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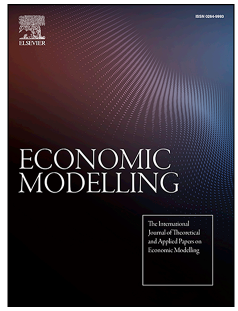

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Does China's emission trading scheme affect corporate financial performance: Evidence from a quasi-natural experiment

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Abstract

Taking China's emissions trading system (ETS) pilots as a quasi-natural experiment, we examine how the ETS affects firms' financial performance. Previous studies highlight the impact of ETS on regional and industrial development; however, few studies focus on its potential impact on firms' performance. Using a time-varying difference-in-differences model and data on Chinese listed firms from 2008 to 2020, we find that the ETS pilots have significantly positive impacts on firms' profitability and value and a negative impact on operating costs. We also find that the ETS pilots improve total factor productivity, but the technological changes indirectly suppress the relation between the ETS and financial performance. Finally, we find evidence that state-owned enterprises experience more significant improvements in their financial performance, led by ETS participation. Our findings have policy implications for firms' sustainable development and the transition to a low-carbon economy.

Keywords: Emission trading scheme; Corporate financial performance; Carbon emission; China

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1. Introduction

The impact of greenhouse gas (GHG) emissions on climate and the environment has been increasing along with climate-related disasters and environmental hazards, requiring urgent mitigation (Henry, 2019). China's exponential industrial and economic development in recent decades has inextricably placed China as the world's largest emitter of carbon dioxide (CO_2) since 2009 (Wu et al., 2018). Under pressure from domestic challenges to the sustainable development of its industry and economy and international concerns about environmental degradation, China has promised to ensure its CO_2 emissions peak by 2030 and become carbon neutral by 2060. This target requires China to constrain its CO_2 emissions below 12Gt per year (Den Elzen et al., 2016), which would grow to 18Gt if no measures were taken.[1]

China may have to confront economic trade-offs to achieve its emission commitments. Mi et al. (2017) predict that peaking carbon emissions by 2026 will cause China's annual gross domestic product (GDP) growth to decrease to 4.5% by 2030. This projection contrasts with its average GDP growth of 8.69% from 2002 to 2021. From a resource-based view, firms' primary concern is the additional costs stemming from GHG emission charges and the redirection of resources from productive activities towards technological innovation to meet emissions-cutting commitments. This transition could adversely impact firms' innovative capacities, productivity, and financial performance. Thus, environmental goals might be realized at the expense of firms' competitive advantage in their products and services (Simpson and Bradford, 1996; Zhang and Liu, 2019).

Porter's hypothesis (1991) challenges the notion of the perceived conflicts between environmental goals and economic prosperity, arguing that such belief arises from a static view of environmental regulations, which incorrectly presumes little development occurs in technology, production, and stakeholder awareness and needs. Extending this argument, Porter and van der Linde (1995) introduce the concept of "innovation offsets." They assert that adequately designed environmental policies and regulations can stimulate technological innovation. This dynamism can lead to cost efficiencies, improved productivity, and the introduction of high-value products and services. Consequently, firms can more adeptly respond to shifting stakeholder requirements and secure an advantage over global competitors. Some empirical studies have echoed this argument, showing that environmental policies and regulations can foster innovative technology development and enhance firms' productivity and competitiveness (Cai et al., 2023; Xie et al., 2023). In light of the disparate empirical evidence and interpretations, it is imprudent to consider environmental regulations as solely facilitators or inhibitors

[1] In 2019, China's CO_2 emissions were 14Gt, exceeding those of all other developed countries and amounting to 26.7% of total global emissions. See https://www.unep.org/emissions-gap-report-2020

of technological progress and firm performance. Academics and regulators are encouraged to further investigate the intricate relationship between environmental policies and their economic implications.

Among the various environmental policies and regulations, the carbon emissions trading system (ETS) is an effective tool for promoting the transition to a low-carbon economy. This market-based regulating instrument allocates GHG emissions allowances or permits to participating companies or entities. According to Porter's hypothesis, the implementation of the ETS will motivate regulated firms to boost their competitiveness and prioritize cost-effective carbon reduction by investing in low-carbon technologies, adopting innovative production approaches, or both (Wang et al., 2019; Fischer et al., 2003).

As the largest emerging economy and a major energy consumer, China recognizes the potential of ETS and regards it as a pivotal tool in transitioning toward a low-carbon economic transformation and achieving a win–win scenario for both the economy and the environment (Stern and Xie, 2023). China initiated eight regional ETS pilots are established in 2013, following other major global economies.[2] By 2017, this initiative was expanded to the national level. After several years of preparation and planning, China officially launched its national ETS in 2021, regulating more than 2,200 energy producers. As a result, China's national ETS has become the world's largest carbon market regarding trading volume and emission coverage (IEA, 2020).[3,4]

Although China's national ETS has begun operating fully, the experiences and lessons from the regional ETS pilots are still vital for shaping and building a successful and effective national carbon market (Linnenluecke et al., 2016). These trials offered valuable insights and understanding crucial for policy adjustment and subsequent policy formulation. Some recent studies suggest that the regional ETS pilots reduced local energy consumption, carbon emissions (Hu et al., 2020; Zhang et al., 2020), and haze pollution (Yan et al., 2020) and improved green total factor productivity (Li et al., 2022). Although the extant literature has highlighted some regional, city, and industry impacts of the ETS, there are limited studies evaluating and analyzing the impact of the pilot ETSs on firms' operations

[2] The European Union commenced a "cap and trade" emission trading scheme in 2005, as the cornerstone of Europe's climate policy. It is the world's largest multi-national GHG emission allowance trading scheme (Brouwers et al., 2018).
[3] See "China's Emissions Trading System will be the world's biggest climate policy. Here is what comes next", by Chris Busch. *Forbes*. See https://www.forbes.com/sites/energyinnovation/2022/04/18/chinas-emissions-trading-system-will-be-the-worlds-biggest-climate-policy-heres-what-comes-next/?sh=4a2daecc2d59
[4] The system's coverage is expected to broaden, encompassing many industries and emission types. By 2025, six newly identified sectors—iron and steel, aluminum, cement, chemicals, papermaking, and civil aviation—will be integrated into the ETS system. For an in-depth discussion, refer to "Overcoming obstacles to expanded industry coverage under China's national carbon emissions trading system" by Chris Bushch, Hu Min, and Chen Meian (Energy Innovation, 2022). See https://energyinnovation.org/wp-content/uploads/2022/04/Overcoming-Obstacles-to-Expanded-Industry-Coverage.pdf

and economic outcomes. Thus, we attempt to fill this gap in this paper by comprehensively analyzing how the pilot ETSs influenced firms' performance.

Implementing an ETS can have varied implications for a firm's performance. Traditionally, compliance with ETS regulations is believed to heighten environmental liabilities and necessitate adaptation expenditures, leading to ongoing cash outflows and increasing financial uncertainty. For example, Fard et al. (2020) show that strong environmental regulations can raise difficulties for firms seeking loans and escalate borrowing costs. Thus, ETS-regulated firms may face more stringent screening and monitoring, suffering from lower financial accessibility and increased debt costs. Conversely, as highlighted in earlier discussions, well-designed environmental regulations can promote technological innovation (Porter and van der Linde, 1995). Empirical evidence indicates that the Chinese ETSs significantly increased innovation activity in low-carbon technologies and enhanced environmental performance among regulated firms compared to their non-regulated counterparts (Wang et al., 2019; Zhang et al., 2017). This enhancement would improve a firm's productivity and reputation and mitigate associated climate risks. Consequently, the advantages stemming from the ETS can potentially outweigh its regulatory burdens, paving the way for better financial outcomes for firms.

This study leverages the quasi-natural experimental setting provided by China's ETS using a time-varying difference-in-differences (DID) model to examine the effects of ETS pilots on the performance of Chinese listed firms. Comparing the financial performance changes between firms regulated under the ETS pilots (the treatment group) and those not regulated (the control group) from the pre-regulation phase (2008–2013) to the during-regulation phase (2014–2020), we reveal the causal impacts of environmental regulatory changes on firms' financial performance. Specifically, our results show that China's ETS pilots markedly increased profitability and overall firm value for the regulated firms. Furthermore, these firms experienced a reduction in their operating expenses. These outcomes align with China's national economic strategy, and the success likely served as a significant catalyst for the Chinese government's decision to roll out its national ETS.

The validity of the parallel time trend assumption is central to our baseline analysis, which underpins our causal interpretation. We extend our analysis to explore the dynamics of the average treatment effect to validate this assumption. The results show that the difference in firm performance between regulated and non-regulated firms is not time-varying before the introduction of the ETS pilots, satisfying the DID research design assumption. The results also show that the ETS has an immediate positive effect on firms' market value and reduces operating costs but has a lagged effect on firms' profitability improvements.

We also apply a propensity score matching (PSM) method to alleviate concerns about the non-random selection of pilot firms and to make our treatment and control firms more comparable. Our matching procedure allows us to construct a group of ETS-regulated firms matched with non-regulated firms with similar observed characteristics. Using different matching criteria and methods, we find that the PSM-DID results align with our main results. Finally, we conduct a placebo test on pseudo-regulated firms randomly drawn from the sample and verify the exogeneity of the ETS shock. By randomly selecting pseudo-treated firms, we show our findings to be robust, thereby ruling out the possibility that other policies or unobservable factors could drive the firms' financial performance improvement.

Beyond the robustness check of our main results, we conduct further analysis to explore some mechanisms/reasons through which the pilot ETSs could have improved the financial performance of firms. First, China's ETS pilots significantly increased firms' technology development. However, the increased technology development suppresses firm performance and value, suggesting that only the weak version of Porter's hypothesis applies to China's ETS scenario (Ambec and Barla, 2006). Since technology development is not a channel through which these ETSs influenced firms, we explain that the improved firm performance and firm value are attributable to firms' improved environmental performance under the regulation of the ETSs, to meeting investors' expectations, and to creating a responsible image (Brouwers et al., 2018). Moreover, we further explore the heterogeneity of the treatment effect. We find that the ETS pilots significantly increased the profitability and firm value of regulated state-owned enterprises (SOEs); however, the ETS policy had a negligible influence on non-SOEs' profitability and a less significant influence on their market value. The results suggest that SOEs are in a more privileged position regarding their ability to access resources and reduce environmental regulatory risks, which improves their financial performance and increases market confidence in their future performance.

The last set of additional tests sheds light on the impacts of two factors embedded in the ETS pilots on regulated firms: the carbon emissions price, which influences the direct expense of compliance, and the volatility of the carbon emissions price, which exposes firms to exogenous risks. Our results show that increases in the carbon emissions trading price and price volatility reduced profitability and market value for the firms. These results are consistent with findings of prior studies that environmental regulations raise production costs and stimulate expenditure on research and development (R&D), leading to lower accounting measures of returns (Brouwers et al., 2017). Meanwhile, the result regarding firms' market value also indicates that the market has a negative reaction to the transition and regulatory risks that regulated firms face.

Our study offers several important contributions. First, it responds to the call of Ilhan et al. (2021) concerning the paucity of finance-related research on climate policy uncertainty. This approach allows us to extend the growing body of literature that investigates the impact of ETSs on various regions and countries, such as the European Union (Dechezleprêtre et al., 2018; Makridou et al., 2019; Adediran and Swaray, 2023), France (Wagner et al., 2014), Germany (Anger and Oberndorfer, 2008; Löschel et al., 2019), and California (Fowlie et al., 2012). Due to the rapidly growing emissions and limited experience in designing and operating market-based environmental instruments, China presents a unique context fraught with uncertainties regarding the ETS policy's design, implementation, and enforcement, contrasting with the more mature ETS frameworks in developed economies. Our research thoroughly evaluates the effectiveness of the ETS within the Chinese market. Some studies demonstrate the impact of the pilot ETS on regional development, including energy conservation (Hu et al., 2020), pollutant emissions reduction (Zhang et al., 2017), carbon intensity (Wu and Zhu, 2021), and income inequality (Fang et al., 2023). Peng et al. (2021) find that China's SO2 Emissions Trading Pilot improves firm productivity. We provide additional empirical evidence on the favorable impact of China's carbon emission pilot ETSs on firm performance, suggesting that those pilot ETSs have achieved measurable progress, thus supporting the policy's continued advancement and refinement.

Our study also provides further evidence of the impact of carbon emissions pricing within ETS on firms' financial performance; carbon emissions trading is both a conventional commodity and an emerging financial instrument. The carbon emissions price within the ETS represents a critical distinction between market-oriented environmental regulation and command and control approaches. According to Porter's hypothesis, firms with higher marginal emissions reduction costs may choose to enhance their low-carbon management practices and foster green innovation in response to the urgent need to cut emissions. Reducing operating costs under carbon emission limits should help firms gain a competitive advantage (Wu and Wang, 2022); however, our study suggests that even though the signal sent by carbon emissions pricing embedded within ETSs can compel regulated firms to transition toward cleaner practices, this strategy does not affect the marginal cost of emissions reduction for businesses. Instead, it reduces the marginal benefits associated with emissions reduction. Our finding reflects the inefficient pricing within China's carbon market and provides evidence that the regulators could further improve the carbon pricing scheme.

The remainder of the paper proceeds as follows. Section 2 provides a summary of the related literature and the development of our hypothesis. Section 3 describes the sample selection and empirical design, and the main and additional test results are presented in Section 4. Finally, Section 5 concludes.

2. Literature review and hypothesis development

The ETS's influence on environmental management and economic outcomes has been debated since the launch of China's ETS pilots in 2013. At the macro level, a body of literature documents the

ETS's influence on regional economic development, with a majority indicating a negative relationship. For example, regions with a high dependence on fossil fuels, particularly coal, may experience economic hardship during the transition (Feng et al., 2018). Chen et al. (2020) and Dong et al. (2019) find that the ETS pilots did not yield significant positive economic outcomes measured by GDP. Nonetheless, several studies confirm the efficacy of the ETS pilots in terms of environmental improvements. For example, Zhang et al. (2016) examine a scenario-based potential effect of carbon trading in China and find that carbon trading could reduce provinces' carbon intensity by between 19.79% and 25.24% on average. Chen et al. (2020) and Zhang et al. (2020) provide similar support for emissions reduction through the analysis of province-level and city-level data, respectively. Furthermore, Yi et al. (2020) reveal regional variations in carbon emission reduction resulting from the implementation of ETS, finding that the policy led to emissions-cutting in the Beijing, Shanghai, and Hubei pilots while simultaneously increasing emissions in Guangdong. From an industrial perspective, concentrating on production-based emissions, Hu et al. (2020) report that from 2005 to 2015, China's ETSs reduced CO_2 emissions by 15.5% and achieved energy conservation of 22.8% within 10 ETS pilot-regulated sectors. Similarly, Gao et al. (2020) show the impact of the ETS on emissions mitigation within the pilot regions and industries. Conversely, compared with the indirect aggregate impact of China's ETS, only a handful of studies have explored its influence on firms' decision-making and outcomes. These include Zhu et al. (2019) and Qi et al. (2021), demonstrating a positive correlation between China's ETS pilots and firms' environmental innovation. Meanwhile, Xiao et al. (2021) suggest that China's pilot ETSs significantly improved firm-level total factor productivity. To fully understand the economic implications of ETS implementation, further research must assess its effects on firms' financial performance and elucidate the mechanisms driving these impacts.

The impact of ETS regulations on a firm's performance is still controversial. On the one hand, an ETS constrains firms' "free" emission behavior and requires them to incur additional expenses if purchasing extra allowances for emissions that exceed their allocated limits, thus increasing their financial burden (Clarkson et al., 2015; Chapple et al., 2013). Given that the ETS operations in China and the market price automatic adjustment process are still immature, the uncertainty of emission allowance supply and demand and the fluctuating trading price may lead to substantial costs and risks (Clarkson et al., 2015; Huang et al., 2022). Such risks could make it challenging for firms to raise funds externally, resulting in a higher cost of capital and harming firm performance and value (Koch and Bassen, 2013; Oestreich and Tsiakas, 2015). Moreover, to meet emission standards, financial resources are likely to be largely diverted away from productive activities towards investments in green technologies, despite the uncertain economic outcomes of such investments (Fard et al., 2020). This transition incurs compliance costs due to plant removal and restoration, product and production line redesign, modification and abandonment, resource and technology acquisitions, and customer-supplier relationship management (Gray and Shadbegian, 1998). As a result, ETS regulations could significantly increase firms' environmental liabilities and financial burdens, thereby decreasing firms' financial performance and value (Palmer et al., 1995).

In contrast, firms achieve better financial performance when complying with ETS regulations. Porter (1991) posits that well-conceived and effectively implemented regulations can benefit both the environment and firms. As one market-driven regulation, ETS is a prime example. The weak version of Porter's hypothesis supports that a well-designed ETS can positively influence environmental innovation, resulting in participants cutting emissions. Meanwhile, the robust version of Porter's hypothesis suggests that the advantages derived from innovation, encouraged by environmental regulations, can surpass the regulatory expenses, thereby boosting financial performance. For example, emissions reductions from green innovations can curtail carbon-related costs under the ETS framework, thereby augmenting a firm's profitability. Hence, according to Porter's hypothesis, attaining positive environmental and financial outcomes through implementing an ETS policy is possible. Beyond the theoretical support, empirical evidence demonstrates how an ETS confers financial benefits, as observed through the perspectives of social capital, innovation, and emissions permit trading.

Complying with environmental regulations and participating in an ETS can help firms shape a more responsible and trustworthy public image (Dhaliwal et al., 2012; Kassinis and Soteriou, 2003). Concurrently, the advancements fostered by ETSs gradually improve the public's green awareness (Ying and Sovacool, 2021). As crucial market participants, capital providers increasingly recognize that firms transitioning swiftly under ETSs—the early movers—will likely gain a competitive advantage over rivals in a low-carbon future (Xie et al., 2023). This perception can result in environmentally reputable firms accessing funds at lower costs.

Moreover, the resource-based view (RBV) suggests that engaging in innovative activities and assimilating new knowledge enable firms to secure valuable, uncommon, difficult-to-replicate, and non-substitutable resources, which emphasizes the importance of innovation as a pivotal route to increasing a firm's competitive edge (Matusik and Hill, 1998). In other words, a firm's innovation ability stands out as a crucial strategic asset. A large body of literature shows that ETSs are crucial in encouraging companies to create low-carbon technological innovations (Wei et al., 2022; Zhu et al., 2019; Rogge and Hoffmann, 2010). Firms with existing strengths in technological innovation are driven by ETSs, and they often experience amplified learning effects, leading to enhanced abatement capabilities. This situation can result in lower compliance costs, increased profitability, and greater competitiveness (Yu et al., 2022).

Furthermore, firms regulated under ETSs benefit from the free allocation of carbon emissions allowances, which have become a commodity property. Trading excessive allowances can strengthen a firm's cash flow and financial position (Oestreich and Tsiakas, 2015). Especially in immature markets, where allowance prices are highly volatile, firms can earn a "windfall" profit from increases in the carbon emissions price (Sijm et al., 2006). Purchasers of the allowances are not worse off, as many of the firms included in China's ETS pilots, such as power, steel, and cement companies, are monopolies. These firms can effectively pass the cost of carbon onto the prices of their products (Veith et al., 2009). When carbon prices rise, the monopolies profit even more from the carbon and product markets (Oberndorfer, 2009). During China's ETS pilot experiment phase, a notable problem was allowance oversupply (Jiang et al., 2016). This issue occurred for several reasons, including allocations based on historically high emissions records, downward economic pressure, immature carbon asset management, and insufficient and rigid demand during the early construction stages of the ETS pilots (Tan and Wang, 2017). Furthermore, local governments tended to allocate excessive allowances to protect local firms. As a result, regulated firms in the ETS pilots were likely to use the excessive free allowances to generate additional cash inflows, increasing their financial accounting performance and market value.

Overall, in light of the competing views on firms' increasing costs, risks, and opportunities under the ETS regulations, we propose the following null hypothesis:

H: China's ETS pilots affect regulated firms' financial performance.

3. Data and empirical methodology

3.1. Sample selection

This paper selects listed firms regulated by China's seven carbon ETS pilot markets from 2008, when the first Environment and Energy Exchange was established in Shanghai, to 2020, preceding the official launch of the national carbon ETS in the subsequent year.

Column (1) in Table 1 shows the number of firms under the regulation of each ETS pilot, with a total of 2,834 firm-year observations regulated under the 7 ETS pilots (i.e., in the cities of Beijing, Shanghai, Tianjin, Chongqing, and Shenzhen, and the provinces of Hubei and Guangdong) during the sample period.[5] Column (2) shows that 479 unique firms are listed or subsidiaries of listed firms.

[5] The Fujian province launched its ETS in September 2016, marking it as China's eighth carbon market pilot, with a broader sector coverage than the earlier pilots. Shortly after that, China announced the implementation of a national ETS in 2017, which led to the rapid integration of Fujian's ETS into this nationwide system. In this study, we have opted to focus exclusively on the seven earlier ETS pilots when considering our treatment group, as the inclusion of Fujian's ETS could

Excluding the subsidiaries, column (3) shows that, in total, 265 listed firms are under the regulation of the ETS pilots. After excluding observations with missing values, our final sample comprises 32,693 firm-year observations covering 2,761 Chinese listed firms over the sample period, including 265 firms under the regulation of the ETS pilots. The financial information for the firm-year observations is obtained from the RESSET and CSMAR databases.

	(1)	(2)	(3)
Region	ETS regulated firms	ETS-regulated firms related to listed firms	Related listed firms
Beijing	656	66	52
Chongqing	213	9	6
Guangdong	379	89	48
Shanghai	493	112	59
Shenzhen	664	135	75
Tianjin	125	7	6
Wuhan	304	61	19
Total	2,834	479	265

Table 1: Distribution of regulated firms under China's pilot ETS

Notes: The table shows the distribution of regulated firms among the seven ETS pilot markets. Column (1) shows the number of regulated firms; column (2) shows the number of regulated listed firms, including their subsidiaries of these listed firms; and column (3) shows the total number of regulated listed firms, excluding subsidiaries. The data is sourced from the seven ETS pilot provinces' (cities') Department of Ecology and Environment or NDRC websites. The sample period is from 2008 to 2020.

A single financial performance indicator only captures firms' financial performance from one perspective, leading to biased and incomplete interpretations, given that a firm's financial performance will comprise multiple aspects. To address this issue, we introduce multiple financial performance indicators, including the operating expense ratio (OER) for cost-effectiveness, the profit margin ratio (PMR) and return on assets (ROA) for profitability, and Tobin's Q (QVal) for a firm's value, to illustrate a more complete picture of the impact of the ETS pilots on firms' financial performance. ROA is the ratio of earnings before interest and tax to total assets. This ratio is a widely adopted measure of a business's financial performance, assessing the financial outcomes of the operations of a business and offering an overall view of a firm's profitability concerning its total assets; however, a

introduce additional variability due to the effects of the national ETS implementation. This approach is consistent with prior studies, providing continuity with the established literature. We have also re-executed our analysis for robustness by including the Fujian province in the treatment group. The main results remained consistent, suggesting that the core conclusions of our study are resilient to the expanded sample.

firm's total assets usually depend on the nature of its business and the industry to which it belongs. As a result, based on this sole indicator, it is not easy to compare the financial performance of firms of different sizes. Therefore, we introduce the OER, calculated as operating expenses divided by net sales, and the PMR, calculated as net profit divided by net sales, as additional indicators of firms' financial performance. Tobin's Q (QVal) measures a firm's assets concerning its market value, reflecting the market's expectations of its future growth, performance, and competitive advantage (Kor and Mahoney, 2005). Various studies have used it to represent a firm's financial performance (Cavaco and Crifo, 2014; Misani and Pogutz, 2015). In sum, we examine the economic consequences of the ETS at the firm level from both the short-term (immediate), captured by financial ratios, and long-term (future), captured by market perceptions of firms' potential and value, respectively.

3.2. Empirical design

We use a DID approach that exploits the variation in ETS adoption across areas to study how the ETS pilots affect regulated firms' financial performance. The DID model evaluates the effect of policy implementation by comparing the difference between the treatment and the control groups before the policy intervention to the difference afterward. Various studies on the impact of the carbon market have adopted the DID approach; however, they have ignored that firms are not typically regulated by ETSs simultaneously but are included in a staggered manner (Yang et al., 2017; Zhang et al., 2016). The multiple changes to the number of regulated firms result in multiple treatment periods. We follow Callaway and Sant'Anna (2021) to consider this and specify a time-varying DID model. Using the firm-level panel data, we estimate the following specifications:

$$DV_{it} = \alpha + \beta(ETS_i \times Post_t) + \sum Controls_{it} + \eta_i + \mu_t + \varepsilon_{it} \quad (1)$$

where the subscripts i and t individually identify different observations for firm i and year t. The dependent variable (DV_{it}) is OER, PMR, ROA, or QVal, and thus reflects various aspects of a firm's financial performance. ETS_i is a dummy variable reflecting whether China's ETS pilots regulate a firm. $Post_t$ is a time dummy variable reflecting whether a firm is regulated by an ETS pilot in year t. Our variable of interest, $ETS_i \times Post_t$, is an indicator of whether firm i has been regulated by ETS pilots by year t. The coefficient β captures changes in the financial performance of the treated firms before and after being included in China's ETS pilots. $Controls_{it}$ denotes control variables that might also affect firms' financial performance, ε_{it} represents the error term, and η_i and μ_t represent the firm-fixed and year-fixed effects, respectively. Firm-fixed effects are included to ensure that static differences across firms do not account for observed patterns in financial performance, and year-fixed effects control for time-period-specific changes in financial performance. In our case, we assign firms that the ETS pilots regulate to the treatment group and firms that the ETS pilots do not regulate to the control group.

Following prior studies, we control for various production and financial dimensions, including size, leverage, solvency, technical progress, and liquidity, that affect firms' financial performance (Makridou et al., 2019). We control firm size (Size) using the natural logarithm of total assets, as the resources a firm has under control can substantially influence its financial performance (Gallego-Álvarez et al., 2014); however, the impact of firm size on net profit often depends on the nature of the business, possibly the period of analysis, and the generation of sales. Therefore, we also include the capital intensity ratio, calculated as total assets divided by net sales, as a measure of a firm's reliance on expenditure on assets to maintain its revenue and growth level over time. Capital intensity is expected to be positively related to firm value, as expenditure on assets signals growth to the market (Fama and French, 1998; Miller, 2006). We use the shareholder equity-to-debt ratio to represent the firm's solvency level. This ratio demonstrates a firm's debt repayment ability. Consequently, a higher equity-to-debt ratio indicates weaker reliance on external debt financing and a stronger ability to cover debt and interests. We also include firm leverage (the debt to total assets ratio) to control for the impact of a firm's financial structure on its performance. High leverage implies a high financial burden and low financial flexibility, which negatively affects firm performance (Makridou et al., 2019). Total factor productivity (TFP) demonstrates a business's ability and efficiency in converting its inputs to outputs and its efficiency in doing so. A firm's technical progress plays a crucial role in determining its TFP; therefore, TFP is used as a proxy for technical progress. The firm-level TFP estimates are obtained as the residual from the production function with capital, labor, and materials as input factors. Finally, the current assets to liabilities ratio measures a firm's liquidity. A higher liquidity ratio suggests a lower liquidity risk, a sounder financial position, and, in turn, better performance (Gupta, 2017). Appendix 1 provides definitions of the variables.

3.3. Descriptive statistics

Table 2 presents the descriptive statistics of the variables. Continuous variables are winsorized at the 1% and 99% levels to minimize the impact of outliers with extreme values. Table 3 provides descriptive statistics of firms' financial performance before and after being regulated by the ETS pilots. Although the mean and median values of the financial performance measures increase or remain after the introduction of the ETS regulation, the standard deviations of OER and QVal show slight declines. This fluctuation means the differences between the regulated firms' financial performance decrease.

These results show that environmental regulations reduce the gap between firms, in line with previous studies (Ambec and Barla, 2006). The following sections investigate the formal interpretation of the impact of the ETS pilots on firms' financial performance.

Variable	Obs	Mean	SD	10th	Median	90th
OER	32,693	0.71	0.18	0.46	0.75	0.91
PMR	32,693	0.07	0.18	0.00	0.07	0.23
ROA	32,693	0.04	0.07	−0.02	0.04	0.12
QVal	32,693	2.66	1.99	1.09	2.02	4.95
Omega	32,693	8.40	1.08	7.14	8.31	9.86
Dbassrt	32,693	0.43	0.21	0.15	0.420	0.72
Size	32,693	22.04	1.30	20.56	21.86	23.81
CI	32,693	2.49	2.16	0.87	1.88	4.56
Currt	32,693	2.52	2.79	0.73	1.63	5.04
SR	32,693	2.48	3.17	0.39	1.37	5.78
Pc	8,392	31.65	17.07	12.90	27.94	57.03
PcV	8,392	4.69	3.56	1.53	3.49	9.44

Table 2: Descriptive statistics of variables

Notes: This table presents sample summary statistics of firm characteristics, the carbon price, and the carbon price volatility. The panel shows the number of observations, mean, standard deviation, 10th percentile, median, and 90th percentile values of each variable. See Appendix 1 for variable definitions.

Variable	Obs	Mean	Median	Std. Dev.	Obs	Mean	Median	Std. Dev.
	Before ETS				After ETS			
OER	1,860	0.76	0.79	0.16	974	0.75	0.78	0.15
PMR	1,860	0.07	0.06	0.11	974	0.07	0.06	0.13
ROA	1,860	0.05	0.04	0.06	974	0.05	0.04	0.06
QVal	1,860	2.14	1.64	1.54	974	2.19	1.78	1.39

Table 3: Descriptive statistics of firms before and after being regulated by pilot ETSs

Notes: This table shows the summary statistics of the dependent variables before and after the firms are regulated by the ETS pilots. See Appendix 1 for variable definitions.

4. Empirical analysis

4.1. Main results

4.1.1. Baseline DID estimation

We estimate Equation (1), the baseline regression, to examine the relationship between the ETS pilots and firms' financial performance. Table 4 presents the regression results, where Column (1) shows that the ETS pilots significantly reduce regulated firms' OER. This result suggests that the firms' operating cost ratios decreased by 0.011, approximately 6% of one standard deviation change after being regulated by the ETS. Columns (2) and (3) report the ETS pilots' impact on the regulated firms' profitability, measured by PMR and ROA. The results are statistically significant and positive. Specifically, after being regulated by ETS, on average, regulated firms could benefit from an average of 2.3% higher profit margin generated from sales and a 1.2% higher net profit generated from total assets. Column (4) shows that the regulated firms' market value (QVal) also increases significantly, reflecting a positive market view of the effect of the ETS pilots on firms' future growth and performance. This finding aligns with the recent study by Dechezleprêtre et al. (2018), which documents an increase in revenue, fixed assets, employment, and profit for firms regulated by the EU's ETS. Our findings show that China's ETS pilots improve the regulated firms' financial performance by decreasing operating costs and increasing profitability and firm value, which is consistent with our hypothesis. Compounding with the functions of ETS in reducing emissions and improving the environment, our findings support Porter's hypothesis and verify the effectiveness of China's ETS in improving economic benefits at the firm level.

	OER	PMR	ROA	QVal
	(1)	(2)	(3)	(4)
ETS*Post	−0.011*	0.023***	0.012***	0.261***
	(−1.88)	(3.34)	(4.10)	(3.70)
Omega	0.014***	−0.056***	−0.042***	−0.406***
	(2.60)	(−8.18)	(−16.87)	(−6.67)
Size	−0.025***	0.018***	−0.014***	−1.264***
	(−5.34)	(3.29)	(−6.92)	(−19.63)
Lev	0.186***	−0.420***	−0.174***	0.095
	(12.87)	(−22.07)	(−27.20)	(0.53)
CI	−0.005***	−0.005*	0.002***	0.039**
	(−2.81)	(−1.94)	(2.83)	(2.22)
Currt	−0.006***	0.009***	0.003***	0.020
	(−4.66)	(5.44)	(5.13)	(1.40)
SR	0.005***	−0.006***	−0.004***	0.003
	(3.86)	(−3.30)	(−6.77)	(0.23)
Year-fixed effect	Yes	Yes	Yes	Yes
Firm-fixed effect	Yes	Yes	Yes	Yes
Obs	32,693	32,693	32,693	32,693
R-Square	0.083	0.155	0.222	0.379

Table 4: Baseline regression results—DID estimation

Notes: This table presents the results of the difference-in-differences estimations that correspond with Equation (1). All robust standard errors are clustered at the firm level. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively. See Appendix 1 for variable definitions.

4.1.2. PSM-DID estimation

Our assumption associated with applying the DID design is that the treatment and control firms must be randomly assigned. China's ETS is a market-based environmental policy within a quasi-experimental framework; selecting regulated firms is not random, which could lead to a self-selection endogeneity problem. To address the potential selection bias, we use the PSM technique to match a control group with the treatment group based on a series of firm characteristics (Heckman et al., 1998; Lechner, 2002).

The conditional probability of each firm belonging to the treatment group can be obtained. We apply kernel matching in the context of China's ETS pilots as follows:

$$ATT = \frac{1}{N^{ETS}} \sum_{i \in ETS} \{Y_i^{ETS} - \sum_{j \in NETS} \frac{Y_j^{NETS} K\left(\frac{e_j(x) - e_i(x)}{h_n}\right)}{\sum_{k \in NETS} K(\frac{e_k(x) - e_i(x)}{h_n})}\}$$

where $N^{ETS}$is the number of firms regulated by the ETS. Y_i^{ETS} and Y_j^{NETS} represent the observational outcomes of firm *i* in the matched ETS-regulated group and firm *j* in the matched non-ETS-regulated group; $e_j(x)$ denotes the propensity score of firm *j* that the ETS does not regulate, and $e_i(x)$ denotes the propensity score of firm *i* that the ETS regulates. Finally, $e_j(x) - e_i(x)$ represents the distance between the propensity scores, and h_n is the bandwidth parameter of the kernel function $K(.)$. Our study uses Gaussian density as our kernel function, giving $K(z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}}$.

After matching and removing the unmatched observations, we perfrom the balance check of the distribution of the covariates between the treated and the control groups. Table 5 shows that none of the firm characteristic variables pass the significance test after matching, meaning no systematic differences exist between the treated and control groups. We then use the matched samples to re-estimate the baseline Equation (1). The results are reported in Table 6. As in Table 4, the interaction variable, $ETS_i * Post$, captures the causal effect of the ETS pilots on the four measures of firms' financial performance. Consistent with the results reported in Table 4, Column (1) of Table 6 shows that regulated firms experience, on average, a 0.9% lower operational expense ratio after ETS.

Similarly, Columns (2) and (3) of Table 6 show positive and significant coefficients on both PMR and ROA, indicating that ETS-regulated firms have higher profitability than non-ETS-regulated firms after the launch of the ETS pilots. Furthermore, the coefficient QVal remains positive and highly significant; therefore, our PSM-DID test results further solidify the causal interpretation of the ETS's positive impact on regulated firms' financial performance.

Variable	Experimental group mean	Control group mean	%bias	T value	P-value
Omega	9.06	9.04	1.8	0.41	0.68
Size	23.08	23.06	2.0	0.43	0.67
Lev	0.47	0.47	−0.7	−0.16	0.88
CI	2.04	2.07	−1.4	−0.45	0.65
Currt	1.73	1.71	0.9	0.33	0.74
SR	1.74	1.71	1.1	0.34	0.74

Table 5: PSM validity test

Notes: This table shows the balance check for the distribution of the covariates between the treated and control groups after propensity score matching. See Appendix 1 for variable definitions.

	OER (1)	PMR (2)	ROA (3)	QVal (4)
ETS*Post	−0.009*	0.023***	0.011***	0.250***
	(−1.73)	(3.56)	(3.96)	(3.65)
Omega	0.015***	−0.055***	−0.044***	−0.343***
	(2.58)	(−8.36)	(−15.70)	(−5.13)
Size	−0.025***	0.016***	−0.013***	−1.072***
	(−5.41)	(3.08)	(−6.14)	(−17.40)
Lev	0.187***	−0.429***	−0.185***	−0.191
	(13.23)	(−23.84)	(−28.51)	(−1.18)
CI	−0.005**	−0.003	0.000	−0.012
	(−2.42)	(−0.82)	(0.30)	(−0.60)
Currt	−0.006***	0.011***	0.004***	0.030**
	(−4.31)	(6.15)	(7.10)	(1.99)
SR	0.005***	−0.010***	−0.005***	0.006
	(3.44)	(−5.40)	(−8.88)	(0.36)
Year-fixed effect	Yes	Yes	Yes	Yes
Firm-fixed effect	Yes	Yes	Yes	Yes
Obs	31,757	31,757	31,757	31,757
R-Square	0.082	0.157	0.235	0.376

Table 6: PSM-DID estimation

Notes: This table presents the results of conducting difference-in-difference estimations corresponding to Equation (1). The t-values, reported in parentheses, are heteroscedasticity-robust and clustered at the firm level. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively. See Appendix 1 for variable definitions.

4.1.3. Dynamic regression results

To control for pre-existing trends and test whether the impact of ETS pilots on firm performance is transitory or lasting, we examine the dynamics of the average treatment effect from before to after a firm is regulated by an ETS pilot based on the PSM sample. We replace $ETS_i \times Post_t$ in Equation (1) and construct the following model:

$$DV_{it} = \alpha + \sum_t \beta_t ETS_i \times Year_t + \sum Controls_{i,t} + \eta_i + \mu_t + \varepsilon_{it} \qquad (2)$$

where $Year$ is a set of indicators that shows whether year t is three years, two years, or one year before, the exact year, or one year, or two years, or three years after the focal firm first entered the ETS regulation list.[6]

Table 7 reports the estimates of the average changes in financial performance and market value around the launch of the ETS pilots. The coefficients for $Before\ 2$ and $Before\ 3+$ are not statistically significant and are indistinguishable from zero. This result indicates that the ETS-regulated and non-regulated firms exhibit no systematic and statistical differences in the outcome variables during the pre-ETS period and are non-randomly assigned to their respective groups. The estimated coefficients for $After\ 1$, $After\ 2$, and $After\ 3+$ are statistically significant for the operating expense ratio and Tobin's Q, suggesting an immediate effect on cutting firms' operational expenses and improving firm values. Meanwhile, there is a lagged effect on the accounting measures of firms' profitability (i.e., *PMR* and *ROA*) until two or more years after ETS. This finding suggests that the market responds to the ETS pilots positively and reprices firms quickly before the occurrence of financial performance. The above results address our concern over pre-existing financial performance and market value trends that might have confounded our DID results. This test provides further evidence that without the intervention of ETS policy, the development trend of the experimental and control group variables remains consistent, supporting the common trend assumption.

[6] Specifically, the variables indicating the year before or after the policy year include the following. $Before\ 3+$ is a dummy variable that takes a value of 1 if the year is 3 years or earlier before the ETS launch year and 0 otherwise. $Before\ 2$ is a dummy variable that takes a value of 1 if the year is 2-year before the ETS launch year and 0 otherwise. $Before\ 1$, $Current$, $After\ 1$, $After\ 2$, and $After\ 3+$ all have similar definitions. To avoid collinearity, we drop $Before\ 1$ in model (3) and conduct the following regression.

	OER	PMR	ROA	QVal
	(1)	(2)	(3)	(4)
Before 3+	−0.004	0.001	−0.001	0.088
	(−0.54)	(0.09)	(−0.25)	(1.23)
Before 2	0.004	0.001	−0.003	0.145
	(1.05)	(0.23)	(−0.92)	(0.76)
Current	−0.011***	0.009	0.003	0.159***
	(−3.42)	(1.32)	(1.19)	(3.59)
After 1	−0.016***	0.012	0.002	0.779***
	(−2.78)	(1.34)	(0.45)	(7.22)
After 2	−0.020***	0.017*	0.007*	0.475***
	(−2.78)	(1.96)	(1.96)	(5.91)
After 3+	−0.020***	0.026***	0.014***	0.253***
	(−2.78)	(2.83)	(3.69)	(3.26)
Omega	0.014***	−0.057***	−0.042***	−0.400***
	(2.58)	(−8.19)	(−16.90)	(−6.58)
Lev	−0.025***	0.018***	−0.014***	−1.260***
	(−5.35)	(3.30)	(−6.90)	(−19.58)
Size	0.186***	−0.420***	−0.174***	0.112
	(12.86)	(−22.07)	(−27.20)	(0.62)
CI	−0.005***	−0.005*	0.002***	0.037**
	(−2.83)	(−1.94)	(2.83)	(2.12)
Currt	−0.006***	0.009***	0.003***	0.020
	(−4.66)	(5.44)	(5.14)	(1.47)
SR	0.005***	−0.006***	−0.004***	0.003
	(3.87)	(−3.30)	(−6.79)	(0.22)
Year-fixed effect	Yes	Yes	Yes	Yes
Firm-fixed effect	Yes	Yes	Yes	Yes
Obs	32,693	32,693	32,693	32,693
R-Square	0.083	0.155	0.222	0.382

Table 7: Dynamic regression results

Notes: This table reports the dynamic effects of China's ETS on four financial performance indexes, which correspond with Equation (2). *Before 3+* is a dummy variable that equals 1 if the year is 3 years or earlier before the ETS launch year and 0 otherwise. Similarly, *Before 2* is a dummy variable that equals 1 if the year is 2 years before the ETS launch year and 0 otherwise. *Before 1, Current, After 1, After 2,* and *After 3+* have similar definitions. We exclude Before 1 in Equation (3) to avoid collinearity and conduct the regression. The t-values, reported in parentheses, are heteroscedasticity-robust and clustered at the firm level. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively. See Appendix 1 for variable definitions.

4.1.4. Placebo tests

When introducing the ETS policy, other factors might contribute to incorrectly attributing differences in financial outcomes between treated and untreated firms to implementing ETS. For example, since the first batch of pilot cities and firms in 2013, subsequent policies and production plans could lead to an increasing number of firms being added to the ETS-regulated list. Furthermore, as significant participants in the market, listed firms are considerably influenced by both upstream and downstream firms. Therefore, changes in corporate financial performance cannot be solely attributed to implementing the ETS policy. This paper adopts the following placebo testing method to eliminate the interference of these factors. The estimated value of the coefficient of the core explanatory variable from Equation (1) is:

$$\hat{\beta} = \beta + \sigma \frac{cov(ETS \times Post, \varepsilon | X)}{var(ETS \times Post | X)}$$

where, only if σ = 0, unobservable factors will not affect $\hat{\beta}$, implying that $\hat{\beta}$ is unbiased. However, since σ is naturally unobservable, we consider constructing a variable alternating $ETS \times Post$; thus, the new variable will not theoretically affect financial performance. In other words, if the new variable is randomly generated, the actual effect β should be 0; therefore, if the following estimated $\hat{\beta}$ is also 0, we can infer that σ = 0, or vice versa. To generate the treatment variable, we randomly selected 265 firms[7] as the pseudo-treatment group and then generated the pseudo-policy dummy variables. After matching these randomly selected firms with the original data and repeating the process 500 times, we obtain 500 sets of coefficients and p-values of the pseudo-policy dummy variables. Figure 1 reports the distribution of $\hat{\beta}^{pseudo}$ for OER, PMR, ROA, and QVal after 500 randomizations, respectively, showing that all the estimates are consistently concentrated around 0. Compared with the coefficients obtained from our main regression, denoted by red dashed vertical lines, we can confirm that our results should not be affected by other unobserved or unexpected factors, and the coefficients from our main models are not obtained by chance. This test maximizes excluding other policies or random factors from interfering with the results, allowing the changes in firms' financial performance to be attributed to ETS policy. As a result, the previous conclusions maintain good robustness.

[7] The number is the same as that of the listed firms in the main sample.

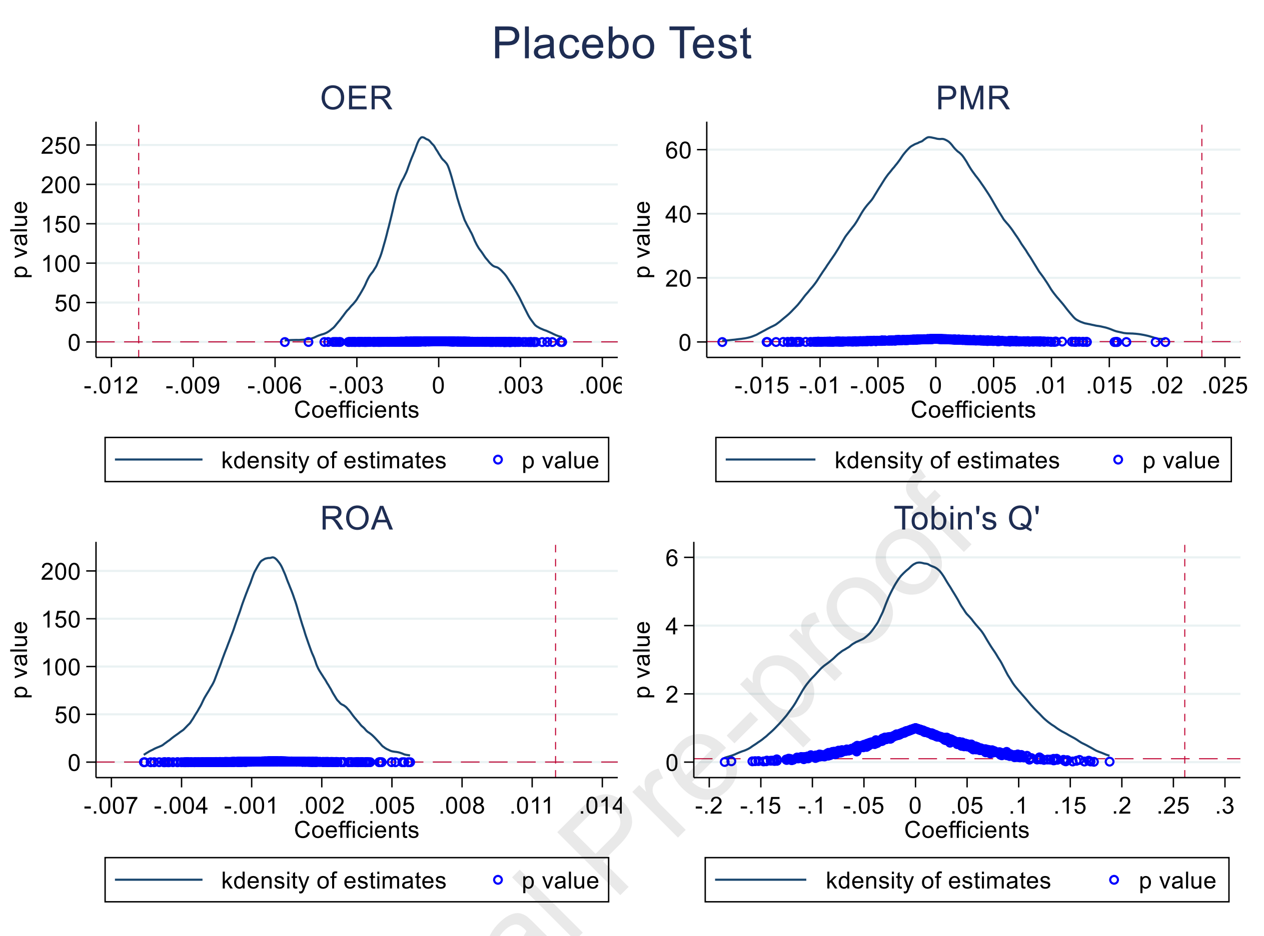

Figure 1: Placebo Tests

Note: These figures report the distribution of the coefficient of the pseudo DID term after 500 randomizations for each dependent variable: OER, PMR, ROA, and Tobin's Q, respectively.

4.2. Additional analyses

4.2.1. Innovation

According to Porter's hypothesis, well-designed environmental regulations can stimulate technological innovation and progress, thereby reducing the operational costs of complying with the regulations, increasing firms' productivity and competitiveness, and consequently improving firm performance. We apply the stepwise hierarchical regression approach and construct a mediation model to test whether technological progress (proxied by $Omega$) totally or partially mediates the relationship between ETS pilots and firm performance. This approach allows us to examine whether the technology channel is how China's ETS pilots improve firm performance. We construct the following system of equations to estimate technology progress's mediating effect:

$$DV_{it} = c(ETS_i \times Post_t) + \sum Controls_{it} + \eta_i + \mu_t + \varepsilon_{it} \quad (3)$$

$$omega_{it} = \alpha(ETS_i \times Post_t) + \sum Controls_{it} + \eta_i + \mu_t + \varepsilon_{it} \quad (4)$$

$$DV_{it} = c^{'}(ETS_i \times Post_t) + bOmega_{it} + \sum Controls_{it} + \eta_i + \mu_t + \varepsilon_{it} \quad (5)$$

Equation (3) tests the relationship between the ETS pilots and firm performance, as a significant link between them is a precondition for the mediating effect. The relationship between ETS and technical progress is examined in Equation (4), and both the ETS and technological progress are included in Equation (5). When considering these three equations together, if the coefficients on $ETS_i \times Post_t$ and $Omega_{it}$ are significant and have the same sign, technological progress will be proven to mediate the relationship between the ETS and regulated firms' financial performance. If they are significant but have different signs, technological progress suppresses rather than mediates. If the coefficient of $ETS_i \times Post_t$ in Equation (3) is significant but loses its significance in Equation (5), the technological progress has a full mediating effect on the relationship between ETS and financial performance.

Table 8 presents the effect of technological progress on the regulated firms' financial performance. Columns (1) to (4) show results generated by Equation (3) with different financial performance measures. The coefficients on $(ETS \times Post)$ are significant for all four financial performance measures (to at least a 10% significance level), meaning that the ETS has a significant positive effect on PMR, ROA, and QVal, and a significant negative effect on OER. These results are consistent with our main tests. Column (5) reports the estimations of Equation (4). The coefficient on $ETS \times Post$ in column (5) is positive and significant, indicating that the technology progress of the ETS-regulated firms increased significantly after the ETS pilot program was launched. This finding aligns with Hu et al. (2020), who found a significantly positive relationship between China's CO_2 ETS and industrial technology efficiency. These results support Porter's hypothesis that environmental regulations stimulate innovation and technological improvement; however, the coefficients on *Omega* in columns (6) to (8) show opposite signs to the coefficients on $ETS \times Post$, suggesting that the technological progress (*Omega*) increases firms' operating costs (OER) and decreases their PMR and ROA. The results suggest that, although the ETS pilots encourage the technological progress of the regulated firms, the expenditure on technology development suppresses the positive impact of the ETS pilots on the regulated firms' financial performance based on the accounting measures. The findings imply that firms perceive ETS pilots as offering more opportunities than they impose risks and are willing to invest in R&D despite adversely affecting short-term profitability (Baum et al., 2006; Bloom et al., 2007). Our findings also suggest that technological progress has no significant mediating effects on the relationship between the ETS pilots and firm value. The negative influence of technological progress on firms' financial performance is likely due to the high initial costs related to environmental technologies, which require significant upfront investments. These costs can strain a firm's financial resources in the short term, affecting financial performance. Our results reveal the differences between the immediate short-term effect technology progress has on firms' financial performance and the market's perception of firms' technology investments in the long term. Based on these findings, we conclude that the technical progress of firms regulated by the ETS could be stimulated, which aligns with the weak version of the Porter hypothesis; however, the technical progress suppresses the impact of the ETS on the regulated firms' financial performance, which rejects the strong version of the Porter hypothesis.

	OER	PMR	ROA	QVal	Omega	OER	PMR	ROA	QVal
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
ETS*Post	-0.011*	0.021***	0.010***	0.248***	0.038*	-0.011*	0.023***	0.012***	0.261***
	(-1.91)	(3.14)	(3.63)	(3.48)	(1.76)	(-1.88)	(3.34)	(4.10)	(3.70)
Omega						0.014***	-0.056***	-0.042***	-0.406***
						(2.60)	(8.18)	(16.87)	(6.67)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	32,693	32,693	32,693	32,693	32,693	32,693	32,693	32,693	32,693
R-squared	0.081	0.146	0.183	0.375	0.790	0.083	0.155	0.222	0.379

Table 8: The mediating effect of technical progress on firms' financial performance

Notes: This table presents some estimates of the mediating effects of China's ETS pilots on regulated firms' financial performance, generated by Equations (3) to (5). The t-values, reported in parentheses, are heteroscedasticity-robust and clustered at the firm level. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. See Appendix 1 for variable definitions.

4.2.3. Heterogeneous treatment effect

Considering that the Chinese government launched the ETS pilots as a policy tool to achieve emission reductions, it is worth investigating whether they affect SOEs and non-SOEs differently. On the one hand, SOEs in China generally bear environmental and social policy burdens and seek to maximize social stability and employment (Fogel et al., 2008). As the most important stockholder or stakeholder, the government actively oversees and assesses SOEs' management and constantly demands that SOEs meet regulatory requirements and fulfill environmental and social responsibilities (Nishitani and Kokubu, 2012). On the other hand, SOEs are systematically favored by the Chinese government, both financially and legally, enjoying privileged positions in finance, taxation, employment, regulation, and investment approval (Shi and Xu, 2018). Hence, we expect that, with the government's involvement, SOEs can weather regulatory shocks and benefit from complying with regulations, which outweigh the costs. Given this, under the ETS regulations, SOEs' privileges and advantages over non-SOEs likely lead to positive financial performance and optimistic market expectations.

We split the sample into two subsamples. The SOE subsample includes central and local SOEs. The non-SOE subsample includes enterprises not regulated by the State-owned Assets Supervision and Administration Commission (SASAC), including privately owned, collectively owned, university-owned, foreign-owned, and otherwise-owned enterprises. The PSM-DID model is applied to both subsamples. Columns (1) to (4) and (5) to (8) in Table 9 show the effects of the ETS pilots on the SOEs' and non-SOEs' financial performance, respectively. Columns (2) to (4) show that the ETSs have highly significant effects (at the 1% level) on the regulated SOEs in terms of increasing their profitability (PMR and ROA) and market value (QVal). In contrast, the insignificant and less significant (at 10% level) coefficients on the interaction terms in columns (6) to (8) suggest that the ETS pilots have negligible influence on the financial performance of the ETS-regulated non-SOEs. The results support our prediction that, compared to the non-SOEs, SOEs are in a more privileged position in accessing resources and reducing their environmental regulatory risks, improving their financial performance, and increasing market confidence in their future development. These findings imply that the benefits received by SOEs from the ETS pilot program outweigh the compliance costs and additional expenditure associated with the ETS regulations; however, non-SOEs do not enjoy such a favorable effect. Our finding has important policy implications, considering the vital contribution that non-SOEs can make to China's commitment to its environmental targets and sustainable development. Regulators should consider providing non-SOEs more support and financial resources to help them endure regulatory shocks and improve firm performance. The government could reduce the abatement costs and provide non-SOEs with finance and subsidies for upgrading green technologies, particularly during the early stages of the green transition. Such support would encourage enterprises to engage in more sustainable initiatives and green innovation, accelerating China's transition to an inclusive green economy (Chang et al., 2024).

	SOEs				Non-SOEs			
	OER	PMR	ROA	QVal	OER	PMR	ROA	QVal
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ETS*Post	-0.012	0.037***	0.016***	0.305***	-0.012	0.003	0.004	0.139*
	(-1.36)	(3.18)	(3.71)	(2.71)	(-1.54)	(0.34)	(1.15)	(1.67)
Year-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	1.129***	-0.722***	0.075*	28.039***	0.987***	-0.408***	0.082**	23.378***
	(11.75)	(-6.20)	(1.78)	(19.30)	(10.51)	(-3.31)	(1.98)	(14.62)
Obs	19,133	19,133	19,133	19,133	13,560	13,560	13,560	13,560
R-square	0.075	0.163	0.229	0.417	0.096	0.137	0.222	0.354

Table 9: Heterogeneity tests

Notes: This table shows the effect of the ETS pilots on SOEs' and non-SOEs' financial performance. The subsample labeled SOE consists of firms owned by the state; the subsample labeled Non-SOE consists of firms not owned by the state. The t-values, reported in parentheses, are heteroscedasticity-robust and clustered at the firm level. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. See Appendix 1 for variable definitions.

4.2.3. The impact of the carbon emission price and the price volatility

Under the ETS regulations, a firm exceeding its allocated allowances must choose between upgrading its production process or buying emissions quotas from the market. Either option implies that the higher the carbon emission price, the higher the expenditure on upgrading firms' technology (due to the higher demand for green technology) or the greater the expenditure on extra carbon emission allowances for production. Prior literature has two contradictory views on these expenses resulting from complying with environmental regulations. On the one hand, the costs incurred by complying with environmental regulations increase operating expenditure, which could outweigh the profits, resulting in worse financial performance. On the other hand, being environmentally responsible and complying with regulations builds a superior firm image and human capital, which can enhance firm performance and value (e.g. Dong 2023). Additionally, recent studies find that firms regulated by ETS can pass the extra costs onto customers when the carbon allowance prices increase, thereby maintaining and even increasing firm performance and value (Sijm et al., 2006). However, this finding is not conclusive. For instance, Makridou et al. (2019) report a negative correlation between the growth rate of carbon emission prices and firm profits. In general, the carbon emission price is expected to rise so that the emission reduction targets can be met (Lin and Jia, 2019), and a higher carbon emission price would strengthen the emission reduction effect of the ETS (Wu and Gong, 2021). Hence, understanding how firm performance reacts to the change in emission price embedded within ETS is essential.

In reality, the price of carbon emission is volatile (Charles et al., 2011; Reboredo, 2014), exposing regulated firms to exogenous risks and leading to higher operational risks that affect firm performance and value (Chapple et al., 2013; Clarkson et al., 2015). Tian et al. (2016) find that the volatility of EU allowance prices has been directly transmitted to the volatility of the producers' later cash flows, resulting in greater volatility of their stock prices; hence, we test how the carbon emission price and its volatility affect regulated firms' performance. To do so, we estimate the following model:

$$DV_{it} = \alpha + \beta_1 Pc_{i,t}\left(or\ PcV_{i,t}\right) + \sum Controls_{it} + \eta_i + \mu_t + \varepsilon_{it}. \tag{6}$$

The carbon emission prices differ among the seven ETS pilots. Therefore, we use the annual average price to represent the carbon emission price in each area (Pc) and the annual standard deviation of the carbon price in each area to represent the carbon emission price volatility (PcV):

The results of the impacts of the carbon emission price and price volatility on measures of firms' financial performance are reported in Tables 10 and 11, respectively. Table 10 shows that increases in carbon emissions prices significantly decrease the firms' profitability (ROA). One possible explanation is that environmental regulation stimulates expenditure on R&D and innovation, leading to lower accounting measures of returns (Brouwers et al., 2018). Furthermore, given the significantly negative effect of the carbon price on firm value (QVal), indicating the market's pessimistic reaction to transition and regulatory risks faced by regulated firms.

	OER	PMR	ROA	QVal
	(1)	(2)	(3)	(4)
Pc	0.000	−0.000	−0.000*	−0.006**
	(1.51)	(−1.49)	(−1.79)	(−2.27)
Control variables	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes
Firm-fixed effect	Yes	Yes	Yes	Yes
Obs	8,392	8,392	8,392	8,392
R-Square	0.058	0.166	0.202	0.409

Table 10: Impact of the carbon allowance price on the regulated firms

Notes: This table shows the impact of the carbon price on the financial performance of regulated firms, corresponding with Equation (6). All control variables are included. The t-values, reported in parentheses, are heteroscedasticity-robust and clustered at the firm level. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. See Appendix 1 for variable definitions.

Table 11 shows the impact of the volatility of the carbon emission price on the four financial performance indexes. The results illustrate the negative influence of carbon price volatility on profitability (PMR and ROA); however, the impact of the carbon emission price volatility on the firm value (QVal) is insignificant. This outcome indicates that the carbon emission price volatility does not immediately improve the long-term evaluation of regulated firms. On the one hand, due to the uneven economic development and different energy consumption patterns, the seven areas covered by the ETS pilots are designed and operated differently regarding allowance allocation, covered sectors, emission reduction costs, and penalties for non-compliance[8]. For example, since 2014, the highest monthly average carbon emission price has reached 93.98 Chinese yuan (CNY)/t CO_2 (in Beijing). In contrast, the lowest monthly average price was just 1.61 CNY/t CO_2 due to the excessive allocation of free carbon emission quotas (in Chongqing) (Huang et al., 2022). The fluctuation of the allowance prices of the separate ETS pilots transmits uncertainties to the regulated firms' future cash flows (Li et al., 2022), forcing them to cut emissions immediately or demand excessive carbon quotas. Hence, the urgent transition and high pressure caused by regulatory requirements may lead to firms' losses, and these uncertainties are challenging for the market to price accurately.

	OER	PMR	ROA	QVal
	(1)	(2)	(3)	(4)
PcV	0.001	−0.002***	−0.000**	−0.007
	(1.64)	(−2.62)	(−2.33)	(−1.36)
Control variable	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes
Firm-fixed effect	Yes	Yes	Yes	Yes
Obs	8,392	8,392	8,392	8,392
R-Square	0.058	0.167	0.203	0.409

Table 11: Impact of carbon price volatility on the regulated firms

Notes: This table shows the impact of carbon price volatility on the financial performance of regulated firms, corresponding with Equation (6). All control variables are included. The t-values, reported in parentheses, are heteroscedasticity-robust and clustered at the firm level. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. See Appendix 1 for variable definitions.

[8] For example, between 2013 and 2022, the trading volumes in the Guangdong and Hubei ETS pilots were eight times those for Tianjian and Chongqing (Huang et al., 2022).

5. Conclusion

In response to domestic and international concerns over the growing deterioration of the environment, China launched pilot ETSs, one of its first market instruments, in several areas to abate carbon emissions. This study evaluates the financial performance of firms under the regulations of these ETS pilots from 2008 to 2020, before the official launch of the national ETS.

We find that, under the regulation of the ETS pilots, firms generally experience a significant reduction in operating costs and an improvement in their profitability and firm value, suggesting that regulated firms benefited from the growth and development of China's ETS pilots. This outcome aligns with China's national environmental and economic strategy. The mediation models report evidence that the ETS pilots positively affect TFP, but TFP negatively mediates the relationship between the ETS pilots and firms' financial ratios. This finding implies that although the (green) technology development encouraged by the ETS pilots immediately improves as regulators expect, it will suppress the regulated firms' financial performance, suggesting only the weak version of the Porter hypothesis applies to China's ETS scenario. Regulators should explore ways to efficiently convert technology investment into competitive advantages that offset compliance costs and generate positive financial outcomes. Considering that the returns from innovation are likely to arise only in the medium-to-long run, financial and policy support from the government will be essential to keep the firms growing and profitable and make economic growth sustainable.

Furthermore, we reveal that the increasing price of carbon emission and market uncertainty jeopardize both firms' short-term financial performance and the market perception of firms' future performance simultaneously. The pessimism reflects market concern about regulated firms' profitability due to restricting carbon emission quotas and potential risk from regulation compliance and cleaner transition. Uneven economic development, misallocation of carbon quotas, and incomplete monitoring, reporting, and verification systems can strongly affect the supply-demand relationship and the volatility in the price of carbon emissions. Regulators need to understand such drivers of the volatility of the carbon emission price and consider taking preventive measures, such as carbon emission financial products, available to firms to hedge against the risk of carbon emission price changes (Huang et al., 2022).

Furthermore, we identify that ETS regulations improve SOEs' financial performance and market value while having a negligible influence on those of non-SOEs. Implementing the ETS pilots does not seem to have brought many benefits or opportunities to non-SOEs to offset the costs arising from compliance with the ETS regulation. We suggest regulators seek auxiliary policies and tools to optimize the process of achieving carbon emission neutrality and provide efficient support to regulated non-SOE firms, which will play a vital role in achieving China's climate commitments and inclusive economic development.

Based on our findings and analysis, we can conclude with a high degree of confidence that the nationwide carbon trading market, officially announced in China at the end of 2017 and fully launched in 2021, is highly likely to promote regulated firms' financial performance. However, the regulators and the government should learn from the experience of operating the ETS pilots and play an active role in developing the carbon emission market and supporting regulated firms. Studying the effect of China's ETS pilots on firms' financial performance provides a depth of information for China's national ETS and helps identify problems and concerns that must be addressed in developing the national ETS. Our study provides a reference for the regulators responsible for monitoring the effect of China's fully national ETS and for estimating the environmental and economic outcomes of any legislative proposals aimed at revising it as China seeks to meet the environmental and climate targets to which it is committed. Our study can also help managers understand the effects of the ETS, determine their firms' strategies for energy management and green technology development, estimate the economic consequences of those strategies, and make relevant financial plans. Lastly, the findings based on the ETS pilots of the largest producer of emissions in the world can provide valuable lessons for other cap-and-trade programs in other jurisdictions and policy and regulatory implications for establishing and developing international ETS markets.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data and codes will be made available on request.

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Appendix 1. Definitions of Variables

	Dimension	Variable	Definition	Data source
Explained Variables	Financial Performance	QVal	Tobin's Q value	RESSET database and own calculations
		ROA	Return on assets = EBIT/Total assets	
		PMR	Profit margin = Net profits (or Income)/Net sales (or Revenue)	
		OER	Operating Expense Ratio= Operating Expenses/Net Sales (or Revenue)	
Explanatory Variables	Does the ETS regulate the firm	ETS	ETS = 1 if the firm is regulated under a pilot ETS; otherwise, it is 0.	The documents released by each pilot province's government
	When the firm joins the ETS	Post	Postt = 1 if the firm is regulated under a pilot ETS in year t; otherwise, it is 0.	
	Carbon Price Volatility	PcV	The annual volatility of the carbon price for China's pilot ETSs.	The official website for each pilot ETS and own calculations
	Carbon Price	Pc	The annual weighted average carbon price for China's pilot ETSs (CNY/ton)	
Control Variables	Firm's technical progress	Omega	Measure by total factor productivity	RESSET database and own calculations
	Firm's size	Size	Natural logarithm of total assets	
	Liquidity	Currt	Current ratio = Current assets/Current liabilities	
	Equity financing	SR	Solvency Ratio = Total debts/ Shareholders funds	
	Leverage level	Lev	Debt to assets ratio	
	Capital intensity	CI	Capital intensity ratio = Total assets/Net sales (or Revenues)	

Highlights

- We study the causal impact of China's pilot ETSs on firms' financial outcomes.
- China's pilot ETSs have improved regulated firms' financial performance.
- Technological progress can suppress the effect of ETSs on financial performance.
- The carbon emission price has a positive impact on firms' market value.
- The ETSs have little impact on enhancing the financial performance of non-SOEs.

Conflicts of Interest Statement

Manuscript title: Does China's emission trading scheme affect corporate financial performance: Evidence from a quasi-natural experiment

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Please specify the nature of the conflict on a separate sheet of paper if the space below is inadequate.

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