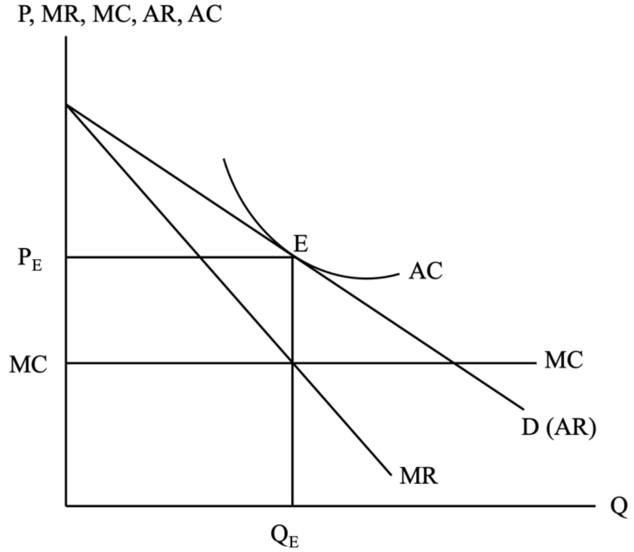

Figure 6.1: Firm Long-Run Equilibrium without Environmental Regulation

Figure source: Own creation.

When the government does not implement environmental regulations, firm can use environmental resources at will and abatement pollutants at will. Firm incurs no environmental costs. However, when the government implements environmental regulations, firm will incur pollution prevention and control costs or pollution abatement fees to reduce pollution emissions. As can be seen in Figure 6.2, firm's average cost rises from *AC* to *AC'* and marginal cost rises from *MC* to *MC'*. Firm's profit has declined, hindering the inflow of FDI and encouraging the outflow of OFDI. That is, firms transfer capital from countries with high environmental regulations to countries with low environmental regulations.

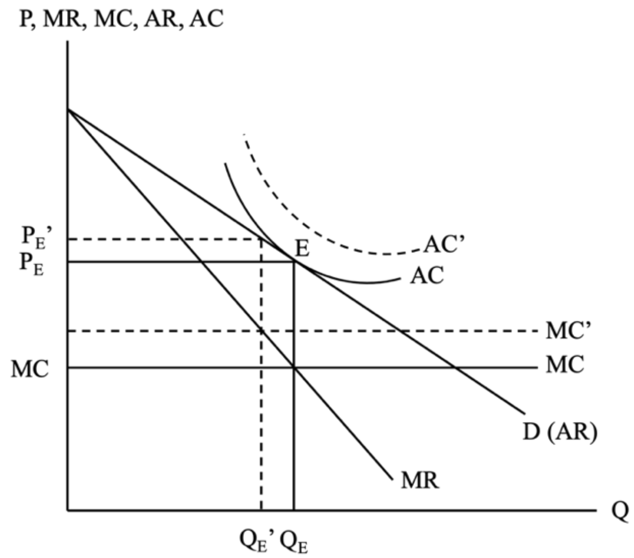

Figure 6.2: Firm Long-Run Equilibrium under Environmental Regulation

Figure source: Own creation.

It can be seen from the above model that environmental regulation affects two-way FDI through the firms' production costs. China's 11th Five-Year Plan sets clear requirements for sulfur dioxide emissions. First, environmental regulations increase firms' pollution reduction costs (Gray, 1987; Testa et al., 2011). In order to meet the emission requirements stipulated by the government, some firms will choose measures such as emissions trading, resulting in an increase in production costs (Frondel et al., 2008; Geng et al., 2021). Second, environmental regulations increase firms' pollution treatment costs. For example, firms purchase new equipment to reduce pollution emissions to meet environmental protection requirements (Kemp and Pontoglio, 2011). The implementation of China's more stringent environmental regulatory policies has brought about an increase in firms' production costs. Driven by profit motives, firms may invest abroad, that is, the strengthening of China's environmental regulations will prompt pollution-intensive firms or industries to transfer the production process to countries and regions with loose environmental regulations and lower production costs, which can reduce the adverse effects of environmental regulations in the home country (Walter and Ugelow, 1979; Copeland and Taylor, 1995). Environmental regulations will increase the entry threshold for FDI, thereby reducing FDI inflows (Rauscher, 1995). Therefore, environmental regulations will bring additional costs, leading to a reduction in FDI and an increase in OFDI. Therefore, this research proposes the following hypothesis:

Proposition 1: Environmental regulations can promote firm OFDI and reduce firm FDI by enhancing production costs.

6.3.2 Innovation Effect

According to the "Porter Hypothesis", reasonable environmental regulatory policies can have a "reverse forcing effect" on firm technological innovation. In order to meet the requirement of environmental protection policies, firms will strengthen green technology innovation and enhance competitiveness, thereby offsetting the negative impact of rising production costs caused by environmental regulations, producing an "innovation compensation effect" (Porter and Van der Linde, 1995). Therefore, strict environmental regulations can promote the innovation of regulated firms (Fu and Jian, 2021; Li et al., 2020). Firms will use innovation to produce better-quality, safer, and lower-priced products. Furthermore, firms will use the first-mover advantage in the market to enable innovative new products to occupy the market and prevent competitors from entering (Rodríguez-Pinto et al., 2007; Cleff and Rennings, 2012;

Kim et al., 2015). Through innovation compensation and first-mover advantages in the market, strict environmental regulations will enable regulated firms to gain an absolute competitive advantage over unregulated firms. Therefore, as can be seen in Figure 6.3, firm's demand curve moves upward from *D* to *D"*. Firm's revenue curve moves upward from *MR* to *MR"*. Firm's equilibrium output rises from Q_E to Q_E", and the equilibrium price rises from P_E to P_E". The average cost drops to *AC"*. Since the firm's average cost *AC"* is less than the equilibrium price P_E", firm can earn excess profits which will promote firm's FDI inflows and OFDI outflows.

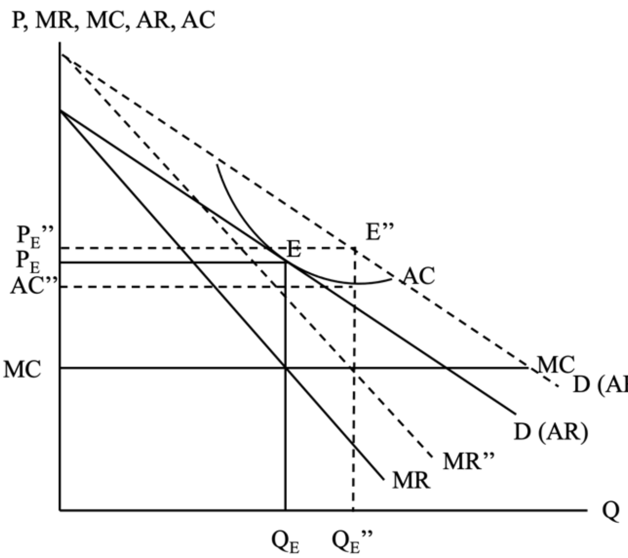

Figure 6.3: Porter Hypothesis under Environmental Regulation

Figure source: Own creation.

It can be seen from the above model that environmental regulation affects two-way FDI through the firms' technological innovation. First, there is a positive relationship between environmental regulation and firm technological innovation (Porter and Van der Linde, 1995). When faced with strict environmental regulations, firms will choose to optimize production processes (Rubashkina, Galeotti and Verdolini, 2015) or develop new technologies (Du and Li, 2019) to achieve the firm's pollution emission goals (Lanjouw and Mody, 1996). Secondly, the improvement in the level of technological innovation promotes firm's FDI and OFDI (Brunnermeier and Cohen, 2003; Elliott and Zhou, 2013). Strict environmental regulations promote firms to improve total factor productivity, and the increase in productivity will further improve the firm's performance and profitability. Therefore, firms have a stronger ability to attract foreign capital and make investments (Helpman et al., 2004; Ambec et al., 2013). Therefore, this research proposes the following hypothesis:

Proposition 2: Environmental regulation can stimulate FDI and OFDI by enhancing firm innovation capabilities.

6.3.3 Financing Effect

Environmental regulations can potentially exacerbate financing constraints for firms through increased production costs. When facing more stringent regulations domestically, firms may be compelled to reallocate financial resources and managerial attention towards environmental compliance rather than more productive investments (Zhao and Sun, 2016). The costs of upgrading equipment, adopting cleaner technologies, and meeting stricter emissions standards can put significant strain on firms' capital reserves (Chen et al., 2024). This leaves fewer internally generated funds available for innovative projects and business expansion. However, firms that successfully develop proprietary environmentally friendly technologies may gain a competitive advantage and find it easier to access external finance from banks and capital markets. Lenders may perceive these firms as having better credit risks due to their regulatory compliance capabilities and expertise with green technologies. Additionally, outward foreign direct investment allows financially constrained firms to transfer production and operations to countries with less stringent environmental regulations but reduces foreign investment inflows to firms (Liu et al., 2022). Relocating manufacturing, distribution, and other facilities overseas reduces domestic production costs and frees up capital that can be channeled towards more productive uses. Hence, environmental regulations impose incentives for foreign direct investment by financially constrained firms as a strategic response to alleviate financing constraints and lower compliance costs. Outward FDI specifically enables firms to leverage advanced environmental technologies and know-how overseas while circumventing the most burdensome regulations in their home country (Zhang et al., 2023). It also allows financial reallocation towards innovation in cleaner technologies that can confer first-mover advantages in global markets (He, 2023; Shi et al., 2023). Therefore, this research proposes the following hypothesis:

Proposition 3: Environmental regulations can reduce firms' FDI and promote firms' OFDI by increasing financing constraints.

As can be seen in Figure 6.4, environmental regulation can affect the firm two-way FDI in three ways. First of all, from the cost effect, environmental regulation can increase pollution reduction costs and pollution treatment costs, and then reduce the firm FDI inflow and increase the firm OFDI outflow. Second, from the innovation effect, environmental regulation can increase firm FDI inflow and OFDI outflow through improving technological innovation. Third, from the financing effect, environmental regulation can increase financing constraints, and then reduce the firm FDI inflow and increase the firm OFDI outflow. In summary, the impact of environmental regulations on firm FDI is uncertain, but environmental regulation can promote firm OFDI.

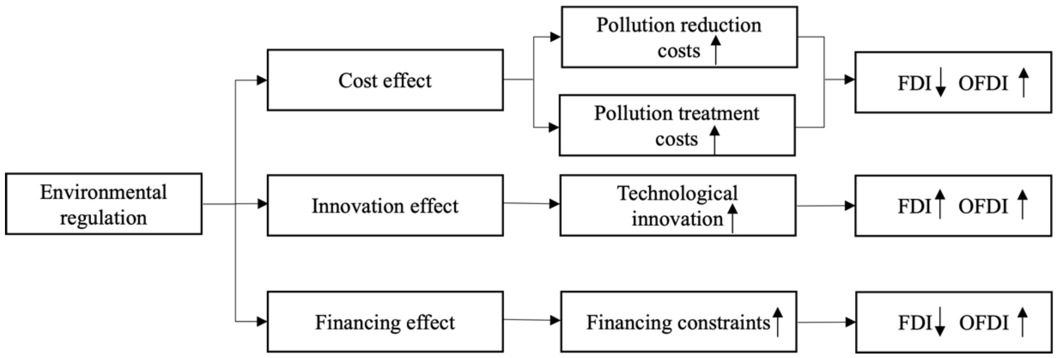

Figure 6.4: Theoretical Mechanism of Environmental Regulation on Firm Two-Way FDI

6.4. Methodology

6.4.1 Model Specification

From the theoretical analysis in section 6.3, it can be found that the impact of environmental regulations on firm FDI is uncertain but environmental regulation can promote firm OFDI, then I set up the following model for exploration. Since investment amounts are non-negative and exhibit a distribution characterized by a pile-up at zero, conventional linear estimation would result in negative predicted values for investment scale, and statistical inference would only be asymptotically valid. Therefore, this chapter employs the Tobit model with a left-censoring limit at zero to estimate the investment equation (Sigelman and Zeng, 1999; Razin and Sadka, 2007; Wang and Yu, 2014). I adopt the continuous DID method and regard the mandatory SO_2 emissions target scheme strengthened in the 11th Five-Year Plan from 2006 as a natural experiment (Liu et al., 2022; Dong et al., 2022). I compare the change in firm level FDI and OFDI before and after 2006, when more stringent environmental regulations were introduced, based on the following model:

$$\ln(Amount+1)_{it}=\begin{cases}\alpha+\beta_1 treat_c\times post_t+\beta_2 treat_c+\beta_3 post_t+\eta X_{it}+\gamma_t+\gamma_c+\varepsilon_{it}, & y^*>0\\ 0, & y^*=0\end{cases} \tag{6.1}$$

Where, *i* represents industrial firms, *c* represents city, and *t* represents year. y^* is the potential logarithmic investment scale, which are respectively foreign direct investment of industrial firm *i* in year *t* and outward foreign direct investment of listed company *i* in year *t*. $treat_c\times post_t$ is a dummy variable, representing environmental regulation. $treat_c$ is the continuous grouping index of the treatment group and the control group that is, the environmental regulation intensity of each city, which is measured by the SO_2 control target (ten thousand tons) of the city *c*. $post_t$ is a dummy variable equals to 0 for all years before 2006, and to 1 from 2006 and onward. X_{it} represents a set of control variables. γ_t is the year fixed effect, γ_i is the city fixed effect, and ε_{it} is the random disturbance term. Because I include year fixed effect, the $post_t$ indicator is collinear with the year dummies and drops out of the regression. So I can't report the coefficient of $post_t$.

6.4.2 Explanation of Variables

6.4.2.1 Research on SO_2 Emissions Regulation and FDI

1. Explained variable. FDI is measured by the logarithm of the total capital of an enterprise from Hong Kong, Macao, and Taiwan and foreign capital. FDI come from Hong Kong, Macao, and Taiwan capital and foreign capital. Since there is no FDI data after year 2007 in the China Industrial Enterprise Database, I selected FDI data from 2000-2007 for research.

I counted the distribution of total OFDI from 2000 to 2007 (see Table 6.1). In terms of investment scale, China's firm FDI has been on a growing trend. In terms of the number of firms with FDI, with the policy support of the Chinese government, China's FDI firms have increased more than 2 times, achieving a stable and good development trend. Skewness is more than 0, indicating that the data distribution is right skewed, and there are fewer data to the right of the mean than to the left of the mean. The kurtosis of the firm FDI is greater than 3, indicating that the data is steeper than the normal distribution. Figure 6.5 shows the distribution of firm FDI. It can be found from the graph that the proportion of firm with FDI of 0 is

79.1%.

Table 6.1: Total Distribution of Industrial Firm Level FDI in China from 2000 to 2007

Year	Mean	Std. Dev.	Skewness	Kurtosis	FDI firm	Obs
2000	4.6549	40.3585	69.7793	9763.866	27,518	126,566
2001	4.9168	38.0559	43.7309	3718.977	30,100	136,544
2002	5.1895	42.6247	42.5926	3175.568	32,043	147,556
2003	5.5309	46.6748	61.4912	7718.871	36,684	166,159
2004	5.2184	49.2426	71.5347	9024.210	51,872	235,161
2005	6.0345	56.3421	59.7432	5882.257	51,980	234,566
2006	6.4900	67.1294	72.6904	8516.839	56,039	262,672
2007	6.9959	72.1656	69.7319	7887.669	61,139	293,666
All	5.8314	56.2012	71.7918	9170.836	347,375	1,602,890

Source: Analysis reported in this thesis. Unit: million yuan.

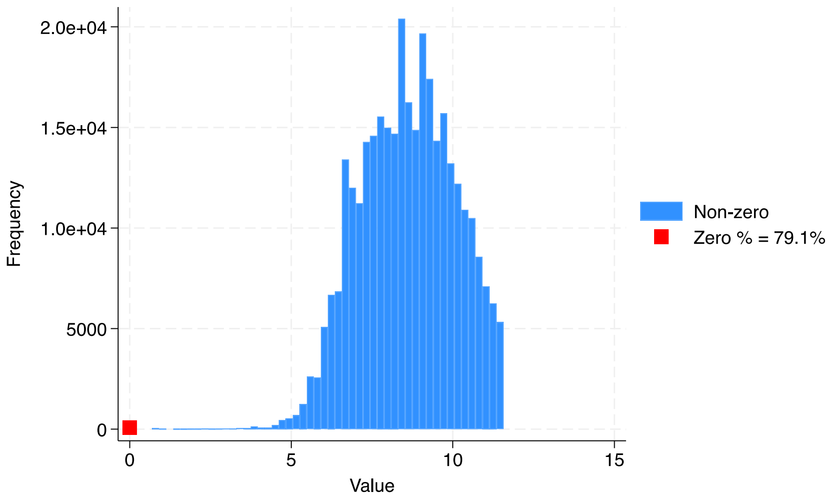

Figure 6.5: The Distribution of FDI

2. Control variables. Drawing on Bu and Ren (2023), to avoid the influence of omitted variables on the estimation results of this section, other variables that affect firm FDI are added to the DID model. I adopted the following control variables. (1) The firm age is measured by adding 1 to the logarithm of the difference between the current year and the year of the establishment of the enterprise. (2) The firm size is measured by the logarithm of total assets. Compared with small enterprises, large enterprises have more capital and technological advantages. (3) The firm capital labor ratio is measured by the logarithmic value of the ratio between the net value of fixed assets and the number of employed persons. (4) The dummy variables of enterprise ownership type. There are many types of ownership in China, including state-owned enterprises, private enterprises, foreign enterprises, mixed ownership enterprises, collective

enterprises and so on. I only controlled the dummy variables of state-owned firms, foreign firms, and private firms. (5) The concentration ratio is measured by the Herfindahl-Hirschman Index of a four-digit industry. (6) Industry size is measured by the logarithm of the four-digit industry employment scale. It is the sum of the market share of the top N largest companies in the relevant market of an industry. It measures the degree of competition and monopoly in the market. (7) Regional economic growth is measured by the log of regional GDP per capita. It measures the level of economic development in a region. (8) Regional industrial structure is measured by the proportion of regional secondary industry to tertiary industry. (9) Regional Internet development is measured by the log of regional Internet usage.

3. Influence variables. (1) Production costs. I use the log value of the firms' production costs to measure. (2) Patent. I measure firm innovation using the logarithm of the number of firm patent applications plus 1. (3) R&D investment. I use the logarithm of firm R&D investment plus 1 to measure. (4) SA index. Referring to Hadlock and Pierce (2010), I use SA index to measure firm financing constraints. The calculation formula of SA index is $SA = -0.737 \times size + 0.043 \times size^2 - 0.040 \times age$. Size is the natural logarithm of the firm's total assets. Age is the business year of the enterprise. The larger the absolute value of the SA index, the greater the degree of firms' financing constraints.

The data in the research on environmental firm FDI mainly come from the China Industrial Enterprise Database (ASIF) from 2000 to 2007. According to Section 3.4.2, I processed the China Annual Survey of Industrial Firms Database and finally got 1,602,890 samples. The descriptive statistics of the variables are shown in Table 6.2.

Table 6.2: Variables Description

	Variable	Abbreviation	Unit	Mean	Std. Dev	Min	Max	Obs
Dependent variable	*FDI*	*FDI*	log of 1000 yuan	1.8938	3.6736	0.0000	11.5688	1,602,890
Independent variable	$treat_c \times post_t$	$treat_c \times post_t$	-	0.8476	2.1070	0.0000	13.0190	1,602,890
Control variables	*firm age*	*age*	log of year	1.9643	0.8612	0.0000	6.0113	1,602,890
	firm size	*size*	log of thousand yuan	9.6752	1.4119	0.0000	18.8558	1,602,890
	capital labor ratio	*kl*	log of 1000 yuan/per	4.9394	1.0339	0.1910	11.5083	1,602,890
	state-owned firm	*soe*	-	0.0970	0.2960	0.0000	1.0000	1,602,890
	foreign firm	*foe*	-	0.1691	0.3748	0.0000	1.0000	1,602,890
	private firm	*pre*	-	0.4859	0.4998	0.0000	1.0000	1,602,890
	concentration ratio	*hhi*	-	0.0021	0.0043	0.0001	1.0000	1,602,890

	industry size	*size_ind*	-	14.6203	0.6391	11.9545	15.6194	1,602,890
	average gdp	*gdp*	log of 10000 yuan/per	11.1136	0.6711	8.6103	13.0665	1,602,890
	industrial structure	*ind*	-	1.3748	0.5279	0.0068	10.5529	1,602,890
	Internet development	*inter*	log of per household	11.7868	3.7336	0.0000	16.1951	1,602,890
Mechanism variables	*production cost*	*cost*	log of yuan	0.2905	0.4255	0.0000	7.4793	1,602,885
	patent application	*patent*	log of number	0.0343	0.2542	0.0000	8.7198	1,602,890
	R&D investment	*rd*	log of yuan	0.0024	0.0050	0.0000	0.0907	1,593,846
	SA index	*sa*	-	-7.0114	1.0243	-13.5706	0.5247	1,602,890

Source: Analysis reported in this thesis.

6.4.2.2 Research on SO_2 Emissions Regulation and OFDI

1. Explained variable. Outward foreign direct investment (OFDI). Most of the existing literature uses a binary variable, i.e., whether an enterprise carries out OFDI or not, without considering the scale of OFDI in the study of firm OFDI. In this chapter, I use the data of the Directory of Overseas Investment Enterprises (Institutions) Records to aggregate and calculate the total investment of listed companies in overseas affiliates as an indicator of firms' outward foreign direct investment (OFDI).

I counted the distribution of total OFDI from 2000 to 2010 (see Table 6.3). In terms of investment scale, China's outward FDI has achieved rapid growth, from 1.4638 million yuan in 2000 to 79.7661 million yuan in 2010, with an average annual growth of 7.8 million yuan. In terms of the number of enterprises with outward investment, with the policy support of the Chinese government, China's outward investment enterprises have increased 10 times, achieving a stable and good development trend. Skewness is more than 0, indicating that the data distribution is right skewed, and there are fewer data to the right of the mean than to the left of the mean. The kurtosis of the firm OFDI is greater than 3, indicating that the data is steeper than the normal distribution. Figure 6.6 shows the distribution of firm OFDI. It can be found from the graph that the proportion of firm with OFDI of 0 is 79.1%.

Table 6.3: Total Distribution of Firm Level OFDI in China from 2000 to 2010

Year	Mean	Std. Dev.	Skewness	Kurtosis	Obs
2000	1.4638	22.5156	25.9370	706.5168	797
2001	1.3922	21.7126	26.8532	758.5403	858
2002	1.5383	21.5520	26.2720	743.3479	902
2003	3.0519	33.8145	16.0253	273.7142	934
2004	3.3246	35.2101	15.8298	274.5191	1,005
2005	18.4197	511.9478	31.9141	1020.9730	1,026

2006	10.8571	196.6313	26.3675	744.9684	1,052
2007	25.9837	420.2612	25.6424	726.7307	1,130
2008	54.8878	754.0272	21.2162	507.6206	1,203
2009	51.9541	652.0371	21.3764	518.1801	1,298
2010	79.7661	873.5388	18.6273	399.6980	1,570
All	27.8829	500.8510	30.4922	1063.3110	11,775

Source: Analysis reported in this thesis. Unit: Million yuan.

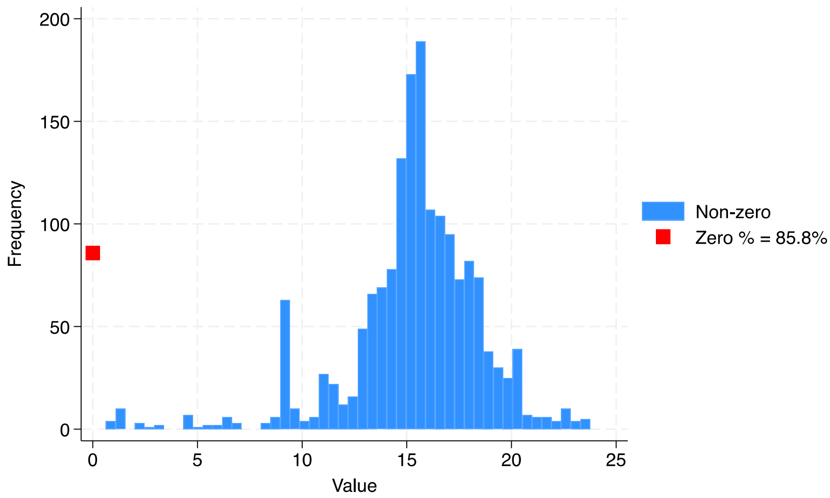

Figure 6.6: The Distribution of OFDI

2. Control variables. (1) The firm age is measured by the difference between the current year plus 1 and the firm established year. On the one hand, older companies have more experienced employees who are familiar with product functions and know how to improve product quality, thus making the company more competitive (Love et al., 2016). On the other hand, the age of the company can be an indicator of the inertia of the management team or the company as a whole. As a result, older companies are more likely to stick to their previous operating model and are reluctant to make outbound investments (D'Angelo et al., 2013). (2) The natural logarithm of a company's total assets is used to measure its size. Large enterprises can take advantage of the scale effect to reduce the average cost, thus influencing their OFDI decisions (Brouthers et al., 2009; Williams, 2011). (3) Asset liability ratio. I use the ratio of year-end total liabilities to year-end total assets. Asset liability ratio shows how a firm operates as a creditor, and therefore may be relevant to the firm's outward investment behavior (Brammer and Millington, 2005, Zeng, 2019). (4) Capital intensity is measured by the ratio of total assets to operating income. (5) Capital liquid ratio. I use the ratio of current assets to current liabilities to represent it. The higher the ratio, the stronger the liquidity of enterprise assets and the stronger the short-term solvency. The current ratio reflects the current financial level of an enterprise from the perspective of current assets and may also

have an impact on an enterprise's OFDI decision (Lanis and Richardson, 2013).

3. Mechanism variables. (1) Production cost. Operating cost is the most important component of a company's production cost, which can to some extent reflect the size of the company's production cost. Therefore, this section selects the operating cost of the enterprise as the proxy variable for the production cost of the enterprise. (2) Technology innovation. As green patent data can more accurately reflect the output of innovation, previous literature on green technology innovation usually adopts the volume of green patents filed and granted. However, the number of patents filed only reflects the level of emphasis on green technology rather than the actual enhancement of the technology. Therefore, following Lin et al. (2023), this chapter chooses to use the number of green patents granted, which better reflects the level of innovation, to measure technological innovation. (3) Financing constraints. Referring to the methods of Hadlock and Pierce (2010), this chapter adopts the SA index to take the absolute value to express.

Descriptive statistics of the variables used in this chapter are shown in Table 6.4. The data come from the Financial Statements Database of Chinese Listed Companies.

Table 6.4: Variables Description

	Variable	Abbreviation	Unit	Mean	Std. Dev	Min	Max	Obs
Dependent variable	*OFDI*	*OFDI*	log of thousand yuan	2.1831	5.4987	0.0000	23.7596	11,775
Independent variable	$treat_c \times post_t$	$treat_c \times post_t$	-	1.6717	3.1969	0.0000	13.0190	11,775
Control variables	*firm age*	*age*	log of year	2.3134	0.4710	0.6931	3.2581	11,775
	firm size	*size*	log of thousand yuan	21.4191	1.0742	19.1389	25.7349	11,775
	asset liability ratio	*kl*	-	0.4673	0.1876	0.0274	0.8871	11,775
	capital intensity	*cap*	-	1.9426	2.5161	0.1975	35.5012	11,775
	capital liquid ratio	*cl*	-	2.5298	2.3113	0.0000	23.4680	11,775
Mechanism variables	*cost*	*cost*	log of billion yuan	0.1947	0.3498	0.0006	5.2080	11,775
	SA index	*sa*	-	-3.4733	0.2120	-4.1524	-2.9376	11,708
	invention patent	*patent*	log of number	0.0581	0.2998	0.0000	5.3471	11,775

Source: Analysis reported in this thesis.

6.5 Empirical Results and Analysis

In this section, I analyze the empirical results of environmental regulation on firm FDI and OFDI. In section 6.5.1, I will analyze the basic regression results. In section 6.5.2, I will analyze the parallel trend test which verified the appropriateness of the DID model. In section 6.5.3, I will do a lot of robustness tests such as two-period double difference method, winsorize, eliminating other policy distractions, changing the dependent variable and using a relative target. In section 6.5.4, I will analyze the impact mechanism of environmental regulation on firm FDI and OFDI from the perspective of cost effect, innovation effect and financing effect. In section 6.5.5, I will analyze the heterogeneity analysis which will include the different firm ownership, the different firm size, the different factor densities, the different regions and the different countries.

6.5.1 Regression Analysis of the Basic Regression Model

6.5.1.1 SO_2 Emissions Regulation on Firm FDI

Table 6.5 reports the benchmark regression results of the impact of environmental regulation policies on firm FDI. Column (1) only controls the year fixed effect and the city fixed effect. I find that the estimated coefficients $treat_c \times post_t$ are significantly negative at the 1% statistical level. Columns (2) - (4) successively increase the control variables at the firm level. It can be found that the estimated coefficient $treat_c \times post_t$ are still significantly negative, indicating that the environmental regulation policies can reduce firm FDI. σ is significant, indicating that the variance of the random disturbance term is significantly not zero, which supports the use of the Tobit model. The estimated coefficient in column (4) is -0.0359 and it means that after 2006, for every 1 unit increase in SO_2 emission reduction target, enterprise FDI decreased by 3.59%. Before 2006, the average FDI after logarithm of a firm is 1.9061. After 2006, for every 1 unit increase in the SO_2 emissions reduction target, a 3.59% reduction in average FDI of a firm decreased the log-transformed intensity from 1.9061 to 1.8702, equivalent to the average FDI of a firm decreased from ￥6727 to ￥6490. After 2006, the average SO_2 emissions reduction target for a firm is 2.44, so after the SO_2 emissions regulation, the average FDI of a firm decreased to ￥6148.72, achieving a ￥578.28 reduction. Similarly, for the firm with FDI greater than 0, the marginal effect in column (4) is -0.0190, which means after 2006, for every 1 unit increase in the SO_2 emissions reduction target, a 1.9% reduction in average FDI of a firm with FDI greater than 0 decreased from ￥5.80 million to ￥5.69 million, achieving a ￥0.11 million reduction. This result is consistent with the findings of

Chung (2014).

Environmental regulations may negatively impact foreign direct investment in a variety of ways. First, regulations increase firms' production costs (Gray, 1987; Testa et al., 2011). Firms need to purchase treatment equipment and improve processes to meet emission standards, which increases the investment cost of entering a country. Secondly, regulations limit the production methods and optimal configurations that companies can adopt, and also require firms to adopt more expensive green technologies. Furthermore, changes in regulatory standards in different countries have increased the investment uncertainty of firms. In addition, regulations have created a "pollution haven effect", with capital flowing from countries with stricter regulations to developing countries with looser regulations. Finally, regulation directly limits the entry of highly polluting industries and raises the threshold for entry into regulated industries, which reduces the possibility of foreign investment. In short, regulations negatively affect foreign investors' investment decisions by increasing production costs and various operating constraints.

Table 6.5: DID Model Regression Results of Environmental Regulation on Firm FDI

Variable	(1)	(2)	(3)	(4)
	FDI	FDI	FDI	FDI
$treat_c \times post_t$	-0.0302***	-0.0333***	-0.0331***	-0.0359***
	(-16.0281)	(-29.5051)	(-29.4082)	(-31.7479)
treat	0.1657***	0.0547***	0.0551***	0.0409***
	(76.3789)	(42.0790)	(42.4087)	(29.5381)
age		-0.2073***	-0.2074***	-0.2111***
		(-98.3391)	(-98.4099)	(-1.0e+02)
size		0.4141***	0.4162***	0.4155***
		(265.6291)	(266.4161)	(265.9338)
kl		0.0226***	0.0199***	0.0192***
		(10.8516)	(9.5599)	(9.2088)
hhi		0.5223	-0.4740	-0.5382
		(1.3568)	(-1.2215)	(-1.3873)
size_ind		-0.5688***	-0.5703***	-0.5660***
		(-87.2419)	(-87.4690)	(-86.7492)
gdp		6.6581***	6.6563***	6.6413***
		(1.2e+03)	(1.2e+03)	(1.2e+03)
ind		-1.0123***	-1.0129***	-1.0106***
		(-2.2e+02)	(-2.2e+02)	(-2.2e+02)
inter			-0.0547***	-0.0566***
			(-20.2088)	(-20.8797)
soe				0.0922***
				(24.5256)

foe				-0.0425***
				(-11.1544)
pre				0.0348***
				(19.1015)
Year FE	YES	YES	YES	YES
City FE	YES	YES	YES	YES
σ	3.4768***	2.0735***	2.0733***	2.0724***
	(895.2346)	(895.2346)	(895.2346)	(895.2346)
margin	-0.0152***	-0.0176***	-0.01757***	-0.0190***
	(-16.0227)	(-29.5007)	(-29.4068)	(-31.7437)
N	1,602,890	1,602,890	1,602,890	1,602,890
Pseudo R-Square	0.0202	0.2103	0.2103	0.2105

Note: Using Tobit model and continuous DID method. *Year FE* is year fixed effect, *City FE* is city fixed effect. *σ* is the standard deviation of the random disturbance term. *margin* is marginal effect where FDI>0. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

6.5.1.2 SO_2 Emissions Regulation on Firm OFDI

Table 6.6 reports the baseline regression results of the impact of environmental regulations on China's OFDI. Among them, column (1) only controls year fixed effects and does not add any control variables. Column (2) controls year fixed effects and firm fixed effects, and no control variables are included in the model. Columns (3) - (4) successively increase the control variables at the firm level. I found that regardless of whether fixed effects and control variables are considered, the estimated coefficient of environmental regulation is positive and statistically significant at least at the 5% level. It shows that environmental regulations can significantly promote firm OFDI. The estimated coefficient of $treat_c \times post_t$ in column (4) is 0.666 and it means that after 2006, for every additional unit of SO_2 emission reduction target, the OFDI of enterprises increases by 6.66%. Before 2006, the average OFDI after logarithm of a firm is 1.2923. After 2006, for every 1 unit increase in the SO_2 emissions reduction target, a 6.66% increase in average OFDI of a firm increased the log-transformed intensity from 1.2923 to 1.3589, equivalent to the average OFDI of a firm increased from ￥3641 to ￥3892. After 2006, the average SO_2 emissions reduction target for a firm is 3.15 in the sample, so after the SO_2 emissions regulation, the average OFDI of a firm increased to ￥4431.65, achieving an increase of ￥790.65. Similarly, for the firm with OFDI greater than 0, the marginal effect in column (4) is 0.0318, which means after 2006, for every 1 unit increase in the SO_2 emissions reduction target, a 3.18% increase in average FDI of a firm with FDI greater than 0 increased from ￥2019.77 million to ￥2091.95 million, achieving a ￥72.18 million reduction. Some important reasons can support this conclusion (Cole and Elliott, 2005). The introduction of environmental regulations will affect firm OFDI decisions. Strict environmental regulations will increase firms' production costs (Gray, 1987; Testa et al., 2011). To reduce profit losses, firms may actively explore new markets and expand scale sales to make up for the short-term profit losses caused by environmental regulations. In addition, to avoid environmental punishment, some companies will choose to transfer highly polluting industries to countries with loose environmental standards and establish overseas production bases through outward foreign direct investment (Walter and Ugelow, 1979; Copeland and Taylor, 1995). Finally, environmental regulatory policies can stimulate enterprises to engage in technological innovation and improve productivity, thus improving firm international competitiveness and outward foreign direct investment (Brunnermeier and Cohen, 2003; Elliott and Zhou, 2013).

Table 6.6: DID Model Regression Results of Environmental Regulation on Firm OFDI

Variable	(1)	(2)	(3)	(4)
	OFDI	OFDI	OFDI	OFDI
$treat_c \times post_t$	0.0520**	0.0615**	0.0615***	0.0666***
	(2.0549)	(2.5541)	(2.6205)	(2.8416)
treat	0.1018***	0.8615**	0.5919	0.6119
	(5.6587)	(2.1558)	(1.5190)	(1.5741)
age			0.1141	0.2192*
			(0.9071)	(1.6724)
size			1.1838***	1.2245***
			(24.7797)	(24.0053)
kl				-0.6093*
				(-1.8757)
cap				-0.1733***
				(-8.1507)
cl				0.0034
				(0.1438)
Year FE	YES	YES	YES	YES
City FE	NO	YES	YES	YES
σ	5.3843***	5.0925***	4.9638***	4.9493***
	(76.7300)	(76.7300)	(76.7300)	(76.7300)
margin	0.0241***	0.0291**	0.0294***	0.0318***
	(2.0548)	(2.5538)	(2.6204)	(2.8414)
N	11,775	11,775	11,775	11,775
Pseudo R-Square	0.0067	0.1246	0.1327	0.1337

Note: Using Tobit model and continuous DID method. *Year FE* is year fixed effect, *City FE* is city fixed effect. σ is the standard deviation of the random disturbance term. *margin* is marginal effect where OFDI>0. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

6.5.2 Parallel Trend Test

I use DID model to evaluate the impact of environmental regulation on firm two-way FDI. However, the DID method should satisfy the parallel trends assumption before the policy is implemented. To this end, referring to Bu and Ren (2023), and the event analysis method is used to test the dynamic effects of environmental regulation. Specifically, some dummy variables are included in the model as follows:

$$FDI_{it} = \alpha + \beta_1 D_{ct}^{-5} + \cdots + \beta_5 D_{ct}^{-1} + \beta_6 D_{ct}^{+1} + \beta_7 D_{ct}^{+2} + \eta X_{it} + \gamma_t + \gamma_c + \varepsilon_{it} \tag{6.3}$$

$$OFDI_{it} = \alpha + \beta_1 D_{ct}^{-5} + \cdots + \beta_5 D_{ct}^{-1} + \beta_6 D_{ct}^{+1} + \cdots + \beta_{10} D_{ct}^{+5} + \eta X_{it} + \gamma_t + \gamma_c + \varepsilon_{it} \tag{6.4}$$

In the model, to simplify the formula, I replace $treat_c \times post_t$ with *D* and express it as a series of dummy variables. When the treatment group is in year *j* before the enforcement of environmental regulation, $D_{ct}^{-j} = 1$, otherwise $D_{ct}^{-j} = 0$. This section excludes the year dummy variable when the year before the environmental regulation policy was implemented, which is equivalent to using this year (2005) as the control group (Liu et al., 2022). The horizontal axis of Figure 6.7 and Figure 6.8 represent the year since the implementation of environmental regulation policy, the vertical axis represents the magnitude of the estimates, the hollow point is the estimated coefficient, and the dashed line is the 95% confidence interval.

Figure 6.7 reports a parallel trend test for firm FDI. It can be seen from the figure that when j<0, the estimated coefficient of *D* is not significant. It shows that before the environmental regulation was issued, the changes trend of firm FDI in the treatment group and the control group were similar. When j>0, the estimated coefficient of *D* on FDI is basically significantly negative at the 5% statistical level. It shows that the enforcement of environmental regulation reduces the FDI, and this effect can last for some time. Figure 6.8 reports a parallel trend test for firm OFDI. It can be seen from the figure that when j<0, the estimated coefficient of *D* is not significant. It means that before the implementation of environmental regulation, the changes trend of firm OFDI in the treatment group and the control group were similar. After the implementation of environmental regulation policy (when j>0), the estimated coefficient was not significant at the 5% level when j=1, This shows that environmental regulations have a lag in promoting the firm OFDI. When j>1, the estimated coefficient is greater than 0 and is significant at the significance level of 5%. It shows that the enforcement of environmental regulation increases the OFDI, and this effect can last for some time.

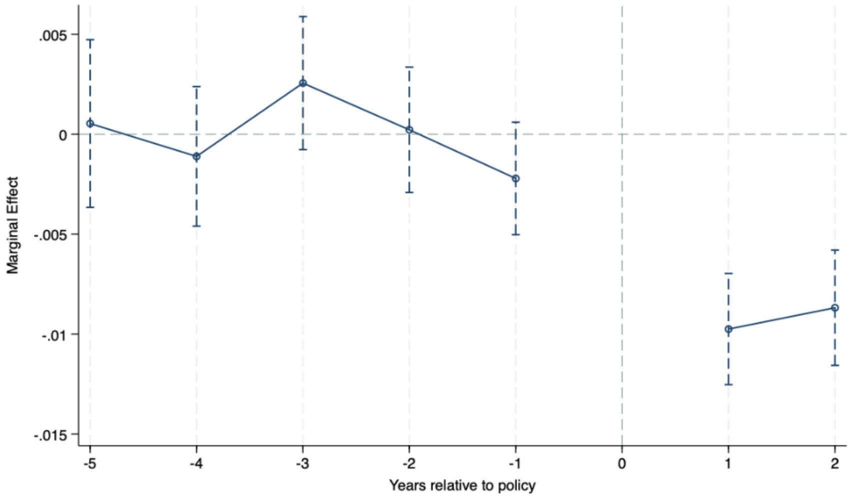

Figure 6.7: Parallel Trend Test on FDI

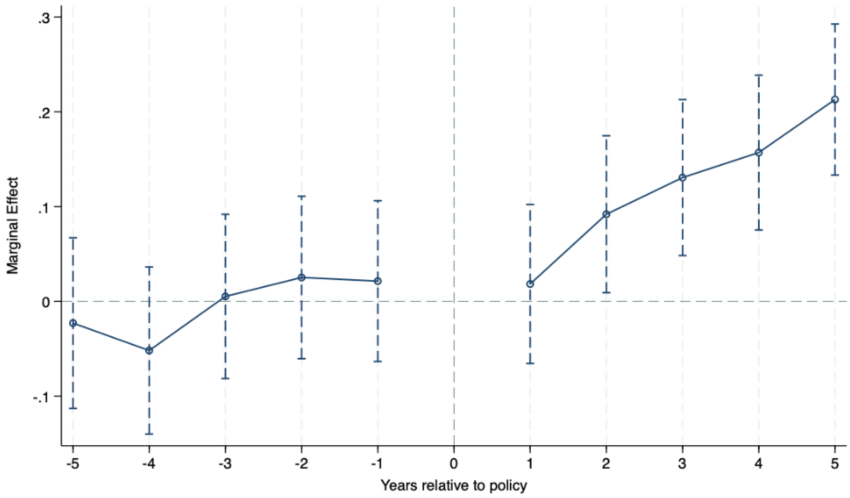

Figure 6.8: Parallel Trend Test on OFDI

6.5.3 Robustness Test

(1) Two-period double difference method. To address potential sequence related issues, I drew the approach of Bertrand et al. (2004) and constructed a two-stage double difference method model for re-estimation. Specifically, I take 2006 as the time node and divide the sample period into two stages: before

the implementation of environmental policy and after the implementation of environmental policy. At each stage, I calculate the arithmetic mean of the variables for each enterprise. Through this method, I can effectively compare the long-term average effect of environmental regulatory policies on firm two-way FDI. Column (1) of Table 6.7 reports the estimation result of the two-period double difference method of environmental regulation on firm FDI. It can be found that the estimated coefficient is still significantly negative, indicating that environmental regulation policy can effectively reduce firm FDI. Column (1) of Table 6.8 reports the estimation result of the two-period double difference method of environmental regulation on firm OFDI. The estimated coefficient is significantly positive, indicating that environmental regulation policy can effectively promote OFDI. The results show that the basic regression results of this research are robust.

(2) Winsorize method. In order to eliminate the influence of extreme outliers, this section winsorizes the extreme outliers in the upper and lower 1% of the explained variables and all continuous variables according to Bu and Ren (2023), and re-estimates the regression. Column (2) in Table 6.7 reports the regression result after winnowing of environmental regulation on firm FDI. As can be seen from column (2) in Table 6.7, after excluding extreme outliers, the estimated coefficient is significantly negative at the 1% statistical level. Column (2) in Table 6.8 reports the regression result after winnowing of environmental regulation on firm OFDI. The estimated coefficient is significantly positive at the 1% statistical level, indicating that the basic regression results of this research are still robust.

(3) Eliminating other policy distractions. The environmental policies implemented during the sample period may have an impact on the firm two-way FDI, especially the typical sulfur dioxide emission trading policy which has been introduced in Section 3.2.5. Therefore, the interaction terms (*pwq*) of dummy variables of the emission trading policy treatment group and the policy time dummy variables are added to eliminate the interference of parallel policies on the estimated results of this research. Columns (3) in Table 6.7 reports the result of environmental regulation on firm FDI. I find that the estimated coefficient is significantly negative. It means that environmental regulation can decrease firm FDI. Columns (3) in Table 6.8 report the result of environmental regulation on firm OFDI and the estimated coefficient is significantly positive. It means that environmental regulation can increase firm OFDI. Therefore, the results again indicate that the basic regression results in this section are robust.

Table 6.7: Robustness Test (1)

Variable	(1)	(2)	(3)
	Two-period DID	Winsorised	Eliminate other policy distractions
	FDI	FDI	FDI
$treat_c \times post_t$	-0.0229***	-0.0357***	-0.0356***
	(-16.2844)	(-31.5851)	(-31.5183)
treat	0.0376***	0.0419***	0.0406***
	(20.8463)	(30.2064)	(29.3098)
pwq			0.0844***
			(7.3540)
age	-0.1482***	-0.2116***	-0.2110***
	(-52.3621)	(-99.8805)	(-99.9613)
size	0.3776***	0.4339***	0.4154***
	(177.5065)	(266.2915)	(265.8215)
kl	0.0016	0.0056***	0.0191***
	(0.5690)	(2.5845)	(9.1515)
hhi	0.0771	2.4509***	-0.5410
	(0.1322)	(4.0187)	(-1.3946)
size_ind	-0.0387***	-0.0592***	-0.0564***
	(-10.7610)	(-21.4637)	(-20.8197)
gdp	0.0768***	0.0860***	0.0922***
	(15.9729)	(22.4956)	(24.5391)
ind	-0.0419***	-0.0172***	-0.0431***
	(-8.7180)	(-3.0873)	(-11.3071)
inter	0.0079***	0.0375***	0.0350***
	(9.0179)	(20.3261)	(19.2273)
soe	-0.4945***	-0.5647***	-0.5652***
	(-51.3999)	(-86.6078)	(-86.6276)
foe	6.9553***	6.6369***	6.6410***
	(849.8530)	(1.2e+03)	(1.2e+03)
pre	-0.9111***	-1.0064***	-1.0114***
	(-1.4e+02)	(-2.2e+02)	(-2.2e+02)
Year FE	YES	YES	YES
City FE	YES	YES	YES
σ	1.7603***	2.0725***	2.0723***
	(583.3241)	(895.2346)	(895.2346)
margin	-0.0120***	-0.0189***	-0.0189***
	(−16.2829)	(-31.5800)	(-31.5147)
N	680,534	1,602,890	1,602,890
Pseudo R-Square	0.2557	0.2104	0.2105

Note: Using Tobit model and continuous DID method. *Year FE* is year fixed effect, *City FE* is city fixed effect. σ is the standard deviation of the random disturbance term. *margin* is marginal effect where FDI>0. *pwq* is the interaction terms of dummy variables of the emission trading policy treatment group and the policy time dummy variables. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

Table 6.8: Robustness Test (2)

Variable	(1)	(2)	(3)
	Two-period DID	Winsorised	Eliminate other policy distractions
	OFDI	OFDI	OFDI
$treat_c \times post_t$	0.0760*	0.0675***	0.0707***
	(1.6981)	(2.9024)	(3.0030)
treat	0.6577	0.5898	0.6142
	(0.8124)	(1.5280)	(1.5802)
pwq			0.3407*
			(1.6928)
age	0.1890	0.2558*	0.2129
	(0.8458)	(1.9207)	(1.6242)
size	1.2481***	1.1983***	1.2241***
	(13.1619)	(23.1369)	(23.9995)
kl	-1.2433**	-0.1893	-0.6173*
	(-2.0190)	(-0.5391)	(-1.9005)
cap	-0.2107***	-0.2012***	-0.1736***
	(-4.8125)	(-8.9280)	(-8.1642)
cl	0.0040	0.0721**	0.0030
	(0.1492)	(1.9835)	(0.1287)
Year FE	YES	YES	YES
City FE	YES	YES	YES
σ	4.4040***	4.9140***	4.9486***
	(37.4166)	(76.7300)	(76.7300)
margin	0.0377*	0.0323***	0.0338***
	(1.6979)	(2.9023)	(3.0026)
N	2,800	11,775	11,775
Pseudo R-Square	0.1406	0.1333	0.1337

Note: Using Tobit model and continuous DID method. *Year FE* is year fixed effect, *City FE* is city fixed effect. σ is the standard deviation of the random disturbance term. *margin* is marginal effect where OFDI>0. *pwq* is the interaction terms of dummy variables of the emission trading policy treatment group and the policy time dummy variables. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(3) Changing the dependent variable. To improve the robustness of the regression results of environmental regulation on firm FDI, I replace the measure of the explanatory variables to re-estimate the model. The results are reported in Table 6.9. In columns (1), I regress the model using the Probit method with a dummy variable for whether the firm had FDI. Similarly, I use a dummy variable for FDI in columns (2) and conduct regression analyses using the Logit method. I find that the estimated coefficients are significantly negative at the 1% statistical level. The regression results show that environmental regulations reduce the probability of firms' FDI, which is also consistent with the above findings. This

result is consistent with the findings of Li et al. (2022).

To improve the robustness of the regression results of environmental regulation on firm OFDI, I replace the measure of the explanatory variables to re-estimate the model (Liu et al., 2022). The results are reported in Table 6.10. Columns (1) presents the result of estimating the logarithmic value of the number of outward foreign direct investments using the Tobit method. In columns (2), I regress the model using the Probit method with a dummy variable for whether the firm invested abroad. Similarly, I use a dummy variable for outward foreign direct investments in columns (3) and conduct regression analyses using the Logit method. The regression results show that environmental regulations increase the probability of firms' outward foreign direct investments, which is also consistent with the above findings. This result is consistent with the findings of Liu et al. (2022).

(4) Using a relative target. I use the percentage of reduction to test whether the basic regression results are robust. Columns (3) in Table 6.9 report the results of environmental regulation on firm FDI. The estimated coefficient is still significantly negative at the 1% statistical level. Columns (3) in Table 6.10 reports the result of environmental regulation on firm OFDI. The estimated coefficient is still significantly positive at the 1% statistical level, indicating the estimated results are robust, that is, environmental regulation policy can effectively reduce firm FDI but increase firm OFDI.

Table 6.9: Robustness Test (3)

Variable	(1)	(2)	(3)
	Change dependent variable	Change dependent variable	Relative target
	FDI	FDI	FDI
$treat_c \times post_t$	-0.0259***	-0.0512***	-0.0343***
	(-21.3917)	(-21.7066)	(-30.9432)
$treat$	0.0279***	0.0576***	0.0297***
	(11.9374)	(12.2158)	(22.0315)
age	-0.1845***	-0.3671***	-0.2113***
	(-61.3116)	(-62.9708)	(-1.0e+02)
$size$	0.2203***	0.4188***	0.4156***
	(80.5477)	(76.8027)	(265.9767)
kl	-0.0130***	-0.0103	0.0193***
	(-3.5561)	(-1.3578)	(9.2408)
hhi	-0.5498	-1.3136	-0.5151
	(-0.9881)	(-1.1954)	(-1.3279)

size_ind	-0.0380***	-0.0755***	-0.0568***
	(-7.9690)	(-7.7790)	(-20.9457)
gdp	0.1104***	0.2367***	0.0904***
	(17.4167)	(18.1500)	(24.0519)
ind	-0.0546***	-0.1173***	-0.0424***
	(-7.4657)	(-7.9172)	(-11.1218)
inter	0.0394***	0.0857***	0.0352***
	(11.8029)	(12.9791)	(19.3128)
soe	-0.3455***	-0.6830***	-0.5681***
	(-30.5657)	(-30.2299)	(-87.0696)
foe	2.4373***	4.2779***	6.6413***
	(340.0689)	(302.4345)	(1.2e+03)
pre	-1.0144***	-2.0521***	-1.0090***
	(-1.7e+02)	(-1.7e+02)	(-2.2e+02)
Year FE	YES	YES	YES
City FE	YES	YES	YES
σ			2.0724***
			(895.2346)
margin			-0.01817***
			(-30.9426)
N	1,602,890	1,602,890	1,602,890
Pseudo R-Square	0.6041	0.6047	0.2105

Note: Column (1) uses Probit model. Column (2) uses Logit model. Column (3) uses Tobit model. This table uses continuous DID method. *Year FE* is year fixed effect, *City FE* is city fixed effect. σ is the standard deviation of the random disturbance term. *margin* is marginal effect where FDI>0. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

Table 6.10: Robustness Test (4)

Variable	(1)	(2)	(3)	(4)
	OFDI_*num*	OFDI_*dum*	OFDI_*dum*	OFDI
$treat_c \times post_t$	0.0073***	0.0224***	0.0378***	0.0616***
	(4.2157)	(3.8513)	(3.6092)	(2.8345)
treat	0.0338	0.0076	0.0136	0.6121
	(1.1815)	(1.5664)	(1.5174)	(1.5746)
age	0.0132	0.2960***	0.5553***	0.2138
	(1.3689)	(8.1343)	(8.1462)	(1.6316)
size	0.1011***	0.3153***	0.5605***	1.2237***
	(26.9100)	(21.7767)	(21.9091)	(23.9876)
kl	-0.0486**	-0.3050***	-0.5264***	-0.6028*
	(-2.0308)	(-3.0706)	(-2.9354)	(-1.8555)
cap	-0.0109***	-0.0574***	-0.1218***	-0.1729***
	(-6.9619)	(-7.6527)	(-7.8422)	(-8.1350)
cl	0.0000	0.0308***	0.0548***	0.0031

	(0.0008)	(4.9026)	(5.0742)	(0.1327)
Year FE	YES	YES	YES	YES
City FE	YES	YES	YES	YES
σ	0.1328***			24.4952***
	(76.7300)			(76.7300)
margin	0.0034***			0.0295***
	(4.2144)			(2.8343)
N	11,775	11,775	11,775	11,775
Pseudo R-Square	0.2151	0.0870	0.0869	0.1337

Note: Column (1) and (4) use Tobit model. Column (2) uses Probit model. Column (3) uses Logit model. This table uses continuous DID method. *Year FE* is year fixed effect, *City FE* is city fixed effect. σ is the standard deviation of the random disturbance term. *margin* is marginal effect where OFDI>0. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

6.5.4 Estimation Results of Influence Mechanism

After the DID baseline regression, I further adopt the mechanism test to discuss the channels through which environmental regulation policies affect the firm two-FDI in China. As mentioned in the previous theoretical analyses, environmental regulatory policies can affect FDI and OFDI through cost effect, innovation effect and financing effect. Since environmental regulation can reduce firm FDI by increasing firms' production costs and financing constraints and increasing firm FDI through increasing firm technological innovation, the impact of environmental regulations on firm FDI is uncertain. However, environmental regulation can increase firm OFDI through increasing firms' production cost, technological innovation and financing constraints. Therefore, I will verify each of these mechanisms through empirical tests.

6.5.4.1 Empirical Analysis of FDI's Influence Mechanism

First of all, I use firm costs as the dependent variable to test the cost effect of environmental regulation policy. I use the log value of the firms' production costs to measure. The regression results in column (1) in Table 6.11 indicate that the coefficient of the interaction term is significantly positive at 10% statistical level, indicating that environmental regulations increase the firms' production costs. The estimated coefficient in column (1) is 0.0037 and it means that after 2006, for every 1 unit increase in SO_2 emission reduction target, firm production cost increase by 0.37%. The Pollution Shelter Hypothesis suggests that firms in countries with high environmental regulations usually transfer polluting industries to countries with low environmental regulations in order to reduce production costs (Walter and Ugelow, 1979; Copeland and Taylor, 1995). As China's environmental regulations have strengthened and costs have risen, firms have transferred production to countries or regions with weaker environmental regulations, resulting in a decrease in FDI.

In addition, I examine the innovation effect of environmental regulations on firm FDI. I measure firm innovation using the logarithm of the number of firm patent applications plus 1 and the logarithm of firm R&D investment plus 1. Column (2) in Table 6.11 reports the result of environmental regulation on firm patents. The coefficient of the interaction term is significantly positive at 1% statistical level, indicating that environmental regulations can increase the number of firm patent applications. The estimated coefficient in column (2) is 0.0021 and it means that after 2006, for every 1 unit increase in SO_2 emission reduction target, firm patents increase by 0.21%. Column (3) in Table 6.11 reports the result of environmental regulation on firm R&D investment. The coefficient of the interaction term is also significantly positive at 1% statistical level, indicating that environmental regulations can increase R&D investment. The estimated coefficient in column (3) is 0.0290 and it means that after 2006, for every 1 unit increase in SO_2 emission reduction target, firm R&D increase by 2.90%. As can be seen in columns (2) and (3), environmental regulation can increase firm technological innovation. According to the "Porter Hypothesis", when environmental regulations become stricter, some firms will increase their investment in technological R&D, thus offsetting the environmental control costs through the "compensatory effect" of technological innovation (Porter and Van der Linde, 1995). Thus, environmental regulatory policy can stimulate technological innovation, thereby increasing the international competitiveness of firms and FDI.

Third, I examine the changes in firms' investment and financing after the release of the environmental regulation policy. Referring to Hadlock and Pierce (2010), I use SA index to measure firm financing constraints. Column (4) in Table 6.11 reports the result of environmental regulation on SA index. I found that the coefficient of the interaction term is also significantly positive at 1% statistical level, indicating that environmental regulations can increase firm financing constraints. The estimated coefficient in column (4) is 0.0007 and it means that after 2006, for every 1 unit increase in SO_2 emission reduction target, firm financing constraints increase by 0.07%. After the release of environmental regulatory policies, there has been a significant increase in restrictions on firms' investment and financing. As a result, the implementation of environmental regulatory policies has effectively increased the financing constraints. It has reduced the firm FDI inflow.

From the above analysis, on the one hand, environmental regulation reduces firm FDI by increasing firms' production costs and financing constraints, and on the other hand, it increases firm FDI by providing firms' innovation capabilities. Comparing the size of the coefficients, the coefficient of the cost effect is much larger than the innovation effect, so the final manifestation is that environmental regulation reduces the firm FDI.

Table 6.11: The Results of Influence Mechanism on FDI (1)

Variable	(1)	(2)	(3)	(4)
	cost	*patent*	*R&D*	*SA index*
$treat_c \times post_t$	-0.0037***	0.0021***	0.0290***	0.0007***
	(-9.5636)	(11.0897)	(358.2799)	(37.4670)
treat	0.0068***	-0.0009***	-0.0042***	-0.0009
	(7.4352)	(-2.9687)	(-33.8847)	(-1.0921)
age	-0.0621***	-0.0008*	0.0028***	0.1123***
	(-47.0219)	(-1.8170)	(12.4537)	(398.1767)
size	0.7873***	0.0443***	0.0002	-0.7418***
	(613.3398)	(40.9400)	(1.3264)	(-6.4e+03)
kl	-0.2927***	-0.0207***	-0.0013***	0.0011***
	(-2.0e+02)	(-21.5747)	(-5.5823)	(11.4229)
hhi	-3.3672***	1.3871***	0.0273	0.0036
	(-12.4974)	(11.7963)	(0.6928)	(0.2701)
size_ind	-0.0189***	-0.0050***	0.0023***	0.0013***
	(-10.5941)	(-8.7291)	(7.8749)	(6.7623)
gdp	-0.0090***	0.0012	-0.0168***	0.0006***
	(-3.7460)	(1.5927)	(-32.0833)	(3.3009)
ind	0.0589***	-0.0009	-0.0397***	-0.0030***
	(21.7982)	(-1.2325)	(-51.2212)	(-11.4790)
inter	-0.0008	0.0048***	0.0113***	0.0002***
	(-0.6812)	(12.1008)	(50.5926)	(3.8404)
soe	-0.4235***	0.0126***	0.0075***	0.0081***
	(-86.1533)	(7.0730)	(10.7599)	(19.3556)
foe	-0.0548***	-0.0166***	0.0078***	0.0008***
	(-15.6590)	(-12.4340)	(12.7101)	(3.9876)
pre	0.0627***	0.0024***	-0.0097***	-0.0004***
	(25.0515)	(3.4914)	(-21.2679)	(-2.9953)
Year FE	YES	YES	YES	YES
City FE	YES	YES	YES	YES
N	1,602,885	1,602,890	1,593,846	1,482,915

R-Square	0.6219	0.6480	0.9386	0.9995

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *City FE* is city fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

The estimated coefficient of the mediator variable (enterprise cost) in column (1) of Table 6.12 is significantly negative, indicating that the increase in enterprise cost reduces FDI. Based on the estimation results in column (1) of Table 6.11, it can be found that environmental regulations can reduce FDI by increasing enterprise costs. Both the absolute magnitude and statistical significance of the interaction terms exhibit a discernible decrease compared to the baseline regression results in columns (4) of Table 6.5 (-0.0359). When I control the cost effect, the negative impact of environmental regulation on FDI becomes less, which provides empirical support for the existence of the cost effect.

In addition, the estimated coefficients of the mediator variables (patents, research and development) in column (2) and (3) of Table 6.12 are significantly positive, indicating that the increase in patents and research and development has increased FDI. Based on the estimation results in columns (2) - (3) of Table 6.11, it can be found that environmental regulation can increase FDI by increasing firm patents and research and development. Both the absolute magnitude and statistical significance of the interaction terms exhibit a discernible increase compared to the baseline regression results in columns (4) of Table 6.5 (-0.0359). When I control the innovation effect, the negative impact of environmental regulation on FDI becomes greater, which provides empirical support for the existence of the innovation effect.

The estimated coefficient of the mediator variable (financing constraint) in column (4) of Table 6.12 is significantly negative, indicating that the increase in corporate financing constraint reduces FDI. Based on the estimation results in column (4) of Table 6.11, it can be found that environmental regulations can reduce FDI by increasing corporate financing constraints. The estimated coefficients and significance of the cross term showed a certain degree of decrease compared to the basic regression results, indicating the existence of this mediating effect. Both the absolute magnitude and statistical significance of the interaction terms exhibit a discernible increase compared to the baseline regression results in columns (4) of Table 6.5 (-0.0359). When I control the financing constraint effect, the negative impact of environmental regulation on FDI becomes less, which provides empirical support for the existence of the financing constraint effect.

Table 6.12: The Results of Influence Mechanism on FDI (2)

Variable	(1)	(2)	(3)	(4)
	FDI	FDI	FDI	FDI
$treat_c \times post_t$	-0.0346***	-0.0399***	-0.0374***	-0.0340***
	(-31.4726)	(-31.7955)	(-32.4561)	(-32.0049)
cost	-0.0900***			
	(-41.2749)			
patent		0.0268***		
		(4.0654)		
R&D			0.0489***	
			(6.1035)	
SA index				-4.3545***
				(-1.1e+02)
treat	0.0403***	0.0409***	0.0416***	0.0382***
	(29.1156)	(29.5563)	(29.2368)	(27.7450)
age	-0.2055***	-0.2111***	-0.2091***	0.3413***
	(-97.2217)	(-1.0e+02)	(-98.9987)	(64.3743)
size	0.3446***	0.4143***	0.4145***	-2.7823***
	(148.4628)	(260.6415)	(264.7103)	(-98.5909)
kl	0.0455***	0.0197***	0.0178***	0.0033
	(20.9090)	(9.4548)	(8.5176)	(1.5654)
hhi	-0.2345	-0.5754	-0.5924	0.1926
	(-0.6047)	(-1.4828)	(-1.5131)	(0.4984)
size_ind	-0.0549***	-0.0564***	-0.0566***	-0.0552***
	(-20.2656)	(-20.8290)	(-20.8363)	(-20.4620)
gdp	0.0930***	0.0922***	0.0933***	0.0864***
	(24.7562)	(24.5170)	(24.8421)	(23.0835)
ind	-0.0478***	-0.0425***	-0.0409***	-0.0491***
	(-12.5464)	(-11.1481)	(-10.7239)	(-12.9441)
inter	0.0348***	0.0346***	0.0359***	0.0277***
	(19.1462)	(19.0274)	(19.5071)	(15.2888)
soe	-0.5279***	-0.5663***	-0.5660***	-0.4112***
	(-80.1534)	(-86.7946)	(-86.3644)	(-61.9259)
foe	6.6462***	6.6417***	6.6438***	6.5919***
	(1.2e+03)	(1.2e+03)	(1.2e+03)	(1.2e+03)
pre	-1.0163***	-1.0107***	-1.0086***	-1.0291***
	(-2.2e+02)	(-2.2e+02)	(-2.2e+02)	(-2.3e+02)
Year FE	YES	YES	YES	YES
City FE	YES	YES	YES	YES
σ	2.0713***	2.0724***	2.0688***	2.0641***
	(895.2332)	(895.2346)	(892.7054)	(895.2346)
margin	-0.0180***	-0.0231***	-0.0198***	-0.0176***
	(-31.4673)	(−31.7919)	(−32.4498)	(−32.0016)
N	1,602,885	1,602,890	1,593,846	1,602,890
Pseudo R-Square	0.2107	0.2105	0.2108	0.2119

Note: Using Tobit model and continuous DID method. *Year FE* is year fixed effect, *City FE* is city fixed effect. σ is the standard deviation of the random disturbance term. *margin* is marginal effect where FDI>0. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

6.5.4.2 Empirical Analysis of OFDI's Influence Mechanism

First, I use the logarithm value of the firms' production costs to measure the cost effect. Column (1) in Table 6.13 reports the result of environmental regulation on firms' production costs. The coefficient of the interaction term is significantly positive at 10% statistical level, indicating that environmental regulation can increase the firms' production costs (Liu et al., 2022). The estimated coefficient in column (1) is 0.0031 and it means that after 2006, for every 1 unit increase in SO_2 emission reduction target, firm production cost increase by 0.31%. When faced with more stringent environmental regulation, firms in countries or regions with high environmental regulations usually transfer polluting industries to countries or regions with low environmental regulations in order to reduce production costs, which indirectly causes the occurrence of OFDI.

Secondly, referring to Persico et al. (2004) and Powell and Seabury (2018), column (2) in Table 6.13 reports the result of the impact of environmental regulation policy on firms' green technological innovation. I measure firm innovation using the logarithm of the number of firm green patent applications plus 1. The regression coefficient of the interaction term is significantly positive at 5% statistical level. It shows that environmental regulation policy increases OFDI by increasing firms' green technological innovation. The estimated coefficient in column (2) is 0.0027 and it means that after 2006, for every 1 unit increase in SO_2 emission reduction target, firm patents increase by 0.27%. There is some literature that supports this conclusion (Porter and Van der Linde, 1995). When faced with strict environmental regulations, firms will improve their production processes (Rubashkina et al., 2015) or develop new technologies (Du and Li, 2019). Thus, environmental regulatory policy can stimulate technological innovation and productivity, thereby increasing the international competitiveness of firms and OFDI (Helpman et al., 2004; Ambec et al., 2013).

Third, I still use SA index to measure firm financing constraints. Column (3) in Table 6.13 reports the results of the impact of environmental regulation policy on firm financing constraints. I found that the regression coefficient of the interaction term is significantly positive at 1% statistical level. The estimated coefficient in column (3) is 0.0013 and it means that after 2006, for every 1 unit increase in SO_2 emission reduction target, firm financing constraints increase by 0.13%. The implementation of environmental regulatory policies has effectively increased the firms' financing constraints, forcing them to undertake outward investment activities in search of overseas markets.

From the above analysis, environmental regulation increases firm OFDI by increasing firms' production costs, technological innovation and financing constraints.

Table 6.13: The Results of Influence Mechanism on OFDI (1)

Variable	(1)	(2)	(3)
	cost	*patent*	*SA index*
$treat_c \times post_t$	0.0031*	0.0027**	0.0013***
	(1.7666)	(2.1582)	(5.8660)
treat	0.0003	-0.0066***	-0.0026**
	(0.0351)	(-3.1299)	(-2.3451)
age	0.0387	0.0867**	-0.0081**
	(1.4098)	(2.4380)	(-2.0458)
size	0.1952***	0.0502***	-0.0360***
	(12.2319)	(3.5046)	(-27.1447)
kl	-0.0170	-0.0531	-0.0259***
	(-0.7773)	(-1.5581)	(-4.7799)
cap	-0.0137***	-0.0004	0.0004
	(-10.6063)	(-0.4361)	(1.2837)
cl	0.0035**	-0.0039	0.0014***
	(2.0170)	(-1.5716)	(2.6612)
Year FE	YES	YES	YES
City FE	YES	YES	YES
N	11,480	11,480	11,416
R-Square	0.9170	0.5283	0.9619

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *City FE* is city fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

The estimated coefficient of the mediator variable (enterprise cost) in column (1) of Table 6.14 is significantly positive, indicating that the increase in enterprise cost has increased OFDI. Based on the estimation results in column (1) of Table 6.13, it can be found that environmental regulations can increase OFDI by increasing corporate costs. Both the absolute magnitude and statistical significance of the interaction terms exhibit a discernible decrease compared to the baseline regression results in columns (4) of Table 6.6 (0.0666). When I control the cost effect, the impact of environmental regulation on firm

OFDI becomes less, which provides empirical support for the existence of the cost effect.

In addition, the estimated coefficients of intermediary variables (patents, financing constraints) in column (2)-(3) of Table 6.14 are significantly positive, indicating that the increase in patents and financing constraints has improved OFDI. Based on the estimation results in columns (2) - (3) of Table 6.13, it can be found that SO_2 emission reduction target can increase OFDI by adding patent and financing constraints to enterprises. The estimated coefficients and significance of the cross term showed a certain degree of decrease compared to the basic regression results, indicating the existence of this mediating effect. Both the absolute magnitude and statistical significance of the interaction terms exhibit a discernible decrease compared to the baseline regression results in columns (4) of Table 6.6 (0.0666). When I control the innovation effect or financing constraints effect, the impact of environmental regulation on firm OFDI becomes less, which provides empirical support for the existence of the innovation effect and financing constraints effect.

Table 6.14: The Results of Influence Mechanism on OFDI (2)

Variable	(1)	(2)	(3)
	OFDI	OFDI	OFDI
$treat_c \times post_t$	0.0584**	0.0628***	0.0661***
	(2.5015)	(2.6968)	(2.8173)
cost	1.9225***		
	(9.6439)		
patent		1.7771***	
		(11.1866)	
SA index			4.3496***
			(8.5660)
treat	0.5507	0.5739	0.5465
	(1.4219)	(1.4840)	(1.4080)
age	0.3061**	0.2698**	1.8140***
	(2.3390)	(2.0686)	(7.9519)
size	0.7954***	1.1332***	1.3885***
	(11.7758)	(22.0494)	(25.3786)
kl	-0.7602**	-0.4538	-0.4824
	(-2.3469)	(-1.4031)	(-1.4752)
cap	-0.1102***	-0.1582***	-0.1822***
	(-4.9696)	(-7.4667)	(-8.5338)
cl	-0.0010	0.0043	0.0011
	(-0.0422)	(0.1844)	(0.0475)
Year FE	YES	YES	YES
City FE	YES	YES	YES

σ	4.9298***	4.9232***	4.9406***
	(76.7300)	(76.7300)	(76.5245)
margin	0.0279**	0.0301***	0.0316***
	(2.5014)	(2.6965)	(2.8171)
N	11,775	11,775	11,775
Pseudo R-Square	0.1349	0.1354	0.1347

Note: Using Tobit model and continuous DID method. *Year FE* is year fixed effect, *City FE* is city fixed effect. *σ* is the standard deviation of the random disturbance term. *margin* is marginal effect where OFDI>0. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

6.5.5 Heterogeneity Analysis

(1) Firm ownership. I use sub-sample regression to test the impact of the implementation of environmental regulation policies on firms of different ownership (Chan et al., 2019). I have standardized the data using Z-score standardization method (Vaccario et al., 2017). Columns (1) and (2) in Table 6.15 report the impact of environmental regulation on firm FDI. The estimated coefficient is significantly negative at the 1% statistical level in non-state-owned firms but is not significant in state-owned firms. The estimated coefficient in column (2) of Table 6.15 is -0.0452 and it means that after 2006, for every 1 unit increase in SO_2 emission reduction target, non-state-owned firm FDI decreases by 4.52%. For the firm with FDI greater than 0, the marginal effect in column (2) of Table 6.15 is -0.0244, which means after 2006, for every 1 unit increase in the SO_2 emissions reduction target, FDI of non-state-owned firm with FDI greater than 0 decreases by 2.44%. Therefore, compared with state-owned firms, non-state-owned firms have a strong inhibitory effect on FDI. The possible reason is that compared with non-state-owned firms, state-owned firms have a natural relationship with the government. State-owned firms have advantages in capital and technology. The implementation of environmental regulation has increased costs for non-state-owned firms thereby reducing firms FDI. Columns (1) and (2) in Table 6.16 report the impact of environmental regulation on firm OFDI. The estimated coefficients are significantly positive at the 10% statistical level in state-owned firms but not significant in non-state-owned firms. The estimated coefficient in column (1) of Table 6.16 is 0.0621 and it means that after 2006, for every 1 unit increase in SO_2 emission reduction target, state-owned firm OFDI increases by 6.21%. For the firm with OFDI greater than 0, the marginal effect in column (1) of Table 6.16 is 0.0300, which means after 2006, for every 1 unit increase in the SO_2 emissions reduction target, OFDI of state-owned firm with OFDI greater than 0 increases by 3.00%. It means that compared with non-state-owned firms, the environmental

regulation policy has a greater promotion effect on OFDI of state-owned firms. The possible reason is that state-owned firms are under the leadership of the government. They have stronger demands for sustainable development and green transformation of firms, as well as stronger social responsibility incentives. SOEs have better access to financing because the Chinese government systematically supports SOEs financially and legally (Huang, 2003; Genevieve and Wei, 2004; Dollar and Wei, 2007). Better access to financing makes it easier for SOEs to adopt advanced technologies (Hering and Poncet, 2014). Therefore, state-owned firms will actively respond to government environmental requirements, and actively carry out industrial transfer and outward direct investment.

Table 6.15: Heterogeneity Analysis (1)

Variable	(1)	(2)	(3)	(4)
	State-owned firms	Non-state-owned firms	Large-scale firms	Small-scale firms
	FDI	FDI	FDI	FDI
$treat_c \times post_t$	0.0532	-0.0452***	-0.0625***	-0.0141***
	(0.0497)	(-38.7992)	(-34.3781)	(-11.9644)
treat	0.0064	0.0461***	0.0700***	0.0101***
	(1.1512)	(32.3261)	(29.5827)	(7.5661)
age	-0.3650***	-0.1913***	-0.2791***	-0.1037***
	(-56.3906)	(-85.4065)	(-77.4779)	(-50.5516)
size	0.1797***	0.4861***	0.5347***	0.2386***
	(46.1672)	(278.8584)	(179.2044)	(87.8874)
kl	0.2319***	-0.0339***	0.0956***	-0.0723***
	(30.3599)	(-15.5417)	(27.6119)	(-33.7892)
hhi	-5.0838***	3.4248***	-0.9487	-0.4213
	(-6.3724)	(7.4828)	(-1.5147)	(-1.0549)
size_ind	-0.0031	-0.0602***	-0.0596***	-0.0285***
	(-0.3387)	(-21.2965)	(-12.8106)	(-10.9460)
gdp	0.1504***	0.0827***	0.1022***	0.0849***
	(10.2428)	(21.3716)	(15.8049)	(23.5381)
ind	-0.0488***	-0.0399***	-0.0500***	-0.0208***
	(-3.5964)	(-10.0390)	(-8.0750)	(-5.3367)
inter	0.0488***	0.0309***	0.0587***	0.0128***
	(9.8341)	(15.6970)	(18.9416)	(7.2661)
soe			-0.9133***	-0.1822***
			(-88.8187)	(-25.0202)
foe			6.6928***	6.2119***
			(747.3469)	(1.0e+03)
pre			-1.4338***	-0.6491***
			(-1.8e+02)	(-1.5e+02)
Year FE	YES	YES	YES	YES
City FE	YES	YES	YES	YES

σ	2.3633***	2.0315***	2.5231***	1.3997***
	(278.8584)	(850.6956)	(633.0320)	(633.0209)
margin	0.0235	-0.0244***	-0.0365***	-0.0067***
	(0.0470)	(−38.7940)	(-34.3731)	(-11.9636)
N	155,524	1,447,366	801,459	801,431
Pseudo R-Square	0.0198	0.2243	0.1877	0.2549

Note: Using Tobit model and continuous DID method. *Year FE* is year fixed effect, *City FE* is city fixed effect. σ is the standard deviation of the random disturbance term. *margin* is marginal effect where FDI>0. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(2) Firm size. There are significant differences in the availability of factors among firms of different scales, which further leads to varying impacts of environmental regulation on firm FDI and OFDI. Large-scale firms have obvious advantages in terms of capital, talents, platforms, etc. This section further examines whether the two-way FDI effect of environmental regulation policy is influenced by the firm size. Specifically, according to the median of the total assets of the firm in the year before the enforcement of the environmental regulation policy, divide whether it is a large firm. If the total assets are higher than the median, it is a large firm, otherwise it is a small firm. I have standardized the data using Z-score standardization method (Vaccario et al., 2017). Columns (3) and (4) in Table 6.15 report the impact of environmental regulation on firm FDI. The estimated coefficients both are significantly negative at the 1% statistical level, but the absolute value of the coefficient of large firms is greater than that of small firms. The estimated coefficients in column (3)-(4) of Table 6.15 are -0.0625 and -0.0141 which mean that after 2006, for every 1 unit increase in SO_2 emission reduction target, large firm FDI decreases by 6.25% and small firm FDI decreases by 1.41%. For the firm with FDI greater than 0, the marginal effects in column (3)-(4) of Table 6.15 are -0.0365 and -0.0067, which means after 2006, for every 1 unit increase in the SO_2 emissions reduction target, FDI of large firm with FDI greater than 0 decreases by 3.65% and FDI of small firm with FDI greater than 0 decreases by 0.67%. Columns (3) and (4) in Table 6.16 report the impact of environmental regulation on firm OFDI. The estimated coefficient is significantly positive at the 1% statistical level in large-scale firms but not significant in small-scale firms. The estimated coefficient in column (3) of Table 6.16 is 0.0988 which mean that after 2006, for every 1 unit increase in SO_2 emission reduction target, large firm OFDI increases by 9.88%. For the firm with OFDI greater than 0, the marginal effect in column (3) of Table 6.16 is 0.0503, which means after 2006, for every 1 unit increase in the SO_2 emissions reduction target, OFDI of large firm with OFDI greater than 0 increases by 5.03%. The coefficient size and significance are larger for large-scale firms than that for small firms. The

results indicate that the effect of environmental regulation policy on firm OFDI is affected by the firm scale, the large-scale firms show a more obvious response to the environmental regulation policy. Due to the possible advantages of large-scale firms in terms of credit qualifications and collateral, they are more likely to access credit resources and R&D capital when facing government environmental regulatory policies. It provides financial support for enterprises to seek overseas markets and international investment (Liu et al., 2022).

Table 6.16: Heterogeneity Analysis (2)

Variable	(1)	(2)	(3)	(4)
	State-owned firms	Non-state-owned firms	Large-scale firms	Small-scale firms
	OFDI	OFDI	OFDI	OFDI
$treat_c \times post_t$	0.0621*	-0.0262	0.0988***	0.0376
	(1.8616)	(-0.4200)	(3.2845)	(1.4114)
treat	0.6971	-0.1406	0.6825	0.7167**
	(1.5010)	(-0.5684)	(0.4588)	(2.3347)
age	-0.1884	0.5573**	0.9488***	-0.2325*
	(-0.8409)	(2.1149)	(4.7040)	(-1.7267)
size	1.2841***	1.7421***	1.6710***	0.6922***
	(18.6205)	(12.9998)	(16.7964)	(5.8473)
kl	1.0874**	-4.2748***	-0.6819	-0.9513***
	(2.2424)	(-6.0268)	(-1.2511)	(-2.6847)
cap	-0.3038***	-0.1481***	-0.3346***	-0.0449*
	(-8.8943)	(-3.0130)	(-9.6108)	(-1.9435)
cl	0.1738***	-0.1127***	0.0839*	-0.0252
	(3.2601)	(-3.4999)	(1.6630)	(-1.1692)
Year FE	YES	YES	YES	YES
City FE	YES	YES	YES	YES
σ	5.0324***	5.3491***	5.7474***	3.6920***
	(55.2087)	(39.3700)	(54.2540)	(54.2586)
margin	0.0300*	-0.0132	0.0503***	0.0167
	(1.8611)	(-0.4199)	(3.2807)	(1.4112)
N	6,096	3,100	5,887	5,888
Pseudo R-Square	0.1389	0.1392	0.1386	0.1254

Note: Using Tobit model and continuous DID method. *Year FE* is year fixed effect, *City FE* is city fixed effect. σ is the standard deviation of the random disturbance term. *margin* is marginal effect where OFDI>0. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(3) Factor intensity. To test whether factor intensity has an impact on the firm two-way FDI, I divide the industries involved into labor-intensive industries, capital-intensive industries, and technology-intensive

industries, and use sub-sample regression to test the heterogeneity. I have standardized the data using Z-score standardization method. Columns (1) - (3) in Table 6.17 report the results of environmental regulation and firm FDI. I found that the interaction terms are significantly negative. By comparing the absolute value of the coefficient, labor-intensive industries are larger than technology-intensive industries, and finally, capital-intensive industries. The estimated coefficients in column (1)-(3) of Table 6.17 are -0.0469, -0.0374 and -0.0296 which mean that after 2006, for every 1 unit increase in SO_2 emission reduction target, labor-intensive industries' firm FDI decreases by 4.69 %, technology-intensive industries' firm FDI decreases by 3.74%, and capital-intensive industries' firm FDI decreases by 2.96%. For the firm with FDI greater than 0, the marginal effects in column (1)-(3) of Table 6.17 are -0.0259, -0.0202 and -0.0149, which means after 2006, for every 1 unit increase in the SO_2 emissions reduction target, FDI of labor-intensive industries' firm with FDI greater than 0 decreases by 2.59%, FDI of technology-intensive industries' firm with FDI greater than 0 decreases by 2.02%, and FDI of capital-intensive industries' firm with FDI greater than 0 decreases by 1.49%. Columns (1) to (3) in Table 6.18 report the results of environmental regulation and firm OFDI. I found that the interaction term in labor-intensive industries is not significant but that in technology and capital-intensive industries is significantly positive. The estimated coefficients in column (2)-(3) of Table 6.18 are 0.1835 and 0.1249 which mean that after 2006, for every 1 unit increase in SO_2 emission reduction target, technology-intensive industries' firm OFDI increases by 18.35%, and capital-intensive industries' firm FDI increases by 12.49%. For the firm with OFDI greater than 0, the marginal effects in column (2)-(3) of Table 6.18 are 0.0846 and 0.0627, which means after 2006, for every 1 unit increase in the SO_2 emissions reduction target, OFDI of technology-intensive industries' firm with OFDI greater than 0 increases by 8.46% and OFDI of capital-intensive industries' firm with OFDI greater than 0 increases by 6.27%. Therefore, compared with the firms in labor-intensive industries, environmental regulation policy has a greater outward direct investment effect on capital intensive industries and technology intensive industries. Labor-intensive industries refer to industries that mainly rely on the use of large amounts of labor for production. These industries often rely less on technology and equipment and are prone to environmental pollution during the production process. The implementation of environmental regulation increases production costs in labor-intensive industries, thereby reducing FDI. For technology and capital-intensive industries with high innovation capabilities and large amounts of capital, the implementation of environmental regulation can promote their foreign investment. Therefore, environmental regulation can better reduce the firm FDI in labor intensive industries and increase the firm OFDI in technology intensive and capital intensive industries.

Table 6.17: Heterogeneity Analysis (3)

Variable	(1) Labor intensive industries	(2) Technology intensive industries	(3) Capital intensive industries	(4) East region	(5) Central region	(6) West region
	FDI	FDI	FDI	FDI	FDI	FDI
$treat_c \times post_t$	-0.0469***	-0.0374***	-0.0296***	-0.0394***	-0.0054	-0.0025
	(-19.7610)	(-19.3525)	(-17.4605)	(-30.2998)	(-0.7677)	(-0.7863)
treat	0.0351***	0.0655***	0.0313***	0.0417***	0.0039	-0.0159*
	(13.1670)	(25.3222)	(15.2303)	(26.3968)	(0.7867)	(-1.8858)
age	-0.1431***	-0.2955***	-0.1513***	-0.2610***	-0.0996***	-0.1348***
	(-34.8951)	(-75.9331)	(-47.8112)	(-97.6281)	(-27.1848)	(-25.0709)
size	0.4348***	0.4709***	0.3263***	0.5150***	0.1867***	0.1380***
	(142.1919)	(165.9553)	(137.8299)	(264.8250)	(64.7923)	(34.4062)
kl	-0.0480***	0.0608***	0.1136***	-0.0262***	0.0812***	0.1912***
	(-12.4772)	(14.5845)	(35.2027)	(-10.4281)	(19.9009)	(31.1045)
hhi	-5.1979***	-3.7327***	8.9583***	0.7430	-0.8284	-2.9644***
	(-4.8709)	(-6.7737)	(13.8269)	(1.5496)	(-1.1714)	(-2.8283)
size_ind	-0.0675***	-0.0699***	-0.0820***	-0.0577***	-0.0503***	-0.0425***
	(-14.3245)	(-11.5182)	(-19.7623)	(-17.5071)	(-9.6442)	(-5.5465)
gdp	0.0993***	0.0664***	0.0758***	0.0977***	0.0225***	0.0065
	(14.7230)	(8.8329)	(13.2505)	(20.9837)	(3.0226)	(0.5983)
ind	-0.0425***	0.0179**	-0.0577***	-0.0293***	-0.0337***	-0.0315***
	(-5.4666)	(2.3130)	(-11.0867)	(-4.7108)	(-7.3998)	(-3.5114)
inter	0.0476***	0.0244***	0.0382***	0.0513***	0.0259***	0.0480***
	(14.0988)	(6.9464)	(13.9301)	(17.3684)	(11.8030)	(9.2365)
soe	-0.9115***	-0.5703***	-0.3486***	-0.6935***	-0.1601***	-0.2453***
	(-67.3880)	(-50.0471)	(-35.7095)	(-76.4307)	(-15.8767)	(-17.3236)
foe	5.9777***	6.7400***	6.9817***	6.4791***	6.4652***	6.9455***
	(562.1471)	(647.7734)	(786.3090)	(1.0e+03)	(397.8112)	(289.9270)
pre	-1.4280***	-1.0139***	-0.7654***	-1.2259***	-0.3199***	-0.5286***
	(-1.6e+02)	(-1.2e+02)	(-1.1e+02)	(-2.2e+02)	(-37.0164)	(-42.1445)
Year FE	YES	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES	YES
σ	2.1298***	2.1454***	1.9362***	2.1749***	1.6222***	1.7176***
	(484.9263)	(499.4097)	(557.0588)	(775.0532)	(361.8922)	(264.1430)
margin	-0.0259***	-0.0202***	-0.0149***	-0.0222***	-0.0023	-0.0011
	(−19.7571)	(−19.3500)	(−17.4597)	(-30.2947)	(−0.7677)	(-0.7864)
N	470,307	498,820	620,629	1,201,415	261,932	139,543
Pseudo R-Square	0.2044	0.2126	0.2166	0.2133	0.1395	0.1388

Note: Using Tobit model and continuous DID method. *Year FE* is year fixed effect, *City FE* is city fixed effect. σ is the standard deviation of the random disturbance term. *margin* is marginal effect where FDI>0. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(4) Different regions. In order to test whether the impact of environmental regulation on two-way FDI differs depending on the geographical location of firms, I divided the regions into eastern, central and western regions according to the division of regions by the Bureau of Statistics of the People's Republic of China. I use sub-sample regression to test the heterogeneity (Shi and Xu, 2018). I have standardized the data using Z-score standardization method. Columns (4) to (6) in Table 6.17 report the impact of environmental regulation on firm FDI in different regions. The interaction term is only significantly negative in the eastern region. The results mean that environmental regulation can reduce eastern region's firm FDI. Columns (4) to (6) in Table 6.18 report the impact of environmental regulation on firm OFDI in different regions. The interaction term is significantly positive in the eastern region but significantly negative in western region. It means that environmental regulation can increase the eastern region's firm OFDI and reduce western's firm OFDI. The possible reason for this is that the economic development in the eastern region was early, fast and at a high level. It has more advantages in environmental protection and industrial structure optimization. The eastern region has earlier changed the types and methods of introducing FDI and has achieved a certain scale of development in environmental regulation. Therefore, a further increase in the intensity of environmental regulation will promote firms in the eastern region to increase OFDI and reduce FDI. Due to various reasons such as low economic level, imperfect infrastructure, and geographical location, the western region cannot afford the increase in production costs caused by environmental regulation, so it will reduce OFDI.

Table 6.18: Heterogeneity Analysis (4)

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	Labor intensive industries	Technology intensive industries	Capital intensive industries	East region	Mid region	West region
	FDI	FDI	FDI	OFDI	OFDI	OFDI
$treat_c \times post_t$	-0.0097	0.1835***	0.1249***	0.1139***	0.0576	-0.3424**
	(-0.2678)	(4.0678)	(2.9131)	(4.7748)	(1.1683)	(-2.4723)
treat	0.5508	0.7200**	-1.9947***	0.2944**	-0.3374	0.4284
	(1.4376)	(2.2147)	(-3.3785)	(2.0449)	(-0.2423)	(0.7237)
age	0.0903	0.0499	0.3664	0.7077***	0.8113***	-0.3357
	(0.4013)	(0.1899)	(1.5683)	(4.2646)	(3.6244)	(-1.5634)
size	1.0779***	1.2675***	1.9624***	1.5936***	0.6896***	0.6508***
	(12.1310)	(14.0196)	(19.2068)	(22.8369)	(7.5055)	(8.1306)
kl	0.3805	-1.7534***	-1.7840***	-0.7464	-0.7115	-0.2841
	(0.7440)	(-2.5941)	(-2.8629)	(-1.6333)	(-1.2590)	(-0.5475)
cap	-0.1365***	0.0016	-0.0780	-0.2163***	-0.1133***	-0.1284***

	(-4.6412)	(0.0325)	(-1.3478)	(-7.4215)	(-3.1377)	(-3.4796)
cl	0.0480	0.0302	-0.0705*	0.0400	0.1467***	0.0403
	(1.0965)	(0.6682)	(-1.8867)	(1.3508)	(3.0023)	(0.9261)
Year FE	YES	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES	YES
σ	4.8187***	3.9696***	5.0446***	5.7628***	3.3546***	3.1439***
	(47.5342)	(35.7841)	(44.5253)	(59.9416)	(33.1587)	(34.5688)
margin	-0.0046	0.0846***	0.0627***	0.0569***	0.0248	-0.1468**
	(-0.2678)	(4.0666)	(2.9125)	(4.7707)	(1.1681)	(-2.4697)
N	4,519	2,561	3,965	7,186	2,199	2,390
Pseudo R-Square	0.1341	0.1646	0.1509	0.1270	0.1265	0.1401

Note: Using Tobit model and continuous DID method. *Year FE* is year fixed effect, *City FE* is city fixed effect. σ is the standard deviation of the random disturbance term. *margin* is marginal effect where OFDI>0. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(5) Country heterogeneity. Since my data only have country-specific data on OFDI, I examine the country-specific heterogeneity of environmental regulations on OFDI. The Environmental Performance Index (EPI), developed by the United Nations Environment Programme (UNEP) and Yale University, is a key indicator for assessing the environmental performance of countries and regions around the world. The EPI is statistically released every two years and is a comprehensive system of indicators reflecting the current focus on socio-environmental challenges. Since my empirical data is between 2000 and 2010, I divide the countries with high Chinese OFDI flows into three sample groups according to the average value of the EPI index for the three years of 2006, 2008, and 2010, i.e., eight low environmental regulation countries (Bangladesh, Nigeria, India, Mongolia, Cambodia, Vietnam, Indonesia, Indonesia, South Africa); 8 medium environmental regulation countries (Thailand, South Korea, America, Mexico, Netherlands, Australia, Brazil, Russia) and 8 high environmental regulation countries (United Kingdom, Japan, Germany, Denmark, Italy, Canada, Malaysia, Spain). The regression results are reported in Tables 6.21. I find that China’s environmental regulation policies drive Chinese firms to invest in low and medium environmental regulation countries. Environmental regulatory policies increase the costs of pollution control for firms, including the purchase of environmental equipment, the implementation of environmental projects, and the payment of environmental fines. If an enterprise invests in a country with low or medium environmental regulation, it can obtain more economic benefits by taking advantage of less stringent environmental requirements and lower environmental costs. Moreover, enterprises can obtain more competitive advantages by investing in low or medium environmental regulation countries. This empirical evidence also indirectly verifies that the “Pollution Haven Effect” holds in China.

Table 6.19: Heterogeneity Analysis (5)

Low ER	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Countries	Bangladesh	Nigeria	India	Mongolia	Cambodia	Vietnam	Indonesia	South Africa
$treat_c \times post_t$	0.0020***	0.0040***	0.0038***	0.0063***	0.0028***	0.0151***	0.0055***	0.0043***
	(2.7436)	(4.7398)	(4.9307)	(3.7447)	(3.3626)	(7.5340)	(3.2534)	(3.9685)
σ	0.2795***	0.6481***	0.5987***	0.6417***	0.3165***	1.5607***	0.6385***	0.4111***
	(12.8452)	(12.8452)	(12.8452)	(12.8452)	(12.8452)	(12.8452)	(12.8452)	(12.8452)
margin	0.0006***	0.0014***	0.0013***	0.0024***	0.0009***	0.0070***	0.0022***	0.0014***
	(2.7029)	(4.5937)	(4.7617)	(3.6907)	(3.3100)	(7.1750)	(3.2181)	(3.8757)
Pseudo R-Square	0.3210	0.0398	0.0439	0.0953	0.2941	0.0462	0.0919	0.1047
Medium ER	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Countries	Thailand	South Korea	America	Mexico	Netherlands	Australia	Brazil	Russia
$treat_c \times post_t$	0.0013**	0.0030*	0.0161*	0.0007	0.0018	0.0009**	-0.0014	0.0023**
	(2.1904)	(1.9647)	(1.6558)	(1.5674)	(1.5550)	(2.0010)	(-0.4110)	(2.3132)
σ	0.2200***	0.5770***	1.9167***	0.1738***	0.4464***	0.1655***	1.3083***	0.3703***
	(12.8452)	(12.8452)	(12.8452)	(12.8452)	(12.8452)	(12.8452)	(12.8452)	(12.8452)
margin	0.0003**	0.0012*	0.0074*	0.0001	0.0006	0.0002**	-0.0006	0.0007**
	(2.1694)	(1.9572)	(1.6530)	(1.5600)	(1.5499)	(1.9851)	(-0.4109)	(2.2930)
Pseudo R-Square	0.6751	0.1087	0.0347	0.1657	0.1114	0.1436	0.0328	0.0894
High ER	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
Countries	United Kingdom	Japan	Germany	Denmark	Italy	Canada	Malaysia	Spain
$treat_c \times post_t$	0.0020	0.0008	0.0043	0.0001	0.0007	0.0022	0.0014	0.0005
	(1.1661)	(1.2589)	(1.3070)	(0.5403)	(0.4660)	(1.0496)	(1.1382)	(0.5459)
σ	0.6358***	0.2263***	1.2439***	0.0943***	0.5675***	0.7996***	0.4771***	0.3251***
	(12.8452)	(12.8452)	(12.8452)	(12.8452)	(12.8452)	(12.8452)	(12.8452)	(12.8452)
margin	0.0007	0.0002	0.0017	0.0001	0.0002	0.0009	0.0005	0.0001
	(1.1640)	(1.2554)	(1.3043)	(0.5390)	(0.4658)	(1.0485)	(1.1363)	(0.5458)
Pseudo R-Square	0.0381	0.0797	0.0258	0.0227	0.0211	0.0586	0.0733	0.0559
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Province FE	YES	YES	YES	YES	YES	YES	YES	YES
N	330	330	330	330	330	330	330	330

Note: Using Tobit model and continuous DID method. *Year FE* is year fixed effect, *Province FE* is province fixed effect. σ is the standard deviation of the random disturbance term. *margin* is marginal effect where OFDI>0. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

6.6 Chapter Summary

In this chapter, I mainly analyze how China's domestic environmental regulation affects firm FDI and OFDI. The main focus lies on Chinese FDI and OFDI because the effect also can show whether or not the Pollution Heaven Hypothesis is valid in the Chinese case.

Theoretical model analysis shows that environmental regulation can affect the firm two-way FDI through cost effect, innovation effect and financing effect. Environmental regulation can increase pollution reduction costs and pollution treatment costs, and then reduce the firm FDI inflow and increase the firm OFDI outflow. Then, environmental regulation can increase firm FDI inflow and OFDI outflow through improving technological innovation. Third, environmental regulation can increase financing constraints, and then reduce the firm FDI inflow and increase the firm OFDI outflow. It means that the impact of environmental regulations on firm FDI is uncertain, but environmental regulation can promote firm OFDI.

Based on theoretical model analysis, I take the implementation of the Eleventh Five-Year Plan in 2006 as a quasi-natural experiment and employ the TWFE model and continuous DID method to test the relationship between environmental regulation and two-way FDI by using the data from the China Industrial Enterprise Database from 2000-2007 and the Cathay Pacific CSMAR database from 2000-2010. The results show that the implementation of the Eleventh Five-Year Plan can strengthen environmental regulation, leading to a significantly negative impact on firm FDI and a significantly positive impact on firm OFDI. My mechanism analysis reveals that environmental regulation can reduce firm FDI through increasing firms' production costs and financing constraints and increase firm FDI through increasing firm technological innovation. But the cost effect and financing effect are much larger than the innovation effect, so the final manifestation is that environmental regulation reduces the firm FDI. Environmental regulation can increase firm OFDI through increasing firms' production cost, technological innovation and financing constraints.

Furthermore, heterogeneity analysis shows that environmental regulation significantly reduces firm FDI of non-state-owned firms, large-scale firms, labor-intensive industries and technology-intensive industries, and firms located in eastern region and significantly increases firm OFDI of state-owned firms, large-size firms, capital-intensive industries and technology-intensive industries, and firms located in eastern region. I also found that China's environmental regulation policies drive Chinese firms to invest in low and medium environmental regulation countries. This chapter also conducts a series of robustness tests, including two-period double difference method, winsorize, eliminate other policy distractions and changing the dependent variable, and the results remain significant.

In the next chapter, I will analyze the relationship between environmental regulation and firm export performance.

7 SO_2 Emissions Regulation and Firm Export Performance

7.1 Introduction

Since China's accession to the WTO, its foreign trade scale has experienced rapid growth (Feenstra, 2010). According to data released by the National Bureau of Statistics of China, despite the severe impact of the COVID-19 pandemic, China's total goods imports and exports reached ¥32.157 trillion in 2020, with exports amounting to ¥17.933 trillion, marking the fifth consecutive year of positive growth. This explosive export growth has propelled rapid economic development in China but has not elevated the country from the low-end segments of the value chain (Sun and Heshmati, 2010; Li et al., 2018). With evolving economic and environmental conditions, the sustainability of trade practices has become an increasingly important issue. Though China has maintained a trade surplus in export trade, the quality of exported products and the added value of exports remain relatively low. According to the 2020 Global Competitiveness Report published by the Lausanne Institute of Management Development, China ranks 20th, dropping six places from the previous year, significantly lagging behind its current economic status and export scale. Since the China-U.S. trade friction that began in 2018, China has faced a continuously deteriorating international market environment (Lu, 2018; Liu et al., 2020; Wei, 2019).

On the other hand, China's economic development has historically relied on a high-consumption, high-emission growth model (Yang and Zhao, 2018). China is ranked at the bottom of the global air quality rankings, especially, China's total sulfur dioxide (SO_2) emissions were 25.888 million tons in 2006, ranking first in the world, of which 84% came from industrial SO_2 emissions. Until 2018, China's sulfur dioxide emissions were 2.578 million tons, ranking third. The environmental cost of China's rapid economic growth is evident. This deterioration in trade conditions and environmental constraints poses obstacles to the sustainable development of China's export trade, making green and innovative development an inevitable choice (Xu et al., 2024). In 2020, the State Council issued the "Guiding Opinions on Building a Modern Environmental Governance System", emphasizing the need to strengthen the governance of enterprise pollution sources, form collaborative efforts, and enhance the enthusiasm of various market entities and the public to create a governance system with clear objectives and multiple stakeholders. In the latest released 14th Five-Year Plan in 2021, it is stated that in the new development stage, efforts will continue to be made in pollution prevention and control, the environmental governance system will be improved.

Over-reliance on energy consumption and extensive development driven by inexpensive labor not only lacks sufficient resilience against external shocks but also brings about worsening environmental problems (Halkos and Tzeremes, 2011; Liang and Yang, 2019). The non-exclusivity of environmental resources, when utilized without effective protection, leads to environmental pollution. Environmental pollution, characterized by negative externalities, often results in free-rider phenomena during the governance process (Cao and Yu, 2024). Hence, relying solely on market self-regulation cannot effectively address environmental problems, necessitating a crucial role for the government in environmental governance and protection (Li and Ramanathan, 2018). The means by which the government addresses resource and environmental issues is through the implementation of environmental regulatory policies, primarily achieving the internalization of environmental costs through measures such as collecting pollution fees and implementing source and end treatment. In recent years, as environmental problems have garnered increasing attention due to their severity and complexity, China's environmental regulatory efforts have gradually intensified (Yin et al., 2019). In the significant strategic aspect of ecological civilization construction, the 19th Party Congress report states that China has transitioned from a high-speed growth stage to a high-quality development stage and is at a critical period of transformation in development momentum and development mode. It emphasizes the need to address prominent environmental issues brought about by development. The 14th Five-Year Plan proposes to enhance the quality and stability of the ecosystem, continuously improve environmental quality, accelerate the green transformation of the development mode, and build a beautiful China.

As worldwide climatic and environmental disruptions intensify, environmental regulations as efficacious policy tools are commanding ever greater governmental and academic attention globally (Ren and Wu, 2022). Such regulations refer to serial state-level environmental edicts and protocols devised and implemented to constrain firm and individual activities provoking ecological damage, ultimately promoting sustainability-focused development and social welfare (Wang et al., 2019). However, definitive regulatory impact mechanisms and pathways influencing export activities contain multifaceted, uncertain elements. Some research indicates environmental regulations may further technological innovation and enterprise efficiency to bolster export competitiveness (Jiang et al., 2023; Chen et al., 2022). The “innovation compensation effect” generated by environmental regulations compensates for pollution costs, enhances product export competitiveness, and expands export volume (Fang et al., 2019). Chen et al. (2022) also suggested that environmental regulations have significantly increased the export competitiveness of Chinese firms. Nevertheless, other studies argue regulatory compliance conversely escalates expenses and hinders export viability. Fang et al. (2019) employed the Annual Survey of Industrial Firms database from 2003 to 2013 and a difference-in-differences identification strategy to examine the impact of environmental regulation on firm exports and its underlying mechanisms. The empirical results demonstrate that China's environmental information disclosure policy significantly reduced export volumes of industrial enterprises in regulated regions, providing evidence for the existence of pollution haven effects in China. Cherniwchan and Najjar (2022) leveraged quasi-experimental variations generated by Canada's air quality standard design to empirically investigate the effects of environmental regulation on exports. Their findings reveal that the regulation decreased export volumes by 32% for the most severely affected manufacturers. Based on the perspective of production costs, some scholars believe that the strengthening of environmental regulations enhances the cost of pollution discharge, leading to a decrease in export competitiveness (Shi and Xu, 2018). Several scholars have also focused on the relationship between environmental regulation and export product quality. Kuang and Xiong (2022), utilizing China’s pollution abatement fee implementation data and a firm-pollution panel dataset, found that government environmental regulations significantly enhanced export product quality. Further analysis indicates that the quality improvement of exports from regulated regions can be attributed to the promotion of corporate innovation and the reduction of resource misallocation. Qi and Cheng (2022) constructed a panel dataset of Chinese listed companies from 2003 to 2016 and treated the emissions trading system (ETS) pilot policy as a natural experiment. Employing a DID model, they examined the policy's impact on export product quality. The study concludes that the ETS pilot policy significantly improved the export product quality of listed companies. In contrast to the above findings, He and Tang (2023) investigated how local environmental constraints (LECs) regarding emission reduction target disclosure affect firms’ export product quality. Using data from Chinese manufacturing firms between 2002 and 2009, they found that LECs led to a 3.57% decline in firms’ export product quality. Moreover, exports themselves constitute a progressively major component of global exchange, amidst broader economic shifts towards eco-conscious production paradigms. As a trade vertical intimately tied into China’s localization of sustainability-focused growth, the export sphere commands profound developmental importance domestically (Dong et al., 2022; Liu et al., 2023). Environmental regulations require enterprises to attain explicit "green" performance thresholds through conservation-focused protocols; in meeting stated benchmarks, regulated businesses then enhance both internal environmental capabilities and downstream exported merchandise qualitatively and cost-efficiently, thereby simultaneously augmenting international market competitiveness. Moreover, sweeping regulatory pressures stimulate ongoing firm impetus for technological innovation, as newly developed green, cost-effective solutions better enable regulatory compliance whilst furnishing fresh competitive advantages overseas. Thereby, elucidating precise mechanisms underlying environmental regulation's capacity to expand exports remains pivotal for sustainably expanding this increasingly vital trade arena whilst facilitating China's broader economic transition.

Stringent and effective environmental governance constitutes a linchpin for unlocking multifaceted pathways powering robust trade development without necessitating ecological sacrifices. Therefore, this research centrally examines whether Chinese environmental regulations actively promote rises in firm product export performance - and if so, which precise mechanisms and heterogeneities are entailed. Answering these questions will not only enable accurate and evidence-based assessments of regulatory variables influencing China's export, but also inform future governmental policy refinements striving for sustainability-focused trade augmentation domestically. Concurrently, such insights provide a valuable knowledge base towards unlocking alternative developmental solutions reconciling the "trade-environment paradox".

Compared with existing literature, the main marginal contributions of this chapter can be summarized in the following three aspects: firstly, among existing literature, this is the first research to combine environmental regulations with enterprise export volume and export product quality for research and analysis within a single framework. It enriches the research on the factors influencing exports, and provides new ideas for developing countries to balance development and environmental relations under the new economic model. Secondly, this chapter explores the heterogeneity of environmental regulations affecting enterprise export volume and export product quality at the enterprise and regional levels. I found that the promotional effect of environmental regulations on firm export volume and export product quality varies depending on the type of ownership, region location and the size of the enterprise. This provides a reference for formulating supporting policies to promote the firm exports. Thirdly, this chapter delves into the channels through which environmental regulations affect enterprise export volume and export product quality, and refines my understanding of the relationship between environmental regulations and enterprise exports. The conclusion indicates that environmental regulations can promote the increase of product exports through technology effects. The chapter provides reference information for policymakers to design systems that can continuously improve air pollution. Finally, this finding that SO_2 regulation policies enhance export volume and export product quality suggests that environmental regulations can serve as a catalyst for industrial upgrading. Policymakers can leverage this insight to formulate targeted industrial policies that encourage enterprises to innovate and improve product quality in response to environmental regulations.

7.2 Literature Review

7.2.1 Environmental Regulations and Export Competitiveness

Conventional economic doctrines imply regulatory enhancements deleteriously impact manufacturing export competitiveness. Pioneering such empirical examinations, Kalt (1985) discovered escalations in American environmental regulatory stringency from 1967 to 1977 dramatically lowered exports across 78 major industry output classifications, and these effects were traced to sizeable firm cost inflations. Adopting extensive previous general equilibrium and input-output analytical frameworks, Huang and Labys (2002) analogously ascertained continual regulatory intensification substantially depresses manufacturing export volumes and international competitiveness. Expanding triangulations incorporating environmental and innovation dynamics, Hwang and Kim (2017) concluded that pollution-intensive manufacturing exports witness significant competitiveness declines following major energy and environmental tax hikes. Moreover, Petroni et al. (2019) argued drastic regulatory burdens compel manufacturing firms towards production and employment downsizing - thereby draining resources for technological enhancements needed to update merchandise and preserve international market viability.

Conversely, the seminal Porter Hypothesis (Porter, 1996) refutes such static perspectives, positing regulatory enhancements instead enable manufacturing export competitiveness improvements due to dynamic efficiencies conferred via elevated innovation and productivity gains counteracting compliance cost inflations. Similarly, Porter and Van Der Linde (1995) showed that appropriately configured environmental regulations successfully motivate manufacturing enterprises to implement technological enhancements yielding production efficiency improvements compensating regulatory cost increases whilst boosting international market participation. Comparing American manufacturing performances following landmark Clean Air Act implementation, Sine and David (2003) correspondingly ascertained substantial advances in export competitiveness traced to electric utility productivity gains underpinning wider technology improvements mandated by new regulatory obligations. Complementing these findings, Ambec et al. (2013) concluded that judiciously designed environmental regulations can simultaneously confer economic efficiency and environmental performance enhancements on manufacturing firms, thereby bolstering international competitiveness. Analyzing manufacturing data, De Santis and Jona Lasinio (2015) further ascertained regulatory enhancements directly stimulate innovations improving production efficiencies - thereby boosting export competitiveness.

7.2.2 Environmental Regulations and Export Volume

The impact of environmental regulation on the export behavior of firms has been one of the focal points of scholarly research. Most early literature showed that environmental standards have no obvious impact on trade, and trying to expand exports by reducing domestic environmental standards cannot achieve the desired results (Tobey, 1990; Grossman and Kruger, 1993; Harris et al., 2002; Busse, 2004). Some studies have noted that the impact of environmental regulation on trade may vary with industry and country (Van Beers and Van den Bergh, 1996; Cole and Elliott, 2003). Kalt (1988) argues that environmental regulation is one of the determinants of trade.

There are three groups of academic views in the existing literature. First, environmental regulation inhibits exports. Since the 1970s, a growing amount of literature has incorporated a country's environmental regulations into traditional international trade theory to analyse their impact on comparative advantage (Huang and Labys, 2002). If a country imposes stricter environmental regulations on its pollution-intensive industries than other countries, this will result in higher production costs. Other things being equal, the industry will then lack a comparative advantage in international market competition. This will lead to a decline in exports. Neoclassical economic theory suggests that environmental regulation internalises external pollution (Walter, 1982; Baumol and Oates, 1988). Therefore, increasing the level of environmental regulation will increase pollution control costs and damage export competitiveness

(Ollivier, 2016). Kalt (1988) drew on the framework developed by Branson and Monoyios (1977) and Stern and Maskus (1981). Kalt added the cost of pollution abatement as a proxy variable for stringency of environmental regulation in a four-factor trade model. The results show that the cost of environmental regulation has a significant negative effect on US net export data.

The second group holds that environmental regulation is beneficial to exports. The Porter hypothesis, proposed by Porter and Van der Linde (1995), also applies to the effect of environmental regulation on exports. Porter argued that appropriate environmental regulations can encourage firms to innovate, improve product quality and enhance their export competitiveness (Porter, 1996; Porter and Van der Linde, 1995). Therefore, the government should implement a strict environmental regulation policy to stimulate enterprises to reform and innovate, which will help to enhance export competitiveness.

In addition to the two opposed hypotheses mentioned above, there is another view that the effect of environmental regulation on export behavior may be uncertain. That is, whether the effect of environmental regulation on firms' exports is positive or negative is determined by a combination of factors. After considering the constraints of environmental regulation and technological innovation on firms' production costs, the outcome of the effect of environmental regulation on firms' exports is uncertain.

There are also no consistent conclusions on the impact of environmental regulation on trade. some literature provides empirical evidence in support of environmental regulations inhibiting firms' exports. Most of the literature used a gravity model of bilateral trade to analyse the impact of environmental regulation on trade. For example, Van Beers and Van Den Bergh (1996) examined the relationship between environmental regulation and exports in 21 OECD countries based on a gravity model. They found that strict environmental regulations had a significant negative impact on exports. Further, Jug and Mirza (2005) by creating a panel using data from 12 importing countries from the EU15 and 19 exporting countries from the EU15 and Central and Eastern Europe during the period 1996-1999 studied whether intra-European export flows were significantly affected by environmental policies when enforcement is more stringent. They measure environmental regulation variables using "Current Environmental Expenditure in Manufacturing" provided by Eurostat. They found that environmental regulations have a negative impact on total intra-EU trade. Specifically, exports from Eastern European countries fell, while the impact of austerity on Western European exporters was negligible. They also show that, contrary to expectations, "polluting" industries among exporting firms are no more affected by environmental policies than "clean" industries. They believe this is because "dirty" companies, that is, pollution-intensive companies, cannot easily change their business locations because they rely on local natural resources.

In addition, Robison (1988) found that for US industries environmental regulation increased the propensity to export by changing the comparative advantage and reducing the cost of pollution control. Cagatay and Mihci (2006) constructed an index to measure the intensity of environmental regulation in a country using data from 31 developed and developing countries and tested the hypothesis that the intensity of environmental regulation inhibits exports. Ederington et al. (2005) also concluded that environmental regulations can dampen trade volumes in research on US manufacturing. Using industry data for the US and Japan respectively, Cole et al. (2005) and Cole et al. (2010) found that, after considering the endogeneity of environmental regulations, environmental regulations had a negative impact on the competitiveness of industries in the US and Japan.

However, Tsurumi et al. (2015) argued that moderate environmental regulation can promote the scale of a country's trade. Costantini and Crepi (2008) tested the Porter hypothesis using a gravity model and found that in the strict environmental regulation sector, exports of environmentally friendly technologies increase. Song and Sung (2014) also concluded that environmental regulation is good for exports, supporting the Porter hypothesis. Applying panel estimations across 15 EU states over 1996-2007, Costantini and Mazzanti (2012) uncovered novel evidence supporting Porter Hypothesis postulations. They found that environmental and energy taxation fails to undermine wider EU export flows. Rubashkina et al. (2015) found that environmental regulation did not have a negative impact on the export competitiveness of manufacturing industries, but instead promoted technological innovation and increased the scale of trade. Yang et al. (2012) found a strong positive relationship between environmental regulation and firm innovation, which significantly boosts firm productivity leading to increased export trade. Joo et al. (2018) ascertained that Korean government environmental policies enhance manufacturing export performance via fortified ecological and technological capabilities conferring global market competitiveness advantages.

In addition, some scholars have also studied imports. Ederington and Minier (2003) and Levinson and Taylor (2008) analysed the impact of environmental regulation on net imports using panel data on manufacturing net imports from Canada and Mexico for the US 4 quartile Standard Industrial Classification (SIC), 1978-1992, and for the US 3 quartile SIC, 1977-1986 respectively. The results showed that the effect of environmental regulation on US net imports was significantly positive and endogenous environmental regulation had a greater impact on net imports than exogenous environmental regulation.

The uncertain effect of environmental regulation on trade is supported by the findings of several studies. Most of the literature focuses on the Heckscher-Ohlin (HO) model, which treats environmental regulation as a factor of production, and tests whether countries with lax environmental regulations have a comparative advantage in the production of pollution-intensive products and can be major exporters of these products under a free trade regime.

For example, Tobey (1990) built on the Heckscher-Ohlin-Vanek (HOV) model and 11 resource endowment variables provided by Leamer (1984) to test the effect of environmental regulation on the trade patterns of pollution-intensive industries. Tobey used the environmental regulation index constructed by Walter and Ugelow (1979) and cross-sectional data for 23 countries in 1975 and concluded that the effect of environmental regulation on exports of polluting industries is not significant. Using cross-sectional data for 60 countries in 1995, Cole and Elliott (2003) built on Tobey (1990) and the HOV model to examine the impact of environmental regulation on the trade patterns of pollution-intensive products. They found that there is no significant relationship between environmental regulation and net exports of polluting products. This result was not altered even when the endogeneity of environmental regulation was taken into account.

Busse (2004) used cross-sectional data for five highly polluting industries in 119 countries in 2001 to test the effect of environmental regulation on net exports using the H-O model. Busse did not find sufficient evidence to support a pollution sanctuary effect. Using similar data and environmental regulation variables as Van Beers and Van Den Bergh (1996), Harris et al. (2002) found that the effect of environmental regulation intensity on trade was no longer significant and attributed this conclusion to the faulty design of Van Beers and Van Den Bergh (1996) research model. An empirical analysis of Romania by Arouri et al. (2012) also found that environmental regulations did not have a significant effect on total export trade. There is not necessarily a statistically significant logical relationship between environmental regulations and export trade (Harris et al., 2002).

Some scholars argue that the impact of environmental controls on export trade has to take into account a combination of factors. Larson et al. (2002), using data from the non-EU Mediterranean region, showed that the impact of environmental controls on exports depends on several aspects such as changes in input costs, the cost share of regulated factors, and industry profitability and changes in the supply of the industry.

Much of the current literature on the impact of environmental regulation on trade focuses on developed countries such as the US and Japan, with less research on developing countries such as China. Hering and Poncet (2014) used the export data from 265 cities in China to examine the impact of two control zone policies on exports. They found that environmental controls reduced exports in urban industries, especially polluting industries in cities. Exploiting double-differenced estimations across Chinese cities spanning intensified air pollution control enactments, Chen and Xu (2021) traced causal links between tightened regulations and export declines. Moreover, harnessing detailed firm-product data panels alongside differencing models, Zhang et al. (2020) concluded stricter Chinese environmental regulations diminish firm exporting propensities and values. Transmission channels encompass market entry/exit adjustments, price effects, destination switching and product transitions. Specifically, increasingly stringent wastewater abatement benchmarks deter new export market entrants vis-à-vis incumbents. Producer polluting firms can preserve relatively greater access via export price and volume adjustments. Correspondingly, Shi and Xu (2018) indicated regulatory tightening reduces firm export propensities and volumes within pollution-intensive industries - albeit with smaller influences on state-owned entities and central and western regions.

Scholars have analyzed the reasons behind why the relationship between environmental regulation and export trade has not reached a unified conclusion in empirical research. Ederington and Minier (2003) believed that the reason why previous studies did not find any significant impact of environmental regulation measures on trade flows was mainly that these studies generally regarded environmental regulation variables as exogenous given, ignoring that trade factors may affect the setting of a country's environmental regulation. Levinson and Taylor (2008) identified the problem of unobserved heterogeneity, the endogeneity of variables and the aggregation bias of macro data as reasons for the inability to confirm that environmental regulatory factors have a significant impact on international trade. Alpay et al. (2002) and Lanoie et al. (2008) argued that one possible reason why empirical studies of the impact of environmental regulation on exports have not reached a consensus conclusion was because of differences in the measurement of environmental regulation.

Obtaining reliable data on environmental regulation has been difficult due to the wide variation in the impact of different policy instruments (Busse, 2004). Ederington et al. (2005) looked for the reasons from an economic standpoint. They argued that the similarity of the level of environmental regulation among developed countries and the difficult migration of pollution intensive industries themselves were the reasons why previous studies could not draw a significant relationship between environmental regulation and trade. To sum up, according to the traditional trade theory, many factors, such as the intensity of production factors and technology will affect the flow of international trade. If these factors play a major role in the production decision-making process of manufacturers, the impact of environmental regulation factors on export trade will not be significant.

7.2.3 Environmental Regulations and Export Product Quality

Export product quality represents a pivotal enterprise competitiveness indicator (Bas and Strauss-Kahn, 2015), enabling market access and conferring revenue and wage advantages (Manova and Zhang, 2012). The State Council (2019) Guiding Opinions on Promoting High-Quality Trade Development further emphasize optimized structures and upgrading within Chinese quantitative growth objectives. Elucidating export quality determinants is of profound policy and theoretical importance.

Extant examinations predominantly concentrate upon intermediary trade liberalization (Bas and Strauss - Kahn, 2015), FDI (Anwar and Sun, 2018), exchange rates (Chen and Juvenal, 2016; Hu et al., 2021), intellectual property protections (Li et al., 2021; Song et al., 2021; Dong et al., 2022) and financing constraints (Fan et al., 2015). However, despite extensive considerations of environmental regulation impacts on trade volumes (Hering and Poncet, 2014; Shi and Xu, 2018; Zhang et al., 2020; Xie et al., 2022), export quality ramifications remain understudied (Deng et al., 2021). Theoretically, the latter constitutes a technological innovation proxy (Dechezleprêtre and Sato, 2017), generating uncertain regulatory outcomes.

Conventional perspectives argue stringency compliance burdens may crowd out R&D expenditures (Gray, 1987; Jaffe et al., 1995; Palmer et al., 1995; Greenstone, 2002), eroding innovation capacities and export quality potential. Exploiting inter-regional emissions control differentials under China's 11th Five-Year Plan, Deng et al. (2021) traced negative links between escalating strictness and export quality. However, abatement outlays merely represent singular tools for minimizing firm environmental footprints (Gutiérrez and Teshima, 2018). More exacting supervision could concurrently spur technological innovation to alleviate emissions through structural enhancements, thereby boosting competitiveness and export quality (Porter, 1996; Porter and Van Der Linde, 1995).

Separately, clean production mandates generated analogous quality upgrades, substantiating stringent regulation export benefits (Ji et al., 2022). Employing mediation analysis, Xie et al. (2020) empirically established those Chinese environmental regulations significantly promote manufacturing export quality upgrades. Driving mechanisms comprise process and product productivity enhancements, albeit with opposing intermediary influences. In conclusion, heterogeneous firms' abatement pathways shape export quality outcomes (Cherniwchan and Najjar, 2022). Whilst innovation-based compliance enhances quality through productivity and competitiveness gains, expenditure-centered responses may compromise innovation capacities and export quality (Deng et al., 2021). Therefore, further rigorous inquiries into export quality dynamics remain imperative.

7.3 Theoretical Analysis and Research Hypothesis

Environmental regulation can serve as a direct driving force for technological innovation (Du et al., 2021). As environmental regulations often set certain environmental standards, firms invest resources into the research, development, and innovation of environmental protection technologies to meet these standards. This direct driving effect can facilitate the rapid development and adoption of technologies. Environmental regulation can also indirectly promote technology innovation. When firms face stringent environmental regulations, they may realize the importance of environmental protection and start paying attention to environmental issues (Li and Gao, 2022). Such attention can prompt firms to conduct research, development, and technological innovation to reduce pollution and improve resource utilization efficiency.

Environmental regulation can improve the level of technology through innovation incentives. Governments can formulate policies to encourage firms to conduct R&D and technological innovation, for example, by providing financial support and tax incentives (Cai et al., 2020). These policies can reduce firms' R&D costs and increase enthusiasm, thereby promoting technological development (Wang et al., 2022). Environmental regulation can increase market competition pressures on firms. When firms face more stringent environmental regulations, they need to improve their own environmental standards to remain competitive. Such competitive pressures can prompt firms to engage in research, development and technological innovation to enhance their own environmental standards and competitiveness. Technological innovation is an important driving force for product exports and a key factor in improving product quality.

With the increase in environmental awareness and tightening of environmental regulations, consumer demand for products continues to rise. To meet market demand, firms need to continuously innovate and research and develop products with more environmental attributes, thereby gaining greater market share and consumer recognition, which in turn facilitates firms' export volume and product quality. Technological innovation enables firms to produce more distinctive and advantageous products, enhancing firms' competitiveness. By adopting more environmentally friendly production methods and materials, firms can make products with less cost and differentiation advantages, allowing them to secure more opportunities and advantages in the market, which in turn promotes firms' export volume and product quality. With heightened global environmental awareness and tightening international environmental regulations, international environmental cooperation is intensifying. By innovating technologies and conducting research and development, firms can obtain more international cooperation opportunities and market share, thereby facilitating firms' export volume and product quality.

Proposition 1: Environmental regulation can promote firms' export volume and product quality by facilitating firms' technological innovation.

The cost effect implies that environmental regulations, by increasing the production costs for businesses, result in a "crowding-out effect" on the input of production factors, thereby inhibiting the upgrade of export volume and product quality. Environmental regulations may require firms to pay more environmental costs such as emissions fees and environmental taxes, directly reducing firm cash flow (Wang et al., 2022). Meanwhile, increased environmental investments may also reduce short-term returns, further impacting firm cash flow. Environmental regulations increase the financing threshold for firms. Environmental regulations may compel firms to meet more stringent environmental standards and requirements, making it more difficult to obtain financing (Liu et al., 2021). Financial institutions may impose financing restrictions on firms that fail to meet environmental standards.

Environmental regulations can increase uncertainty for firms stemming from potential changes in environmental policies and updating of environmental technologies (Zhao and Wang, 2022). In response to environmental regulations, prior to production, companies strive to meet pollution emission and clean production standards by procuring cleaner raw materials and enhancing production processes and technologies to ensure compliance with environmental requirements. During production, companies invest in emission reduction equipment, increase the involvement of staff with expertise in environmental technologies, and allocate resources for employee training. To address pollution generated during the production process, companies implement measures such as increasing pollution treatment and waste recycling to minimize pollutant emissions. All these measures contribute to an increase in the production costs for companies. Faced with cost constraints, companies may undergo a reallocation of resources, reducing investments in areas such as technological research and development and wage levels. Furthermore, due to increased costs, companies might cut back on investments in production, research and development, and other capital inputs, potentially diminishing overall production efficiency and product quality. Additionally, environmental regulations can impact strategic decisions for companies. Firms may regard environmental regulations as factors influencing market entry or exit decisions. If environmental regulations become overly stringent, companies might choose to exit certain markets or reduce investments, thereby affecting both their exports and the quality of exported products.

Proposition 2: Environmental regulation can reduce firms' export volume and product quality by increasing their production cost.

7.4 Methodology

7.4.1 Model Specification

Based on the China Annual Survey of Industrial Firms Database and the China Customs Import and Export Data from 2000 to 2010, I propose to use the implementation of the 11th Five-Year Plan sulfur dioxide reduction policy in 2006 as a quasi-natural experiment and use TWFE model and continuous DID method to discuss the impact and micro mechanism on firm export performance.

$$export_{it} = \alpha + \beta_1 treat_c \times post_t + \beta_2 treat_c + \beta_3 post_t + \eta X_{it} + \gamma_i + \gamma_t + \varepsilon_{it} \tag{7.1}$$

Where, *i* represents the firm, and *t* represents the time, and *c* represents city. I use firm export volume and firm export product quality as the explained variables firm export performance. $treat_c \times post_t$ is a dummy variable, representing environmental regulation. $treat_c$ is the continuous grouping index of the treatment group and the control group and $post_t$ is a time dummy variable. X_{it} represents a set of control variables including firm level controls. γ_t is the year fixed effect, γ_i is the firm fixed effect, and ε_{it} is the random disturbance term. β_1 represents the impact of environmental regulation on firm export performance. Because I include year fixed effect, the $post_t$ indicator is collinear with the year dummies and drops out of the regression. So I can't report the coefficient of $post_t$.

7.4.2 Explanation of Variables

1. The dependent variable is firm export performance. I use firm export volume and firm export product quality to measure the firm export performance.

First, export volume is exported by the logarithm of the total amount of firm export value plus 1. The data come from the matching data of the China Annual Survey of Industrial Firms Database and the China Customs Import and Export Data. The specific merger process and results can be found in Section 3.4.3.

Table 7.1 reports the overall distribution of Chinese firms export volume from 2000 to 2010. It can be found that from 2000 to 2010, the mean, median, 25th percentile and 75th percentile of firm export volume all shows an increasing trend. Skewness is less than 0, indicating that the data distribution is left skewed, and there are fewer data to the left of the mean than to the right of the mean. The kurtosis of the normal distribution is 3, and the kurtosis of the firm export volume is greater than 3, indicating that the data is steeper than the normal distribution. It can be found from Figure 7.1 that the intensity of export value follows a normal distribution.

Table 7.1: Overall Distribution of Chinese Firm Export Volume from 2000 to 2010

Year	Mean	Medium	25% Percentiles	75% Percentiles	Std. Dev	Skewness	Kurtosis	Obs
2000	11.6846	11.9087	10.6997	12.8956	1.8721	-0.7946	4.6746	16,858
2001	11.7042	11.9007	10.7065	12.9108	1.8304	-0.7088	4.4450	19,864
2002	11.8340	12.0195	10.8516	12.9776	1.7603	-0.5885	4.2916	22,772
2003	11.9247	12.0880	10.9728	13.0670	1.7838	-0.6251	4.4595	27,395
2004	11.9758	12.1354	11.0273	13.0975	1.7441	-0.5999	4.4406	42,867
2005	12.1147	12.2784	11.1411	13.2621	1.7532	-0.5946	4.3617	44,292
2006	12.1794	12.3761	11.2154	13.3521	1.7993	-0.6669	4.4633	50,660
2007	13.3864	13.6698	12.1301	14.8359	2.1629	-0.5696	3.8130	61,883
2008	13.7614	14.0051	12.6305	15.1210	2.1056	-0.6297	4.2181	63,319
2009	13.5705	13.8330	12.4216	14.9532	2.1128	-0.6366	4.1352	55,112
2010	13.7707	14.0520	12.5984	15.1789	2.1396	-0.6382	4.0659	65,755
All	12.8420	12.9326	11.5489	14.2746	2.1426	-0.3327	3.7018	470,777

Data source: the matching data of the China Annual Survey of Industrial Firms Database and the China Customs Import and Export Data.

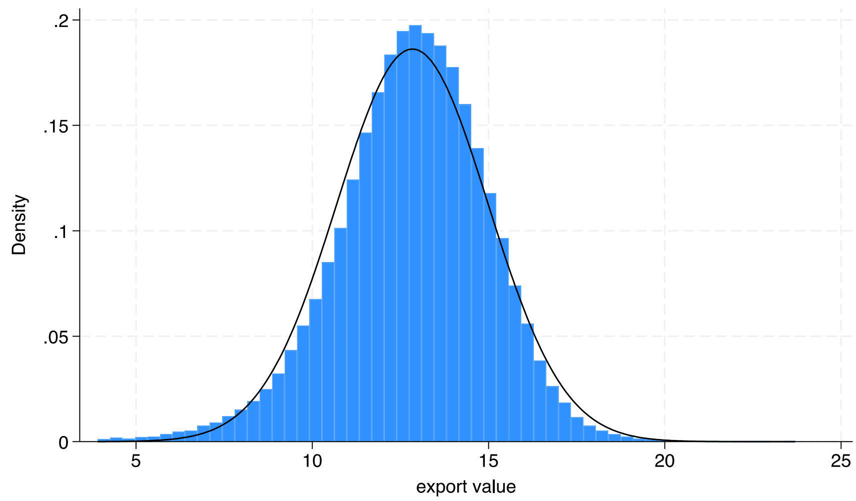

Figure 7.1: The Normal Distribution of Export Value

Secondly, I use the demand residual method to calculate the export product quality. The data come from the matching data of the China Annual Survey of Industrial Firms Database and the China Customs Import and Export Data.

Due to the lack of direct data on export product quality, it is difficult to measure the export product quality. With the enrichment of micro enterprise data, there is more and more research on enterprises' export product quality, and the measurement methods of product quality at the enterprise level are constantly enriched. In recent years, more and more scholars have used the demand residual method to calculate the export product quality. The demand residual method is required to assume that it is a residual factor explaining people's decision to buy something after price, quantity and destination have been taken into account. This method is a popular method to calculate enterprise product quality at present (Amiti and Khandelwal, 2013; Piveteau and Smagghue, 2019).

Following Joel (2011), Roberts et al. (2012) and Gervais (2015), I use the estimation between the price of export products and the sales volume to get the calculation formula as follows:

$$x_{ihdt} = quality_{ihdt}^{\sigma-1} \frac{p_{ihdt}^{-\sigma}}{P_{dt}^{1-\sigma}} Y_{dt} \tag{7.2}$$

x_{ihdt} represents the number of 6-digit HS code products exported by firm *i* to country *d* in year *t*; $p_{ihdt}^{-\sigma}$ represents the price of 6-digit HS code products exported by firm *i* to country *d* in year *t*; $P_{dt}^{1-\sigma}$ represents the price index of country *d* in year *t*; Y_{dt} represents the total income of country *d* in year *t*. According to Khandelwal, Schott and Wei (2013), the logarithm of the above equation was taken, and the residual term of OLS regression was used to estimate the quality of export products:

$$\ln(x_{ihdt}) + \sigma \ln(p_{ihdt}) = \xi_h + \varphi_{dt} + \varepsilon_{ihdt} \tag{7.3}$$

ξ_h is the product fixed effect, controlling the price of the product, and φ_{dt} is the year-destination country fixed effect, controlling p_{dt} and Y_{dt} in country *d*. Therefore, the quality of export product *h* of firm *i* exported to country *d* in year *t* is $quality_{ihdt} = \varepsilon_{ihdt} / (\sigma - 1)$.

In order to calculate the export product quality at the firm and year level, I conduct standardization treatment on the export product quality at the product level. The standardization treatment formula is as follows:

$$r_{quality_{ihdt}} = \frac{quality_{ihdt} - \min quality_h}{\max quality_h - \min quality_h} \tag{7.4}$$

minquality and *maxquality* respectively represent the minimum and maximum value of a certain HS product. The export quality of enterprises is obtained by taking the export amount as the weight and weighting it to the enterprise year level. Thus, the export product quality can be obtained.

Table 7.2 reports the overall distribution of Chinese firms export product quality from 2000 to 2010. It can be found that from 2000 to 2010, the mean, median, 25th percentile and 75th percentile of firm export product quality first increases and then decreases. Skewness is less than 0, indicating that the data distribution is left skewed, and there are fewer data to the left of the mean than to the right of the mean. The kurtosis of the firm export product quality is greater than 3, indicating that the data is steeper than the normal distribution. It can be found from Figure 7.2 that the intensity of export product quality follows a normal distribution.

Table 7.2: Overall Distribution of Chinese Firm Export Product Quality from 2000 to 2010

Year	Mean	Medium	25% Percentiles	75% Percentiles	Std. Dev	Skewness	Kurtosis	Obs
2000	0.5593	0.5676	0.4306	0.6971	0.1921	-0.2895	3.2502	16,858
2001	0.5662	0.5724	0.4395	0.7030	0.1922	-0.3269	3.9743	19,864
2002	0.5699	0.5744	0.4416	0.7052	0.1904	-0.2982	3.5443	22,772
2003	0.5667	0.5705	0.4401	0.7005	0.1884	-0.2534	3.2591	27,395
2004	0.5516	0.5575	0.4289	0.6864	0.1873	-0.3032	3.3129	42,867
2005	0.5405	0.5450	0.4168	0.6729	0.1853	-0.2412	3.1031	44,292
2006	0.5295	0.5341	0.4060	0.6618	0.1872	-0.2438	3.1574	50,660
2007	0.5166	0.5212	0.3918	0.6505	0.1901	-0.2651	3.3415	61,883
2008	0.4878	0.4920	0.3643	0.6212	0.1897	-0.2595	3.2613	63,319
2009	0.4900	0.4923	0.3587	0.6302	0.1967	-0.2421	3.4944	55,112
2010	0.4800	0.4841	0.3474	0.6206	0.1986	-0.2467	3.3945	65,755
All	0.5204	0.5255	0.3924	0.6575	0.1937	-0.2650	3.3354	470,777

Source: Analysis reported in this thesis.

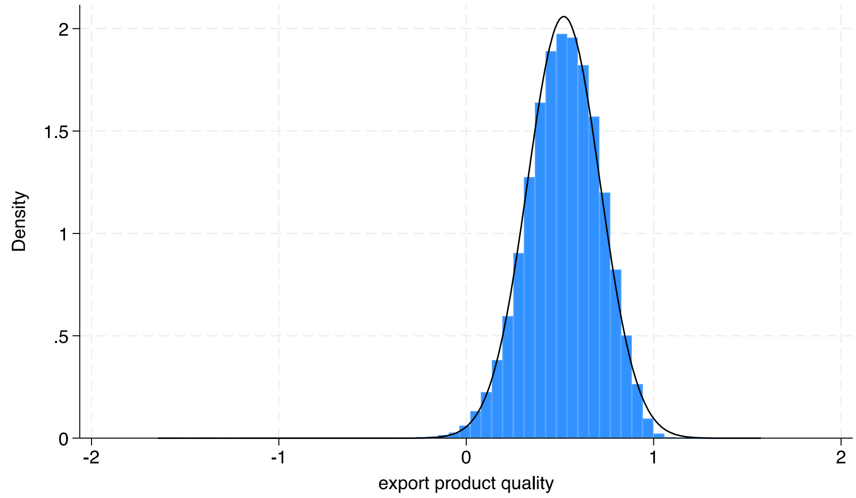

Figure 7.2: The Normal Distribution of Export Product Quality

2. Explanatory variable: Environmental regulations. $treat_c \times post_t$ is a dummy variable, representing environmental regulation. $treat_c$ is the continuous grouping index of the treatment group and the control group and $post_t$ is a time dummy variable.

3. Control variables. Drawing on Chen et al. (2022) and He and Tang (2023), I adopted the following control variables. (1) The firm age is measured by adding 1 to the logarithm of the difference between the current year and the year of the establishment of the enterprise. (2) The firm size is measured by the logarithm of the total assets. Compared with small enterprises, large enterprises have more capital and technological advantages. (3) The firm capital labor ratio is measured by the logarithmic value of the ratio between the net value of fixed assets and the number of employed persons. (4) The concentration ratio is measured by the Herfindahl-Hirschman Index of a four-digit industry. It is a comprehensive index that measures industrial concentration. It refers to the sum of squares of the percentage of total revenue or total assets of each market competitor in an industry, which is used to measure the change of market share, that is, the dispersion degree of manufacturer scale in the market. The smaller the value, the more intense the degree of industry concentration. (5) Industry size is measured by the logarithm of the four-digit industry employment scale. (6) State-owned firm is a dummy variable. If the ownership type of the firm is a state-owned firm, the variable is 1, otherwise is 0. (7) Foreign-owned firm is also a dummy variable. If the ownership type of the firm is a foreign-owned firm, the variable is 1, otherwise is 0. (8) Processing trade firm is a dummy variable. If the firm is a processing trade firm, the variable is 1, otherwise is 0.

4. Mechanism variables. (1) I use patent applications as the proxy variables for the firms' technology innovation. It includes the total number of patent applications and the number of invention patent applications. I use the number of patent applications and the number of invention patent applications plus 1 to measure innovation. (2) The firm production cost is measured by the sum of its main business costs and sales expenses.

This study selects the data of Chinese industrial firm from 2000 to 2010 as the research sample, I use the Chinese Industrial Enterprise Database (ASIF) and the China Customs Data (CCD). According to the Section 3.4, I processed and merged the two databases and finally got 470,777 samples. Table 7.3 is the variables' descriptive statistics.

Table 7.3: Variables Description

	Variable	Abbreviation	Mean	Std. Dev	Min	Max	Obs
Dependent variable	*export volume*	*ex_volume*	12.8420	2.1426	3.9120	23.6994	470,777
	export product quality	*ex_quality*	0.5204	0.1937	-1.6451	1.5724	470,777
Independent variable	$treat_c \times post_t$	$treat_c \times post_t$	1.9683	3.0295	0.0000	13.0190	470,777
Control variables	*firm age*	*age*	2.0424	0.6781	0.0000	5.1358	470,777
	firm size	*size*	5.2344	1.1477	2.0794	12.2009	470,777
	Capital labor ratio	*kl*	5.2197	1.1155	-8.6063	13.4100	470,777
	Concentration ratio	*hhi*	0.0007	0.0036	0.0002	1.0000	470,777
	Industry size	*size_ind*	2.4297	0.1317	0.7872	2.6664	470,777
	State-owned firm	*soe*	0.0409	0.1981	0.0000	1.0000	470,777
	Foreign-owned firm	*foe*	0.5165	0.4997	0.0000	1.0000	470,777
	processing trade firm	*trade*	0.7165	0.4507	0.0000	1.0000	470,777
Mechanism variables	*patent*	*patent*	0.4529	1.6121	0.0000	13.7036	470,631
	invention patent	*in_patent*	0.1934	1.0329	0.0000	13.6544	470,631
	cost	*cost*	0.1453	1.1764	0.0000	184.0535	404,896

Source: Analysis reported in this thesis.

7.5 Empirical Results and Analysis

In this section, I analyze the empirical results of environmental regulation on firm export performance. In section 7.5.1, I will analyze the basic regression results. In section 7.5.2, I will analyze the parallel trend test which verified the appropriateness of the DID model. In section 7.5.3, I will do a lot of robustness tests such as two-period double difference method, winsorize, eliminating other policy distractions, changing PPML method and using a relative target. In section 7.5.4, I will analyze the impact mechanism of environmental regulation on firm export performance from the innovation effect and the cost effect. In section 7.5.5, I will analyze the heterogeneity analysis which will include the different firm ownership, the different firm size, and the different regions.

7.5.1 Regression Analysis of the Basic Regression Model

This section uses a fixed effects model to examine the impact of environmental regulation on firm export performance. Table 7.4 columns (1)-(4) report the regression results of environmental regulations on firm export volume. In order to ensure the robustness of the regression results, I gradually controlled for the fixed effects of years and firms. Column (1) reports the results without controlling variables and only controlling for fixed effects for the year. Column (2) is an estimated result that only controls for fixed effects of the firm. I have considered both year fixed effects and firm fixed effects in column (3). Based on the regression results in column (3), I added all control variables in column (4). After controlling for firm fixed effects, time fixed effects, and control variables, the estimated coefficient of environmental regulation remains significantly positive, indicating that environmental regulation significantly promotes an increase in exports. The estimated coefficient of environmental regulation in column (4) is 0.0173 and it means that after 2006, for every additional unit of SO_2 emission reduction target, the export value of enterprises increases by 1.73%. Before 2006, the average export value after logarithm of a firm is 11.9253, and the average export value of a firm is ￥151040. After 2006, for every 1 unit increase in the SO_2 emissions reduction target, a 1.73% increase in average export value of a firm increased from ￥151040 to ￥153651, achieving an increase of ￥2611. After 2006, the average SO_2 emissions reduction target for a firm is 3.12 in the sample, so after the SO_2 emissions regulation, the average export value of a firm increased to ￥159186.32, achieving an increase of ￥8146.32. After 2006, there are 296729 firms from 2006-2010 in the sample, so the China's export value has an increase of ￥2417.25 million from 2006-2010. This result is consistent with the findings of Xie et al. (2022). Columns (5)-(8) report the regression results of environmental regulation on firm export product quality. Column (5) only controls the year fixed effects and column (6) only controls the firm fixed effects. The estimated coefficients of environmental regulation are significantly positive. Column (7) is an estimated result that controls year fixed effects and firm fixed effects. Based on the regression results in column (7), I added all firm control variables in column (8). The estimated coefficient of environmental regulation remains significantly positive, indicating that environmental regulation significantly promotes an increase in export product quality. The estimated coefficient of environmental regulation in column (8) is 0.0013 and it means that after 2006, for every additional unit of SO_2 emission reduction target, the export product quality of enterprises increases by 0.0013. Before 2006, the average export quality of a firm is 0.5560 in the sample. After 2006, for every 1 unit increase in the SO_2 emissions reduction target, a 0.0013 increase in average export quality of a firm increased from 0.5560 to 0.5573. After 2006, the average SO_2 emissions reduction target of a firm is 3.12 in my data, so after the SO_2 emissions regulation, the average export quality of a firm increased to 0.5601, achieving an increase of 0.0041. It is consistent with the findings of Jiang et al. (2023).

This conclusion also provides basic evidence for further exploring the impact of environmental regulations on firm export performance. One important reason is that environmental regulations can promote enterprises to innovate in environmental protection technology and production. In order to comply with environmental regulations and meet market demand, enterprises need to develop and apply more environmentally friendly production methods and materials. This can promote firms to develop more environmentally friendly and high-quality products, enhance their competitiveness in the international market, and thus promote firm export performance.

Table 7.4: DID Model Regression Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	ex_volume	*ex_volume*	*ex_volume*	*ex_volume*	*ex_quality*	*ex_quality*	*ex_quality*	*ex_quality*
$treat_c \times post_t$	0.0326***	0.2322***	0.0184***	0.0173***	0.0022***	0.0019***	0.0014***	0.0013***
	(19.3125)	(179.9801)	(14.0517)	(13.5015)	(13.4044)	(11.6294)	(12.9898)	(12.0825)
treat	-0.0044***	-0.1062***	-0.0172***	-0.0144***	-0.0071***	-0.0057***	-0.0012***	-0.0011***
	(-3.6887)	(-47.8841)	(-8.1942)	(-7.0543)	(-57.5109)	(-28.4431)	(-6.9971)	(-6.5650)
age				0.0670***				0.0003
				(8.4523)				(0.4359)
size				0.5463***				0.0003
				(83.6167)				(0.6893)
kl				0.1956***				-0.0021***
				(35.4565)				(-5.1114)
hhi				-0.3966				0.1292
				(-0.1972)				(1.0160)
size_ind				0.4245***				0.0204***
				(10.4633)				(6.3310)
soe				-0.0887***				-0.0009
				(-3.4068)				(-0.4268)
foe				0.0379***				0.0038***

				(3.6156)				(4.7144)
trade				-0.0564***				0.0002
				(-9.6442)				(0.3982)
Year FE	YES	NO	YES	YES	YES	NO	YES	YES
Firm FE	NO	YES	YES	YES	NO	YES	YES	YES
N	470,777	431,648	431,648	431,648	470,777	470,777	431,648	431,648
R-Square	0.1539	0.6887	0.7883	0.7957	0.0379	0.0484	0.8479	0.8480

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

7.5.2 Parallel Trend Test

This chapter examines whether there are differences in the distribution of firm export performance between the treatment group and the control group before and after 2006. To verify the appropriateness of the DID model, this part uses the event analysis method to test the common trend of the treatment group and the control group (Jacobson et al., 1993). Specifically, I add a series of dummy variables to the benchmark model (7.1) to establish the following model:

$$export_{it} = \alpha + \beta_1 D_{ct}^{-5} + \cdots + \beta_5 D_{ct}^{-1} + \beta_6 D_{ct}^{+1} + \cdots + \beta_{10} D_{ct}^{+5} + \eta X_{it} + \gamma_t + \gamma_i + \varepsilon_{it} \tag{7.5}$$

The estimated coefficient of D in the regression results represents whether there is a significant difference in the trend of firm export performance between the treatment group and the control group in the j years before and after the implementation of environmental regulation policy. I used the year (2005) before the environmental regulation policy was implemented as a control group (Bu and Ren, 2023). The regression estimation results and confidence intervals are shown in Figure 7.3 and Figure 7.4. Figure 7.3 describes the parallel trend test of the firm export volume, and Figure 7.4 describes the parallel trend test of the firm export product quality. In all figures, the horizontal axis represents the year since the implementation of environmental regulation policy, the vertical axis represents the size of the estimate, the hollow point is the estimated coefficient, and the dashed line is the 95% confidence interval.

In Figure 7.3, when j<0, 0 is within the confidence interval. It means the estimated coefficients are not significant at the 5% level, indicating that before the implementation of environmental regulation policy, there is no significant difference in the changing trend of firm export volume between the treatment group and the control group. Therefore, the DID model can be used to test the impact of environmental regulation on firm export volume. After the implementation of environmental regulation policy (when $j>0$), When $j=1$, the estimated coefficient is not significant at the 5% level. This shows that environmental regulations have a lag in promoting the firm export volume. When $j>1$, the estimated coefficient is greater than 0 and is significant at the significance level of 5%. This indicates that environmental regulations increase firm export volume. In Figure 7.4, when $j<0$, 0 is also within the confidence interval. It also means that the DID model can be used to test the impact of environmental regulation on firm export product quality. When $j>0$, 0 is not within the confidence interval. The estimated coefficient is greater than 0 and is significant at the significance level of 5%. This indicates that environmental regulations increase firm export product quality.

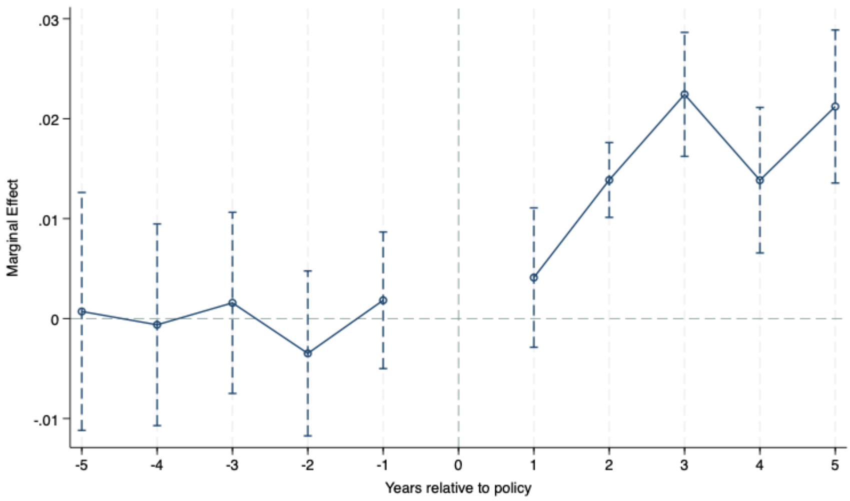

Figure 7.3: Parallel Trend Test on Firm Export Volume

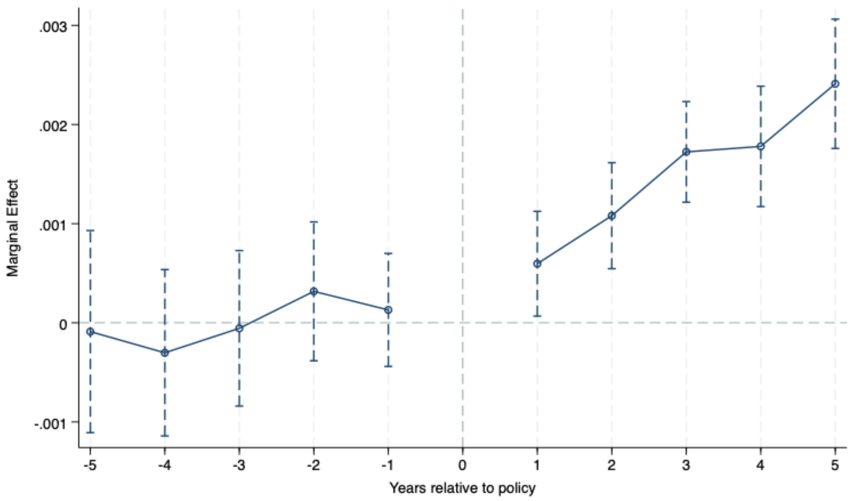

Figure 7.4: Parallel Trend Test on Firm Export Product Quality

7.5.3 Robustness Test

(1) Two-period double difference method. To deal with potential sequence related problems, I refer to the method of Bertrand et al. (2004) to construct a two-period DID method to re-estimate the formula (7.1). Specifically, I regard Year 2006 as a new time node and divide the sample period into two stages: 2000-2005 and 2006- 2010. In each period, I calculate the arithmetic average of the variables of each firm. The regression results are shown in Table 7.5. Columns (1)-(2) report the impact of environmental regulation on firm export volume. The estimated coefficients are still significantly positive at the 1% statistical level, indicating environmental regulation policy can effectively increase firm export volume. Columns (3)-(4) report the impact of environmental regulation on firm export product quality. The estimated coefficients of environmental regulation remain significantly positive, indicating environmental regulation policy can effectively increase firm export product quality. This method verifies the robustness of the basic regression results.

Table 7.5: Two-Period Double Difference Method Results

Variable	(1)	(2)	(3)	(4)
	export volume	*export volume*	*export product quality*	*export product quality*
$treat_c \times post_t$	0.0284***	0.0258***	0.0004***	0.0003*
	(13.0320)	(12.3521)	(2.7406)	(1.9131)
treat	0.1217***	0.1258***	-0.0114***	-0.0108***
	(10.9778)	(11.2022)	(-14.6393)	(-13.3353)
age		0.3769***		-0.0093***
		(16.0901)		(-5.8928)
size		0.8710***		-0.0014
		(53.1764)		(-1.2051)
kl		0.4141***		-0.0094***
		(27.2668)		(-8.4174)
hhi		-17.8680**		1.3364***
		(-2.2074)		(3.0682)
size_ind		1.1233***		0.0174*
		(8.6016)		(1.8973)
soe		-0.0338		0.0007
		(-0.4757)		(0.1533)
foe		0.0440*		0.0034**
		(1.8439)		(2.0696)
trade		0.0020		-0.0054***
		(0.0894)		(-3.2664)
Year FE	YES	YES	YES	YES

Firm FE	YES	YES	YES	YES
N	87,464	87,464	87,464	87,464
R-Square	0.8528	0.8672	0.9077	0.9081

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(2) Winsorize method. To rule out the effect of extreme outliers, I narrow the 1% and 99% quantiles of all continuous variables in the sample. The regression results are shown in Table 7.6. Columns (1)-(2) report the impact of environmental regulation on firm export volume and columns (3)-(4) report the impact of environmental regulation on firm export product quality. The estimated coefficients are still significantly positive at the 1% statistical level, indicating environmental regulation policy can effectively increase firm export performance.

Table 7.6: Winsorize Method

Variable	(1)	(2)	(3)	(4)
	export volume	*export volume*	*export product quality*	*export product quality*
$treat_c \times post_t$	0.0170***	0.0160***	0.0014***	0.0013***
	(13.4878)	(12.9980)	(13.3905)	(12.4544)
treat	-0.0160***	-0.0131***	-0.0012***	-0.0011***
	(-7.8489)	(-6.5644)	(-7.4187)	(-6.9352)
age		0.0689***		0.0004
		(9.0075)		(0.5954)
size		0.5348***		0.0004
		(84.5841)		(0.8513)
kl		0.1948***		-0.0020***
		(36.0349)		(-4.9242)
hhi		-64.6779***		1.6638***
		(-10.0523)		(3.3143)
size_ind		0.3701***		0.0239***
		(9.1758)		(7.3659)
soe		-0.0948***		-0.0005
		(-3.8381)		(-0.2631)
foe		0.0256**		0.0040***
		(2.5369)		(5.0842)
trade		-0.0653***		-0.0000
		(-11.5271)		(-0.0077)
Year FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
N	431,648	431,648	431,648	431,648
R-Square	0.7906	0.7980	0.8518	0.8518

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **,

*** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(3) Eliminating other policy distractions. The environmental policies implemented during the sample period may have an impact on the firm export performance, especially the typical emission trading policy. Therefore, I add the interaction terms of dummy variables of the emission trading policy treatment group and the policy time dummy variables to eliminate the interference of parallel policies on the estimated results of this research. The regression results are shown in Table 7.7. Columns (1)-(2) report the impact of environmental regulation on firm export volume and columns (3)-(4) report the impact of environmental regulation on firm export product quality. The estimated coefficients are still significantly positive at the 1% statistical level, indicating the estimated results are robust, that is, environmental regulation policy can effectively increase firm exports.

Table 7.7: Eliminate Other Policy Distractions

Variable	(1)	(2)	(3)	(4)
	export volume	*export volume*	*export product quality*	*export product quality*
$treat_c \times post_t$	0.0176***	0.0160***	0.0015***	0.0015***
	(13.3989)	(12.5030)	(14.1048)	(14.1048)
SO_2 rights trading policy	-0.0477***	-0.0772***	0.0141***	0.0141***
	(-5.0461)	(-8.2659)	(19.4210)	(19.4210)
treat	-0.0177***	-0.0152***	-0.0009***	-0.0009***
	(-8.4555)	(-7.4359)	(-5.6806)	(-5.6806)
age		0.0671***	0.0002	0.0002
		(8.4664)	(0.3956)	(0.3956)
size		0.5473***	0.0001	0.0001
		(83.6611)	(0.2962)	(0.2962)
kl		0.1973***	-0.0024***	-0.0024***
		(35.7061)	(-5.8930)	(-5.8930)
hhi		-0.3621	0.1229	0.1229
		(-0.1814)	(0.9606)	(0.9606)
size_ind		0.4241***	0.0204***	0.0204***
		(10.4543)	(6.3541)	(6.3541)
soe		-0.0905***	-0.0005	-0.0005
		(-3.4761)	(-0.2631)	(-0.2631)
foe		0.0378***	0.0038***	0.0038***
		(3.5994)	(4.7544)	(4.7544)
trade		-0.0617***	0.0011**	0.0011**
		(-10.4637)	(2.4762)	(2.4762)
Year FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES

N	431,648	431,648	431,648	431,648
R-Square	0.7884	0.7957	0.8482	0.8482

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(4) PPML method. Due to the presence of many zero values in international trade data, the mainstream practice in academia is to add 1 to the original trade value and take the logarithm, resulting in partial distortion of trade data. Therefore, in the field of international trade research, zero trade issues are an important factor that interferes with the authenticity of regression conclusions. This part uses the PPML method developed by Silva and Tenreyro (2006) to address the estimation bias caused by zero trade issues. They presented a simple way of dealing with the heteroscedasticity problem. They show that if the model contains the correct set of explanatory variables, the PPML estimator provides consistent estimates of the original non-linear model. It is precisely the same as running a type of non-linear least squares on the original equation. The results are shown in Table 7.8. Columns (1)-(2) report the impact of environmental regulation on firm export volume and columns (3)-(4) report the impact of environmental regulation on firm export product quality. It can be found that after considering the issue of zero trade, environmental regulations still significantly promote the increase of firm exports, indicating that the benchmark regression results are reliable.

Table 7.8: PPML Method

Variable	(1)	(2)	(3)	(4)
	export volume	*export volume*	*export product quality*	*export product quality*
$treat_c \times post_t$	0.0014***	0.0014***	0.0016***	0.0015***
	(15.7458)	(15.4857)	(8.4789)	(7.7471)
treat	-0.0015***	-0.0012***	-0.0009***	-0.0007**
	(-10.7490)	(-9.1986)	(-2.9640)	(-2.5133)
age		0.0058***		0.0001
		(10.5641)		(0.0662)
size		0.0403***		0.0009
		(90.4555)		(1.1202)
kl		0.0144***		-0.0029***
		(38.2117)		(-4.1365)
hhi		-0.1038		0.1204
		(-0.5876)		(0.6875)
size_ind		0.0367***		0.0476***
		(12.8465)		(8.8948)
soe		-0.0066***		-0.0028

		(-3.5989)		(-0.8164)
foe		0.0023***		0.0052***
		(3.2195)		(3.7665)
trade		-0.0068***		-0.0006
		(-17.6011)		(-0.7369)
Year FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
N	431,648	431,648	431,175	431,175
Pseudo R-Square	0.0582	0.0587	0.0415	0.0415

Note: Using PPLM model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(5) Using a relative target. I use the percentage of reduction to test whether the basic regression results are robust. The regression results are reported in Table 5.5. The estimated coefficients are still significantly positive at the 1% statistical level, indicating the estimated results are robust, that is, environmental regulation policy can effectively increase the export. This result is consistent with the findings of Qi and Cheng (2022).

Table 7.9: Using a Relative Target

Variable	(1)	(2)	(3)	(4)
	export volume	*export volume*	*export product quality*	*export product quality*
$treat_c \times post_t$	0.0119***	0.0111***	0.0010***	0.0009***
	(9.6388)	(9.1626)	(9.7756)	(8.9261)
treat	-0.0010	0.0007	0.0001	0.0000
	(-0.5837)	(0.3775)	(0.3964)	(0.3048)
age		0.0675***		0.0003
		(8.5218)		(0.4991)
size		0.5461***		0.0003
		(83.5826)		(0.6646)
kl		0.1941***		-0.0022***
		(35.2154)		(-5.3326)
hhi		-0.3942		0.1293
		(-0.1958)		(1.0138)
size_ind		0.4300***		0.0207***
		(10.5975)		(6.4478)
soe		-0.0867***		-0.0008
		(-3.3301)		(-0.3715)
foe		0.0409***		0.0039***
		(3.8931)		(4.9178)
trade		-0.0561***		0.0002
		(-9.5886)		(0.4490)

Year FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
N	431,648	431,648	431,648	431,648
Pseudo R-Square	0.7883	0.7957	0.8479	0.8480

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

7.5.4 Estimation Results of Influence Mechanism

The basic results empirically analyzed the direct influence of environmental regulatory policies on firm export performance. Based on this result, the mechanism through which environmental regulations impact firm product exports was further examined. As suggested by the preceding theoretical analysis, environmental regulations can potentially influence firm export performance through technology innovation and production cost.

Environmental regulatory policies directly incentivize firm research and development investment, and may improve technology innovation capacity in the short-term (Borsatto and Amui, 2019). Therefore, I first analyzed the influence mechanism from the angle of technological innovation. Columns (1)-(2) in Table 7.9 report the regression results of technology innovation. The logarithmic value of firm patents and invention patents plus one are utilized as a proxy variable for firm innovation capacity to empirically examine the impact of environmental regulations on firm innovation. As exhibited in columns (1) and (2) of Table 7.10, the estimated coefficients of the interaction term are significantly positive, indicating that environmental regulations exert a markedly positive effect on firm technology innovation. The estimated coefficient in column (2)-(3) are 0.0083 and 0.0074 which mean that after 2006, for every 1 unit increase in SO_2 emission reduction target, firm patents and firm invention patents increase by 0.83% and 0.74%. Environmental regulations impose pressure on firm eco-friendly behaviors, which can stimulate firms to pursue technological innovation (Liu et al., 2021). To comply with environmental laws and satisfy market demand, firms need to research and implement more environmentally friendly production methods and materials, which can promote the development of products with enhanced environmental attributes and higher quality, thereby increasing market competitiveness (Peng et al., 2021). Additionally, environmental regulations can provide economic incentives to facilitate innovation, such as preferential tax policies and subsidies to improve economic returns, thus further propelling firm technology innovation.

Furthermore, production cost was analyzed as a mechanism variable in the influence mechanism of environmental regulations on firm exports. As shown in column (3) of Table 7.10, the coefficient of the interaction term is significantly positive, demonstrating that environmental regulations can decrease firm exports by increasing firm production cost. The estimated coefficient in column (3) is 0.0023 and it means that after 2006, for every 1 unit increase in SO_2 emission reduction target, firm production costs increase by 0.23%. Environmental regulation will lead to the decrease of firm exports through the increase of production cost (Van Beers and Van Den Bergh, 1996). Specifically, environmental regulation will undoubtedly lead firms to increase investment in production technology to meet strict environmental protection standards, such as purchasing emission-reduction equipment and improving high-pollution production technology lines and so on. It will internalize the production environmental costs of products and lead to an increase in firm export costs, which is not conducive for firms to expand export (Cole et al., 2005).

Table 7.10: The Results of Influence Mechanism (1)

Variable	(1)	(2)	(3)
	patent	*invention patent*	*cost*
$treat_c \times post_t$	0.0083***	0.0074***	0.0023**
	(8.1185)	(7.2610)	(2.0203)
treat	0.0114***	-0.0106***	-0.0030
	(12.4468)	(-6.3981)	(-1.4821)
age	0.0036	-0.0718***	-0.0277***
	(1.0321)	(-11.6237)	(-4.5783)
size	0.3282***	0.1462***	0.2039***
	(116.0205)	(29.8813)	(19.5549)
kl	0.2186***	0.0862***	0.1087***
	(93.8133)	(21.9032)	(17.2513)
hhi	-2.5852	2.0285	-1.1032
	(-1.1409)	(1.2012)	(-1.3670)
size_ind	-0.7240***	0.0814***	0.1162***
	(-40.0202)	(3.0355)	(5.5365)
soe	0.3347***	0.0490*	0.0931***
	(18.4772)	(1.9554)	(3.6207)
foe	-0.2296***	-0.0109	0.0094*
	(-47.5628)	(-1.4020)	(1.8484)
trade	0.0634***	-0.0210***	0.0168***
	(12.3012)	(-4.7174)	(3.7205)
Year FE	YES	YES	YES
Firm FE	YES	YES	YES
N	470,631	431,497	372,340

R-Square	0.0963	0.5200	0.7931

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

As exhibited in columns (1) and (2) of Table 7.10, the estimated coefficients of the interaction term are 0.0043 and 0.0074, which are significantly positive at the 1% statistical level. As shown in column (3), the estimated coefficient of the interaction term is 0.0023, which is significantly positive at the 5% statistical level. By comparing the regression results of firm technology innovation and firm cost, it can be found that the size and significance of the estimated coefficient of innovation are greater than that of cost. To sum up, in the examination of the two channels of firm technology innovation and firm production cost, I find that firm technology innovation is an important channel for firm exports, and environmental regulation has a favorable impact on firm exports by promoting enterprise innovation.

The estimated coefficients of the mediating variables (enterprise patents, invention patents) in column (1)-(4) of Table 7.11 are significantly positive, indicating that the increase in enterprise patents and invention patents has improved the export scale and product quality of enterprises. Based on the estimation results in columns (1) - (2) of Table 7.10, it can be found that SO_2 emission reduction target can increase the export volume and product quality of enterprises by increasing invention patents and enterprise costs. Both the absolute magnitude and statistical significance of the interaction terms about the export volume in column (1) and (3) of Table 7.11 exhibit a discernible decrease compared to the baseline regression results in columns (4) of Table 7.4 (0.0173). When I control the innovation effect, environmental regulations have less impact on export volume, which provides empirical support for the existence of the innovation effects. And both the absolute magnitude and statistical significance of the interaction terms about the export product quality in column (2) and (4) of Table 7.11 exhibit a discernible decrease compared to the baseline regression results in columns (8) of Table 7.4 (0.0013). When I control the innovation effect, environmental regulations have less impact on export products quality, which provides empirical support for the existence of the innovation effects.

In addition, the estimated coefficient of the mediator variable (enterprise cost) in column (5)-(6) of Table 7.11 are significantly negative, indicating that the increase in enterprise cost reduces the export volume and product quality of the enterprise. Based on the estimation results in column (3) of Table 7.10, it can be found that SO_2 emission reduction target can reduce the export scale and product quality of enterprises by increasing their costs. Both the absolute magnitude and statistical significance of the interaction terms about the export volume in column (5) of Table 7.11 exhibit a discernible increase compared to the baseline regression results in columns (4) of Table 7.4 (0.0173). When I control the cost effect, the impact of environmental regulation on the quality of export volume becomes greater, which provides empirical support for the existence of the cost effect. And both the absolute magnitude and statistical significance of the interaction terms about the export product quality in column (6) of Table 7.11 exhibit a discernible increase compared to the baseline regression results in columns (8) of Table 7.4 (0.0013). When I control the cost effect, the impact of environmental regulation on export products quality becomes greater, which provides empirical support for the existence of the cost effect.

Table 7.11: The Results of Influence Mechanism (2)

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	export volume	*export quality*	*export volume*	*export quality*	*export volume*	*export quality*
$treat_c \times post_t$	0.0172***	0.0010***	0.0170***	0.0009***	0.0176***	0.0015***
	(13.4837)	(12.0713)	(13.3340)	(12.0252)	(11.4446)	(10.1488)
patent	0.0257***	0.0005***				
	(15.6007)	(3.6497)				
invention patent			0.0310***	0.0008***		
			(12.0513)	(3.5963)		
cost					-0.0251***	-0.0004***
					(-6.6950)	(-3.2319)
treat	-0.0142***	-0.0011***	-0.0141***	-0.0011***	-0.0111***	-0.0014***
	(-6.9393)	(-6.5321)	(-6.9000)	(-6.5120)	(-5.2251)	(-8.3350)
age	0.0689***	0.0003	0.0692***	0.0003	0.0567***	0.0005
	(8.7016)	(0.5267)	(8.7387)	(0.5567)	(6.7970)	(0.7447)
size	0.5392***	0.0002	0.5418***	0.0002	0.5123***	-0.0011**
	(82.4484)	(0.3897)	(82.8797)	(0.4461)	(71.9085)	(-2.2281)
kl	0.1915***	-0.0022***	0.1929***	-0.0022***	0.1738***	-0.0031***
	(34.7159)	(-5.2915)	(34.9650)	(-5.2647)	(28.8661)	(-6.9063)
hhi	-0.4525	0.1276	-0.4559	0.1272	-0.6558	0.2351*
	(-0.2248)	(0.9994)	(-0.2263)	(0.9948)	(-0.2583)	(1.6926)
size_ind	0.4212***	0.0203***	0.4228***	0.0203***	0.3898***	0.0149***
	(10.3852)	(6.3157)	(10.4246)	(6.3213)	(9.0438)	(4.4066)
soe	-0.0907***	-0.0009	-0.0907***	-0.0009	-0.0792***	-0.0013
	(-3.4860)	(-0.4528)	(-3.4841)	(-0.4565)	(-2.9719)	(-0.6040)
foe	0.0383***	0.0038***	0.0383***	0.0038***	0.0460***	0.0035***
	(3.6516)	(4.7231)	(3.6543)	(4.7265)	(4.2179)	(4.2545)
trade	-0.0555***	0.0002	-0.0558***	0.0002	-0.1008***	0.0011**
	(-9.4888)	(0.4273)	(-9.5332)	(0.4238)	(-14.4536)	(1.9750)

Year FE	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
N	431,497	431,497	431,497	431,497	372,340	372,340
R-Square	0.7959	0.8480	0.7958	0.8480	0.7995	0.8566

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

7.5.5 Heterogeneity Analysis

(1) Firm ownership. Subgroup regressions were utilized to analyze the impact of environmental regulatory policy implementation on enterprises with disparate ownership structures (Shi and Xu, 2018). I have standardized the data using Z-score standardization method (Vaccario et al., 2017). Table 7.12 documents the regression outcomes for firms with differing ownership. Columns (1)-(2) report the impact of environmental regulation on firm export volume. The estimated coefficient for state-owned enterprises (SOEs) is significantly positive at the 5% statistical level, and the estimated coefficient for non-state-owned enterprises (non-SOEs) is significantly positive at the 1% statistical level. The estimated coefficient in column (1)-(2) are 0.0094 and 0.0081 which mean that after 2006, for every 1 unit increase in SO_2 emission reduction target, SOEs export volume increases by 0.94% and non-SOEs export volume increases by 0.81%. Columns (3)-(4) report the impact of environmental regulation on firm export product quality. The estimated coefficient for SOEs is insignificant, but the estimated coefficient for non-SOEs is markedly significant. The estimated coefficient in column (4) is 0.0067 and it means that after 2006, for every 1 unit increase in SO_2 emission reduction target, non-SOEs export product quality increases by 0.0067. It can be deduced that environmental regulations elevate firm export amongst non-SOEs, but exert no discernible impact on SOEs.

The main reason is, a predominant distinction between SOEs and non-SOEs lies in the degree of administrative intervention (Lin et al., 2023; Wang et al., 2022). SOEs naturally maintain close government ties and the attribute of public property makes the SOEs have the double loss of production efficiency and innovation efficiency. When environmental regulations are implemented, the innovation performance of SOEs cannot be effectively improved, which is not conducive to firm exports. In contrast, non-SOEs typically encounter more intense market competition, compelling a stronger emphasis on innovation and market demand in production and exports. Non-SOEs continue to increase investment in research and development and improve innovation capabilities, thus boosting firm exports.

Table 7.12: Heterogeneity Analysis of Firm Ownership

Variable	(1)	(2)	(3)	(4)
	export volume	*export volume*	*export product quality*	*export product quality*
	State-owned firms	Non-state-owned firms	State-owned firms	Non-state-owned firms
$treat_c \times post_t$	0.0094**	0.0081***	0.0036	0.0067***
	(2.4424)	(13.4266)	(0.9415)	(12.2179)
treat	-0.0146	-0.0066***	0.0068	-0.0059***
	(-1.5999)	(-6.8624)	(0.7968)	(-6.8517)
age	0.0055	0.0376***	0.0203	0.0025
	(0.2965)	(9.9538)	(1.0325)	(0.7944)
size	0.2433***	0.2598***	0.0538***	0.0007
	(10.6542)	(84.6938)	(2.7207)	(0.3032)
kl	0.1335***	0.0929***	0.0082	-0.0105***
	(6.3931)	(35.9268)	(0.3830)	(-4.9214)
hhi	1.6491	-0.5408	-1.7518***	1.1810*
	(1.3060)	(-0.4783)	(-3.2403)	(1.6839)
size_ind	0.4435***	0.1868***	0.0674	0.1054***
	(3.5268)	(9.6832)	(0.5953)	(6.2408)
foe	-0.0096	0.0181***	0.0429	0.0185***
	(-0.1973)	(3.6514)	(1.0185)	(4.4252)
trade	-0.1193***	-0.0227***	0.0789***	-0.0010
	(-6.1556)	(-8.2637)	(4.1046)	(-0.4302)
Year FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
N	16,416	413,548	16,416	413,548
R-Square	0.7873	0.7978	0.8155	0.8510

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(2) Firm size. To analyze the heterogeneous impacts of environmental regulations on firm scale, firms are bifurcated into large-scale and small-scale groups vis-à-vis the median firm size. I have standardized the data using Z-score standardization method. Table 7.13 documents the regression outcomes for firms of differing sizes. Columns (1)-(2) report the impact of environmental regulation on firm export volume and columns (3)-(4) report the impact of environmental regulation on firm export product quality. The estimated coefficients for large-scale firms and small-scale firms are markedly significant, but the coefficient size and t-value size of large-scale firms are larger than that of small-scale firms. The estimated coefficient in column (3)-(4) are 0.0089 and 0.0033 which mean that after 2006, for every 1 unit increase

in SO_2 emission reduction target, large-scale firm export product quality increases by 0.0089 and small - scale firm export product quality increases 0.0033. It shows that environmental regulations were discovered to exert more pronounced positive influences on firm exports amongst large firms.

The main reason is, large-scale firms customarily possess superior resources and production capacity for channeling greater investments into product R&D, manufacturing, marketing, etc., and can diminish per unit production costs via economies of scale (Lin et al., 2022). Therefore, environmental regulations more profoundly promote exports across large firms. Additionally, large firms generally boast superior technological and economic prowess to better adapt to environmental regulatory demands through technological innovation and product R&D for enhanced compliance with product standards (Hong et al., 2021). Large firms often maintain closer government ties for better cognizance and adaptation towards environmental protection policies and regulations, hence securing elevated policy support and incentives more readily.

Table 7.13: Heterogeneity Analysis of Firm Size

Variable	(1)	(2)	(3)	(4)
	export volume	*export volume*	*export product quality*	*export product quality*
	Large-scale firms	Small-scale firms	Large-scale firms	Small-scale firms
$treat_c \times post_t$	0.0078***	0.0075***	0.0089***	0.0033***
	(9.0206)	(8.3100)	(10.8418)	(3.9578)
treat	-0.0037***	-0.0111***	-0.0096***	0.0002
	(-2.7938)	(-7.4465)	(-7.9085)	(0.1736)
age	0.0401***	0.0486***	0.0028	-0.0011
	(7.5717)	(8.3375)	(0.5869)	(-0.2183)
size	0.3224***	0.2581***	0.0122***	-0.0012
	(61.7917)	(49.8162)	(2.7054)	(-0.2720)
kl	0.1017***	0.0985***	-0.0164***	-0.0084***
	(26.0945)	(26.0879)	(-4.7726)	(-2.6142)
hhi	-1.0673	-0.4653	-0.8375**	2.3636***
	(-0.6500)	(-0.2978)	(-2.1752)	(2.9319)
size_ind	0.2377***	0.1608***	0.1841***	0.0157
	(8.6562)	(5.5324)	(7.4421)	(0.6205)
soe	-0.0116	-0.0438**	0.0111	-0.0258
	(-0.7377)	(-2.0762)	(0.7823)	(-1.3580)
foe	0.0295***	0.0096	0.0342***	0.0051
	(4.2049)	(1.2895)	(5.6682)	(0.8054)
trade	-0.0316***	-0.0311***	-0.0014	0.0092***
	(-8.0798)	(-7.5169)	(-0.3938)	(2.6017)
Year FE	YES	YES	YES	YES

Firm FE	YES	YES	YES	YES
N	214,167	201,222	214,167	201,222
R-Square	0.8096	0.7759	0.8508	0.8616

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

(3) Regional heterogeneity. To analyze the regional heterogeneity of environmental regulatory impacts, the sample was bifurcated into eastern, central and western regions and analyzed the heterogeneity of different samples by using sub-sample regression. I have standardized the data using Z-score standardization method. The regression outcomes are exhibited in Table 7.14. Columns (1)-(3) report the impact of environmental regulation on firm export volume. The estimated coefficients on the interaction term are significantly positive across eastern regions and western regions yet insignificant beyond. Columns (4)-(6) report the impact of environmental regulation on firm export product quality. The estimated coefficients on the interaction term are significantly positive across eastern regions and western regions but significantly negative across central regions.

The main reason is, relative to central areas, eastern China boasts superior economic development, marketization, and international market integration (Wang et al., 2022). Therefore, eastern firms possess greater resources and capabilities to pursue production, technological innovation, and product R&D (Sun et al., 2023), more readily satisfying international environmental standards and market demand for pronounced product export advantages (Chen et al., 2022). The eastern industrial structure favors high-tech and service industries, whereas central areas concentrate on heavy industry and resource-based sectors. Such disparities in industrial composition engender differences in environmental pressures and market demand, thereby influencing the efficacy of environmental regulations in promoting exports across regions. According to the emission reduction targets issued to provinces by the central government, many provinces in the western regions have not set emission reduction targets, which allows some firms to take advantage of this loophole. Relative to central areas, the emission reduction targets can promote firm exports in the western regions.

Table 7.14: Heterogeneity Analysis of Different Region

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	export volume	*export volume*	*export volume*	*export product quality*	*export product quality*	*export product quality*

	Eastern region	Central region	Western region	Eastern region	Central region	Western region
$treat_c \times post_t$	0.0076***	0.0197	0.0216***	0.0065***	-0.0340***	0.0212***
	(12.5776)	(1.4405)	(4.1673)	(11.7142)	(-2.6600)	(4.8811)
treat	-0.0064***	-0.0258	-0.0161	-0.0061***	0.0335*	-0.0089
	(-6.6635)	(-1.4230)	(-0.7337)	(-7.0936)	(1.9281)	(-0.4022)
age	0.0307***	0.0462***	0.0063	0.0035	0.0006	-0.0575***
	(7.8236)	(3.2249)	(0.2961)	(1.0495)	(0.0451)	(-2.9817)
size	0.2597***	0.2534***	0.2453***	0.0019	-0.0168	0.0285
	(81.7359)	(17.3464)	(11.7647)	(0.7786)	(-1.2979)	(1.4823)
kl	0.0936***	0.0899***	0.1056***	-0.0089***	-0.0280**	-0.0497***
	(34.8496)	(7.5830)	(6.0414)	(-4.0466)	(-2.4704)	(-2.8662)
hhi	-0.7318	2.2543**	4.4593	0.8652	-1.0184*	11.7284**
	(-0.6101)	(2.3926)	(1.1365)	(1.2172)	(-1.8132)	(2.2370)
size_ind	0.1841***	0.3840***	0.3965***	0.0941***	0.1699*	0.4710***
	(9.3529)	(3.6355)	(3.2904)	(5.4945)	(1.8580)	(3.8261)
soe	-0.0385***	-0.0063	-0.0546	0.0011	0.0224	-0.1047**
	(-2.8349)	(-0.1608)	(-1.3441)	(0.0897)	(0.7820)	(-2.4745)
foe	0.0158***	0.0513*	0.0340	0.0203***	0.0037	0.0173
	(3.1565)	(1.8293)	(0.9320)	(4.7795)	(0.1611)	(0.5644)
trade	-0.0266***	-0.0211	-0.0404*	-0.0020	0.0421***	0.0497**
	(-9.4842)	(-1.4110)	(-1.9055)	(-0.8416)	(2.9371)	(2.3472)
Year FE	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
N	396,593	22,371	12,004	396,593	22,371	12,004
R-Square	0.7978	0.7603	0.7631	0.8493	0.8303	0.8400

Note: Using TWFE model and continuous DID method. *Year FE* is year fixed effect, *Firm FE* is firm fixed effect. *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

7.6 Chapter Summary

This chapter sought to analyse whether or not the implementation of environmental regulation could affect Chinese exports. From the qualitative and quantitative point of view, I adopted the firm export volume and firm export product quality to measure firm export performance. I first analyzed the relationship between environmental regulation and firm export from the theoretical viewpoint. Theory suggests environmental regulation can promote firm exports by facilitating firm technology innovation but decrease firm exports by increasing firm production costs.

On this basis, this chapter used data from the Chinese Industrial Enterprise Database and China Customs Data from 2000 to 2010 and analyzed the impact of environmental regulatory policies on firm exports using the TWFE model and continuous DID method. I take the implementation of the Eleventh Five-Year Plan in 2006 as a quasi-natural experiment. The research results are as follows. The implementation of the Eleventh Five-Year Plan strengthened environmental regulation, and environmental regulatory policies promoted China's firm export volume and firm export product quality. This conclusion remains valid after a series of robustness tests. I also examined potential impact pathways and heterogeneity from multiple perspectives. The promotion effect of firm technology innovation on firm exports is greater than the inhibition effect of firm production cost on firm exports. Therefore, this promoting effect is mainly attributed to the increased firm innovation capability. Heterogeneity results indicate that environmental regulations have a greater promotion effect on firm exports for non-state-owned enterprises, large-scale enterprises, and enterprises in eastern and western regions of China.

8 Conclusion

As the largest developing country, China has created miraculous economic growth since reform and opening up. However, the accompanying increasingly severe ecological and environmental pollution has restricted economic development. In fact, the government has formulated various policies to actively participate in environmental governance, but it has yet to achieve the desired results of environmental improvement. Therefore, this study conducts an innovative analysis around the effectiveness of China's environmental regulation. This chapter summarizes the main findings, theoretical implications, research deficiencies and research prospects of this research.

8.1 Main Findings

In this thesis, I analyze how effective is China's SO_2 emissions regulation. Specifically, I regard the mandatory SO_2 emissions target scheme strengthened in the 11th Five-Year Plan from 2006 as a quasi-natural experiment and use the DID model to research the impact of SO_2 emissions regulation on firms' pollution emissions and economic status.

Chapter 4 investigates the effect of China's SO_2 emissions regulation on firm pollution emissions using data from the China Annual Survey of Industrial Firms Database and the China Annual Environmental Survey of Polluting Firms Database from 2000 to 2010. I find that the advent of stricter SO_2 emissions regulation has resulted in manufacturers emitting less SO_2. Mechanistic analyses show that, on the one hand, environmental regulation reduces corporate pollution emissions through front-end controls that reduce traditional energy use and end-treatments that increase sewage equipment and improve treatment rates. On the other hand, it also reduces firms' polluting emissions through resource transfers from high-polluting to low-polluting firms, exit of high-polluting firms and entry of low-polluting firms. Heterogeneity test shows that SO_2 emissions regulation has an obvious emission reduction effect on state-owned firms, large-scale firms, firms in labor-intensive and technology-intensive industries, and firms located in the eastern region.

Chapter 5 studies the effect of China's SO_2 emissions regulation on firm total factor productivity. Using data from the China Annual Survey of Industrial Firms Database from 2000 to 2010, I find that the implementation of the Eleventh Five-Year Plan can increase firm total factor productivity. Mechanism analysis reveals two major channels. On the one hand, it directly increases firms' production costs by increasing the use of clean energy and the amount of emission reduction equipment. On the other hand, it can stimulate firms to innovate by increasing investment in R&D and the number of patents to increase firm total factor productivity. Heterogeneity analysis shows that SO_2 emissions regulation significantly increases TFP of state-owned firms, large-scale firms, technology-intensive industries, eastern and central region firms.

Chapter 6 studies the effect of China's SO_2 emissions regulation on firm two-way foreign direct investment using the data from the China Industrial Enterprise Database between 2000 and 2007 and the Cathay Pacific CSMAR database between 2000 and 2010. The empirical results show that SO_2 emissions regulation can lead to a significantly negative impact on firm FDI and a significantly positive impact on firm OFDI. SO_2 emissions regulation reduces firm FDI through increasing firms' production cost and financing constraints, but increases firm FDI through increasing firm technological innovation. Since the cost and financing effects are much larger than the innovation effect, environmental regulations reduce the firms' FDI in general. Additionally, SO_2 emissions regulation can increase firm OFDI through increasing firms' production cost, technological innovation and financing constraints. Heterogeneity analysis shows that SO_2 emissions regulation significantly reduces firm FDI of non-state-owned firms, large-scale firms, labor-intensive industries and technology-intensive industries, and firms located in eastern region and significantly increases firm OFDI of state-owned firms, large-size firms, capital-intensive industries and technology-intensive industries, and firms located in eastern region. I also find that China's SO_2 emissions regulation policies derive Chinese firms to invest in low and medium environmental regulation countries.

Chapter 7 studies the effect of China's SO_2 emissions regulation on firm export performance using data from the Chinese Industrial Enterprise Database and China Customs Data from 2000 to 2010. The empirical results showed that SO_2 emissions regulation policies promoted China's firm export volume and firm export product quality. Mechanism analysis showed that SO_2 emissions regulation can promote firms' export volume and product quality by facilitating firms' technological innovation but can reduce firms' export volume and product quality by increasing their production cost. The promotion effect of firm technology innovation on firm exports is greater than the inhibition effect of firm production cost on firm exports. Therefore, this promoting effect is mainly attributed to the increased firm innovation capability. Heterogeneity results indicated that SO_2 emissions regulation had a greater promotion effect on firm exports for non-state-owned firms, large-scale firms, and firms located in eastern and western regions.

8.2 Implications

Reform and opening up have brought development opportunities to China and facilitated the miraculous economic growth over the past 40 years. However, it is undeniable that environmental pollution has become increasingly prominent. In the production process, corporations' emissions exhibit negative externalities, with the costs of pollutant discharges being borne by society at large. This results in corporate production costs being lower than the true social costs, and revenues exceeding social revenues. Moreover, due to the positive externalities inherent in environmental protection activities, firms engaging in such endeavors are unable to fully internalize the benefits, as other enterprises can free-ride on their efforts. Consequently, corporations lack sufficient incentives to proactively pursue pollution abatement, leading to a market failure. To rectify this market failure in pollution governance, the government must promulgate feasible and efficacious environmental protection policies to constrain corporate polluting behavior and incentivize active corporate participation in environmental remediation, thereby mitigating environmental degradation. However, environmental regulatory policies directly augment corporate production costs, potentially impeding economic development. Therefore, formulating effective environmental regulatory policies that foster corporate technological innovation to offset cost increases, while concurrently achieving a judicious balance between economic growth and environmental preservation, constitutes an exigent issue that China must address. Predicated on this pragmatic imperative, this study investigates the efficacy of China's SO_2 emission regulations, bearing significant theoretical and practical implications.

8.2.1 Theoretical Implications

To comprehensively analyze the efficacy of China's environmental regulation, this research synergizes classical economic theory with a forward-looking methodological approach to systematically construct a theoretical framework for China's environmental regulation on firm pollution and the economy. This endeavor plays a vital role in addressing the lacuna in research related to environmental regulation and has reinforced the theoretical underpinnings for achieving environmental preservation and high-quality economic development.

First, this research elucidates the theoretical analysis and empirical test conclusions of Porter's hypothesis through the lens of a general equilibrium model of heterogeneous firms. The study incorporates environmental regulation policies and technological upgrades into the heterogeneous firm model of Melitz (2003). By analyzing the cost effect of environmental regulation and the compensation effect of technological innovation within a unified general equilibrium framework, it was found that although environmental regulation constraints directly increase firms' production costs and reduce productivity, environmental regulation also compels firms in the market to undertake technological innovation, thereby improving productivity.

Second, while a substantial body of literature has tested the Porter hypothesis, most studies focus on the impact of environmental regulation on total factor productivity, with few examining the effects on two-way foreign direct investment and export product performance. To address this gap, the impact of environmental regulation on two-way foreign direct investment and export product performance was investigated, complementing the shortcomings of existing literature.

Third, in terms of research methodology, this study holds guiding significance for the selection of export product quality measurement methods. Determining how to measure export product quality remains a thorny issue, with no unified measurement standard. To this end, this study amalgamates the latest literature and employs the demand residuals method to calculate firm-level export product quality.

8.2.2 Policy Implications

Since the reform and opening up, China has experienced remarkable economic growth, becoming the primary driver of the global economy. However, the rapid development model employed in the past has caused severe environmental pollution and triggered a series of ecological issues. Air pollution, deterioration of the ecological environment, and increased health risks and disease probability among residents have emerged as significant concerns. These factors can negatively impact the quality of the labor supply and productivity. Pollutant emissions generate external diseconomies, revealing a failure in the market mechanism. Consequently, government intervention through the implementation of environmental regulatory policies is necessary to restrict pollutant emissions and strengthen environmental governance. Under the static analysis framework of neoclassical economics, environmental regulation is perceived to increase production costs and hinder economic development. However, the dynamic analysis framework of the strong Porter hypothesis suggests that the cost effect and resource replacement effect of environmental regulation will compel or encourage firms to innovate technologically, thereby promoting economic growth. Thus, the pressing challenge for China is to formulate effective environmental regulatory policies that incentivize firms to offset costs through technological innovation while simultaneously achieving a balance between economic growth and environmental protection. Given the varying responses to environmental regulations across sectors, China should adopt a more nuanced regulatory framework that accounts for industry-specific characteristics. Heavy polluting industries like power generation and steel manufacturing may require stricter emission caps combined with extended compliance timelines, while technology-intensive sectors could be regulated through performance-based standards that encourage innovation. Small and medium-sized enterprises (SMEs) may need technical assistance and low-cost financing to meet regulatory requirements. This tiered approach would optimize environmental outcomes while minimizing economic disruptions.

Under the new economic normal, productivity improvement has emerged as the primary driving force for economic growth. Consequently, this study focuses on the relationship between environmental regulation and productivity. The research explores the pathways and key influencing factors through which environmental regulation promotes firm productivity. This investigation holds significant practical implications for eliminating the obstacles to economic development caused by environmental constraints. China should invest in next-generation environmental monitoring infrastructure, including widespread deployment of IoT sensors, satellite remote sensing, and AI-powered data analytics. These technologies would enable real-time emissions tracking, more accurate compliance assessment, and targeted enforcement actions. Simultaneously, the government should strengthen third-party verification systems and corporate environmental disclosure requirements to improve transparency.The government should expand and refine its financial support system to facilitate corporate compliance with environmental regulations. This could include establishing dedicated green credit lines through state-owned banks, creating environmental technology subsidy programs targeted at SMEs, and developing risk-sharing mechanisms to encourage private investment in pollution control equipment. Special attention should be given to supporting firms in economically vulnerable regions to prevent widening regional disparities.

China has been successful in attracting foreign direct investment (FDI). However, issues such as environmental pollution and resource scarcity have become increasingly prominent. Therefore, examining the impact of environmental regulation on FDI will assist the government in formulating more precise environmental regulatory policies to achieve green development and promote environmental protection. Moreover, it will further enhance FDI to promote economic development. As global environmental awareness improves, the international community is paying increasing attention to China's environmental pollution problems. Investigating the impact of China's environmental regulatory policies on FDI will help identify deficiencies in policy formulation and implementation and provide recommendations for optimization and upgrading. This, in turn, will promote the sustainable development and refinement of China's environmental protection policies. By dynamically adjusting environmental standards, China will strengthen the environmental access threshold for foreign enterprises, limit the blind expansion of high-pollution and high-emission FDI projects, and establish a negative list and environmental review mechanism to guide foreign investment in green, low-carbon, circular economy and other fields.

Outward foreign direct investment (OFDI) is one of the most classic forms of foreign economic activity and plays a crucial role in China's economic development and industrial structure upgrading. It contributes to filling the gap of key resource shortages, establishing global production networks, and acquiring foreign advanced technology and management expertise. Through this research, two main objectives can be achieved. First, it can provide recommendations for China to adapt to the current trend of environmental protection, modify foreign trade methods, and rationally expand the scale of OFDI. Second, under the current trend, the adjustment of industrial structure and the green transformation of the economy are pressing issues. This research can offer suggestions for China to achieve industrial structure optimization, attain the common development of the economy and environment, and ensure their harmonious coexistence. China should leverage its OFDI growth to promote global clean technology transfer, particularly in developing economies. Bilateral agreements on green FDI, joint R&D initiatives, and harmonized environmental standards can help Chinese firms access advanced technologies while positioning China as a leader in sustainable industrial practices. China can improve OFDI support policies, provide special incentives such as tax credits, financing guarantees and investment insurance for enterprises that carry out green projects such as clean energy and environmental protection facilities overseas, and promote the establishment of green investment cooperation frameworks with host countries to reduce the environmental compliance costs of enterprises' cross-border investment. In addition, it is necessary to strengthen the international coordination of environmental regulation policies, protect the legitimate rights and interests of OFDI enterprises through the signing of bilateral or multilateral environmental investment agreements, and promote the green reconstruction of the global industrial chain.

As the world's largest developing nation and largest exporter, China inevitably faces challenges posed by environmental constraints amidst its economic transformation and export model transition against the backdrop of increasingly prominent environmental issues. Elucidating the nexus between the environment and export performance is imperative. While China's foreign trade has achieved remarkable quantitative and scale milestones, the sustainability of this trade modality has become a pressing concern as economic conditions evolve. Presently, China is undergoing a demographic transition, with the demographic dividend gradually waning compared to the early reform and opening-up era, resulting in a diminished comparative advantage of labor in the processing and manufacturing industries. Moreover, governmental and market forces have intensified constraints on production input factors such as energy and resources, leading to escalating production costs in these sectors. China's export growth model, predicated on the comparative advantage of low costs in foreign trade, is unsustainable. China's trade development approach has prioritized quantitative growth through low-price advantages over increasing added value through quality upgrades of export products, conferring China's exports with distinct low-price and low-quality characteristics, thereby relegating China to a subordinate position in the global value chain. To achieve sustainable export development, China must transform its trade development paradigm, transitioning from the initial stage of reliance on large-scale cheap labor for producing low-priced, low-quality products to derive trade benefits, towards a long-term trajectory of independent research and development, autonomous innovation, and enhancing the quality of export products. China's future trade development must address environmental concerns and product quality upgrades, ensuring environmental preservation and a production model geared towards high-quality, high-value-added products.

To maximize the dual benefits of environmental regulations in enhancing both the quantity and quality of enterprise exports, we propose an integrated "environment-trade" policy framework. First, implement a performance-based incentive system that links environmental compliance with export support policies, offering tiered export tax rebates scaled to corporate environmental ratings, subsidies for international green certifications (e.g., EU Ecolabel), and priority access to national trade fairs like the Canton Fair. Second, develop sector-specific policies: introduce "emission reduction for export quota" mechanisms in traditional manufacturing, incorporate environmental R&D into high-tech enterprise certification standards, and establish a dynamic "compliance-export license" whitelist system for heavily polluting industries. Complement these measures with dedicated funding for green process innovation and clean production technologies. Additionally, create “green supply chain demonstration zones” to cultivate environmentally competitive export clusters, while leveraging Belt and Road cooperation to promote mutual recognition of green standards. This comprehensive approach will transform environmental regulations from compliance costs into drivers of export competitiveness, achieving sustainable synergies between ecological protection and trade growth.

8.3 Research Limitations

Based on micro-enterprise data, this thesis conducts a comprehensive analysis of the ramifications of China’s SO_2 emission regulation on firm pollution emissions and economic performance, yielding preliminary insights. It expands and enriches the extant theoretical and empirical literature to a considerable extent and bears significant practical implications. Nonetheless, this study exhibits certain limitations that warrant gradual refinement in subsequent research endeavors. Specifically, these limitations encompass the following three facets:

First, the limitations of the sample. Considering data availability and the relative completeness of each indicator, this study primarily selects data from Chinese industrial enterprises, mainly collected from quarterly and annual reports submitted by the sample enterprises to local statistical bureaus. However, the sample lacks data on listed companies.

Second, the limitations of the indicator. In this study, the mandatory SO_2 emissions target scheme, strengthened in the 11th Five-Year Plan in 2006, is employed as the SO_2 emission regulation index.

Adopting this policy as a quasi-natural experiment can effectively circumvent endogeneity concerns. However, this policy is narrowly focused on SO_2. The focus on SO_2 emissions targets as the sole regulatory measure overlooks the broader context of China's environmental policy landscape, including water pollution controls, solid waste management, and carbon reduction initiatives that may interact with SO_2 regulations.

Third, the constraints of industry heterogeneity. This study investigates the impact of SO_2 emission regulation on different industries in the heterogeneity analysis. However, this study lacks the influence of heterogeneity from multiple angles. For example, high technology industries and low technology industries, processing trade and non-processing trade, high emission and low emission.

8.4 Future Research

First, in follow-up research, to enhance the credibility of the study and the stability of the conclusions and solve the sample limitation, further expanding the sample scope can be considered to enrich data diversity and reduce errors caused by sample bias. For example, I will use the listed company data from financial disclosures to examine the influences.

Secondly, future studies will necessitate more sophisticated measurement methods to accurately quantify environmental regulations in a comprehensive manner. For example, weight different policy instruments (command-and-control, market-based, informational), incorporate regional enforcement intensity measures.

Thirdly, future studies can also concentrate on a specific industry to enhance the applicability and pertinence of the conclusions. Through an in-depth analysis of samples from a particular industry, the intrinsic characteristics and patterns of that industry can be elucidated more comprehensively, thereby facilitating the derivation of more targeted and industry-specific conclusions.

Appendix A: Chapter 2

A.1 SO_2 Emissions in Three Regions of China from 2000 to 2020

Table A.1: SO_2 Emissions in Three Regions of China from 2000 to 2020

Year	Nation	Eastern	Central	Western
2000	1586.0200	683.4100	384.6900	517.9200
2001	1503.3630	652.0331	375.0532	476.2763
2002	1511.9070	647.0690	376.0736	488.7645
2003	1791.4870	728.7547	442.0095	620.7229
2004	1891.5000	751.6000	494.5000	645.4000
2005	2168.2000	855.6000	586.1000	726.5000
2006	2232.8000	853.6000	592.6000	786.6000
2007	2139.9020	817.9527	571.8675	750.0815
2008	1991.2540	750.7542	534.4370	706.0627
2009	1865.7760	692.1947	505.8580	667.7236
2010	1864.3250	679.7221	512.5969	672.0057
2011	2017.0900	738.7288	558.8620	719.4989
2012	1911.5740	695.6728	523.7324	692.1687
2013	1835.0650	659.2795	503.3606	672.4247
2014	1740.2160	622.2218	477.0526	640.9418
2015	1556.5720	551.7579	432.1128	572.7014
2016	770.2725	279.6968	217.1512	273.4245
2017	529.6919	184.9235	142.7758	201.9926
2018	446.5220	152.6029	114.0379	179.8812
2019	395.1146	131.9354	101.9800	161.1992
2020	252.6349	76.2324	63.3295	113.0730
Mean	1523.8708	581.2258	405.2467	537.3982

Source: Analysis reported in this thesis. Unit: 10000 tons.

A.2 TFP of Three Regions in China from 2000 to 2020

Table A.2: TFP of Three Regions in China from 2000 to 2020

Year	Nation	Eastern	Central	Western
2000	0.537	0.647	0.515	0.449
2001	0.535	0.649	0.511	0.445
2002	0.533	0.654	0.513	0.432
2003	0.531	0.650	0.500	0.443
2004	0.53	0.649	0.516	0.425
2005	0.537	0.653	0.519	0.439
2006	0.530	0.652	0.526	0.411
2007	0.536	0.668	0.522	0.414
2008	0.539	0.677	0.519	0.414

2009	0.537	0.683	0.509	0.410
2010	0.541	0.700	0.507	0.407
2011	0.542	0.706	0.504	0.405
2012	0.542	0.706	0.505	0.405
2013	0.556	0.726	0.519	0.414
2014	0.558	0.729	0.524	0.412
2015	0.572	0.756	0.533	0.417
2016	0.581	0.763	0.546	0.426
2017	0.591	0.778	0.555	0.430
2018	0.599	0.805	0.549	0.430
2019	0.604	0.803	0.555	0.440
2020	0.626	0.834	0.580	0.451
Mean	0.555	0.709	0.525	0.425

Source: Analysis reported in this thesis.

A.3 Export Volume of Three Regions in China from 2000 to 2021

Table A.3: Export Volume of Three Regions in China from 2000 to 2021

Year	Eastern	Central	Western
2000	2268.776	123.9831	99.266
2001	2439.873	131.1761	90.4987
2002	2988.802	149.3402	117.8205
2003	4023.072	196.776	162.4287
2004	5467.147	260.2473	205.862
2005	7032.422	329.5528	257.5591
2006	8906.697	441.4984	341.1602
2007	11107.73	599.6824	470.3449
2008	12845.85	807.6245	653.4532
2009	10944.57	551.1572	520.3873
2010	14215.24	842.1556	720.1489
2011	16747.23	1157.328	1079.248
2012	17590.01	1409.723	1487.407
2013	18700.48	1610.287	1779.273
2014	19433.43	1815.328	2174.173
2015	19038.85	1778.671	1917.166
2016	17817.11	1639.522	1519.683
2017	19010.01	1835.966	1787.735
2018	20644.45	2101.937	2120.431
2019	20431.72	2328.16	2234.944
2020	20871.37	2558.978	2469.166
2021	26917.3	3509.6	3203.5
2022	28424.91	4005.949	3505.158

Source: Analysis reported in this thesis.

Appendix B: Chapter 4

B Heterogeneity Analysis of Different Industries on Firm Pollution Emission

Table B.1: Heterogeneity Analysis of Different Industries (1)

Variable	(1) Processing of Food from Agricultural Products	(2) Manufacture of Foods	(3) Manufacture of Beverages	(4) Manufacture of Tobacco	(5) Manufacture of Textile	(6) Manufacture of Textile Wearing Apparel, Footwear and Caps
$treat_c \times post_t$	-0.0122	-0.0180**	-0.0015	0.0121	-0.0189***	-0.0278***
	(-1.4348)	(-2.4416)	(-0.1945)	(0.4309)	(-3.3947)	(-3.2243)
treat	-0.0097	-0.0176*	-0.2388	0.2520***	-0.5926***	0.0608***
	(-0.0804)	(-1.6917)	(-0.3281)	(4.6675)	(-3.6254)	(4.1594)
age	-0.0061	0.0009	0.0108	-0.0031	-0.0029	0.0556
	(-0.4131)	(0.0600)	(0.8073)	(-0.0769)	(-0.3132)	(1.2264)
size	-0.0681***	-0.0568**	-0.0609**	-0.3024***	-0.0598***	0.0153
	(-3.9898)	(-2.5521)	(-2.5205)	(-4.0271)	(-4.4098)	(0.4339)
kl	0.0210	0.0232	0.0295	0.1297*	0.0214*	-0.0171
	(1.3941)	(1.2705)	(1.3550)	(1.7841)	(1.7876)	(-0.5516)
hhi	-1.3534**	-0.1061	-1.0042	-2.7444**	0.1338	0.7283
	(-2.2353)	(-0.1733)	(-1.0563)	(-2.1024)	(0.3094)	(0.8838)
size_ind	-0.1548*	-0.1240	-0.4501***	-1.0997	-0.2780***	-1.7457**
	(-1.8385)	(-1.4770)	(-2.7771)	(-1.3280)	(-4.5819)	(-2.0513)
gdp	-0.0134	-0.0364	-0.0252	-0.2399***	-0.0256**	-0.0712*
	(-0.7030)	(-1.6164)	(-1.0541)	(-2.9183)	(-2.3197)	(-1.8488)
ind	-0.0027	0.0458**	0.0224	0.1379	0.0975***	0.0519
	(-0.1239)	(2.5561)	(1.0016)	(1.3194)	(5.4218)	(0.7846)
inter	0.0010	0.0022	0.0004	-0.0109	0.0056	0.0262**
	(0.1323)	(0.2686)	(0.0555)	(-0.4043)	(1.3038)	(2.0099)
soe	0.0138	0.0425	0.0105	0.1040	0.0779**	-0.0180
	(0.3809)	(0.9945)	(0.3443)	(1.2179)	(2.2009)	(-0.2052)
foe	0.0416	0.0106	-0.0490	0.0074	0.0039	0.0040
	(1.0876)	(0.1967)	(-1.3113)	(0.1429)	(0.1429)	(0.0656)
pre	0.0165	-0.0078	0.0092	-0.2098	-0.0056	0.0345
	(0.7270)	(-0.2739)	(0.3253)	(-0.8326)	(-0.3596)	(0.7481)
Year FE	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
N	16,750	10,194	9,156	724	27,589	3,403
R-Square	0.7768	0.7660	0.7657	0.8420	0.7292	0.7998

Note: *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

Table B.2: Heterogeneity Analysis of Different Industries (2)

Variable	(7) Manufacture of Leather, Fur, Feather and Related Products	(8) Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm and Straw Products	(9) Manufactur e of Furniture	(10) Manufacture of Paper and Paper Products	(11) Printing, Reproduction of Recording Media	(12) Manufacture of Articles for Culture, Education and Sport Activities
$treat_c \times post_t$	-0.0154	-0.0179	0.0078	-0.0019	0.0104	0.0276
	(-0.9543)	(-1.2184)	(0.4981)	(-0.3801)	(0.9993)	(1.3216)
treat	3.2111***	0.2955***	-0.3501**	-0.3651***	-0.3437**	-0.2792*
	(20.1472)	(2.8099)	(-2.5002)	(-3.9871)	(-2.3792)	(-1.9465)
age	-0.0364	0.0087	0.1369*	-0.0043	0.0396	0.2055
	(-1.1002)	(0.3130)	(1.7020)	(-0.3703)	(0.5835)	(1.6313)
size	-0.0252	-0.0140	-0.0352	-0.0221	0.1864	-0.0327
	(-0.8258)	(-0.3162)	(-0.5277)	(-1.5543)	(1.4539)	(-0.3827)
kl	-0.0100	0.0394	0.0160	0.0038	-0.0892	0.0638
	(-0.4189)	(1.3008)	(0.2748)	(0.2638)	(-0.7554)	(0.7281)
hhi	-1.0962	-1.3927	0.4939	0.2920	2.0546	-0.7205*
	(-1.1698)	(-1.1453)	(1.5916)	(0.6241)	(1.1256)	(-1.8413)
size_ind	8.5181***	-0.5088***	-0.8336**	-0.4249***	-0.7004	-0.0522
	(2.9155)	(-4.4459)	(-2.2643)	(-2.9638)	(-0.5776)	(-0.1527)
gdp	-0.0027	0.0067	-0.0169	0.0115	-0.0732	-0.1236
	(-0.0776)	(0.1387)	(-0.1498)	(0.7532)	(-0.8958)	(-1.2038)
ind	0.0363	-0.0683	-0.0353	0.0171	0.1748	-0.0344
	(0.8617)	(-1.4195)	(-0.3391)	(0.6438)	(1.5370)	(-0.2030)
inter	0.0053	-0.0222	0.0257	0.0079	0.0151	-0.1037**
	(0.4220)	(-1.3045)	(0.8348)	(1.5901)	(0.7041)	(-2.1148)
soe	0.0064	0.0733	-0.3206**	-0.0184	0.0360	-0.1143
	(0.0597)	(0.7438)	(-2.4349)	(-0.4321)	(0.2507)	(-0.6730)
foe	0.0275	0.0544	0.1136	-0.0954**	0.1623	-0.3344*
	(0.4890)	(0.6481)	(0.8232)	(-2.3776)	(0.8011)	(-1.7506)
pre	0.0315	0.0144	0.1501	-0.0120	0.0927	0.3447**
	(0.6592)	(0.3340)	(1.2799)	(-0.7883)	(0.8667)	(2.0803)
Year FE	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
N	3,695	4,354	621	16,534	1,071	735
R-Square	0.7729	0.7506	0.8100	0.7027	0.8055	0.8292

Note: *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

Table B.3: Heterogeneity Analysis of Different Industries (3)

Variable	(13) Processing of Petroleum, Coking, Processing of Nuclear Fuel	(14) Manufacture of Raw Chemical Materials and Chemical Products	(15) Manufacture of Medicines	(16) Manufacture of Chemical Fibers	(17) Manufacture of Rubber	(18) Manufacture of Plastics
$treat_c \times post_t$	-0.0141	-0.0007	-0.0167***	-0.0093	-0.0194*	-0.0166
	(-0.7648)	(-0.1951)	(-2.8268)	(-0.6264)	(-1.8840)	(-1.1545)
treat	-0.1646	0.0010	-0.1750**	-0.0614	-0.6675***	-0.0759
	(-0.2711)	(0.0402)	(-2.2015)	(-0.4897)	(-2.7481)	(-0.1557)
age	0.0173	0.0033	0.0060	-0.0139	-0.0056	0.0261
	(0.4558)	(0.3900)	(0.4647)	(-0.2561)	(-0.2147)	(0.7648)
size	-0.1170***	-0.0463***	-0.0752***	-0.0354	-0.0852*	-0.0786**
	(-2.8570)	(-4.0561)	(-3.3216)	(-0.5852)	(-1.8360)	(-2.0531)
kl	0.0432	0.0132	0.0533**	-0.0735	0.0902**	0.0209
	(1.0718)	(1.2889)	(2.3100)	(-1.0074)	(2.1747)	(0.6650)
hhi	1.3432	0.5280	-0.2805	0.2505	-2.1272**	4.8576*
	(0.8494)	(0.7819)	(-0.0981)	(1.1362)	(-2.5360)	(1.7940)
size_ind	-0.0175	0.1763***	-0.4503***	0.3421	0.1018	-0.2636
	(-0.1154)	(2.9733)	(-2.9940)	(0.9106)	(0.4784)	(-1.5067)
gdp	-0.0666	0.0091	-0.0008	-0.0261	-0.0374	0.0051
	(-1.3068)	(0.7239)	(-0.0338)	(-0.4765)	(-0.8167)	(0.1792)
ind	0.0845***	0.0222	0.0705***	-0.0031	0.0925	0.0857*
	(2.9041)	(1.5490)	(2.6766)	(-0.0309)	(1.2830)	(1.8072)
inter	-0.0506**	-0.0001	0.0104	0.0009	-0.0213	0.0104
	(-2.2269)	(-0.0169)	(1.2165)	(0.0655)	(-1.2148)	(0.7907)
soe	-0.0544	-0.0214	-0.0312	-0.0842	-0.1230*	-0.0137
	(-0.6957)	(-0.9169)	(-0.9947)	(-0.5577)	(-1.6684)	(-0.1145)
foe	-0.0462	0.0017	-0.0503	-0.0496	0.0169	-0.0516
	(-0.4004)	(0.0570)	(-1.0108)	(-0.4650)	(0.2382)	(-0.6913)
pre	-0.0150	0.0008	0.0220	-0.0371	-0.0226	0.0128
	(-0.3061)	(0.0562)	(0.9348)	(-0.4939)	(-0.5339)	(0.2504)
Year FE	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
N	4,579	35,084	11,747	1,449	3,410	3,372
R-Square	0.7740	0.7893	0.7502	0.7637	0.7632	0.7993

Note: *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

Table B.4: Heterogeneity Analysis of Different Industries (4)

Variable	(19) Manufacture of Non-metallic Mineral Products	(20) Smelting and Pressing of Ferrous Metals	(21) Smelting and Pressing of Non-ferrous Metals	(22) Manufacture of Metal Products	(23) Manufacture of General Purpose Machinery	(24) Manufacture of Special Purpose Machinery
$treat_c \times post_t$	0.0106***	-0.0191**	-0.0174*	-0.0044	-0.0199***	0.0067
	(2.5963)	(-2.1983)	(-1.7548)	(-0.6883)	(-2.5934)	(0.5114)
treat	-0.0409	-0.3934	-0.1775	0.0592	-0.3119***	0.0330***
	(-0.2793)	(-1.2448)	(-1.4295)	(0.7992)	(-43.0256)	(5.1884)
age	0.0004	0.0176	0.0421	-0.0185	0.0311	0.0240
	(0.0509)	(0.8670)	(1.3756)	(-0.8805)	(1.6125)	(0.8758)
size	-0.0500***	-0.0389*	-0.0865**	-0.0379	-0.1298***	-0.1452***
	(-4.5548)	(-1.6636)	(-2.1465)	(-1.2813)	(-3.9220)	(-3.4685)
kl	0.0020	0.0316	0.0212	-0.0120	0.0582*	0.0104
	(0.1932)	(1.4423)	(0.6015)	(-0.4777)	(1.9609)	(0.2580)
hhi	0.2144	1.9278	0.7084	1.1734*	-0.3427	0.4488
	(0.4681)	(0.3854)	(1.2877)	(1.7005)	(-1.2424)	(1.5183)
size_ind	-0.5326***	-0.6250***	-0.0735	-0.0701	-0.3759***	-0.1875
	(-5.0432)	(-3.3050)	(-1.4304)	(-0.7743)	(-2.7611)	(-1.3168)
gdp	-0.0226**	0.0280	-0.1408***	-0.0157	0.0451	0.0126
	(-2.0933)	(1.0040)	(-3.4140)	(-0.6100)	(1.4044)	(0.2230)
ind	-0.0045	-0.0770**	0.1253**	0.0030	-0.0586	-0.0660
	(-0.3014)	(-2.4535)	(2.0079)	(0.0732)	(-1.5221)	(-0.8927)
inter	-0.0005	-0.0090	-0.0128	-0.0202**	-0.0243**	-0.0464***
	(-0.1392)	(-0.7903)	(-0.6495)	(-2.2512)	(-2.3071)	(-2.6356)
soe	0.0291	0.0085	0.0560	0.0863	0.0974**	-0.0822
	(1.1810)	(0.1153)	(0.8311)	(0.7646)	(2.1915)	(-1.0918)
foe	0.0116	0.1041	0.0831	-0.0234	-0.0876	0.0540
	(0.4030)	(1.5532)	(1.0559)	(-0.2846)	(-1.2632)	(0.5086)
pre	0.0074	-0.0140	0.0579	0.0002	0.0528*	0.0139
	(0.6897)	(-0.4191)	(1.3840)	(0.0071)	(1.6528)	(0.2316)
Year FE	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
N	45,498	10,418	4,870	7,491	9,982	4,010
R-Square	0.7317	0.7320	0.7836	0.8082	0.8012	0.7923

Note: *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

Table B.5: Heterogeneity Analysis of Different Industries (5)

Variable	(25) Manufacture of Transport Equipment	(26) Manufacture of Electrical Machinery and Equipment	(27) Manufacture of Communication Equipment, Computers and Other Electronic Equipment	(28) Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work	(29) Manufacture of Artwork and Other Manufacturing
$treat_c \times post_t$	-0.0206**	-0.0372***	-0.0263	0.0259	0.0113
	(-2.3374)	(-3.1693)	(-1.5442)	(0.8491)	(1.0324)
treat	-0.0605**	0.6067*	-1.2721**	-0.8364	1.1150
	(-2.4215)	(1.7425)	(-2.0185)	(-0.9206)	(1.4894)
age	0.0206	-0.0149	-0.0720	0.0675	-0.0463
	(1.0167)	(-0.6797)	(-1.5272)	(0.8152)	(-1.0752)
size	-0.1700***	-0.1315***	-0.1201**	-0.0243	-0.0568
	(-4.0613)	(-3.3230)	(-2.1998)	(-0.1846)	(-0.9889)
kl	0.0146	-0.0179	0.0585	-0.0960	0.0652
	(0.3968)	(-0.5318)	(1.0831)	(-1.0055)	(1.2293)
hhi	-0.1412	1.7299*	0.1659	0.4149	1.2388
	(-0.3774)	(1.9311)	(0.1075)	(1.1405)	(0.8554)
size_ind	-0.2490**	-0.0696	-0.2265	-0.3633	0.0173
	(-2.0870)	(-0.3794)	(-1.3553)	(-0.4084)	(0.0769)
gdp	-0.0488	0.0206	-0.0070	-0.0731	-0.0067
	(-1.0049)	(0.4914)	(-0.0859)	(-0.4765)	(-0.0824)
ind	0.0431	-0.0669	-0.3275***	0.1827	0.0783
	(0.9695)	(-1.3132)	(-3.3539)	(1.5085)	(1.0663)
inter	-0.0049	-0.0251**	0.0413*	0.0188	-0.0498*
	(-0.5982)	(-1.9918)	(1.8192)	(0.5799)	(-1.7705)
soe	-0.0172	0.0816	-0.0493	0.1513	0.1928
	(-0.3634)	(1.4166)	(-0.4871)	(0.8374)	(0.9891)
foe	0.1188	-0.0962	-0.2216*	-0.5359	-0.0774
	(1.4430)	(-1.3255)	(-1.7428)	(-1.0882)	(-0.9318)
pre	0.1126**	-0.0149	-0.0720	0.0675	-0.0463
	(2.5698)	(-0.6797)	(-1.5272)	(0.8152)	(-1.0752)
Year FE	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES
N	7,084	4,712	2,522	880	1,524
R-Square	0.8251	0.8130	0.8525	0.8559	0.7938

Note: *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

Appendix C: Chapter 5

C Heterogeneity Analysis of Different Industries on TFP

Table C.1: Heterogeneity Analysis of Different Industries (1)

Variable	(1) Processing of Food from Agricultural Products	(2) Manufacture of Foods	(3) Manufacture of Beverages	(4) Manufacture of Tobacco	(5) Manufacture of Textile	(6) Manufacture of Textile Wearing Apparel, Footwear and Caps
$treat_c \times post_t$	-0.0211***	-0.0177***	-0.0084*	-0.0143	0.0102***	-0.0035***
	(-7.8930)	(-6.6063)	(-1.6908)	(-0.9852)	(8.1059)	(-2.7281)
Control variables	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
N	148,687	57,220	37,786	1,823	223,383	126,533
R-Square	0.4432	0.5357	0.5394	0.8203	0.4545	0.3897

Note: *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

Table C.2: Heterogeneity Analysis of Different Industries (2)

Variable	(7) Manufacture of Leather, Fur, Feather and Related Products	(8) Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm and Straw Products	(9) Manufacture of Furniture	(10) Manufacture of Paper and Paper Products	(11) Printing, Reproduction of Recording Media	(12) Manufacture of Articles for Culture, Education and Sport Activities
$treat_c \times post_t$	0.0042*	0.0171***	-0.0041	0.0002	-0.0171***	0.0053**
	(1.8943)	(5.6761)	(-1.4988)	(0.0822)	(-8.3991)	(2.0924)
Control variables	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
N	62,094	62,404	33,087	72,635	48,461	33,948
R-Square	0.4706	0.4080	0.4559	0.5286	0.6056	0.4654

Note: *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

Table C.3: Heterogeneity Analysis of Different Industries (3)

	(13)	(14)	(15)	(16)	(17)	(18)
Variable	Processing of Petroleum, Coking, Processing of Nuclear Fuel	Manufacture of Raw Chemical Materials and Chemical Products	Manufacture of Medicines	Manufacture of Chemical Fibers	Manufacture of Rubber	Manufacture of Plastics
$treat_c \times post_t$	0.0087	-0.0095***	-0.0224***	0.0154***	0.0034	-0.0061***
	(1.5213)	(-7.4347)	(-7.7568)	(3.0504)	(1.4395)	(-4.6282)
Control variables	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
N	19,047	184,558	49,296	13,486	30,936	126,929
R-Square	0.6062	0.5235	0.5065	0.6396	0.5141	0.4445

Note: *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

Table C.4: Heterogeneity Analysis of Different Industries (4)

	(19)	(20)	(21)	(22)	(23)	(24)
Variable	Manufacture of Non-metallic Mineral Products	Smelting and Pressing of Ferrous Metals	Smelting and Pressing of Non-ferrous Metals	Manufacture of Metal Products	Manufacture of General Purpose Machinery	Manufacture of Special Purpose Machinery
$treat_c \times post_t$	0.0010	0.0040	0.0169***	-0.0096***	0.0123***	0.0083***
	(0.7473)	(1.3256)	(5.1553)	(-7.9135)	(11.6787)	(5.4138)
Control variables	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
N	208,188	53,892	34,837	150,400	218,514	110,416
R-Square	0.4838	0.6118	0.5304	0.4486	0.4861	0.4922

Note: *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

Table C.5: Heterogeneity Analysis of Different Industries (5)

	(25)	(26)	(27)	(28)	(29)
Variable	Manufacture of Transport Equipment	Manufacture of Electrical Machinery and Equipment	Manufacture of Communication Equipment, Computers and Other Electronic Equipment	Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work	Manufacture of Artwork and Other Manufacturing
$treat_c \times post_t$	0.0079***	0.0131***	-0.0092***	0.0136***	-0.0041
	(5.8626)	(9.1565)	(-4.0665)	(4.8542)	(-0.9912)
Control variables	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES
N	125,133	163,934	89,624	36,992	50,206
R-Square	0.6077	0.5513	0.5931	0.5413	0.4167

Note: *, **, *** denote significance levels of 10%, 5% and 1%, respectively, and the brackets represent t-values.

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