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The impact of the carbon trading pilot program on the financing cost of green bonds

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ABSTRACT

We examine the impact of a market-based initiative, the carbon trading pilot program, on the financing cost of green bonds in China. The results indicate that the financing cost of green bonds is significantly lower in regions included in the carbon trading pilot program. This effect is more pronounced in regions with better renewable energy development and a higher level of marketisation. The mechanism analysis suggests that the pilot program promotes corporate green innovation, leading to a lower financing cost of green bonds. The results of this study highlight the beneficial effects of a market-based environmental policy that alleviates green concerns among market participants.

1. Introduction

In response to global climate changes, green bonds, a financing tool designed for facilitating green or low-carbon projects, have gained prominence in green financing (Curley, 2014; Naeem et al., 2021; Tolliver et al., 2019). In December 2015, the China National Development and Reform Commission released the Green Bond Issuance Guidelines, marking the official establishment of the green bond market in China. Since then, the Chinese green bond market has exhibited a clear upward trend as shown in Fig. 1 and Fig. 2, which report the volume of green bond issuance from 2016 to 2022.[1] By 2022, China had become the world's second-largest green bond market (Climate Bonds Initiative and China Central Depository and Clearing Research Centre, 2022).

As the largest carbon emitter in the world (Liu et al., 2016; Shi et al., 2021; Song et al., 2020), China faces an urgent need to reduce carbon emissions. One example of the country's effort to do so is its establishment of a pilot carbon trading market. Since 2013, China has conducted a pilot project for a compliant (mandatory) carbon trading market (hereafter, the carbon trading pilot program) in eight areas: Beijing, Tianjin, Shanghai, Chongqing, Hubei, Fujian, Guangdong, and Shenzhen (Zhou and Li, 2019). Fig. 3 shows the geographic distribution of the carbon trading pilots and the development of the green bond market, revealing that the issuance volumes of green bonds are higher in the pilot regions compared to other areas. By the end of August 2020, the carbon trading pilot program covered over 20 industries, involving nearly 3000 enterprises.[2]

With the accelerating development of the Chinese bond market, green bonds have attracted increasing attention from researchers. Green bonds have been recognised as an important means of reducing carbon emissions and simultaneously lowering the financing

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[1] Green bonds issued by financial institutions and unlisted firms account for a relatively high proportion throughout this period.

[2] In August 2020, the cumulative transaction volume of carbon allowances traded in the market exceeded 400 million metric tons, with a total value of approximately 9 billion RMB (Central Government of the People's Republic of China, 2020).

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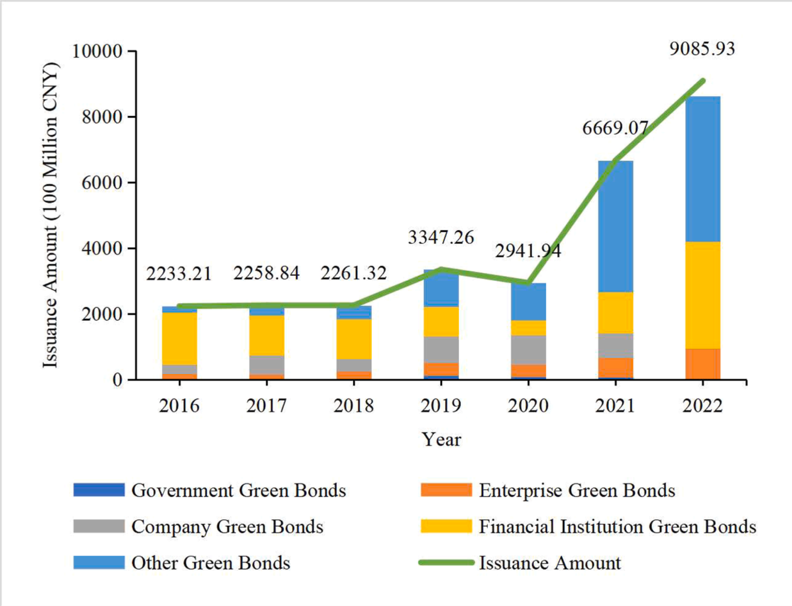

Fig. 1. Green bond issuance volume by bond type.

cost of corporate bonds (Flaherty et al., 2017; Gianfrate and Peri, 2019; Sachs, 2014). The existing literature has investigated the determinants of green bond pricing (Bachelet et al., 2019; Wang et al., 2020a; Qi et al., 2024), the motivations behind green bond issuance (Flammer, 2021; Sangiorgi and Schopohl, 2021), and the promotion effect of green bonds on green innovation (Lin et al., 2022; Wang et al., 2022a; Zhang et al., 2022). However, the impact of the carbon trading pilot program on the financing cost of green bonds has remained understudied.

The existing literature reports conflicting information regarding the possible impact of the carbon trading pilot program on the financing cost of green bonds. The funds required for carbon trading may reduce the amount of short-term cash flows and liquidity of companies included in the carbon trading pilot program. This can cause concerns among investors, which in turn increase the financing cost of corporate bonds (Huang et al., 2024; Lee and Choi, 2021; Lv and Bai, 2021). However, some studies also suggest that the carbon

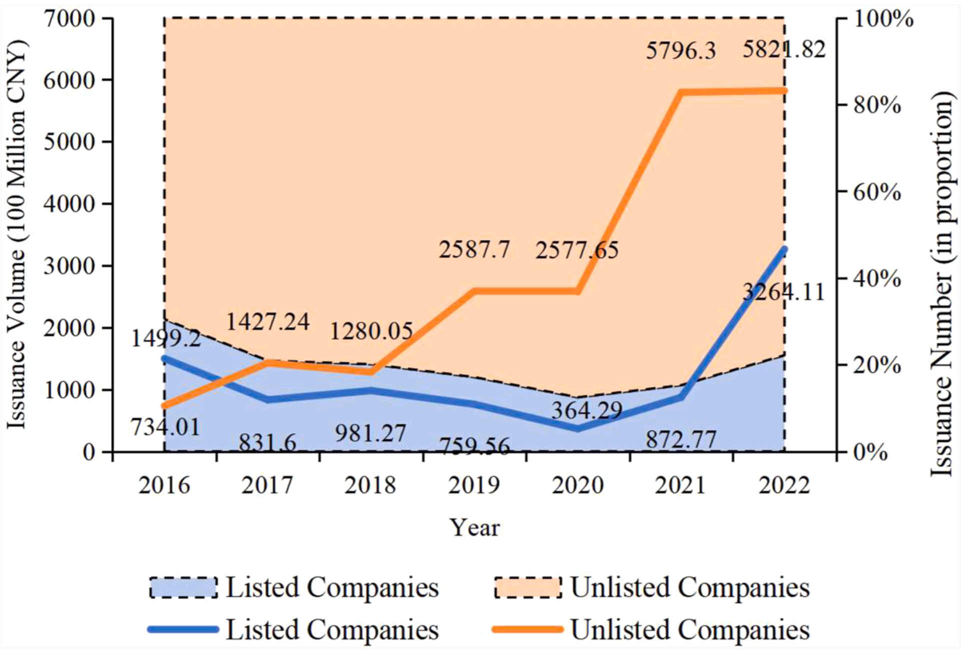

Fig. 2. Green bond issuance by company listing status.

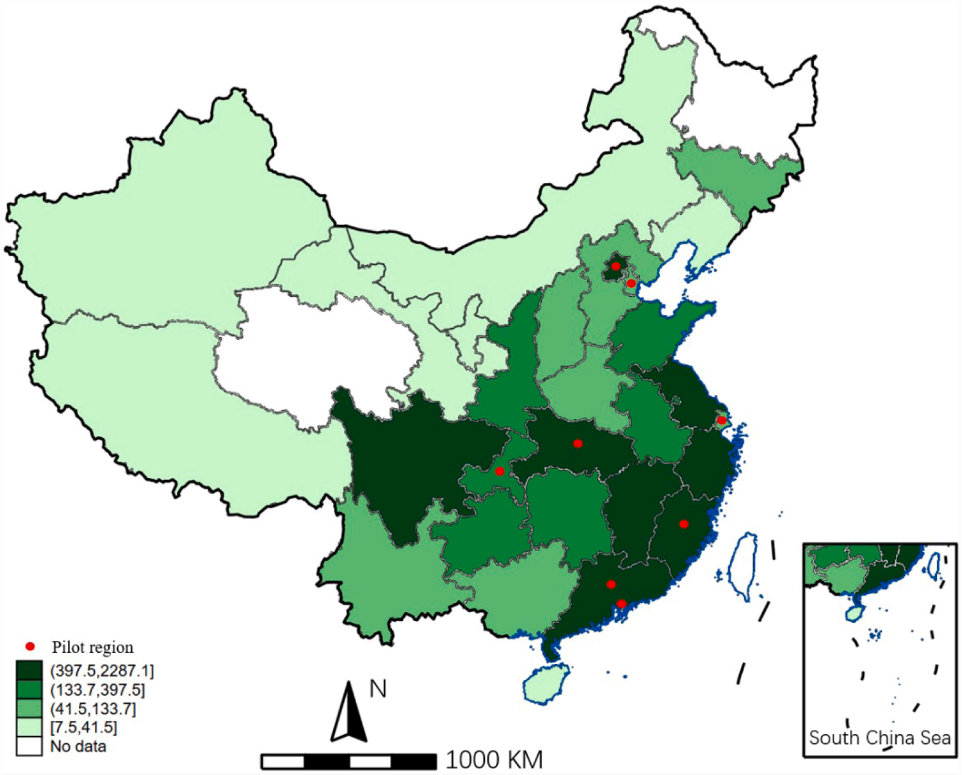

Fig. 3. Green bond issuance and carbon trading pilot regions.

trading pilot program can reduce the financing cost of corporate bonds (Meng et al., 2022; Zou et al., 2023). Therefore, it is beneficial to study the impact of the carbon trading pilot program on the financing cost of green bonds due to the inconsistent information in the extant literature.

Using a sample of green bonds issued by Chinese corporations, we find that the carbon trading pilot program significantly reduces the financing cost of green bonds by promoting green innovation. Moreover, the impact of the pilot program is more salient in regions with better renewable energy development and a higher level of marketisation. This research suggests that a market-based initiative, the carbon trading pilot program, reduces the financing cost of green bonds.

This paper contributes to the existing literature in various aspects. First, the conclusions of this study are more generalisable and enrich the literature by showing that a market-based mechanism can promote green commitment. Previous studies on the carbon trading pilot program often focus on its influence in a particular industry. For example, Zou et al. (2023) highlight the role of the carbon trading pilot program in reducing the financing cost of corporate bonds issued by high-carbon enterprises. Meng et al. (2022) find that the carbon trading program lowers the cost of long-term debt for manufacturing firms facing significant financing constraints. In contrast, this paper provides a broader perspective on the impact of the carbon trading pilot program on the financing cost of green bonds. Second, this research offers bond-level evidence that the pilot program can reduce the financing cost of bonds by promoting corporate green innovation, which is a critical factor in enhancing corporate sustainability. Third, this research holds considerable significance for policymakers and market participants by providing evidence of the positive effects of market-based environmental policies in addressing green concerns among market participants.

2. Hypotheses development

The carbon trading market has been proven to be an effective market-based initiative for reducing carbon emissions (Hu et al., 2020; Shi et al., 2022; Zhang et al., 2020a). Companies can trade carbon emission allowances freely in a carbon trading market, providing an effective market mechanism to internalise the externalities of environmental pollution. Hu et al. (2020) illustrate that the carbon trading pilot program can reduce energy consumption and carbon emissions by improving market efficiency. Furthermore, the pilot trading effect is more pronounced in cities with higher carbon emissions and stricter environmental supervision (Shi et al., 2022).

In the carbon trading market, emissions that exceed a quota hurt company valuation, which affects the financing cost of bonds (Clarkson et al., 2015). Therefore, the financing cost of bonds increases with carbon emissions intensity (Caragnano et al., 2020) and carbon-related risks (Jung et al., 2018). However, studies also suggest that the carbon trading pilot program can reduce the financing cost of bonds for high carbon-emitting companies by improving corporate transparency and reducing information asymmetry (Meng et al., 2022; Zou et al., 2023).

Liu et al. (2022) find that, in terms of external economic factors, stricter environmental regulations and pollution control have the greatest positive impact on green bond issuance volume, while policy support has no statistically significant impact. Moreover, studies suggest that green bond yield spread is driven by the GDP, the consumer price index (Grishunin et al., 2023), external verification (Fatica et al., 2021) and bond characteristics such as size, maturity (Karpf and Mandel, 2018), rating, and coupon rate (Grishunin et al., 2023). Based on the existing literature, we propose the following hypothesis:

Hypothesis 1. **(H1):** The carbon trading pilot program reduces the financing cost of green bonds.

The number of patents for companies included in the carbon trading pilot program has significantly increased, demonstrating an incentive for these companies to reduce carbon emissions via innovation (Calel and Dechezlepretre, 2014; Ren et al., 2020). In addition, both high carbon trading prices and high price volatility encourage firms to enhance innovation activities (Lv and Bai, 2021). According to the existing literature, green innovation can improve a firm's market value (Kajander et al., 2012) and financial performance (Zhang et al., 2020b). This increases the bond repayment ability of the firm and reduces the financing cost of bonds.[3] In summary, the carbon trading pilot program can promote corporate innovation. Based on this analysis, we propose the following hypothesis:

Hypothesis 2. **(H2):** The carbon trading pilot program lowers the financing cost of green bonds by promoting green innovation.

3. Data and methodology

3.1. Sample and data

Since the first green bond in China was issued in 2016, our sample includes all non-perpetual green corporate bonds and green enterprise bonds issued from 1 January 2016 to 31 December 2022 (Su et al., 2023; Wang and Wang, 2024; Zou et al., 2023). The data on the issuance information of green bonds are collected from the CSMAR database. The macro-level data and financial information of issuing companies are obtained from Choice Financial Terminal. We include two types of green bonds, labelled and non-labelled, since both have promoted the development of China's green bonds market (Li et al., 2022; Tang et al., 2023). Labelled green bonds are marked as 'green' at issuance, while non-labelled green bonds refer to those that have not been specifically labelled as 'green' but are invested in green projects and comply with relevant domestic and international green catalogue standards (Li et al., 2022).[4] Bonds with incomplete or missing financial information are excluded, leaving 887 green bonds in our sample.

3.2. Methodology

Following the existing literature (Hu et al., 2022; Su et al., 2023; Zhang et al., 2021), we employ the ordinary least squares regression model to examine the influence of the carbon trading pilot program on the financing cost of green bonds. To address the unobserved characteristics and time-varying heterogeneity, we include industry and year effects in the baseline regression (Xu et al., 2022).

$$Credit\ Spread_{i,t} = \alpha_0 + \alpha_1 Pilot_i + \alpha_2 \sum Bond\ Controls_{i,t} + \alpha_3 \sum Firm\ Controls_{i,t-1} + \alpha_4 \sum Macro\ Controls_{i,t-1} + \varepsilon_{it} \quad (1)$$

where i and t respectively represent bonds and the year of bond issuance. $Credit\ Spread_{i,t}$ refers to the yield spread for bond i at issuance. $Pilot_i$ is a dummy variable that equals 1 if the bond issuer is in a carbon pilot area and 0 otherwise. Following Flammer (2021) and Hu et al. (2022), $Bond\ Controls_{i,t}$ refers to a series of control variables for bond characteristics. Following Wang et al. (2020a), Zhang et al. (2021) and Li, Zhang, and Wang (2022), we also include firm-level ($Firm\ Controls_{i,t-1}$) and macro-level ($Macro\ Controls_{i,t-1}$) control variables, all lagged by one year. All continuous variables are winsorised at the 1 % and 99 % levels. Tables A1 and B1 in the appendices provide the detailed definitions of variables and *t*-test results for the bonds issued in the pilot and non-pilot areas. Table 1 reports the descriptive statistics for the main variables.

[3] A key characteristic of green innovation is its dual externalities – knowledge spillovers and environmental protection – which distinguish it from traditional innovation (Barbieri et al., 2020; Shao & Chen 2022; Tian et al., 2021). Specifically, green innovation activities are more likely to foster knowledge spillovers than non-green activities and can serve as a foundation for future inventions (Barbieri et al., 2020). In addition, green innovation provides positive environmental impacts and benefits to the whole of society, including those that do not bear any costs (Tian et al., 2021). Green innovation has attracted significant attention, prompting many countries to implement various subsidy policies to support its development (Carboni, 2017; Hewitt-Dundas & Roper, 2010; Meuleman & De Maeseneire, 2012), especially in China (Shao & Chen, 2022; Xie et al., 2019). Therefore, we expect that green innovation can serve as a mechanism through which the carbon trading pilot program, a government initiative, can lower the financing cost of green bonds.

[4] The data on labelled green bonds are obtained from the CSMAR database, and the data on non-labelled green bonds are collected from the China Bond Information Network (CBIN) Green Bond Environmental Benefit Information Database.

Table 1
Summary statistics.

Variable	Obs.	Mean	SD	Min	p25	p50	p75	Max
Panel A: Dependent and independent variables								
Credit Spread	887	0.017	0.012	0.003	0.008	0.013	0.025	0.048
Pilot	887	0.486	0.500	0.000	0.000	0.000	1.000	1.000
Panel B: Bond-level controls								
Labelled	887	0.581	0.494	0.000	0.000	1.000	1.000	1.000
Term	887	6.178	2.650	1.000	5.000	7.000	7.000	15.000
Amount	887	1.158	0.754	0.100	0.600	1.000	1.500	3.500
Rating	887	3.485	0.734	1.000	3.000	4.000	4.000	4.000
Redeemable	887	0.018	0.133	0.000	0.000	0.000	0.000	1.000
Puttable	887	0.382	0.486	0.000	0.000	0.000	1.000	1.000
Market	887	0.569	0.495	0.000	0.000	1.000	1.000	1.000
Panel C: Firm-level controls								
Listed	887	0.147	0.354	0.000	0.000	0.000	0.000	1.000
SOE	887	0.948	0.222	0.000	1.000	1.000	1.000	1.000
Lnsize	887	16.220	1.992	13.260	14.670	15.821	17.477	20.876
Cash/debt	887	0.019	0.109	−0.281	−0.042	0.017	0.083	0.309
Quick ratio	887	1.389	1.181	0.175	0.682	1.057	1.669	7.768
ROA	887	0.019	0.019	−0.004	0.006	0.012	0.025	0.091
Panel D: Macro-level controls								
M2 growth	887	0.006	0.007	−0.007	0.002	0.006	0.012	0.022
GDP growth	887	0.058	0.059	−0.195	0.031	0.067	0.082	0.201

This table reports the summary statistics of the key variables used in this study. The sample contains 887 bonds issued from 1 January 2016 to 31 December 2022.

4. Empirical analysis

4.1. Baseline regression

Table 2 reports the baseline regression results. Industry and year effects are not controlled for in Column (1), but both effects are included in Column (2). In both columns, the coefficients of *Pilot* are negative and significant at the 1 % level, indicating that the financing cost of green bonds is lower when the issuers are in a carbon trading pilot area; thus, Hypothesis 1 is proved. The results of the control variables are consistent with those from existing studies (Hu et al., 2022; Su et al., 2023; Zhang et al., 2021).

4.2. Entropy-balanced sample estimation

We employ the entropy balancing method to address the possible issues arising from sample selection bias. Entropy balancing reduces the potential biases due to unobserved confounding variables by using a maximum entropy reweighting scheme to adjust inequalities in representation (Hainmueller, 2012). This method reweights covariates' means and variances between firms located in pilot regions and those in non-pilot regions, thus providing a balanced sample for each matching dimension. Panels A and B in Table 3 report the mean, variance, and skewness of the variables before and after entropy balancing, respectively. The results in Panel B show that the potential sample selection bias has been reduced after entropy balancing. Panel C reports the regression results using the entropy-balanced sample, showing that the results are robust when the sample selection bias has been addressed.

4.3. Mechanism analysis

We next conduct a mechanism analysis to test the underlying channel defined in Hypothesis 2 using the following model:

$$Innovation_{i,t} = \alpha_0 + \alpha_1 Pilot_i + \alpha_2 \sum Bond\ Controls_{i,t} + \alpha_3 \sum Firm\ Controls_{i,t-1} + \alpha_4 \sum Macro\ Controls_{i,t-1} + \varepsilon_{i,t} \quad (2)$$

where $Innovation_{i,t}$ refers to the level of green innovation of a green bond issuer. This is calculated as the natural logarithm of 1 plus the green patent granted, following the existing literature (Quan et al., 2021). Column (1) in Table 4 shows a significantly positive

Table 2
Carbon pilot program and the financing cost of green bonds.

	(1) *Credit Spread*	(2) *Credit Spread*
Pilot	−0.0029***	−0.0025***
	(−4.392)	(−4.145)
Labelled	0.0003	0.0002
	(0.544)	(0.403)
Term	0.0008***	0.0008***
	(6.734)	(7.206)
Amount	−0.0016***	−0.0019***
	(−3.776)	(−4.763)
Rating	−0.0056***	−0.0058***
	(−13.475)	(−15.203)
Redeemable	−0.0030	−0.0039**
	(−1.448)	(−2.085)
Puttable	−0.0028***	−0.0026***
	(−4.481)	(−4.596)
Market	0.0029***	0.0023***
	(4.330)	(3.677)
Listed	0.0050***	0.0036***
	(4.575)	(3.645)
SOE	−0.0085***	−0.0074***
	(−6.257)	(−5.476)
Lnsize	−0.0015***	−0.0013***
	(−7.010)	(−6.559)
Cash/debt	−0.0079***	−0.0087***
	(−2.677)	(−3.055)
Quick Ratio	0.0000	0.0002
	(0.065)	(0.992)
ROA	−0.0359*	−0.0227
	(−1.916)	(−1.322)
M2 growth	−0.0383	−0.0459
	(−1.009)	(−1.325)
GDP growth	−0.0033	0.0076
	(−0.708)	(1.069)
Constant	0.0663***	0.0641***
	(17.867)	(14.290)
Industry Effects	No	Yes
Year Effects	No	Yes
Observations	887	853
Adj. R^2	0.548	0.652

This table reports the baseline regression results. *t*-statistics are reported in parentheses. *, ** and *** indicate significance levels of 10 %, 5 % and 1 %, respectively.

coefficient of *Pilot* on the mediator (*Innovation*), indicating that the carbon trading pilot program increases green innovation. Column (2) shows a significantly negative coefficient of *Innovation*, indicating that the more green innovation a firm engages in, the lower the financing cost of green bonds. In Column (3), the coefficient of *Pilot* is significantly negative; thus, Hypothesis 2 is verified.

4.4. Cross-sectional variation analysis

We also estimate the influence of renewable energy (RE) development and the level of marketisation on the relationship between the financing cost of green bonds and the pilot program.[5] Following Wang et al. (2020b), we define the top 25 % of provinces in the RE development as high RE development regions and the rest as low RE development regions. In addition, using the marketisation index proposed by Wang et al. (2022b), we separate the sample into two subsamples, the eastern region and the rest of the country. The results in Table 5 indicate that the coefficient of *Pilot* is significant for issuers in the high RE development provinces and issuers from the eastern part of China. These results suggest that a higher level of marketisation and RE development promote green development,

[5] According to the existing literature, both renewable energy development and consumption can significantly reduce carbon emissions (Dogan & Seker, 2016; Qi et al., 2014) and promote the achievement of carbon neutrality targets (Dong et al., 2022). Another stream of research indicates that the financing cost of bonds increases with carbon emissions intensity (Caragnano et al., 2020) and carbon-related risks (Jung et al., 2018). Therefore, it is important to examine whether the financing cost of bonds varies with the level of renewable energy development. Furthermore, as a market-based mechanism, the effectiveness of the carbon trading pilot program may be influenced by the level of marketization. Specifically, a higher level of marketization reflects greater efficiency in price discovery (Callon, 2016) and resource allocation (Caliskan & Callon, 2010), making it worthwhile to investigate whether the effect of the carbon trading pilot program is more pronounced in regions with a higher level of marketization.

Table 3
Entropy-balanced sample estimation.

Panel A Entropy balancing: Comparison of means and variance before entropy balancing						
	Treat (n = 431)			*Control (n = 456)*		
	Mean	*Variance*	*Skewness*	*Mean*	*Variance*	*Skewness*
Labelled	0.5592	0.2471	−0.2383	0.6009	0.2404	−0.4120
Term	5.5340	8.9050	1.2920	6.7870	4.4930	0.9703
Amount	1.4040	0.7100	0.8093	0.9243	0.3229	1.4640
Rating	3.7420	0.3638	−2.4920	3.2410	0.5834	−0.4370
Redeemable	0.0139	0.0138	8.2970	0.0219	0.0215	6.5290
Puttable	0.3991	0.2404	0.4122	0.3662	0.2326	0.5553
Market	0.3944	0.2394	0.4320	0.7346	0.1954	−1.0630
Listed	0.2042	0.1629	1.4680	0.0921	0.0838	2.8210
SOE	0.9281	0.0669	−3.3140	0.9671	0.0319	−5.2380
Lnsize	17.0200	3.7860	0.3464	15.4700	2.9860	1.8040
Cash/debt	0.0507	0.0101	−0.0505	−0.0114	0.0117	−0.0675
Quick Ratio	1.0680	0.8329	2.9080	1.6920	1.7410	2.4800
ROA	0.0240	0.0004	1.2360	0.0135	0.0002	2.6030
M2 growth	0.0061	0.0001	0.2204	0.0063	0.0001	0.1575
GDP growth	0.0527	0.0050	−1.2610	0.0635	0.0019	0.1519
Panel B Entropy balancing: Comparison of means and variance after entropy balancing						
	Treat (n = 431)			*Control (n = 456)*		
	Mean	*Variance*	*Skewness*	*Mean*	*Variance*	*Skewness*
Labelled	0.5592	0.2471	−0.2383	0.5591	0.2470	−0.2383
Term	5.5340	8.9050	1.2920	5.5340	8.9040	1.6320
Amount	1.4040	0.7100	0.8093	1.4040	0.7099	0.9611
Rating	3.7420	0.3638	−2.4920	3.7420	0.3638	−2.1720
Redeemable	0.0139	0.0138	8.2970	0.0139	0.0138	8.2980
Puttable	0.3991	0.2404	0.4122	0.3991	0.2403	0.4122
Market	0.3944	0.2394	0.4320	0.3945	0.2394	0.4319
Listed	0.2042	0.1629	1.4680	0.2042	0.1628	1.4680
SOE	0.9281	0.0669	−3.3140	0.9281	0.0669	−3.3130
Lnsize	17.0200	3.7860	0.3464	17.0100	3.7860	0.8069
Cash/debt	0.0507	0.0101	−0.0505	0.0507	0.0101	−0.6700
Quick Ratio	1.0680	0.8329	2.9080	1.0680	0.8330	2.5690
ROA	0.0240	0.0004	1.2360	0.0240	0.0004	0.8102
M2 growth	0.0061	0.0001	0.2204	0.0061	0.0001	0.3733
GDP growth	0.0527	0.0050	−1.2610	0.0527	0.0050	0.1295
Panel C: Regression result using the entropy-balanced sample						
		(1)		(2)		
		Credit Spread		*Credit Spread*		
Pilot		−0.0021**		−0.0018***		
		(−2.289)		(−3.150)		
Constant		0.0097***		0.0457***		
		(5.176)		(8.617)		
Controls		No		Yes		
Industry Effects		Yes		Yes		
Year Effects		Yes		Yes		
Observations		887		887		
Adj. R^2		0.675		0.447		

Panels A and B of this table report the mean, variance and skewness of indicators between issuers located in and out of the carbon pilot regions before and after entropy balancing, respectively. Panel C reports the regression results of using the post-balancing sample. *t*-statistics are reported in parentheses. *, ** and *** indicate significance levels of 10 %, 5 % and 1 %, respectively.

resulting in a pronounced effect of the pilot program on the financing cost of green bonds.

5. Conclusion

This study documents that the carbon trading pilot program in China significantly reduces the financing cost of green bonds by promoting green innovation. Moreover, this effect is more pronounced in regions with high RE development and a high level of marketisation. We contribute to the existing literature by providing a deeper understanding of the impact of market-based carbon trading reform on the financing cost of green bonds. The results of this study offer valuable insights for policymakers and investors. First, the empirical evidence enables policymakers to better understand the effectiveness of the carbon trading program. Second, our mechanism analysis suggests that investment in green innovation has a signal effect that can alleviate green concerns among investors and market participants. Third, our results support the argument that the carbon trading pilot program reduces information asymmetry, increases the effectiveness of bond financing, and to some extent, may prevent companies from using green bonds for greenwashing. Moreover, our study highlights the significance of enhancing market infrastructure to foster sustainable development. Future

Table 4
Mediation effect of green innovation.

	(1) *Credit Spread*	(2) *Innovation*	(3) *Credit Spread*
Pilot	−0.0025***	0.1350***	−0.0024***
	(−4.145)	(3.148)	(−3.857)
Innovation			−0.0012**
			(−2.473)
Constant	0.0663***	−0.1760	0.0639***
	(17.867)	(−0.360)	(10.550)
Controls	Yes	Yes	Yes
Industry Effect	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes
Observations	853	853	853
Adj. R^2	0.652	0.232	0.654

This table shows the mediation effect of green innovation on the financing cost of green bonds. *Innovation* is the natural logarithm of 1 plus the green patent applications. *t*-statistics are reported in parentheses. *, ** and *** indicate significance levels of 10 %, 5 % and 1 %, respectively.

Table 5
Renewable energy development and location of issuers.

	High RE development (1) *Credit Spread*	Low RE development (2) *Credit Spread*	Eastern region (3) *Credit Spread*	Other regions (4) *Credit Spread*
Pilot	−0.0023**	0.0013	−0.0031***	0.0014
	(−2.533)	(1.113)	(−4.321)	(1.136)
Constant	0.0377***	0.0828***	0.0452***	0. 0827***
	(8.884)	(10.210)	(8.148)	(9.934)
Controls	Yes	Yes	Yes	Yes
Industry Effects	Yes	Yes	Yes	Yes
Year Effects	Yes	Yes	Yes	Yes
Observations	491	396	523	347
Adj. R^2	0.606	0.665	0.639	0.661

This table reports the subsample analyses when renewable energy development and the location of the bond issuers are considered. *t*-statistics are reported in parentheses. *, ** and *** indicate significance levels of 10 %, 5 % and 1 %, respectively.

research may investigate additional mechanisms through which the market-based environmental schemes can impact corporate green engagement across diverse regulatory and economic contexts.

CRediT authorship contribution statement

Haojun Yuan: Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis, Data curation. **Jing Liao:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Martin Young:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Appendix A

Table A1
Variable description.

Variable	Definition
Credit Spread	Financing cost of green bonds; calculated as the difference between the yield of a green bond at the time of issuance and the yield of a government bond with the same maturity.
Pilot	Dummy variable; equals 1 if the bond issuer is located in a carbon pilot area and 0 otherwise.
Labelled	Dummy variable; equals 1 if the bond is labelled as a green bond and 0 otherwise.
Term	Bond term.
Amount	Bond issuance amount.
Rating	Bond rating; equals 1, 2, 3 or 4 when the bond rating is less than AA, AA, AA+ or AAA, respectively.
Redeemable	Dummy variable; equals 1 if the bond is redeemable and 0 otherwise.
Puttable	Dummy variable; equals 1 if the bond is puttable and 0 otherwise.
Market	Dummy variable; equals 1 if the bond is issued in more than one market and 0 otherwise.

(*continued on next page*)

Table A1 (*continued*)

Variable	Definition
Listed	Dummy variable; equals 1 if the bond issuer is a listed public company and 0 otherwise.
SOE	Dummy variable; equals 1 if the bond issuer is a state-owned enterprise and 0 otherwise.
Lnsize	Natural logarithm of bond issuer's total assets.
Cash/debt	Bond issuer's cash ratio; calculated as the net cash flows from operating activities divided by total liability.
Quick ratio	Bond issuer's quick ratio; calculated as the sum of monetary capital, trading financial assets, accounts receivable, notes receivable and other receivables, divided by current liability.
ROA	Bond issuer's return on assets ratio; calculated as net income divided by total assets.
M2 growth	Currency supply growth speed; calculated as the current year's money supply minus the previous year's money supply, divided by the previous year's money supply.
GDP growth	Growth of GDP of the city where the bond issuer is located.

Appendix B

Table B1
Comparison between the firms located within and without carbon trading pilot area.

	Without pilot area		Within pilot area		Mean differences	
	Obs.	Mean	Obs.	Mean	Mean	*t*-Value
Credit Spread	456	0.022	431	0.012	0.011***	15.208
Labelled	456	0.601	431	0.559	0.042	1.258
Term	456	6.787	431	5.534	1.254***	7.244
Amount	456	0.924	431	1.404	−0.480***	−9.999
Rating	456	3.241	431	3.742	−0.501***	−10.806
Redeemable	456	0.022	431	0.014	0.008	0.895
Puttable	456	0.366	431	0.399	−0.033	−1.006
Market	456	0.735	431	0.394	0.340***	10.877
Listed	456	0.092	431	0.204	−0.112***	−4.772
SOE	456	0.967	431	0.928	0.039***	2.627
Lnsize	456	15.47	431	17.02	−1.546***	−12.526
Cash/debt	456	−0.011	431	0.051	−0.062***	−8.841
Quick ratio	456	1.692	431	1.068	0.625***	8.155
ROA	456	0.014	431	0.024	−0.011***	−8.758
M2 growth	456	0.006	431	0.006	0.000	0.301
GDP growth	456	0.063	431	0.053	0.011***	2.735

This table reports the summary statistics and the differences between firms located within the carbon trading pilot areas and those outside these areas.

Appendix C. Propensity score matching (PSM) approach

To address the endogeneity issue arising from sample selection, we employ the PSM method to create the comparable treatment (bonds issued by firms that are included in the pilot program) and control group (bonds issued by firms that are not included in the pilot program). Given the relatively small sample size of 887 bonds in this study, we perform matching with replacement for both 1-to-2 and 1-to-3 ratios to expand the matched sample. We construct the matching based on a set of bond and issuer indicators. Bond characteristics include bond term, amount, rating, redeemable, puttable and market nature. Issuer characteristics include firm size, state control, listing status, cash to debt ratio, quick ratio and return on assets.

Panel A in Table C1 reports the *t*-test results comparing the bond and issuer characteristics before PSM matching. The treated group consists of the bonds issued by firms that are included in the pilot program while the control group consists of the bonds issued by firms that are not included in the pilot program. The results show that most of the indicators are significantly different before PSM matching. Panel B reports the *t*-test results after the PSM matching, showing that the differences become statistically insignificant. Therefore, the sample selection bias has been reduced after the matching procedure. Panel C provides the regression results using the two matched samples, e.g., 1-to-2 and 1-to-3 matching. The results confirm that the carbon trading pilot program has a significant negative effect on the financing cost of green bonds, which is consistent with the baseline regression results.

Table C1
PSM approach.

Panel A: Summary statistics and *t*-test of unmatched sample					
Variable	D1=1 (Treated)		D1=0 (Control)		Mean Difference
	Obs.	Mean	Obs.	Mean	

(*continued on next page*)

Table C1 (*continued*)

Panel A: Summary statistics and *t*-test of unmatched sample

Variable	D1=1 (Treated)		D1=0 (Control)		Mean Difference
	Obs.	Mean	Obs.	Mean	
Term	420	5.5210	453	6.6950	−6.84***
Amount	420	1.3970	453	0.9230	9.83***
Rating	420	3.7380	453	3.2430	10.52***
Redeemable	420	0.0143	453	0.0221	−0.86
Puttable	420	0.3830	453	0.3640	0.58
Market	420	0.3930	453	0.7330	−10.78***
Non-SOE	420	0.0738	453	0.0397	2.19**
Lnsize	420	17.0200	453	15.4800	12.37***
Listed	420	0.2070	453	0.0927	4.82***
Cash/debt	420	0.0496	453	−0.0131	8.89***
Quick Ratio	420	1.0730	453	1.6640	−7.95***

Panel B: Summary statistics and *t*-test of matched samples

	1-to-2 Matching					1-to-3 Matching				
Variable	D2=1 (Treated)		D2=0 (Control)		Mean Difference	D2=1 (Treated)		D2=0 (Control)		Mean Difference
	Obs.	Mean	Obs.	Mean		Obs.	Mean	Obs.	Mean	
Term	225	5.612	217	5.664	−0.27	276	5.612	261	5.598	−0.27
Amount	225	1.283	217	1.299	−0.3	276	1.283	261	1.282	−0.3
Rating	225	3.721	217	3.694	0.63	276	3.721	261	3.706	0.63
Redeemable	225	0.015	217	0.010	0.64	276	0.0152	261	0.015	0.64
Puttable	225	0.396	217	0.468	−2.05**	276	0.396	261	0.454	−2.05*
Market	225	0.409	217	0.355	1.54	276	0.409	261	0.360	1.54
Non-SOE	225	0.076	217	0.095	−0.95	276	0.0761	261	0.088	−0.95
Lnsize	225	16.950	217	16.770	1.24	276	16.95	261	16.850	1.24
Listed	225	0.208	217	0.232	−0.82	276	0.208	261	0.252	−0.82
Cash/debt	225	0.044	217	0.039	0.68	276	0.0437	261	0.040	0.68
Quick Ratio	225	1.103	217	1.193	−1.4	276	1.103	261	1.174	−1.4

Panel C: PSM approach analysis

	1-to-2 Matching	1-to-3 Matching
	Credit Spread	*Credit Spread*
Pilot	−0.0019**	−0.0021**
	(−2.041)	(−2.293)
Constant	0.0682***	0.0639***
	(8.772)	(8.436)
Observations	410	502
Adj. R^2	0.638	0.614
Industry Effect	Yes	Yes
Year Effect	Yes	Yes

This table reports the *t*-test results before and after PSM matching and the regression result using the matched samples. Panel A reports the *t*-test results comparing the bond and issuer characteristics before PSM matching. Panel B reports the *t*-test results comparing the bond and issuer characteristics after PSM matching. Panel C reports the regression results using the two matched samples, e.g., 1-to-2 and 1-to-3 matching. *t*-statistics are reported in parentheses. *, ** and *** indicate significance levels of 10 %, 5 % and 1 %, respectively.

Appendix D. Additional checks

To avoid errors due to measurement construction, following Tang et al. (2023), we employ an alternative risk-free benchmark to calculate the financing cost of green bonds (*Credit Spread1*). The new benchmark is the YTM of National Development Bonds with comparable maturity issued by the China Development Bank. As a policy bank led by the State Council, its credit rating is essentially equivalent to that of government bonds. Table D1 reports the results after rerunning the baseline model; they are consistent with the baseline results. We also choose the 2018 Environmental Protection Tax reform as a shock to conduct the placebo test and examine whether yield spread is affected by other policies. Fig. D1 reports the results of this analysis and shows that the real regression coefficient is significantly different from the estimated coefficient, indicating that our baseline results are robust.

Table D1
Alternative measure of the financing cost of green bonds.

	(1) *Credit Spread1*	(2) *Credit Spread1*
Pilot	−0.0030***	−0.0028***
	(−4.764)	(−4.445)
Constant	0.0652***	0.0641***
	(18.390)	(14.159)
Controls	Yes	Yes

(*continued on next page*)

Table D1 (*continued*)

	(1) *Credit Spread1*	(2) *Credit Spread1*
Industry Effects	No	Yes
Year Effects	No	Yes
Observations	887	853
adj. R^2	0.548	0.613

This table reports the results of a robustness check using an alternative measure of the financing cost of green bonds. t-statistics are reported in parentheses. *, ** and *** indicate significance levels of 10 %, 5 % and 1 %, respectively.

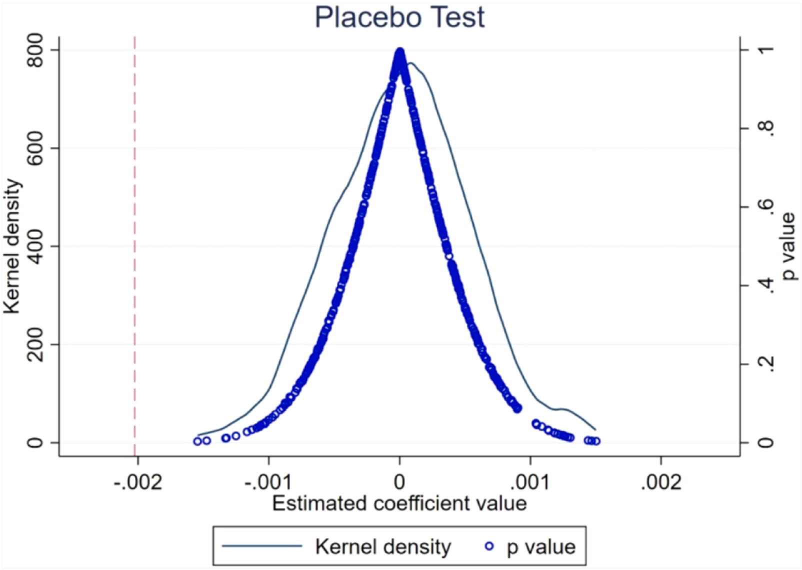

Fig. D1. Placebo test results for 2018 Environmental Protection Tax reform.

Appendix E. Granger causality test

To test the dynamic relationship between the carbon trading pilot program and innovation, we conduct a Granger causality test based on a vector autoregression model. All time series pass the unit root test (Augmented Dicky–Fuller [ADF] test), and the results are reported in Table E1.

Table E2 reports the main results of the Granger causality test. The first row reports the test for the null hypothesis that the carbon trading pilot program does not Granger cause green innovation. The F-statistic is 2.8031, therefore, the null hypothesis is rejected at the 10 % significance level, indicating the presence of Granger causality. The second row shows the test for the null hypothesis that green innovation does not Granger cause the carbon trading pilot program, with an F-statistic of 0.18052. The null hypothesis cannot be rejected, indicating the absence of Granger causality. Therefore, the results suggest that the carbon trading pilot program Granger-causes green innovation.

Table E1
The Augmented Dicky–Fuller (ADF) test.

	ADF test for unit root	**MacKinnon *p*-value**
Pilot	−3.822***	0.0027
Innovation	−5.027***	0.0000

The ADF test reports the unit root test results with the null hypothesis of non-stationarity. *, ** and *** indicate significance levels of 10 %, 5 % and 1 %, respectively.

Table E2
Granger causality tests between green innovation and carbon trading pilot.

Null hypothesis	**F-statistic**	**Test results**
Carbon trading pilot does not Granger cause green innovation	2.8031*	Reject
Green innovation does not Granger cause carbon trading pilot	0.1805	Not reject

The values denote the Wald statistics. *, ** and *** indicate significance levels of 10 %, 5 % and 1 %, respectively.

Data availability

Data will be made available on request.

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