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Environmental Policy, Firm Innovation and Financial Leverage

ABSTRACT

To meet its goals of carbon peaking and carbon neutrality, the Chinese government implemented a Carbon Emissions Trading Scheme (CETS) policy instrument in 2013. This study explores the impact of this environmental policy on the financial leverage of Chinese high-carbon-emitting firms.

We first develop a theoretical model based on traditional trade-off theory and Porter's hypothesis. Then we use the CETS policy as a quasi-natural experiment and employ a Difference-in-Difference research design to tackle the research questions. Our results indicate that, on average, treated firms in regulated regions experience a 14% increase in firm leverage relative to their counterparts following the policy intervention. The primary mechanism is through green innovation. The CETS policy incentivizes firms to engage in innovative activities, resulting in a significant increase in patents and inventions used as collateral for debt financing. Furthermore, we document that this positive relationship is weakened by stronger government-firm relationships and the receipt of environmental subsidies.

Our results underscore the significant influence of environmental policy on firm level investment and financial decision-making, thereby providing a robust empirical basis for the formulation of more rational and effective policy frameworks.

KEY WORDS:

Environmental Policy, Carbon Emission Trading Pilot Scheme, Financial Leverage, Firm Innovation

Contents

1 Introduction

Even though the world's economy is doing better than ever, we're still facing major environmental issues—like climate change, pollution, running out of resources, and losing animal species. These problems are getting worse and could seriously affect our future. As one of the biggest economies and largest populations, China has accomplished rapid annual economic growth rate of 5% in recent years. However, this rapid development has come at a significant ecological cost, raising critical concerns regarding environmental sustainability. Notably, carbon emissions, primarily in the form of carbon dioxide (CO_2), remain persistently high. In 2019, China accounted for 28% of global carbon emissions, with 90% of these emissions originating from domestic consumption and production activities.

Aiming to reconcile its rapid economic development with long-term sustainability, China established "Dual Carbon" goals of peaking carbon emissions and achieving carbon neutrality after the 2016 Paris Agreement. This commitment was further elevated in 2020 when carbon peak and neutrality were designated as one of the eight key national priorities at the Central Economic Work Conference.

To reach these objectives, China has implemented a wide-ranging set of environmental regulations, together with Command-and-Control (CAC) and Market-Based-Instrument (MBI) policies. The previous sets mandatory government targets for emission reductions and the deployment of central environmental protection inspectors, compelling firms to internalize their environmental costs. While effective in curbing emissions, the CAC often imposes significant cash flow pressures on companies and presents challenges in generating swift economic returns. In contrast, MBI creates economic incentives by leveraging market mechanisms. These instruments reduce information asymmetry and allow firms to pursue profit maximization within predefined pollution constraints. By aligning environmental objectives with market forces, this form of regulation mitigates cost pressures on companies, facilitates greater investment in green innovation so that improved environmental performance can support corporate development.

The Carbon Emissions Trading Scheme (CETS) represents an influential form of market-based environmental regulation since its pilot implementation in 2013.

Originally, this policy was implemented in seven regions for high-carbon-emitting companies. Under this mechanism, regulatory authorities establish an emissions cap and allocate corresponding quotas to participating entities. Firms that emit less than their allotted quotas may sell their surplus allowances, thereby generating revenue, whereas those exceeding their limits must purchase additional credits, incurring a financial cost. Consequently, the CETS functions as a canonical market-based instrument, leveraging price signals and tradable permits to incentivize emissions reductions in a cost-effective manner.

How do high-carbon-emitting firms in regulated regions alter their investment and financial strategies to manage the costs and risks of Carbon Emissions Trading Scheme (CETS) in comparison to their counterparts in non-regulated areas? Neoclassical economic theory posits that firms optimize output based on their production and cost functions. Under the assumption of static resources and technology, the introduction of environmental policies alters cost constraints, thereby potentially reducing both productivity and output (Gray, 1987). Consequently, firms may curtail investment and financing activities to avoid penalties associated with non-compliance, while banks respond by tightening lending standards and imposing higher risk premiums in the form of increased interest rates on loans.

In contrast, Porter (1991) contends that well designed environmental policies can encourage technology innovation, potentially offsetting compliance costs through innovation. According to this view, pollution often reflects resource inefficiency; thus, market-based regulations can incentivize firms to improve resource utilization, enhancing both environmental and economic performance. Consequently, by promoting innovation, such regulations may lead firms to increase financial leverage to secure necessary funding for these investments, balancing the dual demands of regulatory compliance and strategic growth.

To answer the above research question, we first develop a theoretical framework based on neoclassical economics and Porter's hypothesis. Then we utilize the CETS as a quasi-natural experiment and employs a Difference-in-Differences (DID) research design on a panel dataset of 3,875 firm-year observations from 358 high-carbon-emitting companies. Our results indicate that, on average, treated firms experience a 14% increase in firm leverage relative to their counterparts following the policy shock. The primary mechanism is through green innovation. The CETS policy incentivizes firms to engage in innovative activities, resulting in a significant increase in patents and inventions used as collateral for debt financing. Furthermore, we document that this positive relationship is weakened by stronger government-firm relationships and the receipt of environmental subsidies.

Our study might have marginal contributions to the two streams of literature:

First, our study extended the existing literature on the impact of environmental policy on firm behaviors, such as positive impact on investments (Leiter et al., 2011; Tang, Li, and Hu, 2024). However, the existing literature presents mixed evidence on corporate leverage. Several studies emphasize the adverse effects of command-and-control policies on firm leverage (Wang and Sun,2021; Yang et al. ,2022). In contrast, other research aligns with the Porter Hypothesis of a positive relationship, positing that regulatory pressures incentivize energy-efficient innovation, leading to high leverage (Herbohn et al., 2019; Sharfman and Fernando, 2008). Our findings support for the Porter Hypothesis that high-polluting firms increased their leverage levels following the implementation of CETS as Market-Based-Instruments through the channel of green innovation outputs as collateralizable assets.

Second, our study also contributes to the extensive stream of research on corporate capital structure. Foundational theories of leverage have long provided frameworks for understanding financing decisions, including trade-off theory (Baxter, 1967), agency cost theory (Jensen and Meckling, 1976), stakeholder theory (Titman, 1984), and pecking order theory (Myers and Majluf, 1984). More recent scholarship has expanded this discourse to incorporate macroeconomic influences; for example, Hackbarth et al. (2006) identify countercyclical fluctuations in capital structure. We introduce the role of governmental policy as a significant determining factor of firm level financial leverage, particularly in response to environmental policies that alter firms' operational and compliance costs. Our findings suggest that market-based environmental policies can motivate firms to increase green innovation, yielding a rise in patentable outputs as collateral, thereby facilitating greater debt financing. These results highlight the efficacy of market-based instruments in promoting environmental objectives and in shaping corporate financial behavior.

This study is organized as follows. Section Two reviews the relevant institutional background and existing literature. Section Three develops a theoretical model and testable hypotheses. Section Four outlines the empirical methodology. Section Five presents the main findings, followed by a mechanism analysis, heterogeneity analyses, and robustness tests. Finally, Section Six concludes key findings and the policy implications.

2 Institutional Background and Literature Review

2.1 Carbon Emissions Trading Scheme

By the close of the twentieth century, the global community had recognized the critical severity of climate change. This growing consensus on the necessity of coordinated international action to reduce carbon emissions is evidenced by key multilateral agreements such as the UNFCCC in 1992, the 1997 Kyoto Protocol, and the 2016 Paris Agreement. The establishment of the European Union Emissions Trading System (EU-ETS) in 2005 signified the first major carbon emissions trading framework on the world.

Under such a cap-and-trade scheme, a regulatory body sets a mandatory cap on total emissions and allocates or auctions tradable allowances to regulated entities. Firms that maintain their emissions below their allotted quota can sell their surplus allowances for a profit, while those that exceed their limit are obligated to obtain additional permits to cover their excess, thereby incurring a financial cost. This market-based environmental instrument creates a price signal for carbon, leveraging economic incentives to encourage emissions reductions in a cost-effective manner, representing a cornerstone of market-based environmental policy.

The EU-ETS has experienced three stages in the past two decades and is now in the fourth stage. The EU-ETS carried out reforms and successfully achieved emission reductions in the second stage (2008-2012). Petrick and Wagner (2014) show that manufacturing companies in Germany cut 25%-28% emissions in the second stage. Martin et al. (2016) conclude that French and German companies reduce 10%-26% emissions in the second phase.

Between 2013 and 2014, China launched a pilot phase of Carbon Emissions Trading Scheme (CETS) across seven regions: Beijing, Shanghai, Shenzhen, Tianjin, Chongqing, Hubei, and Guangdong. The initial trading framework engaged over 1,800 entities, including corporations, public institutions, and building operators. Annually, the trading platform would revise its participant pool by incorporating new entities or delisting existing ones, with updated lists made publicly available.

Owing to disparities in regional development stages and industrial structures, local governments in each pilot area developed customized eligibility criteria designed specifically to target high-carbon-emitting entities. The detailed standards and the respective industries they govern are outlined in Table 1.

Table 1 Outline of China Carbon Emission Trading Pilot Scheme

Pilot area	**Launched date**	**Number of regulated entities**	**Industries involved**	**Annual carbon emissions threshold**
Shenzhen	2013/06/18	635	Manufacturing, transportation, construction	3,000 ton
Beijing	2013/11/28	543	Electricity, heat, cement, petrochemical, manufacturing, service industry, transportation	10,000 ton
Guangdong	2013/12/19	202	Cement, steel, electricity, petrochemical	20,000 ton
Shanghai	2013/12/26	197	Steel, chemical, petrochemical, electricity, non-ferrous, building materials, textile, paper making, rubber, chemical fiber, port, aviation, airport, railway, hotel, commerce, finance	20,000 ton
Tianjin	2013/12/26	114	Steel, chemical, electricity, heat, oil, petrochemical and gas extraction	20,000 ton
Hubei	2014/04/02	138	Steel, chemical, cement, electricity, paper making	60,000 ton
Chongqing	2014/06/19	Undisclosed	Manufacturing	20,000

Source: Development and Reform Commission

Evidences indicate that the CETS generated significant carbon-reducing effect. Li and Lin (2020) find that China CETS reduces carbon dioxide emissions and sulfur dioxide emissions, industrial wastewater, and other solid waste. Most studies believe that the CETS significantly promotes innovation, resulting in more R&D investment (Hu et al., 2020), patent applications (Liu et al., 2022), and patent authorizations (Yu et al., 2022).

2.2 Literature Review

Regarding the effect of environmental policy on firm behaviors, existing research document inconsistent findings based on two competing theories: the neoclassical economic hypothesis and the Porter hypothesis.

Neoclassical economic theory argues that firms are posited to optimize output based on their production and cost functions. Under the assumption of static resources and technology, the imposition of environmental regulation alters a firms cost constraints, thereby leading to a decline in both productivity and output (Gray, 1987). Empirical evidence supports this negative association; for instance, Wang and Sun (2021) identify an adverse impact of the stringent environmental mandates introduced by the Paris Agreement on corporate leverage. Their findings suggest that such policies heighten firms sensitivity to financial distress, prompting a strategic reduction in leverage to mitigate the risk of future operational cash flow shortfalls. Similarly, Yang et al. (2022) observe that environmental policies induce firms to adopt longer-term strategic orientations, curtailing short-sighted investment and financing behaviors to avoid penalties and align with sustainable development objectives.

In contrast, Porter (1991) advanced a competing theory, known as the Porter Hypothesis (PH), suggesting that well-designed environmental policies may incentivize firm-level innovation, potentially offsetting compliance costs and enhancing competitiveness. Jaffe and Palmer (1997) subsequently refined this hypothesis into a three-part typology: the narrow version suggests that environmental policies can stimulate innovative activity; the weak version contends that while regulations may induce innovation, such innovation does not necessarily lead to improved firm performance; and the strong version argues that regulatory stringency can trigger innovation that fully compensates for the associated costs, thereby yielding a net private benefit. A substantial body of empirical research demonstrates a positive correlation between regulatory stringency and firm innovation, which subsequently enhances corporate performance metrics such as total factor productivity and profit margins. For instance, Lanoie et al. (2008) document that firms in Quebec subject to environmental policies experienced gains in total factor productivity following an initial period of compliance investment. Johnstone et al. (2010) observe that public environmental policies raised the number of patent applications in the renewable energy sector across 25 OECD countries. Similarly, Lee et al. (2011) provide evidence that CAC policies in the U.S. automobile industry between 1970 and 1998 spurred significant technological advancements, as reflected in increased patenting activity. Further supporting this innovation-to-performance pathway, Rexhäuser and Rammer (2014) show that environmental policies improved profit margins among German firms by stimulating enhancements in resource efficiency.

Research within the Chinese context similarly indicates a positive correlation between environmental regulation and company performance. Jie et al. (2014) demonstrate that environmental policies promote research and development (R&D) investment among heavily polluting firms. A study by Li et al. (2016) suggests that this improvement in performance is facilitated through a reduction in agency costs. Employing a difference-in-differences (DID) methodology, Zhou et al. (2021) provide evidence that New Environmental Protection Law (NEPL) enhanced the profitability of heavily polluting firms. Liu and Xiao (2022) find that the environmental protection tax reform considerably improved the proportion of green patent applications. Similarly, Tang, Li, and Hu (2024) demonstrate that environmental regulation can improve green investment efficiency. However, the type of regulatory instrument appears to matter. Zhang et al. (2021) contend that while market-based environmental policies can improve firm performance, command-and-control approaches may lead to a reduction in output.

The existing literature presents mixed evidence on corporate leverage. Several studies emphasize the adverse effects of command-and-control policies on firm leverage. For instance, Wang and Sun (2021) demonstrate that the Paris Agreement adversely influenced the leverage of high carbon-emitting firms. Yang et al. (2022), document a deleveraging effect among highly polluting enterprises, due to the New Environmental Protection Law (NEPL). In contrast, other study aligns with the Porter Hypothesis of a positive relationship, positing that regulatory pressures incentivize energy-efficient innovation, leading to high leverage. Herbohn et al. (2019) find that carbon emission disclosures influence lender willingness to extend credit, while Sharfman and Fernando (2008) argue that enhanced environmental risk management could encourage greater financial leverage by lowing the cost of capital.

In summary, the neoclassical economic theory predicts a negative shock of environmental regulation on financial leverage, while the Porter hypothesis predicts a positive effect. This paper attempts to develop a framework of a static trade-off theory model by integrating neoclassical economic elements and the "Porter Effect" to revisit the relation between environmental policy and firm financial leverage decisions.

3 Theoretical Framework and Research Hypotheses

3.1 Theoretical Model Settings

Referencing the theoretical frameworks of Strebulaev and Whited (2012) and Xie et al. (2023), this section establishes a framework of a static trade-off theory model by integrating production, carbon emissions, abatement costs, the "Porter Effect", debt cost mechanisms, firm value definition, and after-tax profit calculation.

3.1.1 Production Process and Firm Value Function

The model starts with a traditional Cobb-Douglas production function (Eq. 3.1), which is a widely used tool in economics to describe how inputs (capital and labor) combine to produce output, adjusted by total factor productivity (TFP).

$$Y = AK^{\alpha}L^{1-\alpha} \qquad (3.1)$$

Where Y is firm production, A denotes the productivity, K is capital, L is labor, and α is the production elasticity of capital, with a value between zero and one.

Each firm's carbon emissions are modeled as a function of its output and abatement investment (Eq. 3.2), reflecting how production activities generate emissions and how abatement efforts can reduce them.

$$C = \varphi_0 e^{-\theta E} Y \qquad (3.2)$$

Where C is carbon emissions and Y is output from Eq. (3.1). φ_0 is the original emission intensity and θ is the reduction efficiency. E is the abatement investment in emission intensity reduction.

The cost of undertaking abatement investment is specified by a quadratic cost function (Eq. 3.3), which is a common choice in economic models to reflect increasing marginal costs of abatement.

$$c(E) = \kappa E^2 \qquad (3.3)$$

c(E) represents the total abatement cost incurred by the firm when it invests E in abatement. κ is the abatement cost coefficient. A higher κ indicates that abatement is costlier for the firm. For instance, a firm in a capital-intensive industry (e.g., steel production) may have a higher κ than a service-based firm because reducing emissions in capital-intensive industries often requires more expensive technologies. E is the abatement investment (as defined in Eq. 3.2). The quadratic form of the function implies that the marginal cost of abatement increases as E increases. This is realistic because firms typically first adopt the least costly abatement measures (e.g., minor process improvements) and then move to more expensive ones (e.g., building new low-emission facilities) as they seek to further reduce emissions.

Under the CETS pilot program, firms are allocated a certain number of emission allowances (Q), and their net carbon cost is determined by the difference between their actual emissions (C) and the allowances (Q) they hold. If C>Q, firms need to purchases quota ΔQ (=C-Q). if C<Q, firms could sell quota ΔQ (=Q-C). The net carbon cost is pc (C - Q), where pc is the carbon price.

The "Porter Effect" (Porter, 1991) posits that environmental regulations (such as CETS) can stimulate companies to invest in abatement, which in turn promotes innovation and improves their overall competitiveness. In this model, the Porter Effect is captured through a patent production function (Eq. 3.4), as patents are a common measure of technological innovation.

$$P = P_0 + \eta E \qquad (3.4)$$

Where P is total number of patents. P_0 is original number of patents, η denotes marginal contribution of abatement investment on patent production and η>0. The abatement investment (E) has a positive effect on patents production.

The model further explores how abatement investment (E) affects the firm's cost of debt (r_D) through two channels: changes in default risk and changes in the value of patent collaterals. The cost of debt is first specified in a basic form (Eq. 3.5) and then expanded into a more detailed form (Eq. 3.6) to incorporate the effects of E.

$$r_D = r_0 + \xi d - \psi P \qquad (3.5)$$

Where r_0 is the risk-free rate of debt, d is the debt level of firm, ξ is the default risk coefficient of debt, ψ is the mortgage efficient of patents, which reduces debt cost by increased patents as collaterals.

We expand Eq. (3.5) into more detailed expression as following:

$$r_D = r_0 + (\xi_0 + \delta E)d - \psi(P_0 + \eta E) \quad (3.6)$$

Where ξ_0 is the original default risk coefficient of debt and $\delta \geq 0$ represents the extent to which environmental investment E raises the default risk coefficient. P_0 is the original number of patents, η is the marginal contribution of abatement investment on patent production and $\eta > 0$. Patents serve as collateral to reduce borrowing costs ($\psi > 0$).

From Eq. 3.6, we can clearly see the dual effects of abatement investment (E) on the cost of debt by raising both collateral (positive effect) and default risk (negative effect).

We assume that firm owners make appropriate management decisions to maximize firm value (V) defined as the capitalized value of its after-tax profits, which is a standard approach in corporate finance to measure the long-term value of a firm.

$$V = \frac{\pi_{net}}{\rho(d, P)}$$

Where π_{net} is the after-tax profit and ρ is the cost of capital (WACC). ρ is a function of debt ratio d and possession of patents P, showing as Eq. (3.7):

$$\rho(d, P) = d \cdot r_D(d, P) + (1 - d) \cdot r_E \quad (3.7)$$

r_D is the cost of debt, r_E is the cost of equity. It is assumed that $r_E > r_D$.
The after-tax profit π_{net} is expressed as following Eq. (3.8):

$$\pi_{net} = (1 - \tau)[\Pi_0] + \tau\, r_D \mathrm{D} \quad (3.8)$$

Π_0 is profit before tax, $\Pi_0 = \mathrm{pY} - \mathrm{wL} - r_K \mathrm{K} - \kappa \mathrm{E}^2 - p_c(\varphi \mathrm{Y} - \mathrm{Q}) + \mu \mathrm{P}$

Where τ is tax rate, p is unit price of output, Y is output quantity, pY is operating revenue (price p × output Y), wL is labor costs (wage rate w × labor input L) and r_kK is capital costs (weighted average cost of capital r_k × capital input K). κE^2 is emission abatement investment costs (κ: cost coefficient, E: abatement effort). $p_c(\varphi Y - Q)$ is net carbon cost (where p_c is carbon price; if $\varphi Y > Q$, purchase allowances; otherwise sell surplus). μP is profit increment from patents (Weak Porter Effect, μ is marginal contribution). $\tau r_D D$ is debt tax shield benefit (tax rate τ × interest payments $r_D D$). D is the debt level. r_D is cost of debt.

3.1.2 Optimal Leverage Decision

This section focuses on how firms determine their optimal debt ratio (d)—a core element of capital structure decision-making—by maximizing firm value, while simultaneously considering the impact of emission reduction investment (E) on both value and leverage. The model's fundamental premise is that firm owners (or managers acting on their behalf) make two key decisions to maximize firm value (V): choosing the debt ratio (d) and determining the emission reduction investment (E).

Consistent with corporate finance principles, the formula for firm value is:

$$V = \frac{\pi_{net}}{\rho(d,P)}$$

To explicitly reflect the impact of CETS and emission reduction investment (E), the model expands the firm value formula to incorporate production, abatement costs, carbon costs, patents, and debt costs. The expanded formula of V is:

$$V = \frac{(1-\tau)[pAK^{\alpha}L^{1-\alpha} - wL - r_K K - \kappa E^2 - pc(\phi_0 e^{-\theta E} AK^{\alpha}L^{1-\alpha} - Q) + \mu(\boldsymbol{P_0} + \eta E)] + \tau(r0 + \xi d - \psi(P0 + \eta E))D}{d(r0 + \xi d - \psi(P0 + \eta E)) + (1-d)rE}$$

Firm owners choose the optimal debt ratio (d) and emission reduction investment (E) to maximize firm value V.

$$\max_{d,E} V = \frac{\pi_{net}}{\rho(d,P)}$$

The first-order condition with respect to d:

$$\partial V / \partial d = 0$$

Solve for d* (see appendix for the detailed derivation):

$$d^* = \frac{\psi(P_0+\eta E) - r_0}{2(\xi_0+\delta E)} + \frac{r_E}{2(1-\tau)(\xi_0+\delta E)} \tag{3.9}$$

3.1.3 Model Prediction and Economic Implications

We use the derived optimal solution Eq. (3.9) to predict how Carbon Emissions Trading System (CETS) affect corporate optimal financial leverage. The core tool is the derivative of d* with respect to E, which measures how a 1-unit increase in E changes d*.

$$\frac{\partial d^*}{\partial E} = \frac{\psi\eta}{2(\xi_0+\delta E)} - \frac{\delta[(1-\tau)(\psi(P_0+\eta E) - r_0) + r_E]}{[2(1-\tau)(\xi_0+\delta E)]^2} \tag{3.10}$$

From the expression of Eq. (3.10), we can see that CETS affect corporate optimal financial leverage through two channels.

$$\frac{\psi\eta}{2(\xi_0+\delta E)}>0$$

The first channel goes through the patent effect. CETS increases firm abatement investment E, so that increases the number of patents (Eq. 3.4), which further increase the collaterals and lower debt cost r_D and therefore raise the optimal leverage d*.

$$-\frac{\delta[(1-\tau)(\psi(P_0+\eta E)-r_0)+r_E]}{[2(1-\tau)(\xi_0+\delta E)]^2}<0$$

The second channel comes from the risk effect. The abatement investment E raises the default risk ($\xi = \xi_0 + \delta$) and operating cost κE^2, which lower optimal leverage d*.

Therefore, there exists a critical level of emission reduction investment ("Threshold Effect"), denoted as E^*, such that when $E<E*$, the patent effect dominates, and $\partial d*/\partial E >0$; when $E>E*$, the risk effect dominates, and $\partial d*/\partial E <0$.

3.2 Hypothesis Development

As the Carbon Emissions Trading Scheme (CETS) imposes a financial burden on carbon-intensive firms that exceed their allocated emission quotas, requiring them to purchase additional allowances for their excess emissions in each compliance period. According to neoclassical economic theory, such scheme ensures that the compliance costs associated with the environmental policy are internalized into the firms total production costs in the short term, prior to any potential benefits that may arise from subsequent innovation. Consequently, firms subject to the CETS face higher carbon risk relative to their counterparts for two primary reasons.

First, these firms are exposed to heightened economic penalties under stringent emission reduction mandates and are directly vulnerable to carbon pricing volatility. This increased carbon risk translates into substantial compliance costs, as expenditures on emission abatement and pollution control divert resources away from productive investments, thereby depressing corporate performance and amplifying financial distress risk (Brunnermeier & Cohen, 2003). Second, carbon-intensive enterprises often operate with high, rigid fixed costs—including expenses related to environmental remediation, regulatory compliance, litigation, and reputational damage. These costs are not only substantial but also largely inflexible, potentially negating the advantages of debt-related tax shields and further straining financial stability.

From the perspective of banks, higher carbon risk implies that carbon-intensive firms face a greater likelihood of litigation and regulatory penalties. Consequently, these firms must allocate increased resources toward compliance expenditures, which can significantly reduce their profitability and operational cash flows. As funds originally earmarked for debt repayment are diverted to cover these costs, the probability of default rises correspondingly. Furthermore, environmental violations can inflict substantial reputational damage on carbon-intensive companies, undermining their market competitiveness and limiting future business opportunities. This erosion of financial standing further diminishes their debt-servicing capacity, thereby amplifying default risk. In response to these heightened risks, banks and other lenders often tighten credit standards and impose higher risk premiums in the form of increased interest rates on loans. Faced with elevated borrowing costs, carbon-intensive firms are subsequently inclined to reduce their reliance on debt financing.

Therefore, this paper proposes hypothesis H1a:

H1a. Following the implementation of CETS, high-carbon-emitting firms will experience a reduction in financial leverage relative to their less-polluting counterparts.

From a firm-level perspective, the Porter's theory suggests that well-designed environmental policies could incentivize innovation in energy efficiency, yet such innovation need to signal credibility to external capital providers. For carbon-intensive enterprises, stringent environmental policies lead to a marked increase in both production costs and emissions abatement expenditures. This cost pressure can compel a shift away from carbon-intensive technologies and toward low-carbon innovation. To maintain market competitiveness, firms pursue innovations expected to yield compensatory effects that offset these elevated costs (Rassier & Earnhart, 2015).

The process of technological upgrading consequently drives higher research and development (R&D) expenditures, a burden particularly acute for pollution-intensive firms that face limited options for resource reallocation (Milani, 2017; You and Wang, 2016). To finance these large-scale transitions in production modes—which generate significant demand for capital (Luo & Qi, 2021)—firms are prompted to seek external financing. This often results in increased debt issuance and higher financial leverage, a strategy that also allows firms to capitalize on the associated tax shield benefits.

As Porter (1991) contends, appropriately designed environmental policies can stimulate innovation within firms. When confronted with stringent and sudden environmental requirements, enterprises often necessitate incremental investments to adapt. Within this process, innovation outputs—particularly patents—play a critical role. First, patents can establish higher market entry barriers, signaling greater technological competitiveness and enhancing firm value, thereby reducing the perceived risk of financial distress (Bai & Tian, 2020; Simeth & Cincera, 2016). Second, patents provide legal protection against intellectual property disputes, which mitigates litigation risks, improves corporate credit profiles, and facilitates access to larger volumes of lower-cost debt (Frey et al., 2020). Finally, patents can serve as collateralizable assets, strengthening a firm's borrowing capacity by offering creditors enhanced protection in the event of liquidation (Horsch et al., 2021).

From the perspective of external lenders, information regarding a firm's carbon emissions significantly influences lending decisions (Herbohn et al., 2019). Enhanced environmental risk controlling is correlated with reduced cost of capital, thereby creating an incentive for firms to increase financial leverage (Sharfman and Fernando, 2008). The underlying rationale is that capital markets assign lower risk premiums to firms that proactively manage environmental exposures, which in turn decreases their overall cost of capital. Within China, particularly following the starter of the Green Credit Policy in 2012, environmental risk has become a critical factor in bank credit assessments. Firms demonstrating lower prospective environmental risks and stronger environmental performance are more likely to receive favorable lending terms and greater access to debt financing (Sun et al., 2023). Thus, our hypothesis H1b is:

H1b. Following the implementation of CETS, high-carbon-emitting firms will experience an increase in financial leverage relative to their less-polluting counterparts.

4 Empirical Research Design

4.1 Regression Model and Variables

Based on the policy shock of CETS, we build a Difference-in-Difference (DID) regression model shown as Eq. (4.1) to test our hypothesis.

$$Leverage_{i,s,t} = \alpha + \beta DID + \gamma Controls_{i,s,t-1} + \delta_i + \eta_t + \phi_s + e \quad (4.1)$$

Where *i* denotes a firm, *s* denotes an area, *t* is the year. The dependent variable is book leverage (*Leverage* = total liabilities/total assets). The key explanatory variable is *DID (DID= Treat×Post)*. *Treat* is a policy dummy and takes 1 if sample firms are in the experimental group in various areas affected by the policy, otherwise *Treat* = 0. Since the CETS started trading from the late 2013 to the early 2014, *Post* = 0 for year before 2014, *Post* = 1 for year in and after 2014.

$Controls_{i,s,t-1}$ denotes the matrix of lagged control variables. Following the literature (e.g., Rajan and Zingales,1995; Huang, 2006; Frank and Goyal, 2009), the control variables are firm size (*Size* = total assets in billion yuan), profitability (*Profit* = net income/average of total assets), growth (*TobinQ* = market value/book value), asset tangibility (*Tang* = PP&E/total assets). One period is lagged for all control variables to avoid reciprocal causation with the dependent variable.

We also include year, firm, region fixed effects. δ_i is firm dummy, η_t is year dummy, ϕ_s is area dummy, and e is the random error term. The details of above variables are presented in Table 2.

According to H1a (neoclassical economic theory), the regulation will reduce the financial leverage, therefore we expect β is significantly negative. According to the H1b, if the Porter's effect exists, the regulation will significantly increase the financial leverage, and we expect a s significant positive β.

To test the mechanism, this paper uses several mediator measures for innovation such as the number of authorized patents (*Patents*) and the number of authorized inventions (*Inventions*). Patents include inventions, utility model patents, and design patents, among which inventions have the highest value under the strictest examination

(Liu, 2015).

Table 2 Detailed definitions of all variables

Type	Variable	Definition	Source
Dependent variable	*Leverage*	Total liabilities/total assets	Wind
Independent variable	*DID*	*Treat* × *Post*	CSMAR, Development and Reform Commission
	Treat	0 for control group and 1 for experimental group	
	Post	0 for year 2010 to 2013, 1 for year 2014 to 2020	
Mediating variables	*Patents*	Number of patents	CNRDS
	Inventions	Number of inventions	CNRDS
Control variables	*Size*	Logarithm of total assets in billion yuan	Wind
	Profit	Net income/average of total assets	
	TobinQ	Market value/book value	
	Tang	PP&E/total assets	
	Firm	Firm dummy	
	Area	Area dummy	
	Year	Year dummy	

4.2 Sample and Data

This study designates firms that participated in the initial 2013–2014 CETS pilot as the treatment group, while selecting firms from non-pilot regions that are similarly exposed to carbon-related risks to serve as the control group. Due to the failure of the Chongqing emissions exchange to disclose its official list of trading entities—essential for identifying eligible pilot firms in the region—companies based in Chongqing have been excluded from the study sample.

The treatment group was initially constructed using data on all inaugural pilot firms sourced from CSMAR database and the respective regional Development and Reform Commissions. To identify listed firm samples across the remaining six pilot jurisdictions, this study then cross-referenced this initial dataset with the CSMAR Listed Companies and Subsidiaries database. Where a pilot firm itself was not listed on the A-share market, its parent company was included as a proxy to maintain relevance to the pilot scheme.

To ensure the treatment group reflects sustained exposure to the pilot policy, a manual year-by-year verification of carbon trading entity rosters was conducted. Firms that were delisted from the trading scheme in subsequent years were excluded from the sample, such that all remaining experimental firms consistently appear on the official trading lists throughout the post-2014 observation period.

The control group was drawn from the universe of A-share listed companies, with an initial exclusion of firms operating within any of the seven CETS pilot regions. To align the control group with the high-carbon exposure characteristic of the experimental group, firms were further filtered to include only those classified under eight high-carbon-emitting industries (as per the CITIC industry classification system) guided by the definition of high-carbon sectors outlined in the 2021 article by the China Council.

Subsequent refinements to the control group involved excluding special treatment (ST) firms, entities with missing key data, and those with negative book equity—adjustments made to ensure data quality and sample comparability. Following these screening procedures, the final sample comprises 81 firms in the treatment group and 277 firms in the control group from year 2010 to 2020, yielding 3,875 firm-year observations for the panel data. To alleviate the potential distorting effects of outliers, all continuous variables were winsorized at the 1% tails.

4.3 Summary Statistics and Parallel Test

Table 3 presents the results of the descriptive analysis of the sample. The mean of financial leverage stands at approximately 51.34%, reflecting the average debt-to-asset ratio across the observed firms. The mean of the treatment indicator (Treat) is 0.229, which implies that 22.9% of the observations in the sample belong to the experimental group. With a mean of 0.641, the post-policy indicator (Post) suggests a relatively balanced distribution of observations between the pre- and post-policy periods.

In terms of innovation-related variables, the sample firms have an average of 20.679 patents in total, with a wide range from 0 to 352, and a median of just 2.000—suggesting a skewed distribution where a small number of firms hold a large share of patents. The mean of invention patents (a more stringent measure of impactful innovation) is 6.432, with a median of 0.000, further highlighting this uneven distribution of innovative activity across the sample.

Firm size (*Size,* before taking logarithm) has a sample mean of 20.693 billion yuan, a median of 6.771 billion yuan, and a maximum of 207.615 billion yuan, indicating significant variation in the scale of firms included. Profitability (*Profit*) has a mean of 3.146% and a range from -10.669% to 17.413%, reflecting differences in operational performance across the sample. TobinQ has a mean of 3.027 and a median of 2.106, suggesting that sample firms generally have positive growth expectations. Asset tangibility has a mean of 0.346 (or 34.6%), indicating that fixed assets account for roughly 1/3 of firms' total assets on average. All variables except dummy variables are standardized in regression analysis to avoid scale interference.

Table 3 Descriptive analysis

Variable	**Obs**	**Mean**	**SD**	**Min**	**Median**	**Max**	**Unit**
Leverage	3875	51.344	20.298	10.189	52.388	89.128	%
Treat	3875	0.229	0.420	0.000	0.000	1.000	-
Post	3875	0.641	0.480	0.000	1.000	1.000	-
DID	3875	0.146	0.353	0.000	0.000	1.000	-
Patents	3875	20.679	57.268	0.000	2.000	352.000	-
Inventions	3875	6.432	20.120	0.000	0.000	129.000	-
Size	3875	20.693	38.310	0.600	6.771	207.615	billion yuan
Profit	3875	3.146	5.039	-10.669	2.665	17.413	%
TobinQ	3875	3.027	3.032	0.606	2.106	17.148	-
Tang	3875	0.346	0.182	0.029	0.335	0.733	-

The DID model requires that the experimental group and the control group have similar trends before the policy applied. Thus we conduct parallel testing. Figure 1 presents the results. Before the policy implementation, we did not find significant differences in firm leverage. However, we observe a positive trend after policy.

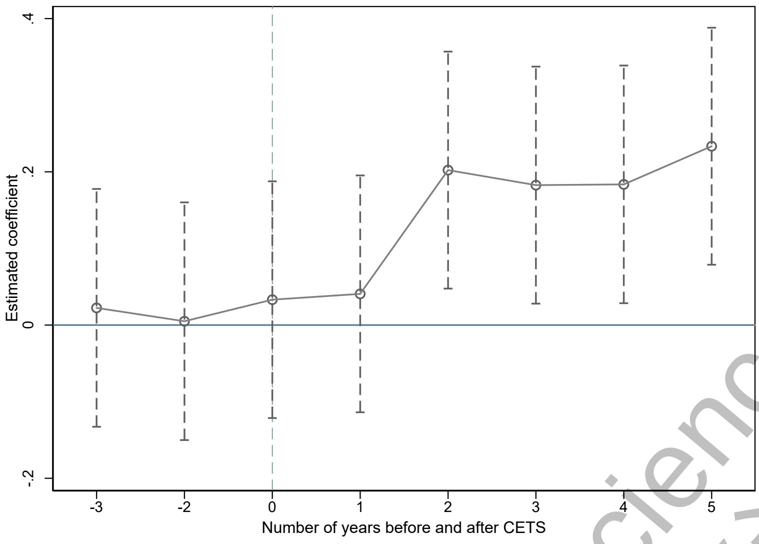

Figure 1 Parallel testing analysis

5 Empirical Analysis

5.1 Baseline Results

Table 4 presents the baseline results. Result in Column (1) excludes control variables, while Column (2) displays findings obtained with control variables but without the inclusion of fixed effects. Column (3), by contrast, presents results that incorporate both fixed effects and control variables. Across these results, the coefficients for *DID* are all statistically significantly positive, indicating that the pilot scheme exerts a positive impact on firms' financial leverage, thereby providing empirical support for Hypothesis H1b.

For control variables, positive coefficients are observed for *Size* and *Tang*, whereas a negative coefficient is associated with *Profit*. Firms of larger scale exhibit superior risk diversification, stronger reputations, and lower default risks—factors that align with the positive coefficient for firm size. For firms with higher asset tangibility, meanwhile, assets are more readily and accurately valued, collateral is more abundant, and bankruptcy costs are reduced, which explains the positive coefficient for this variable. That firms with strong profitability and ample cash flow opt for lower leverage can be well accounted for by pecking order theory, as such entities are able to rely easily on internal financing rather than external capital. A positive coefficient for *TobinQ*, finally, indicates that a firm's growth potential bears a positive relationship with its leverage level.

Table 4 Baseline regression results

	(1)	(2)	(3)
DID	0.252***	0.119*	0.140***
	(3.185)	(1.744)	(3.515)
Treat	-0.307***	-0.350***	
	(-4.865)	(-6.050)	
Post	-0.268***	-0.480***	
	(-7.087)	(-14.486)	
Size		0.563***	0.558***
		(37.106)	(18.566)
Profit		-0.335***	-0.172***
		(-25.060)	(-17.050)
TobinQ		0.309***	0.150***

		(20.584)	(10.737)
Tang		0.035**	0.032*
		(2.548)	(1.929)
Year FE	No	No	Yes
Firm FE	No	No	Yes
Area FE	No	No	Yes
N	3875	3496	3496
Adj. R^2	0.016	0.398	0.797

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

5.2 Mechanism Analysis

Giving the results of baseline regression, Porter's theory is supported. We further test the mechanism. According to Porter's Hypothesis, innovation could be a channel to affect firm behavior under strengthen environmental policies (You & Jiang, 2018; Wang, 2002).

Existing literature documents a positive correlation between innovation output and a companys capability to adjust its capital structure upward. Transparent innovative assets, such as patents, enhance leverage by increasing firm transparency and reducing creditor uncertainty (Vicente-Lorente, 2001; Liu & Wong, 2011; Bartoloni, 2013). Studies by OConnell et al. (2022) and Wei et al. (2022) confirm that patents signify successful R&D outcomes, thereby strengthening debt capacity. Secondly, patents also contribute to higher leverage by de-risking the firm. This occurs through two primary channels: risk reduction and signaling. As patents lessen litigation and credit risks, they can improve firm credit rating (Frey et al., 2020). Moreover, they act as a defensive barrier and a positive signal to the market, demonstrating competitiveness and lower probability of financial distress (Hottenrott et al., 2016; Simeth & Cincera, 2016). This decreased risk of distress, as per trade-off theory, creates the capacity for an upward adjustment in financial leverage. Thirdly, patents are mortgageable assets, and patent pledge financing expands a firms debt financing channels, directly increasing leverage. This is evidenced by a positive correlation between patents and leverage (Horsch et al., 2021). Creditors view patents favorably, demanding lower interest rates from firms with more patents, longer patent validity, and higher patent value (Chava et al., 2017).

To test the mediating role of innovation, this paper employs ln(Patents) and ln(Inventions) as mediating variables. Table 5 presents the results for ln(Patents) and ln(Inventions). Column (1) displays the baseline regression, Columns (2) and (3) outline the mediating effect of patents, and Columns (4) and (5) detail the mediating effect of inventions.

Both the patent and invention coefficients show a statistically significant positive partial mediating effect. Broadly speaking, the Carbon Emissions Trading Scheme (CETS) enhances firms' innovation output, which in turn leads firms to increase their financial leverage. These findings align with Porter's Hypothesis.

Table 5 Firm innovation (Patents and Inventions) and financial leverage

		Patents		Inventions	
	(1)	(2)	(3)	(4)	(5)
	Leverage	Ln(Patents)	Leverage	Ln(Inventions)	Leverage
DID	0.140***	0.132***	0.134***	0.182***	0.130***
	(3.515)	(3.284)	(3.357)	(4.245)	(3.263)
Ln(Patents)			0.047***		
			(2.708)		
Ln(Inventions)					0.054***
					(3.289)
Size	0.558***	0.013	0.548***	0.127***	0.542***
	(18.566)	(0.412)	(17.721)	(3.764)	(17.490)
Profit	-0.172***	0.013	-0.186***	-0.005	-0.185***
	(-17.050)	(1.149)	(-16.838)	(-0.379)	(-16.772)
TobinQ	0.150***	0.005	0.151***	0.022	0.150***
	(10.737)	(0.339)	(10.480)	(1.410)	(10.416)
Tang	0.032*	0.018	0.039**	-0.000	0.039**
	(1.929)	(1.053)	(2.342)	(-0.014)	(2.396)
Year FE	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Area FE	Yes	Yes	Yes	Yes	Yes
N	3496	3496	3496	3496	3496
Adj. R^2	0.800	0.797	0.801	0.772	0.801

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

5.3 Heterogeneity Analysis

A diverse ownership structure characterizes the Chinese economy. Environmental policy authority typically resides with the government, and state-owned enterprises (SOEs) maintain particularly close ties to governmental bodies. Such advantages in government-enterprise relations may result in lax regulatory oversight. Moreover, SOEs are afforded greater access to subsidies, government-backed financing, and other forms of low-cost economic support (Chan et al., 2012).

In this context, SOEs may lack the motivation to follow green transformation, thereby undermining the effectiveness of environmental policies.

By contrast, non-state-owned enterprises (non-SOEs) bear full responsibility for their own profit and loss. When faced with appropriate cost pressures, non-SOEs are driven to optimize and innovate their production processes—ultimately achieving a win-win outcome for both environmental performance and business profitability. Consistent with this, Zhang et al. (2022) observe that the CETS stimulates a greater volume of patent filings among non-SOEs, whereas no such effect is evident for SOEs.

Drawing on the innovation mechanism outlined in this paper, it follows that the increase in leverage should be less pronounced for SOEs. To test such hypothesis, a dummy variable SOE is incorporated to identify whether a firm is state-owned. Our sample is subsequently split into two subgroups: the state-owned group (SOE = 1) and the non-state-owned group (SOE = 0).

Table 6 presents the results of grouped regression. the coefficient for DID in Column (2) remains significantly positive for the non-state-owned subgroup. In contrast, DID in Column (1) yields an insignificant coefficient for the state-owned subgroup, suggesting that SOEs do not adjust their leverage in response to the policy.

Table 6 Heterogeneity analysis of ownership

	SOE=1	SOE=0
	(1)	(2)
DID	0.074	0.253***
	(1.584)	(3.456)
Controls	Yes	Yes
Year, Firm, Area FE	Yes	Yes
N	2228	1268
Adj. R^2	0.831	0.729

Note: Controls include ln(Size), Profit, TobinQ, and Tang.

Since environmental subsidies can act as substitutes for the CETS policy, they may influence how the scheme impacts firm leverage. To further explore whether subsidized enterprises behave differently from non-subsidized firms in upgrading technology and changing leverage, data on the scale of environmental subsidies (“Green subsidies”) was obtained from the CNRDS database.

Table 7 reveals a significant negative moderating effect of subsidies, as showed by the interaction term *DID* × *Green subsidies* in Column (2). This implies that the greater the environmental subsidies a firm receives, the smaller the subsequent increase in its financial leverage—corroborating the compensation effect hypothesized earlier. Results in Columns (3)– (6) show that subsidized firms (With Subsidies) did not secure additional patents or inventions, whereas non-subsidized firms (Without Subsidy) experienced a significant increase in both.

Taken together, the negative moderating effect and the innovation-inhibiting impact of subsidies indicate that environmental subsidies weaken the proposed innovation mechanism, which in turn leads to less change in firms' leverage levels.

Table 7 Heterogeneity analysis of environmental subsidies

			With Subsidies		Without Subsidy	
	(1)	(2)	(3)	(4)	(5)	(6)
	Leverage	Leverage	Patents	Invention	Patents	Invention
DID	0.140***	0.126***	0.043	0.029	0.229***	0.279***
	(3.515)	(3.129)	(0.604)	(0.379)	(4.402)	(4.930)
Green subsidies		0.007				
		(0.617)				
DID×Green subsidies		-0.061**				
		(-2.378)				
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year, Firm, Area FE	Yes	Yes	Yes	Yes	Yes	Yes
N	3496	3496	1118	1118	2327	2327
Adj. R^2	0.800	0.801	0.798	0.762	0.819	0.794

Note: Controls include ln(Size), Profit, TobinQ, and Tang.

5.4 Robustness Tests

We further conduct a series of robustness tests. Firstly, we use different measures of firm leverage as market leverage, using the market value of common equity and debt level as denominate. Secondly, we use different time periods (extended to 2021) and sample (deleting delisted firms). The empirical results show that all the coefficients of *DID* remain significant, indicating that the baseline results are still robust. Thirdly, we adopt the PSM method. Specifically, the Logit model is conducted, where the policy dummy *Treat* is regarded as the dependent variable and firm size, profitability, TobinQ, and tangibility are covariates to use 1:3 nearest neighbor matching. The baseline results are still robust. Finally, the placebo test is conducted to eliminate random factors. Specifically, this paper randomly samples the interaction term *DID* for 500 times. If the coefficient after sampling is significant, then the empirical results may be accidental. We find the distribution basically follows the normal distribution, indicating empirical results consistent.

6 Conclusion

To facilitate the goals of peak carbon emissions and carbon neutrality, a mix of policy instruments has been deployed in China, including both command-and-control (CAC) and market-based instrument (MBI). A notable market-based initiative is the Carbon Emissions Trading Scheme (CETS), introduced as a pilot program in 2013, representing a significant mechanism for addressing carbon emissions through cap-and-trade principles.

This study uses the implementation of the CETS across select regions as a policy shock to examine the relationship between stricter policy and firm-level financial leverage. We first develop a theoretical framework concerning firm leverage decision response to environmental regulation. Then, we evaluate the policy's impact through a Difference-in-Differences (DID) research design, using a panel dataset comprising 3875 firm-year observations. Our empirical results indicate that, on average, treated firms experienced a 14% increase in financial leverage relative to control firms following the policy shock. We identify green innovation—measured through patents and inventions as collateralizable assets—as the primary mechanism driving this effect, as firms are incentivized to innovate in response to market-based carbon constraints. Furthermore, we find that this positive relationship is weakened by closer government-firm relationships and the receipt of environmental subsidies. The findings remain robust across a series of specification and placebo tests.

In summary, our results demonstrate that market-based environmental regulation can increase financial leverage among high-carbon-emitting firms, primarily through incentives for green innovation. The results underscore the significant impact of environmental regulation on firm-level investment and financial decision-making, thereby providing a robust empirical basis for the formulation of more rational and effective policy frameworks.

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Acknowledgement

Our interest in environmental economics is profoundly shaped by personal experiences. It originated with our grandfather, who established a manufacturing firm in Zhejiang Province. He often recounted the complexities of adapting to stringent environmental policies, detailing their effects on operational costs and resource allocation. These firsthand accounts sparked us a deep intellectual curiosity regarding the interplay between regulatory enforcement and corporate decision-making.

Having grown up in Shenzhen—a hub of technological innovation—we witnessed the development of technologies aimed at reducing carbon dioxide emissions. We became particularly interested in their potential application within traditional high pollution industries, such as steel manufacturing, to mitigate environmental impact.

Last year, Jialin participated in S-T Yau science competition in the economics and finance field, investigating the association between environmental judicature and firm productivity. Her paper received the second prize in the southern region competition. This experience provided her with a solid grounding in developing theoretical models based on the neoclassical economic theory and the Porter Hypothesis, and formulating empirical methods to test hypothesis.

Inspired by these experiences, we sought guidance from Teacher Wang Yijun at Shenzhen Middle School for conducting research on examining the impact of an environmental policy of the Carbon Emission Trading Market on a firm's borrowings. We focused on the high carbon-emission firms since they were more likely affected by such policy. Yilin was responsible for identifying the environmental policy and its institutional background in existing literature (both foreign and domestic studies) and developing hypothesis based on the neoclassical economic theory and the Porter Hypothesis. She was also responsible for the primary draft of the paper. Jialin was responsible for formulating the competing theoretical models for optimization through mathematical calculations, developing empirical models of variables analyzing data to obtain regression results and writing the final paper.

Teacher Wang was very helpful in guiding us during the whole process. She firstly explained the related background of such market based environmental policy of carbon emission trading market, especially its motivations and the intended consequences. She also introduced us about related academic literature to construct theoretical frameworks. When we encounter difficulties, she also replied to us promptly. One of the difficulties that the team encountered was about the research design, especially how to identify the treatment and control group since existing studies used various groups. We carefully focused on firms with high carbon-emission and categorized them in treatment group or control group based on different regions and on different year of policy implementation (2013-2014). To ensure the consistency of firms in both prior and post policy period, we manually verified firms through carbon trading entity rosters. Firms delisted from the trading scheme in subsequent years after the policy shock were excluded from the sample.

Another difficulty that we encountered was to identify the underlying channels or mechanisms that link such market-based policy of carbon trading scheme to a firm's borrowing decision. We came across several financial news (anecdote evidences) about how high-carbon-emission firms such as steel companies, developed many new technologies to reduce carbon-dioxide emissions. Another piece of evidence was the financial news, reporting how banks provide supports to high-carbon-emission firms with green credits, encouraging them to invest infrastructures based on their patents. Inspired by the news articles, we conducted extensive literature review to learn about how innovations (patents and inventions) through investments can help reduce information asymmetry between firms and banks by send signals to banks for lower borrowing cost. Therefore, we are deeply grateful to Teacher Wang for her invaluable support throughout the research and writing process without any charges.

Lastly, we thank our parents for their unwavering encouragement and support whenever we faced challenges by providing constructive suggestions. We sincerely hope that our study will raise the public awareness on environmental protection through economic policies and the changed behavior of related firms through policy making.

Appendix

A. Derivation of Optimal Leverage

Giving that V = π_{net} / ρ(d, P), here it is the full expression of V:

$$V = \frac{(1-\tau)[pAK^{\alpha}L^{1-\alpha} - wL - r_K K - \kappa E^2 - pc(\phi_0 e^{-\theta E} AK^{\alpha}L^{1-\alpha} - Q) + \mu(\boldsymbol{P_0} + \eta E)] + \tau(r0 + \xi d - \psi(P0 + \eta E))D}{d(r0 + \xi d - \psi(P0 + \eta E)) + (1-d)rE}$$

Firm owners choose the optimal debt ratio (d) and emission reduction investment (E) to maximize firm value V.

$$\max_{d,E} V = \frac{\pi_{net}}{\rho(d,P)}$$

First-order condition respect to d:

$$\partial \mathrm{V}/\partial \mathrm{d} = 0$$

$$\frac{\partial \mathrm{V}}{\partial \mathrm{d}} = \frac{\frac{\partial \pi}{\partial d}\rho - \frac{\partial \rho}{\partial d}\pi}{\rho^2} = 0$$

$$\frac{\partial \pi}{\partial d}\rho - \frac{\partial \rho}{\partial d}\pi = 0$$

$$\frac{\partial \pi}{\partial d}\rho = \frac{\partial \rho}{\partial d}\pi \quad \text{(a1)}$$

A.1 Derivative of profit (π)

$$\pi_{\mathrm{net}} = (1-\tau)[profit] + \tau \mathrm{r_D D}$$

Only r_D and D directly depend on d.

$$\frac{\partial \pi_{\mathrm{net}}}{\partial d} = \tau \frac{\partial r_D}{\partial d} D + \tau r_D \frac{\partial D}{\partial d}$$

Given

$$\frac{\partial r_D}{\partial d} = \xi \quad (\text{from } r_D = r_0 + \xi d - \psi P)$$

Assuming D=dV

$$\frac{\partial D}{\partial d} = V$$

Thus

$$\frac{\partial \pi_{\mathrm{net}}}{\partial d} = \tau \xi D + \tau r_D V \qquad \text{(a2)}$$

A.2 Derivative of Cost of Capital(ρ)

$$\rho = d r_D + (1-d) r_E$$

$$\frac{\partial \rho}{\partial d} = r_D + d\frac{\partial r_D}{\partial d} - r_E = r_D + d\xi - r_E \qquad \text{(a3)}$$

A.3 Substituting (a2) and (a3) into (a1), we get

$$(\tau \xi D + \tau r_D V)\rho = \pi_{\mathrm{net}}(r_D + d\xi - r_E)$$

Giving

$$V = \frac{\pi_{\text{net}}}{\rho} (\text{i.e.}, \pi_{\text{net}} = V\rho)$$

Both sides divide by ρ:

$$\tau\xi D + \tau r_D V = V(r_D + d\xi - r_E)$$

Substitute D=dV

$$\tau\xi dV + \tau r_D V = V(r_D + d\xi - r_E)$$

Divide by V:

$$\tau\xi d + \tau r_D = r_D + d\xi - r_E$$

Rearrange terms:

$$\tau r_D = r_D + d\xi - r_E - \tau\xi d$$
$$\tau r_D = (1-\tau)\xi d + (r_D - r_E)$$

Given $r_D = r_0 + \xi d - \psi P$

$$\tau(r_0 + \xi d - \psi P) = (1-\tau)\xi d + (r_0 + \xi d - \psi P - r_E)$$

Then

$$\tau r_0 + \tau\xi d - \tau\psi P = (1-\tau)\xi d + r_0 + \xi d - \psi P - r_E$$

Rearrange terms:

$$\psi P(1-\tau) = 2(1-\tau)\xi d + (1-\tau)r_0 - r_E$$

Then

$$2(1-\tau)\xi d = (1-\tau)(\psi P - r_0) + r_E$$

Solve for d*

$$d^* = \frac{(1-\tau)(\psi P - r_0) + r_E}{2(1-\tau)\xi}$$
$$d^* = \frac{\psi P - r_0}{2\xi} + \frac{r_E}{2(1-\tau)\xi}$$

Giving $P = P_0 + \eta E$ and $\xi = \xi_0 + \delta E$

$$d^* = \frac{\psi(P_0 + \eta E) - r_0}{2(\xi_0 + \delta E)} + \frac{r_E}{2(1-\tau)(\xi_0 + \delta E)}$$