The Impacts of China's ETS on Firm Competitiveness; Evidence from the Power and Heat Production Sector

by

Mingming Zhang

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Carbon emissions are one of the primary causes of climate change. In the coming decades, the economic costs to deal with climate change are estimated to be 10% of the global GDP. To mitigate the threats, Emission Trading Scheme (ETS) is proposed as a cost-efficient carbon pricing approach to reduce the CO2 emissions in industrial production. Since 2013, the Chinese government has launched seven pilot ETS projects, and successionally, in 2021, the national carbon trading market was established. The national ETS in China covers more than 2,000 power and heat production plants, which accounts for 40% to 50% of China's industrial emissions and 10% of worldwide carbon emissions. Even though the expansion of China ETS is rapid, there is a limited number of analyses on the effectiveness and impacts of ETS. This study aims to further the understanding of the impacts of China’s pilot Emission Trading Scheme (ETS) on firm competitiveness in the power and heat production sector. According to the market externality of environmental emissions and Resource Dependency Theory (RDT), the pilot ETS will inevitably affect the firms’ production and introduce uncertainties to their decision-making process. However, there has been no consensus for debates between the Compliance Cost Hypothesis and the Porter Hypothesis over the impact of environmental regulations on firms. Maintaining firms’ competitiveness in the sluggish market is critical after the COVID pandemic. Firms with better competitiveness are more attractive to external resources and show stronger resilience in a volatile environment. Governments are expected to roll out appropriate regulations to minimize the financial costs of regulations compliance and, meanwhile, guarantee effectiveness. Hence, it is essential to study and understand how ETS affects the firm competitiveness in seven pilot projects.

This study explores the firm competitiveness of participants in the power and heat production sector from the perspectives of firm profitability, production investment, and environmental performance. The data on Return-of-Assets (ROA), operating costs, and carbon emissions at the firm level have been collected from the China Stock Market & Accounting Research Database (CSMAR) and the Carbon Emission Accounts & Datasets (CEADs). The Difference-in-Differences (DID) method is employed for data analysis, and complete robustness tests are conducted to justify the validity of the study. The results indicate that implementing pilot ETS could increase firm profitability but reduce the production investment, and the environmental performance of the firms reveals that the pilot ETS has achieved emission reduction during the observation period without time lag. This study makes the following contributions to the current academic literature. First, it could serve as a micro-economic analysis of ETS impacts. Second, it compares different definitions of firm competitiveness and establishes a multi-dimensional measurement framework for analyzing the performance of high-carbon firms in the ETS. At the same time, the results may also help firms further understand the ETS regulations and build optimal strategies in the market. Finally, the study is also expected to support decision-making in regulation modification and stakeholder engagement in the future.

Key Words: Emission Trading Scheme (ETS), carbon emission trading, environmental regulation, firm competitiveness, Compliance Cost Hypothesis, Porter Hypothesis

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Chapter 1 - Introduction

This chapter introduces this study in four sections. The first section is the background of the study, including the threats of climate change and an overview of China’s industrial emissions. The second section is the problem statement. The research objectives and research questions in this study are described in the third section. The last section illustrates the contributions of this study to the previous literature.

1.1 Background

Over the decades, with the development of environmental science, it has been proven that climate change has accelerated the melting of glaciers and increased the frequency and intensity of extreme weather events (IPCC, 2018). The main contributor to climate change is carbon dioxide emissions. By absorbing ultraviolet and infrared rays from the sun, carbon dioxide has increased the temperature of earth's surface by1-degree Celsius since 1880. The increasing global temperature could induce environmental and social degradation involving energy insecurity, income inequality, public health, food scarcity, and damage of social infrastructure (Gasper, 2011).

Carbon dioxide is mainly produced from industrial production and human daily life. The combustion and consumption of fossil fuels produce significant carbon emissions. According to the claims of the Global Carbon Project in 2022, the total carbon emissions worldwide is 40.5 Gt (World Economic Forum, 2022). The top 3 main emitters are China, the US, and the EU, and the sum of emissions from these countries and regions occupies more than half of the total emissions worldwide (IPCC, 2022). In the coming decades, the economic costs which are caused by climate change are estimated to be 10% of the global GDP (World Economic Forum, 2021). Governments have taken multiple administrative measures to cope with the negative consequences of carbon dioxide.

Environmental regulations are one of the measures to control carbon emissions. The command-and-control approach formerly prevailed in environmental regulations, which required participants to take specific measures and comply with typical standards. This approach causes low administration flexibility and demands high regulation costs during implementation (Zhao et al., 2015). In addition, due to widespread carbon dioxide emissions in industrial production, it is hard to generate a single standard for different producers. Such inconvenience and implementation barriers inspired scientists to look for different approaches. In response to the expectation of controlling carbon emissions and mitigating carbon intensity at acceptable costs, market-based environmental regulations named Emission Trading Scheme (ETS) have been launched by multiple authorities. With ETS, the carbon emissions will be recognized as a production resource and charged additional costs by the governments (Jiang, 2016). The aim of ETS is to encourage firms to transfer to a low-carbon production mode by reducing carbon emissions in production.

China is one of the leading authorities attempting to conduct ETS to control the rising national carbon emissions, and it is regarded as the biggest carbon market in the world but with barely any experience (Karplus & Zhang, 2017; Jiang, 2016). Since 2013, the Chinese government has initiated seven pilot ETS projects in Shanghai, Guangdong, Tianjin, Shenzhen, Beijing, Hubei, and Chongqing (Jiang, 2016). These cities and regions all enjoy an important economic status in China. The pilot ETS mainly regulates the high carbon-intensity industries in the regions. The emissions given off by the regulated firms account for 7% of the total national emissions, among which Guangdong ETS contributed the most and Beijing ETS did the least (Zhang et al., 2014; Chen & Xu, 2018). In the pilots, the government has clarified the goal for emission reduction and granted the pilots high regulation flexibility to ensure the effectiveness of the trading scheme regulated (Duan et al., 2014).

Based on the previous literature, the carbon trading markets of the pilots demonstrate several apparent characteristics. Regarding trading performance, Chen and Xu (2018) evaluated the seven pilot projects in China in terms of carbon price and trading volume. They found that the average price of carbon allowance in the pilot projects is around CNY30/t, with acceptable fluctuations in the year. The carbon price in Shenzhen is the most unstable, ranging from CNY 24 to CNY 122; while the price in Hubei is the most stable, fluctuating between CNY 10 and CNY 29 (Chen & Xu, 2018). As for the trading volume in the pilots, the study found the volume increased significantly before the compliance cycle, but most of the time, the transaction was relatively inactive (Chen & Xu, 2018). According to the researchers, only 1.4% of the allowances are traded in all seven pilots.

With four years of practical experience in the pilots, the government established the national trading market in 2017 and decided that the first compliance cycle would commence in 2021 (China Ministry of Ecology and Environment, 2021). The national ETS gathered more than 2,200 power plants into the market from the power and heat production sector. These plants were responsible for 40% to 50% of China industrial emissions, which equaled 10% of emissions worldwide (Cao et al., 2021). However, building a scientific and cost-effective ETS is still a long way off.

The goal of China pilot ETS is to collect practical evidence and identify potential barriers during implementation (Zhang et al., 2014). Thorough analysis and understanding of the pilot ETS will contribute to improving governance efficiency and reducing the regulatory risks of the national carbon trading scheme.

1.2 Problem Statement

Given the rapid rate at which China's ETS market is expanding, there has been minimal evaluation of the pilot ETS effectiveness. For newly regulated firms, the challenges and impacts brought by the regulations are unclear. After the COVID pandemic, it is critical to maintain economic vitality in the sluggish market. The uncertainty of ETS impacts can negatively affect the firm decision-making process and reduce their enthusiasm to participate in carbon trading. Governments are expected to implement appropriate regulations to guarantee the effectiveness and, meanwhile, minimize the economic costs of the implementation. Therefore, researchers are demanded to explore existing impacts at the firm level in pilot ETS to understand the regulation effectiveness and inspire future national market design.

1.3 Research Objectives and Research Question

The objective of this research is to understand the pilot ETS impacts on firm competitiveness in the power and heat production sector. The evaluation framework for firm competitiveness in this study will be based on firm profitability, production investment, and environmental performance. The target of this study is firms in the power and heat production sector, because it is a significant contributor to China's carbon emissions and the first sector to be included in the national ETS. Unlike most previous studies focusing on an industry or regional performance, this study explores the firm-level scenario and provides microeconomic evidence for evaluating pilot ETS. The central question guiding this research is: *What are the effects of China's ETS on firm competitiveness in the power and heat production sector?*

1.4 Contributions

The main contribution of this study is to advance the understanding of China's pilot ETS impacts on firm competitiveness. This study is an ex-post analysis of the pilot ETS, thereby allowing for an assessment of the performance of the regulations. Through the regulation performance, it could be determined whether the design and implementation effect of the regulations meets the government's initial expectations. This is important given China's rapid expansion of its national carbon market. A more detailed and comprehensive evaluation and understanding of the pilot market will help inform the development of future regulation design and reduce regulation implementation costs within the national carbon market.

This study investigates the microeconomic context of the pilot ETS. Analyzing the competitiveness of the participants will help to provide a micro-level evaluation of the regulations on firms and allow the government to identify business barriers for the implementation of cost-efficient practices. The study will also enable the regulated businesses to better understand changes in their business environment. In the context of severe environmental problems, fierce international competition, and post-pandemic economic pressure, it is critical for regulated firms to maintain business competitiveness. This study offers an overview of the pilot ETS impacts on firm competitiveness and serves as a reference to guide the expansion of ETS in China.

Understanding the power and heat production sector in China ETS is essential to energy security and economic prosperity. Electricity consumption has continued to increase as the environmental costs rise. The annual primary energy consumption of the power and heat production sector accounts for 4.64 billion tons of coal, making it the largest contributor to national carbon emissions (Wong, 2021). Interpreting firm performance in the sector may help regulate high-emission participants and facilitate the transition to low-carbon economies.

Finally, this study enriches the literature on evaluating firm competitiveness. The literature on assessing the firm competitiveness is extensive and accompanied by various measurements and focuses. However, few studies highlight the competitiveness framework of high carbon intensity participants in environmental regulations. This thesis attempts to construct a competitiveness framework for assessing the financial and non-financial capacity of firms in the high-carbon sectors under environmental regulations. As China sets its sights on expanding the national ETS to firms in other high-carbon sectors, such as building, paper, cement, oil, and gas, future participants may also benefit from this study on building their competitiveness strategy.

This thesis is laid out as follows: Chapter 1 introduces the background of China ETS, the problem of the ETS, the research objectives and research questions of this study, and the possible contribution of the study. Chapter 2 explores the relevant literature about the ETS and its impacts on firms and concludes with several hypotheses based on the research gaps. Chapter 3 introduces the methodology of the study, including the rationales for choosing the competitiveness indicators and the analysis model of Difference-in-Differences (DID). Chapter 4 presents the data significance of empirical results and the robustness tests for validity. Chapter 5 discusses the regression results from a broad view of the literature and elucidates how the results help inform the extant literature. Finally, Chapter 6 concludes the thesis and highlights the limitations and areas for future research.

Chapter 2 - Literature Review

This chapter is composed of four sections. The first section is the literature review of the carbon emission trading scheme (ETS) from its origins to its current achievements. The second section focuses on the theoretical framework of environmental regulations in a business situation. The third section explores the literature on firm competitiveness and firm-level performance in response to environmental regulations. The fourth section summarizes the insufficiency in previous literature and proposes the hypotheses based on the competitiveness framework, which is designed to assess the firm performance in the high-carbon sectors under environmental regulations.

2.1 ETS

As one of the approaches to reducing greenhouse gas emissions, the emission trading scheme is characterized by a market-based nature. In this section, the details of the emission trading scheme are discussed based on the previous literature, including its development and influence in many countries and regions.

2.1.1 The Features of ETS and Its Development

ETS is an environmental regulation that uses market-based mechanisms to minimize carbon dioxide emissions and energy consumption (Jiang, 2016). The scope of ETS can be regions, nations, or multination. ETS controls GHG emissions by regulating the total emissions of participants or the emission intensity (Diaz-Rainey & Tulloch, 2018). The complete emission control ETS is a cap-and-trade system in which the government determines the "cap" of the aggregate of absolute emissions from the participants and then allocates the emission allowance to each emitter. Alternatively, the emission intensity control is framed by regulating the emission amount per unit of input or output to facilitate a low-carbon economy.

In cap-and-trade ETS, emitters are required to reduce their actual emissions to less than or equal to their limited allowance in the compliance cycle. Emitters who are likely to exceed their emission allowance can buy additional allowance from other emitters or third parties to comply with the requirement. According to the regulations, the carbon emission allowance is regarded as an environmental resource of government property and it is transferable in the carbon market (Hu et al., 2020). The “cap” of emissions indicates the scarcity of carbon emission allowance in the market. The gap between actual emissions and emission allowance will activate the transaction of the allowances between firms. The total carbon emission of the participants is thereby under control by limiting the “cap” emissions.

ETS has been theoretically regarded as the most cost-effective approach to reduce emissions. For both regulators and participants, it could control carbon emissions with optimal flexibility and compatibility (Alberola, 2009; Aakre, 2010; Kim & Yu, 2018; Jiang, 2016; Narassimhan et al., 2018). In ETS, participants will be burdened with an extra carbon price in addition to their usual production costs. Participants who are heavily reliant on carbon consumption in production will start to seek other alternatives to reduce their carbon intensity. If they fail to comply with the “cap” at the end of the compliance cycle, they will be subject to financial penalties issued by the government and a more severe emission cap for the next cycle. By implementing ETS, some participants will try to minimize their carbon emissions in production and sell surplus allowance for profit. Consequently, driven by not only the potential profit but also the pressure of additional production costs, all participants in the scheme tend to achieve low-carbon intensity production (Zhang, 2014; Kopsch, 2012).

Because of its market mechanism, the ETS is also cost-efficient in emission control. Before EU ETS, environmental regulations were dominated by the command-and-control mode in which the government issues specific standards and technology requirements for participants to abide by (Zhang & Wei, 2010). The command-and-control mode usually involves spending a giant subsidy from the government to support firms to comply with the regulations. For example, the command-and-control regulations require firms to install specific pollution treatment equipment, and the firms will enjoy financial support from the government for the installation costs (Zhao et al., 2015). In addition to the high implementation costs, the command-and-control mode offers limited flexibility for firms to consider their specific operational situation, which could also cause high compliance costs to firms.

Quite different from command-and-control regulations, ETS is supported by the market-based mechanism. The regulations allow more private sectors to join the GHG emissions reduction rather than merely relying on fiscal support (Schlamadinger et al., 2005). ETS allows participants to gain market transaction proceeds and could expand emission reduction capacity per unit of capital (Evans, 2003; Pizer, 2006). Because the nature of business is profit-seeking, ETS could reduce the cost of regulation implementation and motivate participants with initiative.

Compared with other environmental regulations which set fixed constraints to the specific economic entity, ETS offers a low-risk method to enhance the tolerance level of regulation design by balancing the enforcement of government and the flexibility of the market. The grandfathering allocation method in ETS can specify emitters' initial emission levels based on their historical data. However, when a government allocates the initial allowance, it may not be the most cost-efficient for emitters to achieve reduction. For example, Factory A and Factory B have had similar emission amounts in the past. Following the grandfathering method, a similar emission allowance will be allocated for them in the next compliance cycle. In the new cycle, Factory A deploys advanced equipment for emission reduction, which reduces their emissions much more than expected. Meanwhile, Factory B plans to increase production, which makes its emissions much higher than before. As a result, Factory A will have surplus emission allowances, and Factory B will experience an allowance shortage. This will introduce the risk of limiting the development speed of participants as they need extra emission allowance before increasing their production.

ETS relieves this constraint by establishing a free transaction carbon market or auction scheme for the emitters so that participants are allowed to freely transaction upon their business strategies (Hu et al., 2020). For example, Factory A could sell surplus emission allowance to Factory B and earn revenue to compensate for its cost of deploying advanced emission reduction equipment. Factory B can also benefit from this transaction to comply with its business plan and regulatory requirements.

Another significance of ETS is that ETS introduces a practical and collaborative concept that the total reduction in GHG emissions is more important than any individual participant achieving a certain reduction goal (Narassimhan et al., 2018). This mechanism aims to encourage participants to achieve emission reduction with abatement costs as it focuses on the total cap instead of urging every participant to reduce emissions equally. If the participants' abatement cost is higher than the market price of allowance, they can buy allowance from other participants with lower abatement costs. Emission reduction is achieved with low economic costs by ETS and participants own flexibility to make their optimal emission reduction plan based on their specific costs. Hence, ETS is a practical and collaborative design for emission control, and it places the responsibility of emission reduction on a group rather than on an individual by imposing a group cap (Narassimhan et al., 2018).

In general, the emergence of ETS brings about the opportunity to organize GHG emissions reduction with lower abatement costs, lower fiscal pressure, and lower risk than traditional command-and-control regulations by a flexible market mechanism. These characteristics make ETS enjoy preference from authorities when making regulations.

Reviewing the history of ETS development, several milestones are worth highlighting. In 1997, the Kyoto Protocol was signed by the United Nations Framework Convention on Climate Change (UCFCCC) as an international document. The agreement required developed countries to curb climate warming and reduce GHG emissions by 5% from 1990 (United Nations, 1997). Kyoto Protocol proposed three approaches to control GHG emissions, which are the Emission Trading Scheme, Clean Development Mechanism (CDM), and Joint Implementation (JI) (Kyoto Protocol, 1977). Because of the theoretical benefits and global environmental concerns, ETS enjoys a markable expansion among governments who would like to take responsibility for climate change conservation.

In response to the Kyoto Protocol obligation, the first ETS was conducted in the European Union (EU) in 2005. It was the most extensive and multi-national ETS before the ETS in China was launched. Since then, this novel market-based paradigm to control emissions has become the common practice of managing environmental affairs and has expanded to different parts of the world. Following EU ETS, multiple authorities like New Zealand, the United States, Japan, Australia, Canada, South Korea, and Switzerland have started to build their emission trading map regionally or nationally (Alberola, 2009; Aakre, 2010; Kim & Yu, 2018; Jiang, 2016).

2.1.2 Environmental and Economic Performance

Researchers have been working on exploring ETS performance from perspectives of environmental and economic categories with diverse findings. EU ETS, the most representative market, covered nearly half of the EU emissions, and it was believed that 24% of GHG emissions had been reduced among participants in the first ten years of operation (Joltreau & Sommerfeld, 2019). Since 2008, New Zealand has implemented an emission trading scheme in several sectors, but the government had not set a national cap for the market until 2015. Thus, there is little evidence to show that it did achieved an adequate emission reduction (Narassimhan et al., 2018). Indeed, a study investigating NZ ETS's legislation design concluded that NZ ETS did not satisfy emission reduction expectations (Bracey, 2017).

The United States officially signed the Regional Greenhouse Gas Initiative (RGGI) in 2009, applying the entire auction method to allocate emission allowance (Narassimhan et al., 2018). Unlike the NZ ETS, the RGGI is believed to have reduced more than 20% of carbon emissions in regulated regions compared with non-regulated regions in its first five years (CERES, 2015).

Other authorities have also made attempts to build ETS. The Japanese government established two emissions trading schemes in Tokyo and Saitama, which successfully cover nearly half the commercial and industrial emissions and one-fifth of the country's CO2 emissions (Nguyen et al., 2019). The government of Australia issued a fixed carbon price policy for the national emission trading market in 2012, and three years later, a floating carbon price policy was adopted (Siriwardana, & Nong, 2018). When looking at Australia ETS, by adopting the Computable General Equilibrium (CGE) modelling, researchers concluded that Australia ETS would contribute to reducing national emissions (Adams et al., 2014).

Canada also followed the ETS trend to control emissions. In 2014, the government of Quebec aligned with California to launch a transnational carbon trading market and was targeted to reduce their current emission level by up to 80% of the 1990s (Purdon et., 2021). One year later, South Korea launched its emission trading scheme and imposed significant penalties on non-compliance participants (Kim & Yu, 2018).

In general, multiple countries worldwide are implementing carbon trading schemes with more or less environmental achievements and expanding trends.

On the other hand, researchers have also analyzed the economic impacts of carbon markets under ETS. Researchers believed that the EU ETS would increase the costs of firms in the energy industry, but there is no noticeable impact on overall sectors (Zhang & Wei, 2012). The same situation occurred when investigating whether EU ETS had contributed to technology investment in the energy industry. When looking into the market performance of NZ ETS, researchers noticed that the intensity-based NZ ETS was closely linked to the international ETS market. They concluded that a small trading system linked to the international market might help release abatement costs pressure on domestic participants but would also challenge the national market credibility and cause distortion (Diaz-Rainey & Tulloch, 2018). The Australia ETS was believed to negatively impacted employment in the short term with societal concern (Adams et al., 2014).

However, researchers experienced a shortage of data availability, and due to the limited data resources, they found it hard to evaluate the existing ETS economic efficiency from the perspective of compliance costs or administration costs. Even though they made some arguments based on evaluating marginal abatement costs, they claimed that the credibility of simply evaluating marginal abatement costs to understand the ETS economic efficiency is still in concern because those with high marginal abatement costs under ETS may be related to another governance mechanism (Chan et al., 2013; Narassimhan et al., 2018).

The studies of the economic assessment of ETS are diversified, and after exploring dozens of literature, it is hard to find a comprehensive or robust evaluation framework for the ETS assessment (Jiang, 2016; Hoffmann, 2007; Carratù et al., 2020). Most studies have investigated several indicators to describe the implementation situation, but they have made different elucidations (Chen et al., 2021; Lv & Bai, 2021; Xiao et al., 2021; Zhang & Wang, 2021). Although the barriers to understanding economic impacts have been constantly broken down, contradictions in research findings and the heterogeneity of industries and regions reveal structureless ETS economic impacts. This issue could be a research gap that needs to be demonstrated and resolved by this study.

2.1.3 ETS Studies in China

China established the pilot ETS in 2013, and since then relevant studies on China ETS have been conducted. China's ETS market is expected to have the most trading volume and participants once the national market starts trading (Karplus & Zhang, 2017; Jiang, 2016). Associated studies can be categorized into ex-ante and ex-post on the environmental performance of pilot ETS and its economic impacts.

Ex-ante studies about China ETS have employed multiple models to predict the potential emission reduction performance and energy efficiency. For example, researchers constructed the Computable General Equilibrium (CGE) model to forecast the emission reduction performance in Guangdong Province (Cheng et al., 2015). They found that the pilot ETS could reduce air pollutant emissions by over 10% even in the business-as-usual scenario. When looking into energy consumption, a study on Chongqing employed the Long-range Energy Alternatives Planning System (LEAP) model to conclude that, compared with no constraints, China ETS would guide Chongqing to transform to higher energy efficiency and a lower GHG emissions mode (Liang et al., 2014). Besides, this study insisted China ETS had achieved the best performance when compared with other emission constraints in Chongqing, such as low carbon development (LCD) strategy, business-as-usual policies, and coal consumption controlling (CCC) action. Different conclusions about industry heterogeneity can be found in the literature. As researchers used the CGE model to assess the impacts of ETS in four energy-intensive sectors, they conducted the simulation and explicated that the ETS would be able to curb the carbon abatement costs in the refinery, iron and steel sectors while raising the costs in the power and cement sectors (Wang et al., 2015). Furthermore, the ETS would create a fair carbon market value for the whole economy, in which partial abatement costs pressure could be impressively released (Wang et al., 2015; Zhang et al., 2017).

Furthermore, diversified studies have applied programming models to simulate the potential economic performance of China's pilot ETS. A study investigated the ETS economic impacts with a general equilibrium model, the China-in-Global Energy Model (C-GEM) designed to assess both the national and international effects of Chinese climate policy. The estimation shows that once China's domestic ETS market is established and linked to other inter-regional ETS markets worldwide, it will help transfer China's industrial structure to clean energy development by reducing fossil energy consumption (Zhang et al., 2017).

In addition to these macroeconomic impacts, some studies illustrate the ETS potential implications at the micro-level. They contend that business strategies are interwoven with business situations. A study in China mentioned that in the assumed ETS implementation, the employment need of different sectors shows heterogeneity (Cheng et al., 2016). Firms in the service and clean energy sectors showed an increasing demand for employees, because ETS could motivate the development of low-carbon structural transformation and induce vitality in those sectors with low-carbon intensity. Increased occupations could be emission trading related and require clean energy professionals. The negative impact may happen to firms in the iron and steel sector, which will suffer from the pressure of employment decrease (Cheng et al., 2016). The business supply chain will also be affected, according to the pertinent literature. Researchers insisted that, in the scenario of ETS, the low-carbon preference would change the market supply chain of emission-dependent manufacturers (Du et al., 2016). The ETS will enhance environmental awareness among consumers and provide an added market for manufacturers with a better carbon footprint. Therefore, driven by the profit-seeking nature, manufacturers will change their product competition strategy and adopt the new low-carbon supply chain to fit the trend (Du et al., 2016).

Ex-ante studies could provide a theoretical prediction of the performance of China pilot ETS, but the actual effectiveness is not likely to align with ex-ante analysis. Therefore, ex-post analysis is essential for examining unexpected issues and discovering non-apparent factors to China pilot ETS. Some previous literature about the ex-post studies of China pilot ETS are reviewed in the following paragraphs.

China pilot ETS applies four carbon allowance allocation approaches, which are benchmark, grandfathering, auction, and self-declaration (Zhang et al., 2015). The four approaches can be classified into payment required and non-payment required. The auction approach requires covered firms to purchase allowance, while benchmark, grandfathering, and self-declaration are free allocation approaches (Pang et al., 2018). The benchmark allocation approach regulates the emissions of covered firms by setting a sectoral unified emissions intensity (Pang et al., 2018). The grandfathering allocates allowance according to the firms' historical emissions (Pang et al., 2018). The self-declaration approach is specifically employed by the Chongqing pilot, in which the emission allowance is allocated according to the firm emissions between the years 2008 to 2012 (Pang et al., 2018). Even though the allocation approaches could induce different carbon reduction performances due to their fairness and efficiency, much literature supports that China's ETS will positively impact emission reduction (Zhang et al., 2015). A study investigating China ETS impact on reducing carbon intensity elucidated that regional ETS controlled the carbon intensity without time lag (Zhou et al., 2019). In the first four years of implementing the ETS, the pilot provinces achieved a carbon intensity reduction of around 0.026 tons/10,000 CNY annually. Furthermore, other researchers found that among the seven pilots, Hubei and Guangdong achieved the most markable carbon emissions reduction. The emissions decreased by 59.5 and 37.1 million tons, respectively (Chen & Xu, 2018).

Some arguments stated that the reduction was associated with production concession rather than improvement of energy efficiency. After observing 37 different industries in China, Zhang and Duan (2020) found that China ETS can contribute to emission reduction but at the cost of reducing production. Researchers analyzing the gross industrial output value and the employment of the target industries concluded that China ETS had failed to separate the economic output from achieving emission reduction. The employment of the covered industries had shrunk. Coincidentally, by observing the listed firms in the Shanghai and Shenzhen stock exchanges, it was believed that the pilot ETS had decreased the production value of the covered firm (Chen et al., 2021). The decrease is reflected in the shrinking of firm revenue, operating costs, and total assets.

The above ideas align with an earlier study which believes that due to the mechanism design of China ETS, it is hard for China to achieve emission control by improving energy efficiency (Jiang, 2016). The pilot ETS has been questioned for weak data quality, loose allowance allocation, low market liquidity, and controversial transparency. Jiang (2016) believed that the mechanism of China pilot ETS was merely at the stage of accumulating experience for market participants and the government rather than functioning well to reduce emissions.

The economic impacts of China ETS include financial losses, investment expenditure shrinkage, and total factor productivity decline. Some firms experienced financial losses in the ETS. Evidence shows that the compliance of some ETS participants is driven by government decisions instead of profit expectations (Cao et al., 2021). In the coal-fired power firms covered, ETS didn't change their marginal costs significantly. The electricity sector is not fully market-oriented in China. Most of the electricity is dispatched on order at controlled prices. To comply with the emission allowance, these firms chose to reduce coal consumption which led to a production decline and financial losses (Cao et al., 2021).

The business may have different attitudes toward operating decisions when regulated by the constraints of ETS. The investment expenditure is believed to be a reference to the firm's future production and operation strategies. Researchers analyzed the high energy-and-carbon-intensive industries in pilots and argued that, from the industry perspective, the investment expenditure of steel and building material sectors was reduced while no significant evidence about other sectors was found (Zhang & Wang, 2021). From the regional perspective, firms in Guangdong and Beijing were reducing their investment conservatively, while firms in Tianjin were increasing their investment expenditure. The reducing impact started in the second year of the regulation implementation and appeared to be strengthened by year (Zhang & Wang, 2021).

While analyzing the productivity of ETS participants, economists took total factor productivity (TFP) as a popular indicator. The TFP of the listed firms was estimated to be advanced by 14% in the pilot regions (Xiao et al., 2021). Certainly, industrial heterogeneity existed, and the TFP of the power sector and coal sector were found to be inhibited.

In summary, the above studies observed the carbon reduction performance and the accompanying economic phenomenon in the regional ETS. However, researchers conducted an overview of China ETS studies and agreed that there is still a need for more ex-post studies to examine regulatory achievements (Jiang, 2016; Chen & Xu, 2018; Lv & Bai, 2021; Luo et al., 2021). The operating challenges and latent effects in the microeconomic environments which are experienced by high carbon-intensity participants are waiting to be explicated (Zhang & Wang, 2021). These effects and challenges could threaten the business environment and firm capacity in the market. Even though the primary goal of the pilot ETS is not to promote firm vitality, the government does not expect economic dynamism to be constrained on its way to carbon reduction (Zhang et al., 2014; Xiao et al., 2021).

2.2 Environmental Regulation Mechanism and Its Impacts

Environmental regulation is an approach enforced by the government to protect the environment and manage natural resources. In this section, Resource Dependency Theory is discussed first to help explain the relationship between firms and external resources. Then, the intention and significance of environmental regulation are reviewed as well as the economic effects to understand its impact mechanism.

2.2.1 The Resource Dependency Theory

To advance the understanding of ETS and its influence on regulated firms, this study will refer to the theoretical arguments and empirical evidence grounded in environmental regulation studies.

The Resource Dependency Theory (RDT), originating from Pfeffer and Salancik (1978), analyzes the relationship between the external environment and business behaviours. It believes that firms are relying on their external resources during the production process (Pfeffer & Salancik, 1978; Oliver, 1991; Drees & Heugens, 2013; Delke, 2015; Hillman et al., 2009). The theory is based on the inevitability of business activities to acquire resources and improve self-competitiveness (Pfeffer & Salancik, 1978). It generates business effectiveness, business environment, and constraints as three main contextual perspectives to illustrate the external environment impacts on firms (Delke, 2015; Hillman et al., 2009).

The RDT provides a theoretical explanation for how external changes in a firm will impact its behavior and decision-making (Pfeffer & Salancik, 1978). In the RDT, external resource autonomy and legitimacy will directly impact the firm's coping strategies. Resource autonomy means the optimal ability to control the critical production resources in need, and legitimacy means the ability to ensure the business can comply with requirements and avoid operation uncertainty (Drees & Heugens, 2013). The theory believes that firms are pursuing external resource autonomy and trying to avoid potential uncertainties in the market (Pfeffer & Salancik, 1978). When an external agent reallocates the business's critical resources, the business will take active measures to respond to the changes and strive to maintain its market competitiveness (Oliver, 1991). According to previous literature, the ETS makes emission allowance a limited production resource for firms (Hu et al., 2020). It can be regarded as an allocation scheme of firm property rights of external resources, which will affect the firm resource supply and transaction efficiency (Coase, 1960; Zhao et al., 2015). In this case, following the RDT, ETS can inevitably influence the decision-making of firms and induce external uncertainty to regulated economic activities.

RDT has been frequently leveraged and tested by researchers in multiple fields including organizational sociology, human resource strategies, organizational behaviours, firm supply management, structure transaction, external resources stability, communication service decisions, educational organizations decision-making, and community sports relationships evaluations (Nienhüser, 2008; Usdiken & Pasadeos, 1995; Delke, 2015; Rowans, 1982; Mwai et al., 2014; Hutchinson & Misener, 2020; Drees & Heugens, 2013; Nienhüser, 2008). For example, Oliver (1991) explores the convergence of RDT and intuitional theory to explain the relationship between the firm and different regulatory pressures to predict strategic organizational response.

RDT has been regarded as a premier resource for probing relations between an organization and its environment (Oliver, 1991). Affected by multiple factors, a firm's coping strategies could generate different outcomes in responding to external regulatory changes (Snowdon & Stonehouse, 2006). As for whether the impact of environmental regulations is positive or negative, Cohen and Tubb conducted studies on 107 environmental regulations and concluded that the number of positive and negative reports are basically equal (Cohen & Tubb, 2018). This finding makes the impact of environmental regulations on business more intricate.

2.2.2 Environmental Regulations

In order to better understand the pilot ETS, this section explains the principle and influence mechanism of environmental regulations. Growing material prices and labour costs force firms to look for opportunities to control the input at every production stage. Firms did not hesitate to sacrifice long-term environmental benefits for a substantial profit. Destruction of ecosystems, water sources, and vegetation widely exists in business-as-usual scenarios. Massive consumption of ecological resources and unrestrained pollutant discharge have intensified environmental degradation. Conflicts between human economic activities and environmental conservation are increasing, which brought about the debate on how environmental regulations could effectively contribute to economic performance (Greenstone, 2012).

This study follows the definition of environmental regulations by regulatory economics, which is:

> *Environmental regulations are the general rules and specific actions enforced by administrative agencies so as to control pollution and manage natural resources with the purpose of protecting the environment and internalizing externalities, including direct and indirect interventions. (Stavropoulos et al., 2018)*

Environmental problems are characterized by externality which means the third parties will gain benefits or burden costs without joining the market (Pigou, 1920). Evidence is obvious that even though an individual factory emits pollutants, the consequences of the pollution will be shared by the public. This characteristic could inflict the environmental burden of overwhelming pollutants on the public. The consequences could be the "Tragedy of the Common" which is the situation in which people will not be governed by structures or formal rules if there is open access to resources (Hardin,1968; Lloyd, 1833). Suppose firms can emit pollution without constraints, then they will not be motivated to take responsibility to improve their environmental performance. Firms will prefer to reduce their treatment costs by emitting untreated pollutants into the environment and share the pollution consequences and the treatment costs with others in the region.

Due to the problematic approach to distributing environmental interests and unclear property rights, the market's regulatory roles to handle environmental problems generally fail. This phenomenon requires environmental regulations as an enforcing approach to internalize environmental costs to individual liability and guide economic activities (Besanko & Spulber, 1989).

There are two common categories of environmental regulations. One is command-and-control regulations, which are also called administrative-based regulations. Another is market-based regulations, which are also named market-motivated regulations (Stavropoulos et al., 2018; Zhao et al., 2015). The primary difference between command-and-control and market-based regulations is that command-and-control regulations set explicit standards and specific guidance to supervise environmental degradation activities while, without specifying a restriction approach, market-based regulations focus more on the expected outcome that locates pollution activities with economic costs and unitizes market mechanism to incentive participants to adjust their behaviours (Beiser-McGrath et al., 2022).

Evidence shows that environmental regulations have optimal contributions to pollution reduction worldwide. Researchers in China utilized 270 questionnaires to inspect command-and-control and market-motivated regulations on emission reduction performance. Studies found that these regulations were able to contribute to cleaning production by requiring firms to consume environmentally friendly raw materials or control waste in the production process (Zhao et al., 2015). A study conducted in the BRICS (Brazil, Russia, India, China, and South Africa) also concludes that environmental regulations positively impact local emission mitigation goals and can effectively contribute to environment conservation (Danish et al., 2020).

However, negative environmental impacts can also be found in the studies. Researchers identified that environmental regulations could induce negative impacts on regional ecological efficiency when lacking legislation support (Yasmeen et al., 2020). It might induce carbon leakage in the regulated regions that factories move away from the regulated regions to the non-regulated regions and keep emitting pollutants to reduce regulatory costs in production. As a result, the total nationwide emissions are not controlled effectively. Economic costs will definitely happen to the regulated regions in the carbon leakage situation.

2.2.3 Economic Impacts

Besides exploring environmental performance, economists and entrepreneurs started questioning the economic burdens of the regulations on business.

Several hypotheses and findings about how environmental regulations will impact the economy were discussed in the literature. Most arguments can be classified into two categories. One is that environmental regulations will increase business operation costs and negatively affect production efficiency (Barbera & McConnell, 1990; Gray & Shadbegian, 1995; Greenstone, 2012; Chikán, 2008; Copeland & Taylor, 1994; Sun et al., 2019); the other is that environmental regulations will positively contribute to the business with an innovation offset to cover additional regulatory costs (Porter & Ver der Linde, 1995).

The first category argument is based on the Compliance Cost Hypothesis (Barbera & McConnell, 1990; Gray & Shadbegian, 1995). Some researchers believe that environmental regulations will bring additional costs to businesses and decrease direct production input, which will negatively impact overall performance. The study observed 1.2 million plants in the U.S. manufacturing industry from 1972 to 1983 and concluded that, except for carbon monoxide regulations, strict air quality regulations had made the industry's TFP of the manufacturing plants decrease by 2.6% of US$21 billion (Greenstone, 2012).

Some studies believed that due to the imbalanced economic development and the limitation of regulation design, business was suffering from a predicament of insufficient vitality (Chikán, 2008). This argument is also supported by the Pollution Haven Hypothesis when evaluating the impact of environmental regulations on the industrial structure or carbon leakage. The Pollution Haven Hypothesis believes that industries would like to get rid of stringent environmental regulations (Copeland & Taylor, 1994). Not only will the regulated regions face challenges, but the economic situation of regulated sectors will also be threatened. Observing nearly 300 cities in fifteen years, evidence from China shows that air quality regulations will decrease local employment opportunities and drive labour migration to non-regulated sectors (Sun et al., 2019).

The second category with positive altitude is supported by researchers following the Porter Hypothesis. The hypothesis states that well-designed regulations will improve the firm innovation ability and R&D investment, hence, improving the firm productivity and competitiveness (Porter & Ver der Linde, 1995). He defined competitiveness according to the capability of continual innovation at every stage of production and argued that there is an innovation subsidy which can mitigate the cost of stringent environmental regulations (Porter & Ver der Linde, 1995). This argument questions the ability of firms to achieve profit maximization, because the firm's managers are believed to be bounded-rational and present-biased, and short-term profit is preferred without perceiving other potential opportunities which maximize the profit (Ambec et al., 2013). Hence, a well-designed regulation can point out market failure and direct business attention to resource efficiency. The regulation may provide firms with the authority to support environmental investment and reduce external uncertainty (Cohen & Tubb, 2018).

The criteria for well-designed regulations are based on open innovation opportunities, minimizing uncertainty, and sustainable improvement. Researchers believe market-based regulations are in conformity with these criteria rather than command-and-control regulations (Ambec et al., 2013).

The Porter hypothesis has been extended into several versions by later studies: the narrow, weak, and strong version (Jaffe & Palmer, 1997; Cohen & Tubb, 2018). The narrow version describes that when compared with command-based regulations, market-based environmental regulations can motivate production and decrease negative effects. The weak and strong versions of the hypothesis both claim that well-designed environmental regulations benefit involved firms. While the weak version advocates the benefit depends on opportunity costs and may happen in some cases, the strong version advocates the benefit generally exists and could bring net profit to the firms. Aligning with the Porter Hypothesis, researchers thought the positive impact could be found in high-tech development, firm competitiveness, and environmental awareness (Snowdon & Stonehouse, 2006).

In addition to the positive and negative impacts of regulations, other arguments about the relationship are also found in previous literature. Those arguments elucidate that the impact of regulations could be different at different stages. Researchers have attempted to clarify whether it is a stable increasing, reducing, increasing at first and reducing later, or reducing at first and increasing later trend in the business. According to the Porter Hypothesis, some researchers believe that environmental regulations can increase the firm innovation capacity and improve competitiveness as a linear trend (Lv & Bai, 2021). However, researchers analyzed the provincial data from China's iron and steel industry and concluded that environmental regulations are associated with industrial performance in a U-shaped relationship (Wu & Lin, 2021). The threshold relationship between regulations and their impacts implies there could be a time delay in business impact after the regulations have been pressed on, which especially occurs in business innovation performance (Zhao & Sun, 2016). Researchers found that the time delay effect mainly happens in informal regulations, while both command-and-control regulations and market-based regulations could be effective in the implementation (Li & Ramanathan, 2018). The command-and-control regulations could even start to impact in the preceding year (Li & Ramanathan, 2018).

In general, different research contexts and data sources yield diversified conclusions on the impacts of environmental regulations on micro-economy performance. The impacts may also depend on the type of environmental regulations, the regulated regions, and the covered sectors. The complex phenomenon and mechanism ask for targeted observation of specific regulations under different backgrounds.

According to RDT, the pilot ETS in China may impact business performance because the ETS has made emission allowance an additional critical resource requirement to the participants and exposed participants to the uncertainty of penalty due to over-discharge. The ETS regulated sectors are high-carbon intensity sectors whose economic performance is influential to the social economy. Exploring the economic performance of China ETS could provide a more thorough understanding of the regulation practice and an evaluation of its effectiveness. The exploration may also help to benefit the subsequent regulation revision and domestic carbon market expansion as a micro-economic reference.

2.3 Firm Competitiveness

Firm competitiveness is an essential indicator of a firm's ability to compete in the market. Therefore, to identify the impact of pilot ETS on business performance at the microeconomic level, firm competitiveness is adopted as a crucial measurement of the effectiveness of pilot ETS. This section discusses firm competitiveness and how it is affected by ETS in previous literature.

2.3.1 Measurement of Firm Competitiveness

Firm competitiveness is a concept of depicting firm performance and assessing the microeconomic environment, and it is quite popular in the fields of organizational operations, business strategic management, and economics (Porter & Van der Linde, 1995; Chikán, 2008; Snowdon & Stonehouse, 2006). It implies the ability of a firm to continually meet market demand and achieve its profit simultaneously, and it also emphasizes the capability of a firm to effectively respond to structural changes and consistently obtain cutting-edge market information (Falciola et al., 2020; Beck, 1990; Chikán, 2008). Firm competitiveness believes that firms should be robust to "compete" and become more successful than rivals to maintain their market (Summers, 2020). In the context of severe environmental problems, fierce international competition, and post-pandemic economic pressure, it is critical to maintain business competitiveness in the market.

In research on strategic management, firm competitiveness is regarded as the same as business performance, which mainly depends on the firm internal resources and organizational ability to control (Chikán et al., 2022; Wernerfelt, 1984; Zhao et al., 2015; Wu, 2008). Capturing the competitiveness of a firm can help researchers identify the firm's financial situation, productivity, employment, and market influence in the dynamic surrounding (Joltreau & Sommerfeld, 2019). Additionally, firm competitiveness generates sustainability, as it values the long-term possibilities of a firm and pays attention to continuous improvement (Joltreau & Sommerfeld, 2019; Luo et al., 2021). For example, the traditional way to evaluate employment performance focuses on the number of employees, while the firm competitiveness emphasizes the quality and specialization degree of the employees (Snowdon & Stonehouse, 2006). Managers and investors in the market could construct their strategies according to the performance of firm competitiveness and forecast market movement. Because firm competitiveness is regarded as a signal of firm capacity, it can drive the preference for private sector investment in the market (Hermundsdottir & Aspelund, 2021).

Firm competitiveness also enjoys significance in political economics. Firm competitiveness is regarded as an indicator to assess regulation performance (Cetindamar & Kilitcioglu, 2013). Porter (2004) stated that not only regulations will affect firms' market performance, vice versa, the firm market performance will determine the regulatory achievement. The competitiveness fluctuation of participants can reflect the effectiveness of the environmental regulation design. Exploring these fluctuations contributes to understanding regulations and could provide policymakers with a reference for future regulation modification. However, even though the idea that firm competitiveness has important contributions to economics and political science is generally accepted, previous literature still has not made adequate exploration to firm competitiveness in a regulation mechanism (Cetindamar, & Kilitcioglu, 2013; Luo et al., 2021).

Firm competitiveness is a branch of competitiveness discussion. The earliest studies on competitiveness can be traced to the 1990s when the focus of competitiveness studies was conducted at the national level (Falciola et al., 2020; Porter & Ver der Linde, 1995). Because competitiveness research emerged from the international trade theory, the beginning of the national-level research was targeted at analyzing the trading patterns among different national sectors (Falciola et al., 2020).

The general competitiveness concept describes the capacity of an economic actor to expand market share, gain investment, and compete with other market participants (Falciola et al., 2020). The competitive advantages of an entity comprise minimizing labour costs, local trading scheme advantage, productivity, and financial efficiency (Krugman, 1986; Brander & Spencer, 1985; Porter, 1990; Snowdon & Stonehouse, 2006). Initially, believing it is productivity that dominates the competing ability, business administration and economic research have adopted productivity as the common key indicator of competitiveness evaluation. (Falciola et al., 2020; Cohen & Tubb, 2018).

Over time, with the debate about competitiveness becoming more nuanced, the competitiveness concept has extended to different levels. Referring to previous economic literature, competitiveness studies can be categorized into two groups macro-economic and micro-economic. The macro-economic group explores competitiveness in terms of nation and region, while the micro-economic group measures competitiveness in terms of firms, facilities, and industry (Snowdon & Stonehouse, 2006; Liargovas & Skandalis, 2010; Falciola et al., 2020). The shifting of the research interest lies in the argument that firms are individual entities which compete in the market rather than the entire nation. As a result, studies began to focus more on the firm level. Meanwhile, the improved ability of firm data management provides abundant data availability and the microeconomic perspective for competitiveness research, which further motivated the research interest transition from national level to firm level (Porter, 1998; Kurtzman, 1998; Falciola et al., 2020; Cetindamar, & Kilitcioglu, 2013). However, many studies neglected the difference in evaluations of different levels of competitiveness.

To better differentiate national and firm competitiveness, Snowdon and Stonehouse (2006) interviewed Porter who was devoted to competitiveness studies and was assigned by the American then-president Reagan to develop a measurement of national competitiveness. Porter believed that national competitiveness aims to measure the resource-utilized productivity, whereas firm competitiveness targets to measure the performance of its profitability and market share (Snowdon & Stonehouse, 2006). Dresch et al. (2018) also attempted to conceptualize the three levels of competitiveness. They advocated that national competitiveness seeks to measure the macroeconomic performance, the regulation mechanism, and international resource access of the country. While regional competitiveness emphasizes infrastructure design, firm competitiveness should focus on internal organization evaluation.

2.3.2 Firm Competitiveness in the ETS

While exploring the ETS impact on firm competitiveness, different results have been discussed as follows. Researchers in the EU investigated 5873 firms from the power, cement, and steel industries and found impact heterogeneity exists in different sectors (Chan et al., 2013). In the power industry, EU ETS increased its material cost by 8% and revenue by an average of 30% (Chan et al., 2013).

However, no significant impact is observed on firm competitiveness in the cement or steel sector. These findings were supported by another case study in the iron and steel industry under EU ETS. After evaluating firm competitiveness by profitability and production indicators, researchers thought the influence in the iron and steel industry was virtually absent (Demailly & Quirion, 2008). Another study conducted in the EU by Joltreau and Sommerfeld (2019) also believed that EU ETS will not harm firm competitiveness, because of the loose allocation of emission allowance and the compliance costs pass-through by the firms.

Zhang and Duan (2020) conducted a study and found that the pilot ETS could not avoid negatively impacting competitiveness, because the production in China is highly reliant on resource consumption and the economic output is tightly correlated to carbon emissions. Their research observed the green innovation patents in China ETS and found the weak version of the Porter Hypothesis did not yield obvious results (Chen et al., 2021). This is probably because the pilot ETS may lead to a reduction in a firm's expected revenue, which indirectly affects the research and development (R&D) investment capacity of firms.

However, it has been noticed that there are some positive impacts on firm competitiveness in China ETS. A group of Chinese researchers observed a satisfying effect on competitiveness in the refinery sector. It is shown that the fluctuation of manufacturing costs caused by the emission trading market would bring technological and facilities innovations to the firm and industry employment opportunities would proliferate in the labour market (Wang et al., 2015). Another study that tries to identify the impact of China ETS on firm green competitiveness and cost competitiveness states that ETS can improve both of them through technological innovation and carbon asset management (Luo et al., 2021). Moreover, the transmission effect of firm behaviours in competitiveness has also been verified in the study. It is believed that by conducting carbon asset management, carbon transactions, and technological innovation step by step, the influence of firm behaviours on competitiveness will be deepened gradually.

2.4 Research Hypotheses

Compared to other ex-ante studies of ETS, there are few ex-post studies which directly discussed the relationship between China ETS and firm competitiveness. Based on the literature review, the insufficiency of previous studies related to how ETS would affect firm competitiveness could be summarized as follows.

First, it is hard to generate a conclusive agreement over the economic effect of China ETS since the economic impacts of the regulations are heterogeneous and inconsistent. As the literature review indicates, the impact studies of environmental regulation could be divided into two categories, the Compliance Cost Hypothesis and the Porter Hypothesis. Both of them are supported by plenty of scholars and are proven in a lot of research. After analyzing more than one hundred studies on environmental regulation, researchers Cohen and Tubb (2018) concluded that the number of studies supporting positive effects and negative effects are equal. The earlier studies mostly prove that environmental regulations have a negative influence on firm competitiveness, while studies in recent years prefer to confirm a positive influence of regulations on competitiveness. It is not surprising to see that, in the ex-post studies of ETS performance, different research subjects could make different conclusions. The instability and heterogeneity of the regulation effect highlight the urgency of further specification in the field. It is also necessary to discuss the sectors respectively while designing the research. This thesis selected the power and heat production sector as the research subject because the power and heat production sector, which has been included in all the pilots, plays an important role in China pilot ETS. (Luo et al., 2021; Xiao et al., 2021). The emission of the sector accounts for around 40% of the national carbon emissions and could meet 60% of the market demand for power (China Electricity Council, 2023). It is also one of the main stakeholders of the pilot ETS. Exploring the situation of the power and heat production sector in ETS could improve the understanding of China ETS performance.

Second, current research lacks ETS evaluation on the firm level. In the literature of ETS ex-post analysis, most of the studies focus on exploring the regional and industrial scale (Cao et al., 2021; Demailly & Quirion, 2008; Zhang & Duan, 2020; Cheng et al., 2015; Hoffmann, 2007). However, there are relatively few researchers working on the micro-level analysis of the firm performance or power plants (Cetindamar & Kilitcioglu, 2013; Jiang, 2016). Aligning with the resource dependency theory and institutional theory, as participants of the ETS, firms are experiencing numerous regulatory obstacles and challenges, such as additional compliance costs (Pfeffer & Salancik, 1978; Oliver, 1991; Drees & Heugens, 2013; Delke, 2015; Hillman et al., 2009; Coase, 1960; Zhao et al., 2015; Drees & Heugens, 2013; Oliver, 1991). The business environmental changes will have an inevitable impact on the production and operation of firms. Investigating the performance of the firms that are subject to the regulations and depicting this microeconomic landscape will serve as a bottom-up participant view for the decision-makers. Based on the arguments and gaps highlighted above, this study proposes the following hypotheses to understand the effect of China pilot ETS on firm competitiveness in the heat and power production sector:

H0: *There is no relationship between the implementation of China pilot ETS and regulated firm competitiveness in the power and heat production sector;* $\beta_1 = 0$.

H1: *There is a relationship between the implementation of China pilot ETS and regulated firm competitiveness in the power and heat production sectors;* $\beta_1 \neq 0$.

The third problem of previous research is that different researchers employed different concepts for firm competitiveness and applied diversified measurements to evaluate firm competitiveness, some concepts are quite misleading as the researchers did not distinguish between national competitiveness and firm competitiveness when choosing indicators. For example, *productivity* is the most frequently used indicator in studies exploring national competitiveness, industrial competitiveness, or firm competitiveness (Greenstone et al., 2012; Snowdon & Stonehouse, 2006; Falciola et al., 2020; Dresch et al., 2018), while Porter mentioned in an interview that he supposed *profitability* and *resource efficiency* are the key indicators in firm competitiveness studies, while *productivity* is more suitable in national and industrial competitiveness studies (Snowdon & Stonehouse, 2006).

Chikan (2008) emphasized firm competitiveness should be measured by a framework with consideration of resource, managerial capability and outcome indicators (Cetindaar, & Kilitcioglu, 2013). The resources are mainly composed of financial, technology, and human resources. The managerial processes and capability of a firm refer to how firms can organize their resources. The outcome indicator signifies the profit and growth of the firm. Other researchers argued that firm competitiveness is best evaluated by its ability to compete in the market, to adapt sustainably, and to update on value information (Falciola et al., 2020). This measurement concentrates on the dynamic characteristic of competitiveness and aims to assess the ability of a firm to constantly respond to the external environment. Besides, the firm competitiveness can also be evaluated in terms of the internal ability of the firm and external market performance or measured by indicators related to adding value, reducing cost, and non-financial resources (Chikán et al., 2022; Hermundsdottir & Aspelund, 2021; Dresch et al., 2018; Wu, 2008). It is evident that most frameworks of firm competitiveness assessments have their own focuses, but in general, they have taken the market performance into account as the external perspective or the outcome perspective. At the same time, the production or managerial process is widely considered in the assessment as the internal ability of the firm or the incentive of firm competitiveness.

The deficiency of non-financial facets in the evaluation is obvious. For environment regulation studies, non-financial facets like environmental performance are not only the indicator for regulation evaluation but also the indicator of firm capacity. Previous studies prefer using simple financial indicators when measuring firm competitiveness, like profitability or investment (Hermundsdottir & Aspelund, 2021; Zhang & Wang, 2021; Carratù et al., 2020). However, other intangible resources and environmental capacities are not evenly considered, and competitiveness could depend on environmental facets, including public image, Corporate Social Responsibility (CSR), Environmental, Social and Governance (ESG), customer satisfaction, environmental contribution, energy efficiency, and even firm culture (Zhang, 2015; Cohen & Tubb, 2018; Snowdon & Stonehouse, 2006). Hence, both financial capacity and environmental capacity should be considered in a broad view.

The research gaps noted above signal a need for studies using a multi-dimensional approach to examine firm competitiveness. Because different measurements of firm competitiveness will provide different results, this study combines theoretical approaches to clarify the characteristics of firm competitiveness in the pilot ETS (Hermundsdottir & Aspelund, 2021; Falciola et al., 2020). Besides, the primary goal of ETS is to control emissions, while the power and heat production sector is high carbon intensity and under intense scrutiny (Zhang et al., 2014; Xiao et al., 2021). In this case, this study proposes three sub-hypotheses of the relationship between firm competitiveness and pilot ETS from profitability, production investment, and environment perspectives:

H2: *The China pilot ETS improves the firm profitability performance in the power and heat production sector;*

H3: *The China pilot ETS increases the firm production investment in the power and heat production sector;*

H4: *The China pilot ETS positively affects the firm environmental performance in the power and heat production sector.*

Chapter 3 - Methodology

The purpose of this study is to advance the understanding of China pilot ETS' impact on firm competitiveness. This chapter explains the methodology of this study, starting with the philosophical stance. The second part of this chapter, research design, describes the content from constructing the framework of firm competitiveness to the indicators and measurements. Data selection about the applied databases and sampling process are included in the third part of the chapter. Then, the Difference-in-Differences (DID) model is explained by principles, advantages, previous applied cases, and contributions to the study.

3.1 Research Philosophy

Research philosophy is the philosophical stance of the world. It initiates the study and provides the basic belief of the research method (Creswell & Creswell, 2017). Positivism is referred to as the research philosophical stance of this research, which advocates the significance of pursuing a genuine understanding of the world by continuing testing and refining theory. It also focuses on the validity of analyzing numeric data and measurement to phenomenon observation (Creswell & Creswell, 2017). Positivism aligns with the deductive approach in research. Studies guided by positivism start with a hypothesis and then followed by numeric data analysis to verify or reject the hypothesis (Crowther & Lancaster, 2008). In research methods, positivism prefers quantitative research for validity. Hence, this study will adopt the quantitative method to measure the firm competitiveness and analyze the pilot ETS effect.

3.2 Research Design

It is hard to capture the comprehensive effect of pilot ETS by a single indicator or measurement, so the multi-dimensional assessment framework is proposed. To test the hypotheses and avoid the bias and insufficiency of measurements in previous studies, evaluation indicators are selected based on the commonness of firm competitiveness definitions and the observed firms' characteristics.

3.2.1 Indicators and Measurements

Chikan (2008) concludes that firm competitiveness is the capacity to achieve the dual purpose of sustainably meeting customers' demand and achieving profit. It can also be described as the ability of firms to constantly adapt to changes and seize the opportunity for innovation (Falciola et al., 2020; Porter & Ver der Linde, 1995). They respectively highlight the short-term and long-term evaluation of a firm ability. The first focuses on the external ability of the firm for market performance and the latter focuses on the internal ability of the firm for production. Hence, firm competitiveness tries to emphasize a comprehensive adaptability and resilience of firms based on traditional profitability.

In addition, firms in the power and heat production sector are characterized by high carbon intensity and heavy dependency on production (Cao et al., 2021). Meanwhile, they are under stringent governance by the authority for energy security. Binding the triple pressures from profit, production command compliance, and environmental conservation, indicators evaluating the business competitiveness of these firms may be different from those of fully market-oriented ones.

Indicators for measuring firm ability in the previous literature are compared in terms of profitability, production investment, and environmental facets. Profitability for a firm means how well the firm has been managed and its ability to generate value (Petersen & Schoeman, 2008; Chikán et al., 2022). The firm profitability perspective of competitiveness focuses on the external assessment of the market performance or value-creation activities. For example, researchers used turnover to observe the firm competitiveness in the power, cement, and iron and steel industries (Chan et al., 2013). In contrast, another group of researchers employed international cross-listing activities for firm market competitiveness (Oxelheim, 2019). The firm market share can be adopted for assessing the firm main product competitiveness and serves as a reference for market power in research (Alvarez et al., 2009). To analyze the firm capacity to add value, other indicators like trade performance, revenue, return on assets (ROA), return on sales (ROS), return on equity (ROE), growth in sales, net profit margin, stock market returns and EBITDA margin are also employed by researchers for distinct angles (Joltreau & Sommerfeld, 2019; Hermundsdottir & Aspelund, 2021; Liargovas & Skandalis, 2010; Chikán et al., 2022).

For the validity and reliability of the analysis in this study, firm competitiveness is observed in terms of profitability by the Return on Assets (ROA) which measures the ratio of net profit to the total assets of the firm. The net profit is usually the net income of the firm after tax, and the total asset for the listed firm is the sum of total liability and equity. The ROA has been regarded as a significant indicator of firm value and attraction to shareholders, as it shows how much value will be created at an average level based on every unit of assets (Petersen & Schoeman, 2008). Husna and Satria (2019) revealed that a high ROA, which enjoys market-confident investment sentiment, would raise the stock price of a firm and strengthen competitiveness. Hence, this study employs the ROA as the profitability indicator to observe the firm competitiveness in pilot ETS.

The production perspective focuses on the internal assessment of the firm to understand its competitiveness. After analyzing one hundred studies about firm production competitiveness, researchers advocated that the production capacity of a firm is usually evaluated by efficiency and quality (Hermundsdottir & Aspelund, 2021). For example, some efficiency indicators aim to capture the production situation by output per unit, such as productivity in gross output or export, the total-factor productivity (TFP), employment in the number of employees, observation of governance system, and the average wage rate (Petrick & Wagner, 2014; Chan et al., 2013; Joltreau & Sommerfeld, 2019; Oxelheim, 2019; Greenstone et al., 2012; Van Beveren, 2012). The total-factor productivity (TFP) is worth mentioning specifically because it is a popular indicator in previous research in which labour and capital are comprised in calculation formulas with standard weights (Greenstone et al., 2012; Van Beveren, 2012). Indicators like production cost reduction, subsidies from the government, and cost competitive advantage that can describe the picture of firm production are also likely found in numerous studies (Hermundsdottir & Aspelund, 2021; Zhao et al., 2015; Luo et al., 2021).

The production of a firm demonstrates the process of transforming raw material into a commodity, and, in this study, the firm competitiveness in production is estimated by operating costs. The production and dispatch in power and heat production sectors are mostly command-oriented in China, which means the electricity generation quotas are not decided by the firms (Cao et al., 2021).

The operating costs of a firm is the cost related to business operations and is composed of equipment maintenance, raw material cost, and labour salary. Evaluating the operation costs of firms in China ETS can help to identify their production strategy and attitude. It can reflect how firms respond to the dynamic change and uncertainty brought by the regulation (Yang et al., 2018). In the power and heat production sector, raw material cost is the expense of fuel consumption which accounts for the largest part of the operating costs (Yang et al., 2018). The fuel consumption is mainly determined by operating hours and the quantity of electricity generators. And usually, the more electricity they produce, the higher the operating costs will be. Hence, the indicator of operating costs is valid to exhibit the production situation of the firms. To eliminate the problem of heteroscedasticity of data and facilitate calculation, the measurement of production competitiveness indicator is the logarithm of operating costs.

The third perspective of analyzing firm competitiveness is environmental performance. In recent studies, market reputation and environmental performance have been regarded as firm resilience and ability to respond to accidents or dynamic business situations. Researchers started to value the environmental performance of the firm as an intangible asset based on coal efficiency and consumption, emissions reduction, corporate image improvement, or green technology (Cao et al., 2021; Zhao et al., 2015; Chen et al., 2021). Other stakeholder engagements are treated as environmental evaluation indicators as well, such as environmental information disclosure for shareholders and the environmental quality of the production process (Zhao et al., 2015; Oxelheim, 2019; Rennings & Rammer, 2009). All these observations generate a broader view of firm competitiveness beyond the financial facet and capture the regulation achievements from a political-economic perspective. In pilot ETS, the primary goal of the regulations is to control the emissions caused by power and heat production without imposing too many restrictions on production (Zhang et al., 2014; Xiao et al., 2021). Therefore, this study explicitly defines the non-financial evaluation of firm competitiveness by tracking the emission performance of the observed firms.

The carbon emissions of power and heat production firms primarily come from the power conversion process, such as fuel combustion. The emissions from the power and heat production firms not only occupy the largest portion of industrial emissions in China but also have a huge impact on global emissions. It is believed that half of the emissions from Chinese industrial production are generated by the power and heat production sector, which constitutes a tenth of the world emissions (China Electricity Council, 2023; Cao et al., 2021). Managing emissions in this sector could significantly contribute to global GHG emission control. In the pilot ETS, identifying the emission performance could provide a reference for regulation effectiveness or inefficiency and serve as a reference to future regulation modification and energy structure upgrading.

The carbon emissions data of this study are expected to be acquired from the firms. However, there is no public access to firm-level emission data in China (Lv & Bai, 2021). As an alternative option, this study chose to calculate the firm emission data to align with the firm production scale according to province sectoral data. The measurement is the provincial sector emissions multiplied by the ratio of the firm operating costs to the total operating costs of firms in the provincial sector. The emission data accounts for the carbon dioxide in the unit of Mt and follows the IPCC sectoral approach. If the firm emission level is lower than itself in the past, it will be regarded as having better environmental performance with a satisfying competitive capacity.

In general, based on the previous studies that evaluate firm competitiveness from diversified perspectives, this study selects the profitability, production investment, and environmental perspectives to analyze the firm performance for a comprehensive view. In line with the principle of validity and credibility, the characteristics of the power and heat production sector have been considered while choosing the indicators. Finally, the firm ROA, operating costs, and carbon emissions are selected to assess the firm competitiveness. The measurements of dependent variables are listed as follows.

a. Profitability perspective: *ROA*. Measured by – ROA (net profit/ total asset)

b. Production investment perspective: *Operating costs*. Measured by – the logarithm of operating costs

c. Environmental perspective: *Emissions*. Measured by – firm operating costs/ the sum of the operating costs of all local firms in the sector *provincial sector carbon emission (mt)

Referring to previous studies, control variables are selected to manage other potential factors that may impact the competitiveness indicators (Lv & Bai, 2021). The leverage, liability, Tobin's Q, firm size, and firm age are selected and measured as follows.

Tobin's Q. Tobin’s Q is recorded according to the ratio of firm market value to asset replacement costs as a selected control variable (Zhang & Wang, 2021). It can determine whether the firm is overvalued by the market. Firms with Tobin’s Q below one are likely to attract more investment interest and enjoy an increasing stock price (Fu et al., 2016).

Leverage. The firm competitiveness indicators can be affected by leverage, which is the ratio of the firm's total liability to a total asset. A firm with high leverage means it is heavily dependent on debt to operate the business. By the leverage, the profit of the business could be amplified, and at the same time, the investment risk could also be informed (Chen et al., 2021).

Liability. Liability is the money that a firm owes, and the liability of firms is also controlled during observation. It is measured by the natural logarithm of the firm total liability (Winton, 1993). It could be the bills that the firm needs to pay for debt, payroll, or tax. Firms with high liability may be accompanied by solvency risks that could affect the firm equity position and competitiveness (Winton, 1993; Haji et al., 2018).

Firm size. Firm size could be another factor able to affect firm competitiveness, because firms with large scale can mobilize more resources in the competitive market. For example, they can have more available capital to maintain business while responding to the regulations and they are less dependent on specific production resources and more innovative in challenges (Bibi et al., 2020). In this study, the firm size is measured by the natural logarithm of the firm employees.

Age. The age of the firm is calculated by the natural logarithm of the firm's listed age. It can be regarded as an intangible asset of the firm. The longer a firm has been listed, the better market influence it is likely to enjoy, which plays a positive role in promoting the firm's financial constraints and reputation (Chen et al., 2021). In the light of more market experience of the firm, its intangible assets can be benefited in a disguised way and, therefore, enhance its competitiveness.

3.2.2 Databases

All financial data in this study are generated from the China Stock Market & Accounting Research Database (CSMAR), which is one of the most authoritative financial and economic databases in China. It provides research data for nearly 100,000 research papers and is a widely used database for policy research papers and economic evaluation papers (CSMAR, n.d.). The environmental performance data is collected by the Carbon Emission Accounts & Datasets (CEADs). It is a publicly available database that generates energy consumption, pollution emissions, and other economic data from developing countries. The database is supported by the projects of the Ministry of Science and Technology of China, the National Natural Science Foundation of China, and the Research Councils UK to ensure authority (Chen et al., 2021).

3.2.3 Data Selection

The sample of this study is selected from all A-share listed firms in China power and heat production sector from 2010 to 2019. The starting year of the observation is 2010 to avoid the impact of the 2008 and 2009 global economic crises. The ending year of the observation is 2019 to avoid the societal impact of COVID-19 in 2020. The regulation implementation time is set as 2013, while most of the pilot ETS programs were launched in 2013, and only two of the seven pilots were launched in 2014. The regulation implementation time aligns with most of the previous studies (Xiao et al., 2021; Zhang & Wang, 2021; Lv & Bai, 2021; Qi et al., 2021).

To examine the ETS impact on firm competitiveness in the sector of power and heat production, the process of firm selection is listed below:

A) First, the list of all A-share listed firms before 2010 from the CRMAR database was downloaded. A-shares are common stocks issued by Chinese firms for domestic institutions, organizations, or individuals to subscribe for and trade in CNY (Chakravarty et al., 1998).

B) After downloading the list of all A-share listed firms, according to the Industry Classification Code of China Securities Regulatory Commission (2012), the listed firms in the power and heat production and supply industry with the industry code D44 shall be retained.

C) Then, for the remaining firms, based on their financial statements and news, a manual selection is made according to their business operations situation. Eliminate firms in biomass power generation and power information technology services, such as hydro power, wind power, nuclear power firms.

D) Finally, according to the registration location of the firms, eliminate the firms that have registration change during the observation period to ensure the validity of the subsequent grouping.

According to the above screening criteria, only 40 firms were retained as observation targets at the end. Firms in the pilot provinces were classified as *the treatment group*, and others were *the control group*.

3.3 Data Analysis

This section introduces the Difference-in-Differences model for estimating the causal effect of an intervention as well as the Stata statistical software in which DID executes.

3.3.1 Difference-in-Differences

This research applies the Difference-in-Differences (DID) model to analyze the data. DID is a representative quantitative research method in applied economics research (Angrist & Krueger, 1999; Puhani, 2012). The method compares the treatment group and the control group to evaluate the impact of a treatment in the same context and period. The first difference is the outcome difference between the pre-treatment and post-treatment of each group, while the second difference is the gap between the two groups' outcomes (Schwerdt & Woessmann, 2020). It requires the treatment group and control group to comply with a parallel trend before the treatment, which means the difference between the two groups before the treatment should be constantly stable. In this way, the effect of external and unobserved factors on the experimental results can be mitigated (Angrist & Krueger, 1999). By analyzing the panel data, the difference-in-differences method can also take time trends and contextual changes into the effect evaluation as controlling variables to improve the research validity (Dimick & Ryan, 2014).

The DID used to be a research method to analyze medical issues in 1855, according to Goodman-Bacon (2021). Then, in economic studies, it was initially used to identify the issues in employment effects and labour income fields (Ashenfelter, 1978; Angrist & Krueger, 1999). Because the analysis model is simple to understand and helps to control selection bias in the process of research, DID method has been favoured by economic studies (Brewer & McEwan, 2010; Barrett & Just, 2022).

The DID is a suited and widely used approach in research on regulation evaluation (Angrist & Krueger, 1999; Dimic, & Ryan, 2014; Conley & Taber, 2011; Stuart et al., 2014; Clair et al., 2015; Saeed et al., 2019; Raifman et al., 2017). Many empirical studies of carbon trading have adopted the DID method to analyze the regulation impacts. Researchers applied the DID method to analyze the firm's CO_2 emission reduction possibilities of stringent environmental regulations (Fan et al., 2019). Yang (2018) used the DID method to evaluate the ETS's carbon price fluctuation caused by auction and investment access. Zhou et al. (2019) used the DID method to explore ETS's practical utility on China's carbon intensity and emission reduction. Another study used the DID method to evaluate 267 cities' data to identify whether the ETS has contributed to the emission reduction of China's collaborative governance (Yan et al., 2020).

Previous studies also conducted the DID method in mapping the ETS regulation impacts on business. German researchers used the DID method to detect European Union (EU) ETS impacts on manufacturing financial performance (Löschel et al., 2019). Zhang and Duan (2020) adopted the propensity score matching technique and difference-in-difference models (PSM-DID) while exploring the relationship between China ETS and gross industrial output value (GIOV) at the provincial level. Researchers applied DID in identifying the China ETS function on firm total factor productivity (TFP) (Xiao et al., 2021). While investigating the characteristics of firm investment decisions under China ETS, Zhang and Wang (2021) used DID to analyze the firm panel data in eight high carbon-intensity industries.

In general, previous regulation evaluation studies and econometric studies have achieved satisfying analysis outcomes by employing the DID method. This study is inspired by the previous literature and applies the DID method in the competitiveness analysis. Meanwhile, the method will be accompanied by sufficient robustness tests. Considering the limitation of the DID method, which is not able to detect the causal mechanism leading to the differences between groups, related studies will be supplemented to figure out the reasons.

To explore the impact of China ETS on firm competitiveness based on the previous variables, the DID general formula of the analysis model is as follows for each individual *i*:

$$\begin{aligned} &Competitiveness\ indicator_{it} \\ &= \beta_0 + \beta_1 Pilot_i \times Time_t + \beta_2 Pilot_i + \beta_3 Time_t + \sum_{k=4}^{8} \beta_k\ CON_{it} + \gamma_i + \gamma_t + \varepsilon_{it} \end{aligned}$$

The $Competitiveness\ indicator_{it}$ corresponds to the three competitiveness indicators in this study, which are profitability, production investment, and environmental performance, respectively. Following the DID model, this study induces the dummy variable, $Pilot_i \times Time_t$, to reflect the nature of regulation time and groups. *Pilot*: This dummy variable reflects whether the firm belongs to the *treatment group*. If the firm belongs to the *treatment group*, the *Pilot* value equals one. If the firm belongs to the *control group*, the *Pilot* value equals zero. *Time*: This variable is also a dummy variable that reflects whether the observed time is before or after the regulation time. This study chooses 2013 as the regulation effect year. The *Time* value equals zero if the year is before 2013. The *Time* value equals one if the year is in or after 2013.

$$Pilot_i = \begin{cases} 0 & \textit{if the firm i is not covered in the pilot} \\ 1 & \textit{if the firm i is covered in the pilot} \end{cases}$$

$$Time_t = \begin{cases} 0 & \textit{if year<2013} \\ 1 & \textit{if year = or > 2013} \end{cases}$$

In the model, the $Pilot_i \times Time_t$ is the dummy variable of pilot and time interaction, the coefficient $\beta_1$demonstrates the net impacts of pilot ETS on the firm competitiveness during the observation period. The CON_{it} represent the control variables in the study. γ_i is the individual fixed effect that captures the factors affecting the firm competitiveness which are vary between individuals but not vary over time. Then, γ_t is the time-fixed effect on the firms representing factors changing with time and can affect firms. ε_{it} is the error term. To control the standard error of the data, some variables are measured in logarithms.

Table 1 Variables Description

Variable	**Symbol**	**Definition**	**Measure**
Dependent variable	*Profitability*	ROA	net profit/ total asset
	Production	Operating Costs	the logarithm of operating costs
	Emission	Carbon dioxide emissions	firm operating costs/ the sum of the operating costs of all local firms in the sector *provincial sector carbon emission (mt)
Independent variable	*Time*	Regulation time	0, if year < 2013; 1, if year = or > 2013
	Pilot	Pilot project location	0, if the firm i is not covered in the pilot 1, if the firm i is covered in the pilot
Control variable	*TobinsQ*	TobinsQ	the ratio of market value to asset replacement costs
	Leve	Leverage	Total liability/ total asset;
	Lliability	liability	the natural logarithm of the firm total liability
	lnemp	Firm size	the natural logarithm of the firm employee
	lnage	Age	the natural logarithm of the firm being listed

3.3.2 Stata

The Stata, a professional statistical software, will be used to process the panel data and regression. It is one of the most popular software for data manipulation in the economic field. In the majority of DID studies, Stata is the applied statistical software. According to Xu (2021), Stata has some advantages over other statistical software. For example, its commands and syntax are easy to grasp. It does not require researchers to have advanced programming ability. Stata also displays the output clearly. It can transform the output into tables or graphs and export them to the document directly. Another function of Stata is that it can quickly fulfill many repeated random samplings and present the regression results efficiently. This advantage contributes to the robustness test in this study.

To sum up, this study is proposed in view of positivism with a quantitative method to analyze the firm competitiveness. The competitiveness is evaluated in terms of the profitability, production, and environmental performance of the firms in the pilot ETS program. All listed firms in the power and heat production sector from 2010 to 2019 are selected and 2013 is set as the regulation implementation year. The study employed the DID model to analyze these data, while firms in the regulated regions are the treatment group and firms in the non-regulated regions are the control group. Regression results and the discussion are generated in the next chapter.

Chapter 4 - Results

The impact of ETS implementation is estimated by the Difference-in-Differences method in terms of firm competitiveness based on ROA for profitability, operating costs for the production investment and carbon dioxide emission for the environmental performance. The result proves that China ETS has non-negligible impacts on firm competitiveness, and the null hypothesis is rejected. In detail, China ETS increased the firm profitability and reduced the firm operating costs. For environmental performance, the regulations significantly reduce the emission level. This chapter interprets the DID regression results of the research question and discusses its correlation with previous studies in the context of literature.

4.1 Variables Descriptive Statistics and Correlations Analysis

Table 2 and Table 3 show the descriptive statistics of the study and matrix of variables correlations analysis.

In Table 2, 40 firms are divided into the treatment group of 15 firms in regulated areas and the control group of 25 firms in non-regulated areas. The observation of each competitiveness indicator is 398. The maximum ROA for profitability is 0.29, and the minimum is -1.303. The highest operating costs indicator of observed firms is 25.738, while the lowest is 18.479, and the average is 22.054. The carbon emission of each firm ranges from 0.492 to 581.997 Mt, while the mean of the emission amount is 93.065 Mt. The value of lnage starts from 0 to 1.45. The earliest listed firm was listed in 1993, while the latest listed firm was listed in 2010. Table 2 also shows the leverage level of firms varies from 0.937 to 0.051, where the average is around 0.6.

To test the multicollinearity of the regression model, this study has adopted the correlation coefficient method and variance inflation factor method (VIF) in the analysis. It was believed that if the correlation coefficient is greater than 0.8 or the VIF is larger than 10, the regression will be highly risky in multicollinearity and further discussion of the model should be needed for estimation stability and accuracy (Alin, 2010).

In Table 3, the largest VIF listed is 4.67 and the mean VIF is around 2.41, which are significantly lower than 10. The correlation coefficients between each variable are lower than 0.8, which means the regression model does not have a significant multicollinearity problem that will seriously affect the result.

Table 2 Descriptive Statistics

Variables	Obs	Mean	Std. Dev.	Min	Max
treatment	15	1	0	1	1
control	25	1	0	1	1
profitability	398	.022	.081	-1.303	.29
production	398	22.054	1.558	18.479	25.738
emission	398	93.065	108.36	.492	581.997
leve	398	.59	.187	.051	.937
Lliability	398	22.818	1.747	17.277	26.433
TobinsQ	398	1.373	.881	.798	8.55
lnemp	398	3.43	.559	2.104	4.765
lnage	398	1.203	.158	0	1.415

Table 3 Matrix of Correlations and VIF

Variables	(1)	(2)	(3)	(4)	(5)
(1) leve	1.000				
(2) Lliability	0.692	1.000			
(3) TobinsQ	-0.471	-0.598	1.000		
(4) lnemp	0.464	0.769	-0.362	1.000	
(5) lnage	0.004	0.199	-0.054	0.245	1.000
VIF	2.03	4.67	1.63	2.61	1.10

4.2 Empirical Results

Based on the regression model in 3.4, the impact of China ETS on firm competitiveness in the power and heat production sector is analyzed by the DID method. During the regression, this study adds the individual fixed effect and time fixed effect. The fixed effects functioned as control variables to represent the unobservable factors with fixed characteristics for each individual or each year in the regression.

The research purpose of this study is to observe the effects of ETS on firm competitiveness in China, and the results of competitiveness indicators are shown in Table 4. Table 4 displays the DID regressions for firm profitability, production investment, and carbon emission indicators in sequence. It shows that the pilot ETS affects the competitiveness of the covered firms in terms of profitability, production, and carbon emissions simultaneously. Because *did* coefficients of all the competitiveness indicators are significant, it is rational to reject the null hypothesis *H0* that pilot ETS will not affect the firm competitiveness in the power and heat production sector. Column (1) indicates that the introduction of ETS during the observation period improved the firm profitability performance. The coefficient of the independent variable *did* is 0.0324, which means this study finds a positive relationship between pilot ETS and the firm profitability. Hence, *H2* is supported in this study. According to Column (2) of Table 4, the impact of the ETS implementation on firm operating costs is negative with the coefficient -0.245 at a 5% significant level. While the *H3* assumes that the ETS will increase the firm production investment, it should be rejected according to the negative coefficient.

From the environmental perspective, the carbon emission of firms exhibited an evident reduction from 2013 to 2019. Table 4 shows that the coefficient value of the reduction effect is -15.86, which is significantly justified at the level of 95% ($\beta_2 = -15.86$, $p<0.05$). Due to the firm carbon dioxide emission unit of the account being Mt, the coefficient value of the reduction effect is dramatically outstanding and satisfactory. Hence, the *H4* is supported, which proposes that the ETS had brought positive contributions to the firm emission performance. These results are important to understand the pilot ETS impact.

Table 4 The Results of DID Analysis

DID	(1)	(2)	(3)
Variable	Profitability	Production	Emission
did	0.0324*	-0.245**	-15.86**
	(0.0162)	(0.104)	(6.563)
Time	-0.0707	0.236	36.86**
	(0.0464)	(0.159)	(16.35)
o.Pilot	-	-	-
TobinsQ	-0.0460**	-0.0249	-0.130
	(0.0190)	(0.0262)	(1.882)
leve	-0.325**	-1.199**	-51.24*
	(0.136)	(0.450)	(27.94)
Lliability	0.0410	0.537***	12.29*
	(0.0313)	(0.160)	(7.069)
lnemp	-0.0340	0.459	-16.74
	(0.0363)	(0.280)	(14.74)
lnage	-0.0564	-0.138	-28.94
	(0.0618)	(0.562)	(30.50)
Constant	-0.460	9.078***	-79.00
	(0.488)	(2.887)	(122.4)
Observations	398	398	398
R-squared	0.263	0.681	0.199
Number of idcode	40	40	40

Robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

The DID results of this study in the observation period indicate that the implementation of China pilot ETS affects the firm competitiveness in the power and heat production sector. Implications of the results are explained in the next chapter.

4.3 Robustness tests

This study adopts the DID method to observe the firm performance in the ETS pilot program. Several robustness tests have been initiated to ensure the validity of the DID results, including two parallel trend tests, two placebo tests, and one dynamic DID analysis.

4.3.1 The Parallel Trend Test

Before implementing the regulation, the treatment group and control group conform to the parallel trend, which is a prerequisite for the DID analysis. Two approaches are initiated to perform the parallel trend test. One is the graphic method, and the other is event analysis. The outcomes are written as follows:

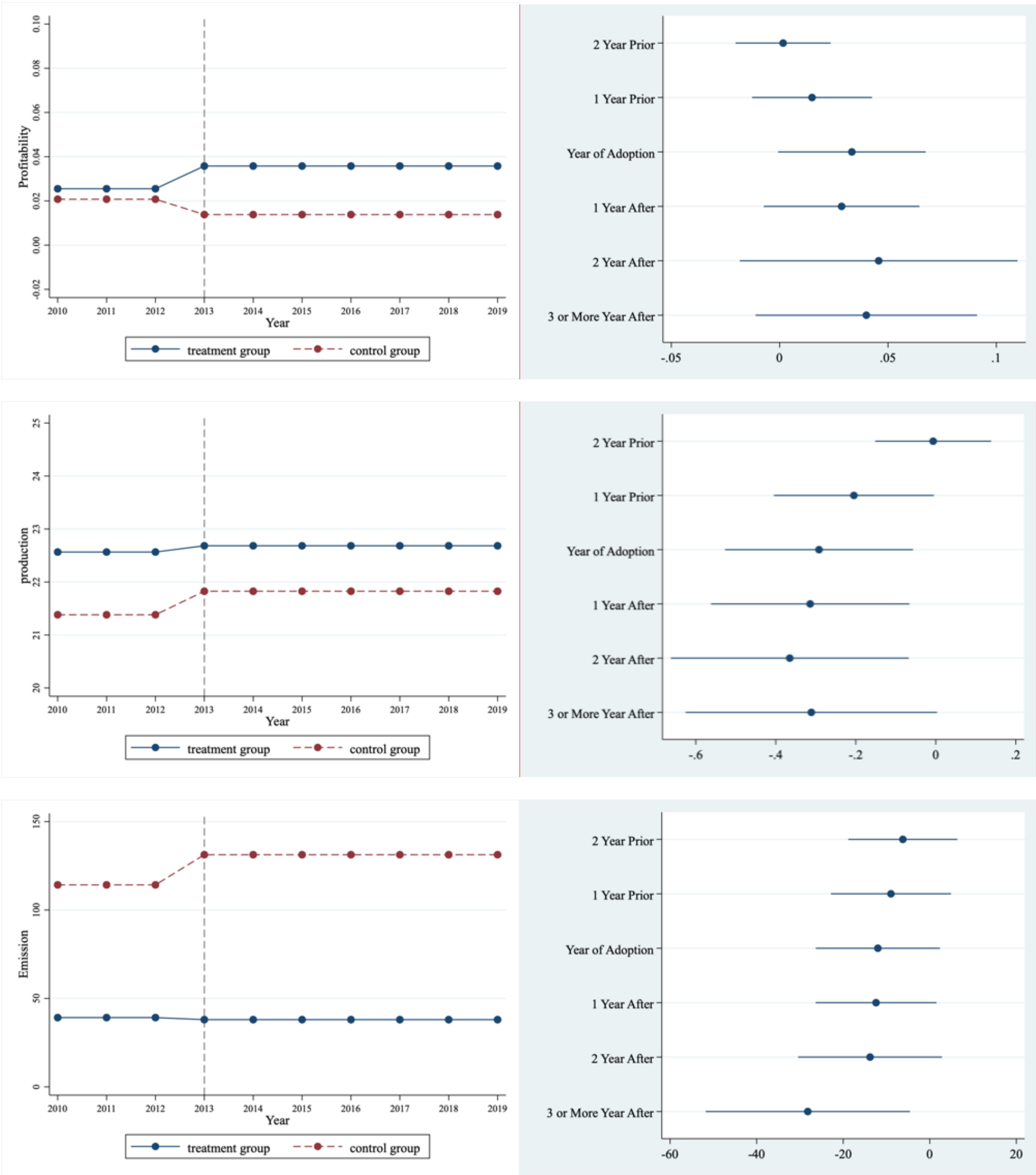
Referring to previous literature, the time trend of firm profitability, production investment, and emissions are observed in the treatment group and control group (Schwerdt & Woessmann, 2020; Angrist & Krueger, 1999). As shown in Figure 1, from 2010 to 2013, the regulated firms and non-regulated firms share relatively the same trend in all three indicators. The three indicators pass the parallel trend and support the validity of DID results.

The event analysis also proved that the treatment group and control group confirmed the parallel trend before regulation implementation. For the regression, the interaction term between the time dummy variable and the treatment group dummy variable was created as the independent variable. The indicators of ROA, operating costs, and emissions were selected as dependent variables in the analysis selectively. The difference in each competitiveness indicator between the treatment group and the control group each year could be reflected by the coefficients of the interaction terms. It is necessary for each competitiveness indicator that passes the event analysis to show insignificant interaction terms before the implementation year.

As shown in Figure 1, before the treatment year, the two groups are in line with the parallel trend distribution of the three indicators. The trend of the interaction variable coefficient is flat, the coefficients approximate zero before the year of adoption, and the 95% confidence interval contains the 0 value. This indicates that before implementing China ETS, there was no heterogeneity difference between the treatment and control groups. Hence, by event analysis, it could be concluded that the treatment group and control group satisfied the parallel trend before the regulation implementation. In addition, the event analysis exhibits a clear downward trend in the production and emission indicators since China ETS was implemented. Simultaneously, the trend of the profitability indicator showed an ascending curve after the pilot ETS.

In general, the graphic method and event analysis method indicate that the DID model of this study conforms to the parallel trend assumption, and the regression result is robust.

Figure 1 The Robustness Test of Parallel Test



4.3.2 Placebo Test

To further test the validity of the study results, the placebo test was introduced to the analysis. There are mainly two approaches to conducting placebo tests. One is a time-based approach which introduces an assumed regulation implementation time, and the other is a group-based approach which randomly assigns treatment groups. This study conducts both of them for robustness.

(1) Time-based placebo test

Introducing an assumed regulation time in the placebo test is to shift the launch of the regulations to years earlier and observe the significance of the interaction coefficients. If the interaction coefficients are not significant in the assumed time, the test is passed. The actual outset of regulation implementation is in the year of 2013. To conduct the placebo test, the two years before 2013 in the observation period were used as an assumed regulation year for regression analysis.

Table 5 shows the regression analysis of the placebo test on assumed regulation time. The *Before2, Before1, Current, After1, After2, and After3* are dummy variables. When it is two years before treatment, the dummy variable *Before2* is taken as one, otherwise, taken as zero. If it is one year before treatment, the *Before1* is taken as one, otherwise, taken as zero. When the observation is in the year of treatment, the *Current* is taken as one. When the observation is one year, two years, and three years more after treatment, the *After1, After2*, and *After3* are taken as one respectively, otherwise taken as zero.

The regression result is shown as follows:

Table 5 The Placebo Test of Assumed Regulation Time

	(1)	(2)	(3)
VARIABLES	profitability	production	emission
Time	-0.0749	0.263	44.09**
	(0.0504)	(0.171)	(19.23)
o.Pilot	-	-	-
Before2	0.00161	-0.00655	-6.215
	(0.0109)	(0.0716)	(6.228)
Before1	0.0149	-0.205**	-8.963
	(0.0137)	(0.0989)	(6.859)
Current	0.0333*	-0.292**	-12.00*
	(0.0168)	(0.116)	(7.095)
After1	0.0286	-0.314**	-12.41*
	(0.0178)	(0.123)	(6.899)
After2	0.0457	-0.365**	-13.79
	(0.0317)	(0.147)	(8.220)
After3	0.0400	-0.311*	-28.18**
	(0.0253)	(0.155)	(11.66)
leve	-0.329**	-1.193**	-43.00
	(0.142)	(0.457)	(27.47)
Lliability	0.0421	0.534***	10.09
	(0.0324)	(0.159)	(7.276)
TobinsQ	-0.0459**	-0.0223	-0.999
	(0.0188)	(0.0259)	(1.981)
lnemp	-0.0355	0.474*	-14.53
	(0.0374)	(0.279)	(14.60)
lnage	-0.0534	-0.147	-34.43
	(0.0614)	(0.564)	(31.65)
Constant	-0.480	9.108***	-34.78
	(0.507)	(2.843)	(130.3)
Observations	398	398	398
R-squared	0.264	0.685	0.220
Number of id	40	40	40

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 5 shows the coefficients in assumed regulation time for profit and emission indicators, which are evident that neither of them is significant. The coefficients of production indicators were also insignificant in the assumed regulation year of 2011 (*Before 2*), but they became significant in the year of 2012 (*Before 1*). This can be explained as a front-loading effect of the regulations.

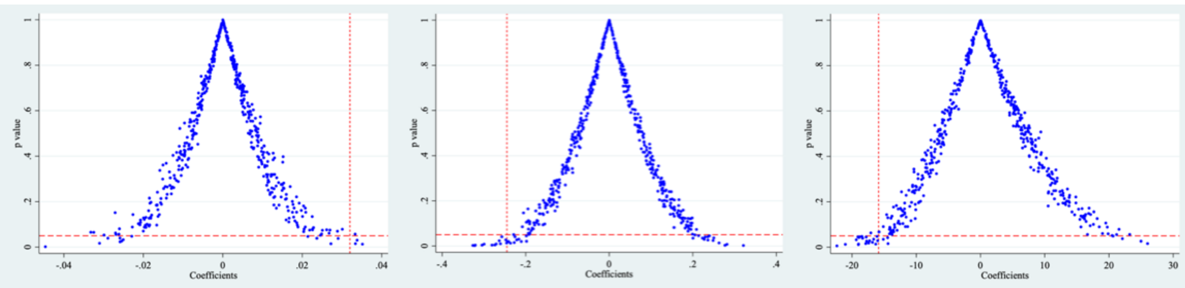
The *Before1* coefficient is significant because of the announcement of the regulations in 2011. In that year, the Chinese government released an announcement declaring that there would be a pilot ETS program launched in seven provinces in the next few years. As a response, relevant firms may immediately start to adjust their production strategy ahead of the implementation to avoid the risk of violation. Based on the data in the firm's annual reports, it is expected that the operating costs started to reduce in the year right after the announcement. Therefore, the reductive operating costs that happened in 2012 makes the *Before1* coefficient significant.

(2) Group-based placebo test

This study also introduces a random treatment group to test the observation results. An equal number of firms were randomly selected from all the observed firms as in the actual treatment group, which is 15 in this study, and they are taken as an assumed treatment group. The random selection will be done 500 times and observed the regression results respectively. The placebo test of randomized treatment groups was able to identify whether the observed regulation effect was caused by other factors. If the placebo test is passed, in which the test results differ significantly from the actual regulation effects results, the DID results can be justified without disturbance of other factors.

As shown in Figure 2,

Figure 2 The Placebo Test of the Random Group



The blue spots represent the coefficient of competitiveness indicators and the corresponding p-value of every regression in total 500 times. Most blue spots are located higher than the red significant reference line on the Y-axis (p value=0.05), regardless of which competitiveness indicator it is. It concludes that, for the three competitiveness indicators, most of the placebo test regression results are insignificant. At the same time, every X-axis reference line represents the actual DID regression coefficient corresponding to each indicator. It is also evident that there are only a few spots located around the actual coefficients with significance in all the 500 observations. The outcomes obtained from the placebo test further demonstrate the validity and reliability of the findings.

4.3.3 DID Dynamic Effect Analysis

The robustness of this study also has been proved by the DID dynamic effect test. Like the placebo test to construct a dummy regulation time method, the dynamic analysis adopted an event analysis approach to create new interaction dummy variables referring to every single year in the observation period. While the placebo test emphasizes identifying if any replacement will influence the result, the dynamic effect analysis tends to measure the coefficient of competitiveness indicators every single year. Dynamic effect analysis contributes to the robustness of the result in determining the level of the independent variable's influence on the dependent variable each year and provides additional information to understand the consequences of regulation implementation on firm competitiveness.

As shown in Table 5, the profitability regression is only significant in the year of launching ETS, while in the rest years of the observation, it is insignificant. The production regression shows that the coefficient has been significant since 2012 and has lasted for the whole observation period. The coefficient of emission indicator is all significant with an increasingly negative effect during the observation except for the third year from the outset of the implementation. These significant coefficients are robust to the results of the study.

Chapter 5 - Discussion

This research is conducted to better understand the effects of ETS on firm competitiveness in China. The observed firms come from the power and heat production sector which is the highest carbon-intensity. This research also proposed a new framework for evaluating firm competitiveness after exploring the relationship between ETS regulations and the firm's operations. This chapter discusses the profitability analysis, production investment analysis and environmental analysis of firm competitiveness observed. The last part of the chapter highlights the limitations of this research and proposes recommendations for future studies.

5.1 The Impact of ETS on Firm Competitiveness

As stated in the literature, the ETS has been recognized as the most effective market-based regulation for controlling environmental emissions and incentivizing business initiatives in the process (Jiang, 2016). According to Pigou (1920), environmental pollution creates a negative externality on economic production which must be quantified and priced accordingly. To promote market efficiency and sustainable production, the Chinese government has implemented a pilot ETS which limits firm emissions rather than allowing unrestricted pollution. Since then, firms can sell excessive emission allowances in the carbon market and enjoy direct profit from emission abatement. By complying with the profit-seeking attribute of firms and the flexibility of the market, the ETS regulations help the government reduce administrative costs and motivate participants with economic methods to control pollution.

Aligned with RDT, the ETS regulations will affect the operation strategies and efficiency of a firm as a governance mechanism to manage external resources (Pfeffer & Salancik, 1978; Oliver, 1991). Consequently, the firm competitiveness in the market will be impacted. In the post-pandemic period, both the government and firms are experiencing fiscal pressure and financial challenges. Studying the firm competitiveness in ETS can help identify the effectiveness as well as the economic costs of the regulations. In the study, firm competitiveness is assessed according to its profitability, production investment, and environmental performance, where the firm Return of Assets (ROA), operating costs, and carbon emissions have been observed as dependent variables. The Difference-in-Differences approach has been employed to estimate the impacts of China pilot ETS on the firm competitiveness. The findings might serve as a microeconomic reference for the government in evaluating the regulation design and adaptation. At the same time, this study can benefit the firms by assessing the risks brought by the regulations and simultaneously inspiring firms to further develop their coping strategies in the future.

5.2 Profitability Analysis of Firm Competitiveness in ETS

According to previous literature, China pilot ETS will drive additional emission abatement costs to the regulated firms while motivating the firm's innovation. In the Compliance Cost Hypothesis, the increasing abatement costs will indirectly reduce the production investment of the firms, which induces negative effects on profitability (Barbera & McConnell, 1990; Gray & Shadbegian, 1995). The argument is challenged by the Porter Hypothesis which believes that market-based regulations will contribute to promoting the efficiency of firm production as well as profitability (Porter & Ver der Linde, 1995; Ambec et al., 2013). In accordance with the Porter Hypothesis, some studies have verified a satisfying result of ETS on profitability in the EU with evidence of growing revenue (Demailly & Quirion, 2008). Thereby, Hypothesis 2 has been proposed that China pilot ETS will improve the firm profitability in the power and heat production sector. The profitability in firm competitiveness describes the firm external capacity in the market (Cetindamar & Kilitcioglu, 2013). It reflects the firm efficiency of adding valuable activities and financial quality (Dresch et al, 2018). Firms with higher profitability enjoy preference from investors and stronger financial competitiveness in the market (Husna & Satria, 2019). The firm profitability is measured by ROA in this study. Based on the previous arguments and research, it is expected to see an improvement in the firm ROA indicator after the China pilot ETS is implemented.

Referring to the regression result in Table 4, the *did* coefficient value of profitability performance is significantly positive. It means that during the observation period, the China ETS regulations significantly promoted the firm profitability in the power and heat production sector. The coefficient value of the profitability indicator is 0.0324, which indicates that, over the observation time, the ETS implementation was able to improve the ROA of regulated firms by approximately 3.24%. Consequently, it can be concluded that the pilot ETS implementation is able to induce profitable opportunities for firm competitiveness. Hence, Hypothesis 2 was successfully supported by the DID regression results.

These findings are consistent with prior studies that ETS helps improve firm profitability in some scenarios through rational trading behaviours (Jiang, 2016). The Chinese government issues free emission allowances tradable in the carbon market to regulated firms. In the face of resource constraints, regulated firms tend to regard emission allowance as valuable production material to meet their emission needs. Just like other firms in emission-dependent sectors, the power and heat production firms will be prudent in their emission trading decisions to make expected profit in the market (Zhang et al., 2011). The marginal effect between firm emission abatement costs and the allowance sale revenue facilitates firms to design a rational trading strategy to comply with emission restrictions and also helps them achieve profit maximization.

Researchers discussed the profit opportunities brought to firms by the price difference between single-time emission purification and carbon emission allowance in three scenarios (Zhang et al., 2011). In the first scenario, the firm purification cost is lower than the carbon allowance price. It means that the firm enjoys a higher carbon abatement efficiency with a lower expense on every emission reduction unit, so the firm will voluntarily exert itself to achieve emission reduction and sell its excessive allowance to the market. The gap between allowance sales income and emission abatement costs will then benefit the firm with increasing profitability. The second scenario refers to a situation where the purification costs and allowance price are equal, and there is no space for profit in this scenario. The third scenario reflects the situation in the emission allowance price is lower than the firm purification costs. In this case, the firms are more likely to purchase allowance from the market according to their emission level to minimize regulatory costs. Consequently, in the first scenario in which the purification costs of the firm is lower than the market allowance price, a rational carbon trading decision could benefit the firm profitability.

From the perspective of optimal production, the finding that ETS helps improve profitability also aligns with arguments from the Porter Hypothesis statement that environmental regulation can benefit firm profitability under certain conditions. Porter and Ver der Linde (1995) argued that environmental regulations might induce low-carbon innovation activities of the covered subjects. If the regulations are well-designed, firms will be motivated to increase investment in technology or facility innovation, such as process innovation, green-patent innovation, product innovation, innovative human resources, and clean energy facility upgrading (Wu & Lin, 2022; Lv & Bai, 2021). The increased innovation activities will improve the productivity of firms. If productivity is improved, firms will be able to create more profit with the unit input. Thus, improved productivity contributes to the firm profitability in this path. In general, the Porter Hypothesis holds that the innovation compensation effect can make the firm profitability positively affected by the regulations (Lv & Bai, 2021). The Porter Hypothesis is also the expected achievement of the government while designing environmental regulations. The government hopes to achieve environmental conservation and economic vitality simultaneously (Cohen & Tubb, 2018).

Porter Hypothesis has been proven to exist in China while implementing environmental regulations in some studies (Wu & Lin, 2021; Wang & Lin, 2018; Cheng et al., 2016). From the industrial perspective, ETS implementation was believed to make the low-carbon intensity production burst into life. A previous study mentioned that ETS could improve employment in some industries, especially high clean energy occupations in the power and heat production sector (Cheng et al., 2016). High clean energy is a relatively innovative part of the sector. Increasing employment opportunities in the innovative part of the sector illustrates that firms may increase their efficiency and financial performance through regulations.

5.3 Production Analysis of Firm Competitiveness in ETS

Due to the flexible market mechanism which empowers participants to transact their carbon assets and financially benefit from emission reduction, ETS has been regarded as one of the most cost-efficient approaches to managing emissions (Jiang, 2016). According to the studies about the Porter Hypothesis, well-designed regulations can increase the competitiveness of regulated firms by motivating production (Jaffe & Palmer, 1997; Cohen & Tubb, 2018; Snowdon & Stonehouse, 2006). Hence, Hypothesis 3 was proposed, which indicated that China pilot ETS would increase the firm production investment in the power and heat production sector. The production investment is significant to explore in high-carbon firms as it can determine the operations and development capability of a firm (Zhang & Wang, 2021). At the same time, it can also reflect the firm confidence in the dynamic environment and show the firm resilience as an internal competitiveness indicator.

The production investment is measured by the logarithm of the firm operating costs from the annual financial reports. Referring to the linear regression results in Table 4, the coefficient of operating costs is significantly negative at the 5% level. It means that, during the observation from 2010 to 2019, there was a negative relationship between the pilot ETS and firm operating costs. The operating costs of listed firms in the power and heat production sector have been reduced by 24% since the regulation was implemented.

Hypothesis 3 should be rejected with respect to the results. This result is contrary to the positive arguments generated in the EU ETS but is aligned with some previous studies in the pilot ETS (Zhang et al., 2016). The rationale could be interpreted as follows. While as the high carbon-intensity sector, the operating costs of the power and heat production sector is closely impacted by raw material expense, labour, and equipment maintenance (Yang et al., 2018). The decrease in the firm operating costs under ETS may be caused by the reduction of the production scale and the lack of confidence in the firm's production strategy (Zhang & Duan, 2020).

It is believed that, in the pilot ETS, high-carbon sectors can hardly separate the economic output from the emissions (Zhang & Duan, 2020). Literature indicates that, in most jurisdictions like China, the production of firms in the power and heat production sector is controlled by governments or related organizations (Cao et al., 2021; Teng et al., 2014). The sector is not fully market-oriented, which means the regulations will have a more pronounced effect on firm decisions even though it may hurt the interest of the firms. The primary goal of ETS is to achieve GHG emission reduction and comply with international conventions (Zhang et al., 2014; Xiao et al., 2021). Effectively reducing carbon dioxide emissions in production has become a major challenge for firms in the power and heat production sector. Referring to ETS, the regulations mainly manage the carbon emissions which are emitted directly by the firms. Firms in the Chinese power and heat production sector produces power dominantly by consuming coal, which emits a vast quantity of carbon emissions (China Electricity Council, 2023; Cao et al., 2021). Under the pressure of emission control regulations, cutting electricity output and production downscale is highly practical and effective.

Literature provides plenty of potential rationales to support the idea that firms are reducing their production output and investment expenditure to commit to the ETS regulations (Zhang & Wang, 2021; Du et al., 2016). The RDT theory believes that the uncertainty from the business environment restrains investment in operations (Duncan, 1972; Bernanke, 1983). The uncertainty is driven by political, market, technical, and other external environmental factors (Wang et al., 2023). Because it is more practical and efficient for a firm to cut operating costs than improve revenue once it confronts business risks, the declining operating costs could be an economic outcome of the uncertainty of China ETS regulations.

Chinese ETS regulations induce both political and market uncertainty to the covered firms on operating investment. The purpose of building the pilot China ETS program is to accumulate experience and identify implementation problems for the future national ETS program. The regulation design and complements to governance mechanisms are still in the trial and observation phase. Implementation challenges in the pilot ETS are widely comprised of data credibility, the rationality of allowance allocation, MRV, trading transparency, regulation continuity, legislation, and other potential practical barriers (Jiang, 2016). Bearing varied implementation challenges, China ETS leaves participants with uncertainty and risks.

Firm investment decision demonstrates sensitive sentiment on regulation uncertainty and profitability opportunity (Bernanke, 1983; Aldy & Viscusi, 2014). These political uncertainties and risks will threaten the investment profitability in the firm operations and impact the business cycle. The business profit-seeking nature encourages firms to avoid risk and pursue optimal financial performance. The implementation of China pilot ETS will induce external drivers to change firm resource allocation and production costs. Concerning the unpredictable impacts, as a response, the majority of regulated firms choose a wait-and-see strategy to delay investments (Chen et al., 2021; Feng et al., 2021).

In this situation, firms in the power and heat production sector will become more conservative in production and operation. To minimize the additional production costs and default risk, some short-term solutions for emission reduction will be considered. The reduction solutions urge for high pertinence and effectiveness within the compliance cycle. Reducing production and cutting operating costs meet these urges and will simultaneously achieve the dual goal of emission reduction and control risks (Zhang & Duan, 2020).

As for market uncertainty, unsatisfactory carbon trading market performance could be another rationale for firms to reduce operating costs. The trading markets are designed to reduce the cost of abatement for firms and profit the firms to achieve better emission performance by selling the remaining emission allowance. However, the carbon trading price and trading volume have not reached the expectations of the designers.

Though the carbon price fluctuated in the initial period of the regulation, the price remained relatively stable for the long term. However, the trading prices have been significantly different among different market pilots during the implementation of China ETS (Chen & Xu, 2018). The carbon price in the Beijing trading market is the highest at CNY120, but in Chongqing, the trading price is the lowest at CNY1. The average prices in Shenzhen and Beijing are more than twice as expensive as those in Chongqing and Hubei. Apparent price differences in pilots may lead to distrust and negative attitudes of firms about future market trend and production strategies.

According to researchers Chen and Xu (2018), since the inception of the market, carbon trading vitality has been limited. The most active trading period is at the end of each compliance cycle, while there is no trading activity on the majority of the days. Besides trading activities, the total trading volume is rather low. The ratio of trading volume to the allowance cap is around 5% in the most active market among the seven pilots, where nearly half of the market trade is less than 1%. The total trading volume in the seven pilot markets is insufficient for the overall cap of emission allowances.

The inactivity of the market implies that the covered firms prefer to regard emission trading as a regulatory requirement rather than a profitable investment. The trading behaviours and emission abatement are conducted with the purpose of avoiding the penalty for excessive emissions.

These sector production interventions and market uncertainties introduce additional risks to regulated firms, which may encourage the wait-and-see situation and negative expectations of the production environment (Chen et al., 2021; Feng et al., 2021). In conclusion, the pilot ETS may fail to induce positive motivations to the production capacity in firm competitiveness.

5.4 Environmental Analysis of Firm Competitiveness in ETS

To align with the increasing demand for reducing global GHG emissions, how to effectively control carbon dioxide emissions in industrial production has become a challenge for environmental regulation design. Previous literature indicates that environmental regulation helps mitigate the market externality of production emissions by putting a price on every unit of emissions (Pigou, 1920). The price will induce profit-seeking firms to re-organize their emission plan to minimize compliance costs and maintain profitability. The goal of implementing ETS in China is to reduce emissions, and previous findings indicate that pilot ETS will successfully achieve its goal at different levels. Both ex-ante and ex-post studies have found positive evidence. Researchers believe that pilot ETS in China will induce a lower emission mode in the society, and the emission intensity will begin to reduce immediately after the implementation year without time lag (Cheng et al., 2015; Liang et al., 2014; Zhang et al., 2015; Zhou et al., 2019). Therefore, Hypothesis 4 has been initiated, which expects to see the emission diminishing in the power and heat production firms.

Referring to Table 4, the coefficient of carbon emission is significantly negative, which implies that during the observation period, China pilot ETS successfully affected the firm emission level. The carbon emissions of regulated firms in the power and heat production sector have decreased remarkably once the regulations were implemented. According to the firm competitiveness framework of this study, from the environmental perspective, China ETS strengthens the firm competitiveness with evident emission reduction performance. With respect to the linear regression result, Hypothesis 4 passed.

This result is supported by some previous research findings. With the compliance costs concern, firms will make efforts to reduce carbon emissions. In the ETS, the “cap” of the regulations characterizes emission allowance with scarcity and constraints, which injects economic vitality into emission control (Jiang, 2016). The emission allowance is regarded as a production resource with both risks and opportunities for the covered firms. The risks come from the situation that the emitter default risk. When the covered firms emit more than the allowance they own, they will be subject to penalties, including financial fines and emission allowance reduction in the future compliance cycle (Chen & Xu, 2018). The opportunities happen in the scenario that the covered firms have more allowance than their emission so that they can trade the rest of the allowance as a commodity for profit. Because firms aim to gain expected profit with production, both the risks and profit opportunities can propel firms to reduce their emissions.

A possible reason for emission reduction in the power and heat production sector is production reduction. There is evidence showing that the investment expenditure of covered firms in the ETS would generally be reduced (Zhang & Wang, 2021). The investment expenditure reflects the investment decisions of the covered firms in the ETS, including high-tech innovation, production, operation, and market expectation. Due to the cost concern, covered firms may not choose to install high-tech facilities in the short term (Zhang et al., 2011). Instead, firms prefer to reduce production. The production value and business output of the high carbon-intensity sectors in China ETS have been proven to decrease (Chen et al., 2021). Besides, in section 4.2, this study has identified the production investment of the power and heat production sector is declining, so it is rational to conclude that the power production sector is controlling emissions by directly reducing production.

However, the desire of the government to design the regulations is not to limit production but to induce a low carbon-intensity economy (Zhang & Wang, 2021; Zhou et al., 2019). Theoretically, firms’ innovation could lead to a low-carbon transformation in the power and heat production sector. It is expected that regulations could improve the innovation capacity of the covered firms and bring opportunities to production efficiency (Porter & Ver der Linde, 1995; Ambec et al., 2013; Jaffe & Palmer, 1997; Cohen & Tubb, 2018). Some scholars credited China ETS with injecting vitality into innovation according to the analysis of research on patent quantity (Lv & Bai, 2020). Lv and Bai (2020) argue that, after the pilot ETS implementation, patent applications increased in high-carbon emission sectors (Lv & Bai, 2020). However, it is doubtful whether the number of patent applications will improve the firm capacity to reduce emissions. Conversely, green patent data in China shows that the ETS fails to achieve the green innovation capacity of firms (Chen et al., 2021). Hence, this study is more inclined to believe that the emission reduction found in the regression results is caused by firm production reduction rather than by green technology innovation.

Based on the above findings, the contribution of green innovation in emission reduction should be focused on future research. Some argue that green innovation in China can be improved in three aspects: energy innovation pre-combustion, carbon productivity during combustion, and emission purification after combustion (Kanniche et al., 2010). Clean energy, such as photovoltaic power, wind power and hydropower enjoy dynamic vitality in the power sector. Through continuous development, the application costs of such clean energy exhibit a declining trend. Wood Mackenzie (2019), one of Britain's top three stockbrokers, postulates that by 2026 China will be able to achieve the same cost of photovoltaic and conventional coal-fired power. The declining trend of clean energy costs is inspiring and should be expected to induce firms to introduce low-carbon energy in production and contribute to lower carbon emissions.

5.5 Limitations and Future Studies

According to the DID results, ETS will increase the profitability of regulated firms and reduce their operating costs and CO2 emissions. Through multiple robustness tests, it is rational to reject the null hypothesis, which denotes there is no effect of pilot ETS on firm competitiveness. However, every study has its limitations.

The sample size of this study is relatively small, which may have low generalizability for other high carbon-intensity sectors as this study focused on firms only in the power and heat production sector.

After the data selection process, only 40 firms are left for observation. Future studies could further analyze the firm competitiveness in more sectors with a larger sample size or dive into the data from the plant-level once available to the public.

Researchers hold that the constraint of emission allowance availability in the power production sector will impact the firm production and emissions, involving multiple unobserved idiosyncratic factors (Chan et al., 2013). Further research can enhance comprehension of the effect of ETS on firms, particularly with regard to conflicts that arise between authoritative control of production and market-based regulatory mechanisms.

Besides, multiple studies have mentioned that there is merely no available emission data of firms currently (Lv & Bai, 2021). This study tries to calculate the firm emission data based on sector emission data according to the firm production scale. However, there will be some differences with actual firm emission data. With the development of ETS data transparency and availability, further studies could measure the firm emissions with more direct and exact data to observe the regulation effect.

Finally, the results of this study might serve as a piece of sectoral evidence to help inspire future studies on corporate behaviours and strategic operation fields.

Chapter 6 - Conclusion

With carbon emissions increasing, the environmental capacity and economic society of urbanization have been affected. Carbon dioxide is regarded as the major source emission contributing to climate changes, which could lead to severe issues like energy insecurity and food scarcity. To mitigate the situation and propel more countries to burden their environmental responsibility, the *Kyoto Protocol* has been signed by the UN with an emission reduction goal. ETS has been regarded as the most cost-efficient regulations to induce a market incentive on emission reduction activities. The principle is to characterize carbon emission allowance with scarcity and make emissions at cost. China has been implementing the pilot ETS since 2013, in which seven provinces were selected as the pilots. In the expanded path, the government launched the national ETS in 2017 and made the years 2021 the first compliance cycle.

The aim of the pilot ETS is to accumulate experience for constructing the national carbon market. However, the insufficiency of pilot firm-level observation means that knowledge of China ETS needs further exploration. By conducting ex-post studies on the firm performance in the scheme, the research purpose of this study is to advance understanding of the China ETS impact on firm competitiveness. Observed indicators are firm ROA in terms of the profit capacity, operating costs from the production investment, and carbon emission from the environmental performance. The selected sector is the power and heat production sector which is one of the eight highest carbon emission sectors in China. By conducting a DID model for data analysis, this study found that there is a significant impact on the regulated firms in their competitiveness performance. The ETS regulations can improve the firm's profitability and environmental performance in the observation period, and it also reduces the firm's operating costs but is probably due to the production reduction. The robustness tests have supported the credibility and validity of the DID results.

The findings about the ETS effect on firms could emerge with several political implications for the government and regulated firms. Based on the limited trading volume in the market and firm operating costs reduction, this study suggests that the government might improve the ETS stakeholder engagement for better public acceptance. It should promote the firms' understanding of the regulations and their trading awareness of the carbon allowances. With the expansion of the ETS in China, the carbon allowance is expected to become an investment commodity in the trading market rather than a simple regulatory binding on firms. The trading behaviour should be active in the compliance cycle and profitable for the participants. The stakeholder engagement in the ETS may contribute to encouraging firms to join the market and sell surplus allowances for revenue.

Additionally, the government might take measures to improve the legislation system for the ETS, such as a scientific approach to allocate allowances, to clarify penalties for over-emitting, and financial incentives for technology innovation. The improvement in regulation design could mitigate the regulatory uncertainty and risks for the firms. The regulatory uncertainty is likely to induce a wait-and-see strategy in the business field which may reduce the firms' enthusiasm to participate and even threaten the normal production plan (Chen et al., 2021; Feng et al., 2021). Over time, a negative impact on economic efficiency will become irreversible. It is believed that a scientific regulation design will instill innovation vitality into production, compensate for the compliance costs of the firm, and achieve the emission goal simultaneously.

At last, regulated firms are expected to actively participate in the trading market. By joining the market, firms with surplus allowances could gain profit from the transaction and they can also accumulate trading experience in the practices, which will be conducive to their prospect because the Chinese government intends to extend the implementation of the ETS. In the next few years, more sectors and participants might be included in the markets. Sustainable financial derivatives and trading forms in the carbon market will both be developed and enriched. The earlier a firm joins the carbon market, the more advantage it will take in the subsequent transaction.

The main argument of this study is that the pilot ETS could impact the firm competitiveness in terms of the profitability, production strategy, and emission perspectives. The limitations of the study are the small data size of selected firms and the unavailability of actual or direct firm emission data. Future research could investigate the mechanism rationale of the ETS effect on the firm competitiveness and explore the evaluation framework of firm competitiveness to further fit the characteristics of the sector and the market background.

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