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Financial constraints under carbon emissions trading: a quasi-natural experiment approach

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ABSTRACT
Diverse carbon finance policies have been implemented to reduce enterprise carbon emissions and enhance carbon finance performance. Among these policies, carbon emissions trading (CET) is designed to incentivize enterprises to raise funds through carbon credits, promoting the efficient allocation of carbon resources. While existing research underscores CET's positive impact on corporate carbon financial performance, its effects on corporate financial constraints and the underlying mechanisms remain underexplored, particularly in emerging markets. Our research addresses this gap by examining the impact of CET on firms' financial constraints using a quasi-natural experiment approach, analyzing 23,147 observations from listed enterprises in mainland China. The study reveals that CET policies significantly reduce firms' financial constraints. Additionally, supply chain diversity and green innovation further enhance the effectiveness of CET policies in mitigating these constraints. These findings deepen understanding of the implementation of the CET policy, providing valuable insights for enterprises seeking to improve green innovation capabilities and diversify supply chains to comply with CET regulations. Moreover, this research provides managerial implications for emerging markets, supporting the development of customised policies to facilitate the transition toward a carbon-efficient economy.

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Carbon emissions trading policy; financial constraint; difference-in-differences; supply chain diversity; green innovation

1. Introduction

The continuing degradation of the natural environment has compelled both governments and businesses to take proactive measures (An et al. 2021; Zhang, Zheng, et al. 2024). Under these circumstances, carbon finance has emerged as a crucial mechanism to support carbon reduction and alleviate ecological deterioration (Wang, Wei, and Wang 2022). Of particular concern is the carbon emissions trading (CET) policy, which is one party pays another to obtain permits for greenhouse gas emissions (Tang and Yang 2020). Countries such as Australia, Japan, and Canada have made significant progress in developed domestic carbon markets (Hua, Cheng, and Wang 2011). Also, the European Union Emissions Trading System (EU ETS) market is widely recognised as the 'first-mover' and the most active CET market globally. Launched in January 2005, it currently involves over 11,000 energy-intensive companies (Feng, Zhao, and Yan 2024).

In addition to active promotion by developed markets, as one of the world's major greenhouse gas emitters, China launched its domestic carbon trading pilot in 2013. Since then, it has grown into the world's largest compliance carbon market, covering over 4 billion tons of emissions—nearly three times the amount covered by the EU scheme (Mundy and Reiter 2024). Beyond promoting environmental initiatives, as demonstrated by Zhang, Zhang, and Yu (2019) Wu et al. (2024); Tang and Yang (2020); Feng, Zhao, and Yan (2024), CET also has profound effects on the financial status of firms (Fu, Chen, and Ding 2023; Wang, Xu, and Chen 2024; Xia et al. 2023). Existing studies have shown that environmental-driven policies impose significant pressure on corporations, compelling them to allocate substantial funds toward green technologies to meet the demands of production upgrades (An et al. 2021; Qin et al. 2021).

However, the low-carbon transition often results in a cost–benefit dilemma, exacerbating corporate financing constraints by restricting access to the funds needed to meet projected investment demands (Fowlie, Greenstone, and Wolfram 2018; Semieniuk et al. 2020; Zhang, Zheng, et al. 2024). This situation can further weaken a company's financial position. Conversely, other studies suggest that carbon market trading offers companies a pathway to mitigate financial pressures (El Ghoul et al. 2011; Feng, Zhao, and Yan 2024). For example, by selling surplus emission allowances, firms can ease short-term

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financial burdens while simultaneously improving their environmental performance and brand reputation. These efforts are expected to alleviate financing constraints (Ren et al. 2023; Wu et al. 2024).

Specifically, existing literature on CET policies and carbon finance has been dominated by proposing the positive impact of CET policies on firms' carbon finance performance: 1) the operational mechanisms of carbon trading markets, such as price formation and market efficiency (Feng, Zhao, and Yan 2024; Wu and Kung 2020; Wu and Wang 2022); 2) decision-making behaviour analysis, e.g. how firms adapt their strategies and management practices in response to policy orientations (An et al. 2021; Hua, Cheng, and Wang 2011; Qin et al. 2020); 3) the impacts of CET policies, particularly their effects on energy structure, carbon emissions, financial performance, and technological innovation (Ren et al. 2023; Wang, Wang, et al. 2023; Wu and Wang 2022). Also, some studies have extended CET policies to corporate financing. For instance, Zou et al. (2023) indicate that CET policies encourage companies to enhance carbon risk management, which significantly reduces bond spreads. Similarly, Jung, Herbohn, and Clarkson (2016) suggest that while companies exposed to higher carbon risks tend to face increased costs of debt financing, firms with strong carbon awareness can effectively mitigate these costs.

However, there is a paucity of research exploring the effects of CET policies on financial constraints. In particular, compared to established CET systems such as the EU ETS and the Chicago Climate Exchange, research on CET systems in emerging markets remains relatively scarce (Ren et al. 2023). Understanding the relationship between CET policies and financing constraints is essential for corporates to adjust their long-term strategies and balance the costs and benefits of CET strategies (Semieniuk et al. 2020). That is, these insights will assist firms in emerging markets to respond effectively to the challenges posed by carbon policies and maintain financial stability. Therefore, gaining a comprehensive understanding of how CET policies influence financing constraints is essential for businesses operating in these markets.

In addition to examining the impact of CET policies on financing constraints, there is a greater need to understand how companies can maximise the benefits of CET policies accordingly. First, to effectively realise the benefits of CET policies, focal firms should engage with diverse trading partners within their supply chain networks, including their customers and suppliers (Gomez et al. 2021). Supplier and customer diversity can serve as competitive resources, enhancing the company's ability to reap more benefits from climate policy risk (Leung and Sun 2021; Sordi, Tate, and Huang 2022). However, the relationship between supply chain diversity and firms' financial constraints remains ambiguous (Chen et al. 2016; He et al. 2023; Jääskeläinen 2021).

Second, companies are expected to develop 'green innovation capabilities', which involve creating and implementing new processes, products, or practices that reduce environmental impact and support sustainability objectives (Xiang, Liu, and Yang 2022). However, existing studies hold differing views on the impact of green innovation on corporate finance. Some argue that investments in green innovation can exacerbate financing challenges (An et al. 2021; Wu and Kung 2020), by contrast, some suggest the 'green innovation offset effect' can help mitigate these challenges and even generate profits (Porter and Linde 1995; Yang, Jiang, and Pan 2020). These contrasting perspectives highlight the need to understand its moderating effect on the relationship between CET policies and financial constraints, particularly in the emerging markets. Therefore, this study aims to explore *how supply chain diversity and green innovation moderate the relationship between CET policies and financial constraints*?

To answer the question, we use the difference-in-differences (DID) model to test the impact of CET policies on financial constraints and the moderating effects of green innovation and supply chain diversity, based on the 23147 observations from listed companies in mainland China during the period from 2008–2021. Results indicate that the CET policy has significantly alleviated firms' financial constraints. Furthermore, supply chain diversity and green innovation enhance the effectiveness of CET policies in reducing firms' financial constraints. Additional tests reveal that firms operating in regions with stringent environmental regulations and those with a high level of ownership concentration are better able to alleviate financial constraints under CET policies.

This study makes the following contributions. First, responding to the calls from Stroebel and Wurgler (2021) and Dang, Gao, and Yu (2022), we conduct an empirical study to demonstrate the alleviating effects of between CET policies and firms' financial constraints in an emerging market context. By providing this empirical evidence of how CET policies influence firms' access to finance, our study adds to the growing literature on the interplay between environmental policies and corporate financial behaviour (Dang, Gao, and Yu 2022; Ren et al. 2023; Zhang, Zheng, et al. 2024). This provides theoretical evidence that environmental regulations can leverage market mechanisms for driving green innovation and enhancing carbon finance performance. Specifically, we examine two key moderating factors – supply chain diversity and green innovation – to provide deeper insights into how firms can effectively manage carbon financial risks. By highlighting the roles these moderators play in shaping the impact of CET policies on financial constraints, our findings contribute to a more nuanced understanding of underlying mechanisms at work. These insights thus not only fill an important gap in understanding the economic implications of CET policies but also provide practical insights for policymakers striving to balance environmental goals with sustainable economic growth.

The remainder of our study proceeds accordingly: Section 2 provides the theoretical background and develops the research hypotheses. Section 3 outlines the CET policy background and describes the research methods. Section 4 presents the results of the DID model, robustness checks, and post-hoc tests, followed by the discussion of the theoretical and practical implications in Section 5.

2. Theoretical background and hypothesis development

2.1. Carbon emission policy and financing constraints

CET policy is closely linked to fluctuations in global economic policies. Specifically, the intensifying geopolitical conflicts not only heighten global economic uncertainty but also increase financial market volatility, leading to reduced lending, investment, and economic activity, thereby further exacerbating financial frictions for firms (Boungou and Yatié 2022; Saharti et al. 2024). In this context, the CET policy, as a market-driven environmental regulation policy (Tang and Yang 2020), demonstrates dual potential to effectively reduce firms' financial constraints.

First, CET policy can reduce corporate financing constraints by broadening financing channels and lowering operational costs. CET policy creates new external financing channels, allowing companies to raise funds by selling carbon quotas to support carbon reduction projects or meet operational needs (Zou et al. 2023). This not only enhances cash flow flexibility but also reduces overall financing pressure (Feng, Zhao, and Yan 2024). Additionally, the CET policy fosters increased interaction among trading entities, enhancing information flow and improving the accuracy of price signals in the carbon market (Wu and Wang 2022). This allows for a precise assessment of the marginal costs and benefits of carbon reduction projects (Wu et al. 2024). With more precise pricing information, firms can develop tailored carbon emission strategies that align with their operational goals, ultimately reducing costs and improving efficiency. Furthermore, governments often provide environmental subsidies to pilot enterprises that meet emission reduction targets, which further lowers operational costs and effectively supports their low-carbon development trajectory (Qin et al. 2020).

Second, CET policies enhance firms' financing capabilities by creating new business opportunities in expanding the sustainable development market potential. These policies also strengthen a firm's reputation by signalling a commitment to environmental responsibility and adherence to global emission standards. Firms that actively comply with CET policies thus gain valuable reputation capital, which enhances their market credibility and translates into improved creditworthiness and easier access to financing (Qiu et al. 2020). Furthermore, prior studies consistently show that environmentally responsible firms face fewer financial restrictions, as their sustainability efforts align with the preferences of external stakeholders (El Ghoul et al. 2011; Jung, Herbohn, and Clarkson 2016). Therefore, we propose:

> Hypothesis 1: The implementation of the CET policy reduces firms' financial constraints.

2.2. Moderator of supply chain diversity

Supply chain diversity, which includes both customer and supplier diversity, is a critical strategic resource for companies navigating complex market environments and policy changes (Gomez et al. 2021; Sánchez and Pérez 2005). Supplier diversity refers to a corporation's ability to establish relationships with a variety of suppliers, which can potentially enhance its bargaining power (Zhang, Mo, et al. 2024), and mitigate the effects of supply chain disruptions (Gomez et al. 2021). Sordi, Tate, and Huang (2022) highlighted that supplier diversity drives innovation by leveraging the agility and flexibility of diverse suppliers, enabling better adaption to evolving external factors, such as shifts in institutional policies. Within the CET policy framework, firms with a diverse supplier network can access a wider range of options for procuring carbon credits. This diversity not only broadens the firm's procurement channels but also significantly strengthens its negotiating position (Zhang, Mo, et al. 2024). Consequently, firms are better positioned to secure more favourable terms, such as lower carbon trading prices or advantageous green collaboration agreements (Huang, Yang, and Tu 2019). This competitiveness is crucial for managing costs effectively to meet stringent carbon emission targets. Furthermore, supplier diversity allows firms to adapt their procurement strategies more flexibly to the challenges of carbon reduction (Mizgier, Wagner, and Jüttner 2015), ensuring operational stability while complying with CET regulations.

Customer diversity highlights a company's ability to connect with a broad customer base (He et al. 2023),

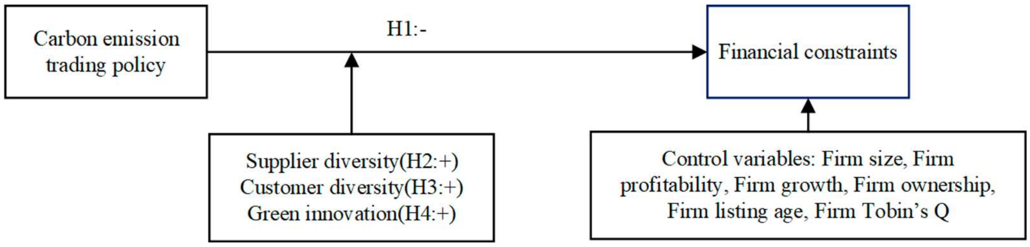

Figure 1. Conceptual model.

capturing varied market demands and serving as a critical tool for mitigating market risks and enhancing adaptability (Ni et al. 2023). Leung and Sun (2021) demonstrate that customer diversity can boost a firm's performance, particularly during periods of policy uncertainty. CET policies aim to reduce carbon emissions and promote industrial restructuring, and firms with diversified customer bases enjoy distinct advantages. Such customer diversity enables companies to more effectively distribute market risks and mitigate the negative impact of reduced demand from specific customer segments (Wang, Zhou, and Zhao 2023). Therefore, we propose:

> Hypothesis 2: The reducing impact of the CET policy on financial constraints will be strengthened when the level of supplier diversity is higher.

> Hypothesis 3: The reducing impact of the CET policy on financial constraints will be strengthened when the level of customer diversity is higher.

2.3. Moderator of green innovation

Green innovation is an advanced paradigm designed to mitigate environmental burdens while enhancing economic, social, and ecological benefits (Wong, Wong, and Boon-itt 2020). Green innovation plays a key role in the impacts of the CET policy on firms' financial constraints, which refers to a comprehensive transformation towards sustainability, including products, processes, services, and management practices (Wang, Li, et al. 2023; Xiang, Liu, and Yang 2022).

First, under the CET policy, enterprises can either leverage their green innovation capabilities to optimise production and operational activities or participate in carbon trading markets (Wang, Wang, et al. 2023; Zhang, Shi, and Jiang 2019). This flexibility enhances firms' bargaining power in the carbon market and potentially reduces the risk of financial constraints. As shown by Wong, Wong, and Boon-itt (2020), more substantial green innovation leads to greater reductions in operating costs, thereby alleviating financing constraints. Furthermore, firms with strong green innovation capabilities are better positioned to detect shifts in institutional policies and adopt advanced green technologies, improving their adaptability to uncertainties during the transition to CET policy (Wu et al. 2024).

In addition, the enhanced brand image through CET policy can be further amplified with robust green innovation capabilities. Active participation in CET policy demonstrates a firm's commitment to proactive corporate social responsibility (Wu and Kung 2020). Leveraging advanced green innovation, such firms can develop cutting-edge products, services, and efficient production models that meet low-carbon and environmental standards, showcasing their commitment to fulfil environmental compliance (Wang, Huang, et al. 2023). Accordingly, this strengthened brand image not only increases the likelihood of securing financing but also aligns with the global shift toward a low-carbon economy. As governments prioritise green development and lenders increasingly factor 'carbon risk' into their evaluation criteria, companies with strong environmental credentials are better positioned to meet these evolving expectations (Jung, Herbohn, and Clarkson 2016; Ren et al. 2023). Consequently, we propose:

> Hypothesis 4: The reducing impact of the CET policy on firms' financial constraints will be strengthened when the level of green innovation is higher.

> Based on these hypotheses, we propose the conceptual model as Figure 1 shows.

3. Research design

3.1. CET policies and sample firms identification

We first identified the CET policies outlined in the '*Notice on Carrying Out Carbon Emissions Trading Pilot Programs*', an official announcement by the National Development and Reform Commission (NDRC) in 2011.[1] This announcement designated the regions selected to initiate CET projects in China, including Shenzhen, Shanghai, Beijing, Tianjin, Guangdong, Chongqing, and Hubei. Following this announcement, these eight pilot regions gradually began implementing CET projects between 2013 and 2016, with several regulatory frameworks and trading platforms developed to support their execution. To pinpoint the exact launch dates of the CET policies, we

Table 1. The implementation of CET Policy in pilot cities.

Year	Pilot Region
2013	Shanghai Beijing Tianjin Guangdong Shenzhen
2014	Chongqing Hubei
2016	Fujian

examined government websites for each of these regions. The enactment years for the eight CET pilot regions are summarised in Table 1.

We identified the treatment firms by focusing on those with headquarters located in the eight CET pilot regions. The headquarters information was obtained from the China Securities Market and Accounting Research (CSMAR) database. Firms with headquarters outside these regions were considered control firms. Our final sample is composed of 3,509 firms, including 1,526 treatment firms and 1,983 control firms. Since the DID model requires consideration of both pre- and post-treatment years to estimate the effect of CET, we thus selected a sample period from 2008–2021 for both treatment and control firms. This period provides sufficient benchmark years and allows for the examination of the CET policy's long-term outcomes.

3.2. Difference-in-differences estimation

After identifying the control and treatment enterprises, we construct a DID model to estimate how the CET policy affects financial constraints and examine the moderating roles of supplier diversity, customer diversity and green innovation. The DID model calculates the difference between two key measures: first, it calculates the changes in financial constraints for the control group before and after the policy implementation; second, it calculates the changes for the treatment group over the same periods. The net difference between the two groups reflects the actual impact of the CET pilot (Zhang et al. 2020). This approach effectively isolates the net impact of the shock and is commonly employed to analyze the effects of various policies or initiatives (Wang, Wang, et al. 2023; Ye, Yeung, and Huo 2020). The DID model is constructed as follows.

$$\begin{aligned} & \mathit{Financial\ Constraints}_{i,t} \\ & \quad = \beta_0 + \beta_1 \mathit{Treat}_i{}^* \ \mathit{Post}_t + \beta_2 \mathit{Treat}_i{}^* \ \mathit{Post}_t{}^* \\ & \qquad \mathit{Moderators}_{i,t} + \alpha \ \mathit{Control}_{i,t} + u_i + \gamma_t + \varepsilon_{i,t} \end{aligned} \quad (1)$$

where t indicates the year and i indicates the individual firm. $Treat_i$and $Post_t$ are dummy variables.

$Treat_i{}^*\ Post_t$ represents the effect of CET policy on financial constraints. Samples located in the pilot regions, and that fall within the year of inclusion in the pilot programme or subsequent years, are assigned a value of 1. Samples located in non-pilot regions or in pilot regions prior to the programme's initiation are assigned a value of 0. $Moderators_{i,t}$ refers to the supplier diversity, customer diversity and green innovation. u_i represents the firm fixed effects. γ_t represents the year fixed effects. $\varepsilon_{i,t}$ is the error term.

We then conducted a parallel trend test to compare the financial constraints across the treatment and control firms during the sample period (Wu et al. 2024; Ye, Yeung, and Huo 2020). Specifically, we regress the interaction $Treat_i{}^*\ Year_t$ on the financial constraints. The model specification is as follows:

$$\begin{aligned} \mathit{Financial\ Constraints}_{i,t} = \beta_0 + \sum_t \beta_t (\mathit{Treat}_i{}^* \ \mathit{Year}_t) \\ + \alpha \ \mathit{Control}_{i,t} + u_i + \gamma_t + \varepsilon_{i,t}. \end{aligned} \quad (2)$$

where $Year_t$ represents the number of years relative to the year of CET policy implementation.

Using the equations above, we then plotted the estimated coefficients with 90% confidence intervals in Figure 2. Essentially, if there is no difference in pre-trends between the treatment and control firms, the coefficients of $Treat_i{}^*\ Year_t$ should not be significant before the CET policy implementation. As shown in Figure 2, all of the coefficients of $Treat_i{}^*\ Year_t$ over the year t-1 to t-5 are insignificant. Therefore, there is no evidence of a significant difference in pre-trends between the treatment and control firms, supporting the parallel trends assumption required for performing the DID model. As a robustness check, we also perform propensity score matching (PSM) to match treatment firms to control firms that have similar propensities to be treated, making our analysis even less susceptible to the self-selection concern. We will explain this robust test further in the following sections.

3.3. Data collection variable operations

We collected firms' financial data and supply chain data from the CSMAR database, and green patent application data from the CNRDS database to construct the following variables. Table 2 summarises the details for all variables.

Financial Constraints. To measure firms' financial constraints, we used the SA index, originally developed by Hadlock and Pierce (2010). The SA index quantifies financial constraints using a weighted combination of

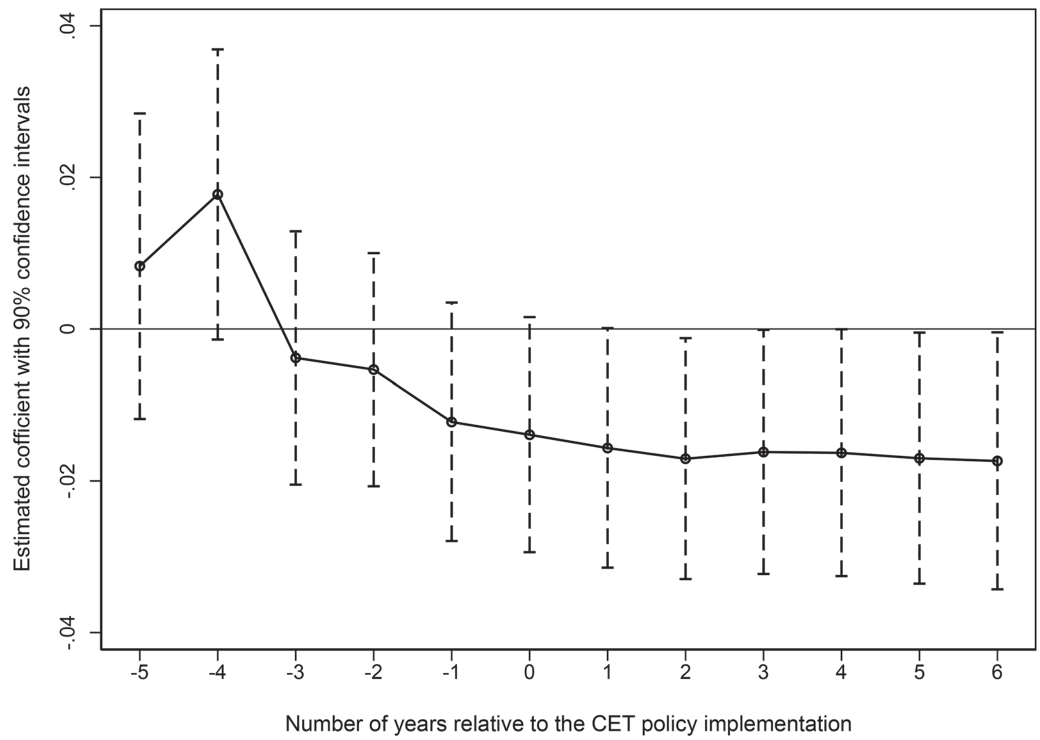

Figure 2. Parallel trend.

Table 2. Variables descriptions.

Variable	Measurement	Reference
Financing constraints	Measured as SA index formula	Hadlock and Pierce (2010)
Treat	Equals 1 for firms located in the eight CET pilot regions and 0 for firms located in non-pilot regions	Wu et al. (2024)
Post	Equal to 0 if the year is before the CET policy implementation; 1 if after	Wu et al. (2024)
Supplier diversity	Purchases from the top five suppliers divided by focal firms' total procurement	Wang, Zhou, and Zhao (2023)
Customer diversity	Sales to the top five customers divided by focal firms' total sales	Wang, Zhou, and Zhao (2023)
Green innovation	Natural logarithm of the number of green patent applications by firms plus one	Wang, Li, et al. (2023)
Firm size	Natural logarithm of total assets	El Ghoul et al. (2011)
Firm profitability	Net income divided by total assets	Wang, Wang, et al. (2023)
Firm growth	Revenue growth rate	Ren et al. (2023)
Firm ownership	Equal to 1 for state-owned enterprises; 0 otherwise	Wang, Zhou, and Zhao (2023)
Firm listing age	Current year minus the by focal firms' listing year	Zhang, Shi, and Jiang (2019)
Firm Tobin's Q	Firm market value divided by replacement cost of assets	Wang, Wang, et al. (2023)

firm size and firm age, as specified in Equation 3. Higher SA index values indicate greater financial constraints faced by firms.

$$SA_{i,t} = -0.737^{*}\ Size_{i,t-1} + 0.043^{*}\ Size^{2}_{i,t-1} - 0.040^{*}\ Age_{i,t-1} \quad (3)$$

where$Size_{i,t-1}$ is the natural logarithm of companies' total assets, $Age_{i,t-1}$ is the natural logarithm of years since companies have been listed.

Supplier Diversity (Customer Diversity). We measure supplier diversity based on the study by Wang, Zhou, and Zhao (2023), calculating it as the ratio of firm's procurement from its top five suppliers to its total procurement. Similarly, customer diversity is measured by the ratio of total sales to the top five customers to the firm's overall sales. We collected the supply chain data of sample firms from CSMAR.

Green Innovation. Following the research of Wang et al. (2023), we measure the firm's green innovation by the number of green patent applications. We collected the green patent application data of all sample firms from the CNRDS database.

Control Variables. We also incorporate various control variables from previous studies that could impact financial constraints. The specific measurement methods for the control variables are summarised in Table 2.

Table 3. Results of DID model.

	(1) Financing constraints	(2) Financing constraints	(3) Financing constraints	(4) Financing constraints	(5) Financing constraints
Treat × Post	−0.0103**	−0.0114**	−0.0241***	−0.0305***	−0.0203***
	(0.00500)	(0.00492)	(0.00697)	(0.00780)	(0.00751)
Treat × Post × Supplier diversity			−0.0371***	−0.0293**	−0.0221*
			(0.0120)	(0.0119)	(0.0117)
Treat × Post × Customer diversity				−0.0305**	−0.0327**
				(0.0137)	(0.0134)
Treat × Post × Green innovation					−0.00825***
					(0.00270)
Supplier diversity		0.0132*	0.0251***	0.0223***	0.0197**
		(0.00679)	(0.00829)	(0.00824)	(0.00822)
Customer diversity		0.0224***	0.0222***	0.0322***	0.0327***
		(0.00733)	(0.00732)	(0.00871)	(0.00866)
Green innovation		−0.00949***	−0.00948***	−0.00954***	−0.00641***
		(0.00109)	(0.00109)	(0.00109)	(0.00134)
Firm size		0.0151***	0.0149***	0.0149***	0.0150***
		(0.00352)	(0.00351)	(0.00351)	(0.00351)
Firm profitability		−0.0786***	−0.0785***	−0.0777***	−0.0784***
		(0.00963)	(0.00964)	(0.00965)	(0.00969)
Firm growth		−0.00733***	−0.00728***	−0.00731***	−0.00745***
		(0.00179)	(0.00179)	(0.00179)	(0.00179)
Firm ownership		0.0182***	0.0184***	0.0184***	0.0186***
		(0.00498)	(0.00498)	(0.00497)	(0.00494)
Firm listing age		0.0248***	0.0248***	0.0247***	0.0243***
		(0.00713)	(0.00717)	(0.00714)	(0.00711)
Firm Tobin's Q		−0.00352***	−0.00357***	−0.00358***	−0.00359***
		(0.000812)	(0.000813)	(0.000811)	(0.000810)
Constant	3.136***	2.782***	2.789***	2.792***	2.788***
	(0.00504)	(0.0765)	(0.0765)	(0.0765)	(0.0765)
Firm fixed	Yes	Yes	Yes	Yes	Yes
Year fixed	Yes	Yes	Yes	Yes	Yes
Observations	23,147	23,147	23,147	23,147	23,147
R-squared	0.105	0.147	0.148	0.149	0.152
F	41.98***	47.17***	46.58***	45.25***	43.94***

Note: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Cluster standard errors in parentheses.

4. Results

4.1. Results of DID model

Table 3 presents the empirical results. First, we initially included only the *Treat* × *Post* interaction term in Model 1. We then added the three moderating variables one by one in Models 3 through 5. The *R*-square values span from 0.105–0.152, and the *F*-values span from 41.98–47.17, indicating that all models are statistically significant. We tested our hypotheses using Model 5(the full model). As shown in Model 5, As shown in Model 5, the *Treat* × *Post* interaction term coefficients are significantly negative ($p < 0.01$). This result confirms that the CET pilot programme effectively alleviated the financial constraints of firms within the pilot regions, thereby supporting Hypothesis 1. Then, we tested the moderating effects of supplier diversity, customer diversity, and green innovation on financial constraints under the CET policy. In Model 5, the coefficient for the interaction term *Treat* × *Post* × *Supplier Diversity* is negatively significant ($p < 0.1$), supporting Hypothesis 2. Similarly, the interaction term *Treat* × *Post* × *Customer Diversity* is also negatively significant ($p < 0.05$), supporting Hypothesis 3. Lastly, the results of Model 5 show that green innovation further strengthens the alleviation of firms' financial constraints by CET policy ($p < 0.01$), supporting Hypothesis 4. Overall, our results indicate that the implementation of the CET policy has significantly alleviated firms' financial constraints in the pilot areas. Additionally, the effect of the CET policy in alleviating financial constraints is stronger in firms exhibiting higher supplier diversity, customer diversity, and green innovation.

4.2. Robust tests

We performed various robustness tests to confirm the validity of our DID model. First, following the study of (Shi, Li, and Liu 2023), we employed the Financing Constraint Index (FC index) as an alternative measure of financial constraints. The FC index is generated by the CSMAR database and is tailored to reflect the characteristics of Chinese listed companies. This makes it particularly suitable for capturing the financing constraints of the firms in our sample, which are grounded in the Chinese context. FC index is a continuous measure ranging from 0 to 1, where higher values indicate greater financing constraints. The index is calculated by performing a Logit regression to fit the probability of the occurrence of financing constraints for each firm annually (Shi, Li, and Liu 2023). Equation 4 and Equation 5 outline the measurement of FC index.

$$P(QUFC = 1 \; or \; 0|Z_{i,t}) = \frac{e^{Z_{i,t}}}{1 + e^{Z_{i,t}}} \quad (4)$$

where quantified unobservable financing constraints (QUFC) is a dummy variable used to classify firms based on their level of financing constraints. The classification relies on the upper and lower tertiles as thresholds. Firms ranked above the 66th percentile are categorised as having low financing constraints (QUFC = 0), while those ranked below the 33rd percentile are categorised as having high financing constraints (QUFC = 1). This classification is determined using the ranking in ascending order of three annually standardised variables: firm size, firm age, and cash dividend payout ratio. $Z_{i,t}$ serves as the linear predictor in the regression model, capturing the combined effect of several firm-specific explanatory variables, as specified in Equation 5.

$$\begin{aligned} Z_{i,t} &= \alpha_0 + \alpha_1 \, Firm \; Size_{i,t} + \alpha_2 \, Firm \; Lev_{i,t} \\ &+ \alpha_3 \left(\frac{Firm \; Cashdiv}{Firm \; Assets} \right)_{i,t} + \alpha_4 \, Firm \; MB_{i,t} \\ &+ \alpha_5 \left(\frac{Firm \; NWC}{Firm \; Assetsts} \right)_{i,t} + \alpha_6 \left(\frac{Firm \; EBIT}{Firm \; Assets} \right)_{i,t} \end{aligned} \quad (5)$$

Where $Firm\ Size_{i,t}$ is the natural log of companies' total assets; $Firm\ Lev_{i,t}$ indicates the financial leverage of the firm, with the debt-to-asset ratio calculated as total liabilities divided by total assets; $Firm\ Cashdiv_{i,t}$ refers to the cash dividends paid by the company in the current year; $Firm\ MB_{i,t}$ is the market-to-book ratio of the firm, calculated as market value divided by book value; $Firm\ NWC_{i,t}$ signifies net working capital, defined as working capital minus cash and minus short-term investments; $Firm\ EBIT_{i,t}$ stands for earnings before interest and taxes; $Firm\ Assets_{i,t}$ is total assets.

The results based on this alternative measure are documented in Model 1 of Table 4, which shows consistency with our original DID analysis ($p < 0.1$). This result indicates that our main results are less sensitive to the alternative measurement of financial constraints.

Second, to verify further whether alternative control groups could bias our results, we adopted the Propensity Score Matching (PSM) to construct control groups and perform DID model (Ye, Yeung, and Huo 2020). Specifically, we applied our DID model to alternative control groups that are similar in both firm and city characteristics but have not been exposed to CET policies.

In particular, we employed three propensity score matching (PSM) methods – Mahalanobis Distance Matching, Nearest Neighbor Matching, and Kernel Matching – to construct control groups and perform the DID analysis. Mahalanobis Distance Matching considers the covariance matrix among variables, allowing for a more accurate assessment of sample similarity in multidimensional space and reducing matching errors. Nearest Neighbor Matching and Kernel Matching, on the other hand, used a logit model to estimate propensity scores based on selected covariates.

Both firm-level and city-level characteristics were included as covariates for these matching methods, as both types of factors are likely to influence a firm's likelihood of being part of the treatment group. Firm-level covariates included variables such as firm size, Tobin's Q, firm growth, ownership structure, and firm listing age. City-level covariates included per capita GDP, foreign trade dependence (e.g. imports and exports as a share of GDP), general public budget expenditure, and industrial share (e.g. the gross output of the secondary sector as a share of GDP).

To enhance the quality of matching, we established several criteria for each matching method. For Mahalanobis Distance Matching, we applied a calliper value of 0.04, representing the maximum allowable matching distance. For Nearest Neighbor Matching, we adopted a calliper value of 0.04 with a 1:3 matching approach. For Kernel Matching, the Epanechnikov kernel function was used. All matching processes were conducted on an annual basis, and only pairs that met these pre-set matching criteria were retained for subsequent DID model analysis. Models 2–4 in Table 4 present the results based on Mahalanobis distance matching, nearest neighbour matching, and kernel matching. The results are consistent across all matching methods ($p < 0.05$).

Last, we conducted a placebo test to confirm whether the observed alleviating effect of the CET policy on financial constraints is genuinely attributable to CET rather than other unobserved factors. First, we randomly generated a policy variable (i.e. a falsified policy variable) and then performed a DID analysis. If the changes in firms' financing constraints in our study were indeed caused by the CET policy, the estimated coefficients of the falsified $Treat \times Post$ interaction should not be significant. We repeated this process 1,000 times, each time randomly generating a treatment group and running the DID model. In Figure 3, the t-values and estimated coefficients for the $Treat \times Post$ are plotted. As shown, both are centred around zero for the falsified $Treat \times Post$ interaction. This indicates that most of the fabricated $Treat \times Post$ interaction coefficients are not statistically significant. Therefore, we can conclude that our research

Table 4. Robust tests.

	(1) Alternative measurement	(2) Mahalanobis distance matching	(3) Nearest neighbour matching	(4) Kernel matching	(5) Treat × Post	(6) Financing constraints
Treat × Post	−0.0104*	−0.0137**	−0.0201**	−0.0203**		−0.0115*
	(0.00606)	(0.00653)	(0.00989)	(0.0101)		(0.00624)
Temperature variation × Post					0.276***	
					(0.00784)	
Supplier diversity	−0.0150	0.0266**	0.00887	0.0148	0.0360*	0.0132*
	(0.0109)	(0.0115)	(0.0234)	(0.0125)	(0.0191)	(0.00680)
Customer diversity	−0.00898	−0.0230	0.0239	0.0400***	−0.00652	0.0224***
	(0.0132)	(0.0240)	(0.0249)	(0.0143)	(0.0229)	(0.00733)
Green innovation	−0.000669	−0.00277**	−0.00904**	−0.0106***	−0.00331	−0.00949***
	(0.00137)	(0.00110)	(0.00397)	(0.00209)	(0.00306)	(0.00109)
Firm size	−0.202***	0.0299***	0.00756	0.0168***	0.0101	0.0151***
	(0.00441)	(0.00996)	(0.0110)	(0.00538)	(0.00755)	(0.00352)
Firm profitability	0.894***	−0.0786***	−0.0463	−0.0580***	−0.0520	−0.0786***
	(0.0231)	(0.0150)	(0.0316)	(0.0179)	(0.0344)	(0.00964)
Firm growth	−0.0137***	−0.0147**	−0.0162*	−0.00916**	−0.00733*	−0.00733***
	(0.00235)	(0.00617)	(0.00966)	(0.00457)	(0.00378)	(0.00179)
Firm ownership	−0.00620	0.0105	0.00361	0.0182**	0.0230	0.0183***
	(0.00756)	(0.00904)	(0.0176)	(0.00762)	(0.0167)	(0.00499)
Firm listing age	−0.0320***	0.0216***	0.0399**	0.0404***	−0.0427**	0.0248***
	(0.00847)	(0.00527)	(0.0203)	(0.0134)	(0.0174)	(0.00713)
Firm Tobin's Q	−0.0412***	0.00248	−0.00593	−0.00180	0.00285	−0.00352***
	(0.00178)	(0.00259)	(0.00456)	(0.00201)	(0.00207)	(0.000810)
Constant	4.976***	2.519***	2.962***	2.719***	–	–
	(0.0958)	(0.210)	(0.233)	(0.115)		
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Kleibergen-Paap rk LM						703.666***
Kleibergen-Paap Wald rk F						1236.336[16.38]
Observations	23,147	4,356	2,499	6,310	22911	22,911
R-squared	0.491	0.511	0.0971	0.152	0.3902	0.0473
F-value	341.14***	57.75***	2.79***	13.44***	97.06***	24.68***

Note: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Cluster standard errors in parentheses.

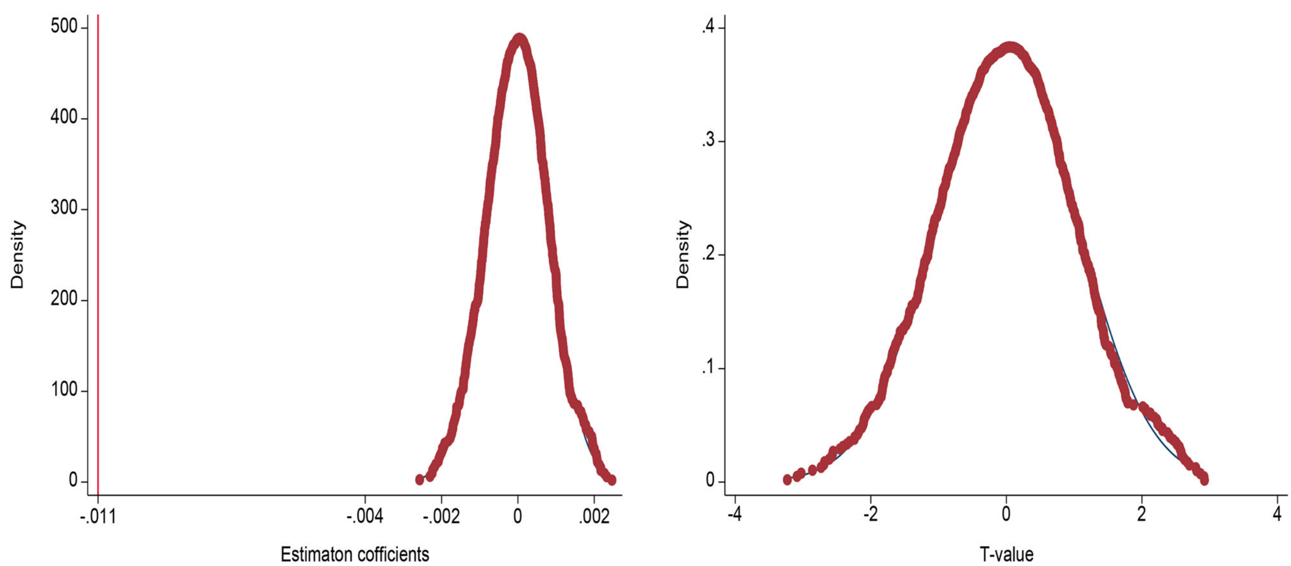

Figure 3. Density plots of estimated coefficients and T-values.

findings are robust and unaffected by other unobserved factors.

To address potential endogeneity arising from the non-random selection of pilot regions for the CET, this study employs the instrumental variable two-stage least squares (IV-2SLS) method. We use the logarithm of the interannual variation in provincial average annual temperatures plus one as an instrumental variable. Regions with larger temperature variations are more likely to face greater environmental governance pressures, increasing their likelihood of being chosen as pilot regions. However, average temperature variation does not directly influence firms' financial constraints. These conditions validate the suitability of interannual variation in provincial average annual temperatures as an instrumental variable, as it satisfies the relevance condition (being strongly correlated with the endogenous explanatory variable, the selection of CET pilot regions) and the exclusion restriction (not directly affecting firms' financial constraints). Temperature data is sourced from the China Meteorological Data Service Centre.

Table 4 reports the estimation results using the IV-2SLS method. The first-stage regression results, shown in model 5 of Table 4, indicate that the regression coefficient of the instrumental variable is significantly positive ($p < 0.01$), supporting the relevance condition. In the second-stage regression, the Kleibergen-Paap rk LM statistic is significant at the 1% level, rejecting the null hypothesis of under-identification of the instrumental variable. Additionally, the Kleibergen-Paap rk Wald F statistic, presented in model 6 of Table 4, exceeds the critical value for the Stock-Yogo weak instrument test at the 10% significance level, rejecting the null hypothesis of weak instruments. These test results indicate that the chosen instrumental variable is valid and reliable. Furthermore, Model 6 in Table 4 shows that the coefficient of *Treat* × *Post*, estimated using IV-2SLS method, remains significant, further validating the robustness of the results ($p < 0.1$).

4.3. Post-hoc tests

This research also conducted several post-hoc tests to further explore under varying levels of regional environmental regulation and different levels of firm ownership concentration the impact of the CET policy on firms' financial constraints. Regional environmental regulation intensity reflects local governments' enforcement efforts in environmental governance. Its variation may influence enterprises' motivation to comply with the policy, leading to changes in their behavioural responses (Zhong, Xiong, and Xiang 2021). Meanwhile, corporate ownership concentration, as a critical aspect of the corporate governance structure, is directly related to the efficiency of corporate decision-making and its specific responses to external policies (Wang, Wang, and Wang 2021). We categorise the full sample into different sub-groups based on the level of environmental governance and ownership concentration to provide a more comprehensive analysis of the impact of the CET policy on corporate financing constraints under varying conditions.

First, we categorised our sample firms into two subgroups: high and low regional environmental regulation. This classification is based on the environmental regulation intensity of the provinces where their headquarters are located, measured by the ratio of industrial pollution control investment to industrial added value (Liu, Kong, and Xu 2024). We collected these data using the China National Bureau of Statistics. As indicated in Models 1 and 2 of Table 5, the coefficient for *Treat* × *Post* is significantly negative only for the sub-sample with high environmental regulation intensity. The result reveals that the CET policy significantly alleviates financial constraints for firms located in areas with high environmental regulation ($p < 0.01$). The likely reason is that in these regions, companies are more motivated to comply with policies, invest in green initiatives, and disclose carbon emissions to secure financing support. In contrast, in provinces with low regulation, companies have less incentive to comply, leading to a less pronounced alleviation of financial constraints.

Similarly, we divided our full sample based on shareholding concentration into two groups: high and low shareholding concentration. Firms were classified as having high shareholding concentration if their largest shareholder's ownership ratio is among the top 50 percent of the equity distribution, and as low shareholding concentration if it is below 50 percent. The results, presented in Models 3 and 4 of Table 5, show that the coefficient for *Treat* × *Post* is significantly negative only for the subsample with high shareholding concentration ($p < 0.01$). As ownership concentration increases, controlling shareholders have greater motivation and control over corporate governance, allowing them to more effectively limit opportunistic behaviour within the firm (Wang, Wang, and Wang 2021). This heightened oversight enables a proactive response to the CET policy, which in turn significantly alleviates the firms' financial constraints.

5. Discussion and conclusion

5.1. Theoretical implications

The study contributes to the carbon finance literature on financial constraints in the context of CET implementation based on an emerging market. Previous research on CET policies has predominantly focused on the policy implementation performance (Zhang et al. 2020; Zhang, Zhang, and Yu 2019), while discussions on financial constraints have mainly centred on identifying influencing factors and exploring potential remedies (Chava, Livdan, and Purnanandam 2009; Ni et al. 2023; Shi et al. 2024). For instance, previous studies (e.g. Shang, Bai, and Sun (2024); Xia et al. (2023); Liao and Zhang (2024); Wang, Xu, and Chen (2024)) combined carbon reduction with corporate financing, examining strategies to optimise the use of corporate funds for more efficient operations within the broader context of carbon reduction. However, these studies largely emphasise the

Table 5. Results of post-hoc tests.

	(1) High environmental regulatory intensity	(2) Low environmental regulatory intensity	(3) High shareholding concentration	(4) Low shareholding concentration
Treat × Post	−0.0273***	−0.0103	−0.0177***	−0.00602
	(0.00816)	(0.00707)	(0.00663)	(0.00678)
Supplier diversity	0.0155	0.00501	0.0173**	0.0175**
	(0.00977)	(0.00873)	(0.00869)	(0.00891)
Customer diversity	0.0315***	0.0158	0.00462	0.0296***
	(0.00917)	(0.00981)	(0.0111)	(0.00897)
Green innovation	−0.00953***	−0.00743***	−0.00983***	−0.00866***
	(0.00158)	(0.00131)	(0.00138)	(0.00153)
Firm size	0.0168***	0.0175***	0.00639	0.0242***
	(0.00498)	(0.00500)	(0.00488)	(0.00421)
Firm profitability	−0.0634***	−0.0758***	−0.0639***	−0.0797***
	(0.0151)	(0.0119)	(0.0147)	(0.0114)
Firm growth	−0.00819***	−0.00563**	−0.00604**	−0.00946***
	(0.00267)	(0.00265)	(0.00296)	(0.00240)
Firm ownership	0.0215***	0.0214***	0.0295**	0.00848*
	(0.00718)	(0.00647)	(0.0123)	(0.00471)
Firm listing age	0.00403	0.0216**	0.0304***	0.0194*
	(0.00922)	(0.00930)	(0.00756)	(0.0112)
Firm Tobin's Q	−0.00359***	−0.00156	−0.000233	−0.000468***
	(0.00119)	(0.000956)	(0.00100)	(0.00116)
Constant	2.784***	2.746***	2.946***	2.597***
	(0.114)	(0.109)	(0.108)	(0.0913)
Firm fixed	Yes	Yes	Yes	Yes
Year fixed	Yes	Yes	Yes	Yes
Number of observations	11,918	11,229	11,544	11,603
R-squared	0.151	0.156	0.104	0.181
F	22.05***	24.11***	18.44***	23.72***
Coefficient difference	−0.0116***		−0.0134***	
	(0.002)		(0.005)	

Note: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Cluster standard errors in parentheses.

optimisation of financing models, neglecting to explore how the CET policy, as a market-oriented regulatory tool, influences corporate financial constraints and the mechanisms underlying this impact.

Specifically, this study advances the carbon finance literature by moving beyond the traditional focus to uncover the underlying mechanisms through which CET policies influence corporate financial constraints, supported by robust empirical evidence. As a market-oriented environmental regulation tool, CET policies incentivize firms to pursue green innovation and enhance supply chain diversity. These market-driven adaptations not only boost environmental performance but also improve firms' competitiveness, achieving the 'innovation offset effect' (Wu and Wang 2022). By demonstrating this innovation offset, the study highlights how CET policies enable firms to leverage market mechanisms to drive green innovation while simultaneously strengthening their competitive position. This further illustrates how environmental regulations can transcend their primary goal of emissions reduction to foster organisational efficiency and financial resilience. In general, these findings offer an integrated perspective, showcasing how market-based tools can concurrently address environmental and economic objectives, positioning CET policies as critical mechanisms for sustainable corporate growth (Chava, Livdan, and Purnanandam 2009; Ni et al. 2023; Shi et al. 2024).

Second, our research deepens the understanding of the positive moderating effects of supply chain diversity and green innovation in alleviating the financial constraints imposed by CET policies. These moderators not only buffer the financial pressures created by CET implementation but also enhance policy effectiveness by facilitating smoother transitions to low-carbon operations. Firms with strong green innovation capacity are better positioned to leverage CET policies through financial incentives, such as cost savings from emissions reductions and revenue generated by trading allowances, enabling them to invest in eco-friendly technologies that strengthen competitiveness (He et al. 2023; Huang, Yang, and Tu 2019; Zhang, Mo, et al. 2024). Similarly, firms with diverse supply chains demonstrate greater resilience to policy-driven costs and market volatility by distributing risks and reducing financial pressures (Wang, Huang, et al. 2023; Wong, Wong, and Boon-itt 2020). The interaction of these factors maximises a firm's flexibility, adaptability, and competitiveness under CET policy implementation. For instance, investments in green innovation can foster partnerships with sustainable suppliers, indirectly enhancing supply chain diversity, while diverse networks can expose firms to cutting-edge technologies, further boosting their innovation capacity (Durak Uşar and Soytas 2023; Wong, Wong, and Boon-itt 2020).

5.2. Managerial implications

These findings provide valuable practical insights for the development of CET markets. From the policymakers' perspective, our results demonstrate that CET markets in pilot cities help firms reduce their financial constraints and achieve more efficient resource allocation. Moreover, the study further reveals that the CET policy is more effective in alleviating financial constraints in regions with stronger environmental regulations and has more pronounced impacts on firms with high ownership concentration. These findings suggest that policymakers should consider both regional and firm-specific characteristics to maximise the policy's benefits when promoting its implementation on a nationwide scale (Wang, Chen, and Song 2018). For regions with low environmental regulatory intensity, enforcement of CET policies should be strengthened to ensure effective implementation. For firms with low ownership concentration and decentralised governance structures, where policy execution may be less effective, the government can optimise carbon market incentive mechanisms. These include increasing the flexibility of carbon quota allocation and lowering trading thresholds to enhance policy responsiveness.

From the perspective of enterprises, the findings suggest that enterprises should design tailored carbon finance strategies to align with carbon policies. For instance, by capitalising on eco-friendly operational practices, companies can achieve long-term market viability while also selling surplus carbon emission quotas for short-term financial gains, thereby alleviating financial constraints. Additionally, enterprises should focus on diversifying their supply chains to enhance flexibility and resilience against risks. However, it is crucial to strike a balance, as excessive diversification may lead to unintended negative consequences (Wang, Zhou, and Zhao 2023). Furthermore, enterprises are encouraged to develop green innovation capabilities (Kusi-Sarpong, Gupta, and Sarkis 2019). This should be coupled with advancing sustainable production practices and optimising operational activities, which can be further supported through supply chain diversity (Zhang, Shi, and Jiang 2019).

5.3. Conclusions and limitations

This research evaluates the impact of the CET policy on firms' financial constraints using a DID approach, based on 23,147 observations from listed companies in mainland China. The findings reveal that the CET policy significantly alleviates financial constraints in pilot regions. Additionally, supply chain diversity and green innovation can further amplify the effectiveness of CET policies in alleviating firms' financial constraints. These results offer valuable insights for optimising carbon finance policies and improving their practical implementation.

However, we acknowledge limitations for further research. First, although we explore China as an emerging and important carbon trading market, further validation is needed to expand the findings' generalizability in different institutional conditions. Future research could incorporate cross-country comparative studies to examine the similarities and differences in carbon trading policies between developed economies and emerging markets. Such studies could shed light on how institutional design influences policy outcomes. Second, the CET policies not only directly impact the carbon emission behaviour of individual enterprises but also ripple through the supply chain, reshaping collaboration and competitive dynamics among firms (Zhang et al. 2024; Zheng et al. 2024). Future research could explore how CET policies impact other supply chain stakeholders, particularly in terms of their financial performance and interorganizational relationships. This would provide deeper insights into the broader systemic effects of CET policies across entire supply chains.

Note

1. See https://zfxxgk.ndrc.gov.cn/web/iteminfo.jsp?id=1349 (accessed on June 1, 2024).

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Data availability statement

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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