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If Money Talks: Climate change-related regulation and firms' cost of debt

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ABSTRACT

This study uses a novel dataset from 54 countries and regions to explore how exposure to climate change regulatory shocks influences firms' debt costs. The findings reveal that such exposure generally increases the cost of debt. However, this scenario is reversed for firms that find greater opportunities within climate change regulations, suggesting that the regulatory risk premium associated with climate change may not always be positive. The results also indicate that the negative impact of regulations is more pronounced in companies with a higher beta, greater asset tangibility, and poorer environmental innovation performance. Furthermore, this increase in debt costs can be partially attributed to heightened profitability volatility and diminished growth prospects arising from reduced capital expenditures. These insights underscore the need to refine climate regulation policies to better support firms' transition toward environmentally sustainable practices.

1. Introduction

The cost of debt is a crucial determinant of a firm's financial decisions and performance (Binsbergen et al., 2010; Santosuosso, 2014). The existing literature has extensively investigated the factors influencing firms' debt costs, focusing on variables such as ownership structure, business group affiliation, audit quality, and social performance (Bacha, 2019; Byun et al., 2013; Magnanelli & Izzo, 2017; Ratajczak & Mikołajewicz, 2021; Sánchez-Ballesta & García-Meca, 2011). From a macro perspective, factors such as financial market development, macroeconomic risk, country-level sustainability, and climate regulatory risk are also discussed (Chen & Manso, 2017; Hoepner et al., 2016; Khan, 2001; Seltzer et al., 2022).

With increasing global attention on climate change, countries around the world have implemented a series of regulatory policies to address these issues (Fekete et al., 2021; Guterres, 2022; Roelfsema et al., 2020). These policies primarily aim to reduce greenhouse gas emissions, promote renewable energy use, and facilitate the transition to a low-carbon economy (Girod, 2016; Tang, 2022). In line with the Paris Agreement, nations have formulated Nationally Determined Contributions (NDCs) tailored to their specific circumstances, pledging to regularly update these commitments to reflect their evolving ambitions (Röser et al.,

2020). Through measures such as carbon taxes, carbon emissions trading systems, mandatory regulations, and public disclosure (Narassimhan et al., 2018; O'Mahony, 2020; Tam et al., 2021; Foulon, Lanoie, & Laplante, 2002), an increasing number of countries and regions are using economic incentives and legal mechanisms to reduce greenhouse gas emissions, thereby encouraging firms and individuals to adopt more environmentally friendly behaviors.

Climate change-related regulatory policies can have several impacts on corporate financing. On one hand, they may restrict external financing accessibility from banks in industries with high carbon emissions (Reghezza et al., 2022). On the other hand, these policies can increase companies' environmental costs, such as carbon emission taxes and investments in environmental protection, thereby increasing overall financial expenses. Additionally, compliance with climate regulations often necessitates substantial investments such as improving technology and maintaining energy-related infrastructure (Bataille et al., 2018; Zhou et al., 2019). These initial expenditures not only increase short-term financial burdens but also raise long-term operational costs and compliance risks.

The existing literature primarily focuses on the impact of climate risks, such as transitional and physical risks, on firms' debt costs, with relatively less attention given to the effects of climate change-related

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regulations. Additionally, most studies are limited to evaluating specific policy tools or programs at the macro level, often assuming uniform regulatory exposure across all sampled companies. However, the impact of the same climate policy can vary significantly across industries, levels of emissions, and the energy intensity of companies. Moreover, even within the same industry, companies may experience varying degrees of policy exposure owing to differences in geographic location and strategic adaptation capabilities. The current research landscape has not adequately addressed the variations in regulatory exposure that different companies may face, nor has it sufficiently distinguished between climate regulatory opportunities and risks or explored the heterogeneity of these regulatory opportunities.

This study contributes to the existing literature in several innovative ways. First, it employs a novel micro-level dataset to examine how varied climate regulation exposures affect debt costs, thereby broadening the scope of research on the factors that influence firms' debt costs. Second, by distinguishing between firms facing high and low regulatory opportunities, this study reveals that the climate change regulatory risk premium may not always be positive, thus extending our understanding of the economic implications of climate change-related regulations. Third, this study explores the transmission channels through which climate regulatory exposure impacts firms' debt costs, including profitability volatility and growth prospects, providing valuable insights for firms aiming to refine their climate adaptation strategies. Fourth, it examines the roles of systematic risk, asset tangibility, and environmental innovation performance in the relationship between climate regulation exposure and firms' debt costs, contributing to the development of more nuanced climate change-related regulation policies.

2. Literature review

2.1. Determinants of firms' debt costs

Firms' debt costs are influenced by various factors, including firm characteristics and broader market dynamics. Previous research indicates that executive backgrounds, religiosity, political connections, and institutional monitoring have explanatory power for debt financing costs (Jiang et al., 2018; Tee, 2018; Xie et al., 2024). Additionally, the quality of information, as evidenced by interactions between investors and listed companies and media coverage, plays a pivotal role (Gao et al., 2019; Zhao et al., 2023). Furthermore, social responsibility performance, environmental concerns, and ESG disclosure have also been shown to favorably influence firms' debt costs (Chava, 2014; Duggal et al., 2024; Raimo et al., 2021). Notably, innovations in digital finance have emerged as a potential avenue for reducing debt costs (Tang & Geng, 2024), while market dynamics such as equity investment by sovereign wealth funds and oil price uncertainty also exert notable impacts (Chen et al., 2023; Gan et al., 2023). This body of research not only deepens our understanding of the determinants of firms' debt costs but also provides strategic insights for effective debt financing management.

2.2. The economic and environmental outcomes of climate change-related regulations

Recent research has increasingly focused on the multifaceted impacts of climate change-related regulations on corporate strategies and performance. Yan et al. (2023) and Park (2021) underscore the dynamic effects of such regulations on firms' energy consumption behaviors, investment decisions and adaptive capacity for climate management, highlighting the complexities of regulatory compliance. Furthermore, Bauckloh et al. (2023) examine the relationship between mandatory climate reporting and firms' carbon performance, revealing notable improvements in carbon intensity among firms subjected to the Greenhouse Gas Reporting Program. Additionally, Wang and Lin (2022) and Yang et al. (2022) investigate how environmental regulations interact

with firms' bargaining power to influence firm performance. Collectively, these studies offer insightful perspectives on how regulations shape firms' behaviors and performance in the face of climate change-related challenges.

2.3. The impact of climate-related regulations on firms' debt financing

In recent years, the intersection of climate change-related regulations and corporate finance has attracted significant research interest, particularly concerning how carbon regulatory measures and climate change mitigation strategies influence firms' financial structures and costs. Studies indicate that carbon regulatory policies such as Emissions Trading Systems impact firms by elevating the cost of debt (Ni et al., 2022). Concurrently, environmental regulations have been found to foster the development of green finance and moderate the role of debt on the performance of small and medium-sized enterprises (SMEs) in the energy sector (Cariola et al., 2020; Xu et al., 2022). However, these policies can also lead to unintended consequences, including regulatory arbitrage and negative effects on debt financing, especially following participation in an emissions trading scheme (Bartram et al., 2022; Huang et al., 2024).

Moreover, the scale of debt financing is notably reduced in enterprises under high environmental regulatory pressure (Chen et al., 2022). In addition, environmental penalties tend to increase debt costs due to their adverse impact on disclosure quality (Ding et al., 2022). Furthermore, the uncertainty surrounding climate policies constrains excessive debt, demonstrating regional and enterprise-specific effects (Ren et al., 2023). Additionally, the introduction of carbon taxes raises credit risk and alters the geography of bank lending, particularly affecting fossil fuel companies (Aiello & Angelico, 2023; Laeven & Popov, 2023). Finally, environmental transaction costs slow the adjustment to target financial debt levels among carbon emitters (Tascon et al., 2020). This body of literature highlights the intricate relationship between climate change-related regulations and firms' debt financing, underscoring the necessity for a nuanced understanding of the financial impact of these policies.

3. Hypothesis

Climate change-related regulations can affect firms' debt costs through several mechanisms. First, these regulations may necessitate investments in energy-saving and emissions-reduction activities, leading to an increased financial burden and higher financing costs (Liu & Wang, 2017; Zhao et al., 2022; Zhou et al., 2019). Second, compliance with climate regulations necessitates higher standards of auditing and environmental disclosure (Mishra et al., 1997; Palea & Drogo, 2020). These requirements can affect both compliance costs and debt expenses. Third, changes in market demand and supply chain risks driven by climate change-related regulations may increase the volatility of corporate profits, potentially leading to a decline in corporate credit ratings. It has been observed that firms' carbon footprints are closely related to their likelihood of default, particularly through the asset volatility channel, with the 2015 Paris Agreement serving as a policy turning point that affects firms' credit risk (Faralli & Ruggiero, 2022). Creditors may demand higher risk premiums to compensate for these risks, thereby leading to an increase in firms' debt costs. Based on these considerations, the following hypothesis is proposed.

H1a. Increased regulatory exposure to climate change tends to result in higher debt costs for firms.

However, climate change-related regulations have spurred the growth of industries such as renewable energy, waste management, and air purification, endowing these sectors with expanded market prospects and the potential for development (Gielen et al., 2019; Horbach et al., 2012; Mathiesen et al., 2011). Moreover, companies exhibiting strong adaptability are more likely to secure government subsidies (Santos,

2019). They may also find it easier to navigate the industry access, procurement, and bidding processes. If these opportunities are recognized by the market, they can contribute to improving firms’ financing conditions, including reducing debt costs (Ali et al., 2023). Mueller and Sfrappini (2022) reveal that banks, which lend to firms adversely affected by regulations in Europe diversify their portfolios by extending loans to firms that benefit from such regulations. This diversification approach not only helps banks manage the risks associated with lending to vulnerable firms but also enables them to leverage the potential advantages of supporting firms that could benefit from the regulations. Based on this understanding, the following hypothesis is proposed.

H1b. Firms with significant opportunities arising from climate change-related regulations may experience lower debt costs.

4. Methodology

4.1. Sample and data

To investigate the impact of climate change-related regulations on firms’ debt costs, this study utilizes firm-level climate change regulation exposure data from Sautner et al. (2023), who generated climate change exposure-related indicators from the earnings call texts of over 10,000 global firms. Firm-level financial data and ESG-related data are sourced from Bloomberg and Refinitiv Eikon database. Financial firms were excluded from our sample, along with observations of missing core variables. Additionally, observations from countries or regions with two or fewer companies were excluded to ensure that the analysis remained robust and statistically reliable because having too few companies from a single country or region could skew the results and reduce the generalizability of the findings. All continuous variables are winsorized at the 2% level to reduce the effects of outliers. The final sample comprises 32,685 annual observations from 54 countries and regions from 2002 to 2022. The distribution of the sample results is reported in Tables 1 and 2.

4.2. Model

This study aims to understand the impact of climate change-related regulations on firms’ debt costs by applying multivariate panel models. The baseline regression model is as follows:

$$KD_{i,t} = \alpha + \beta_1 Rgexpo_{i,t} + \beta_2 Controls_{i,t} + year + firm + industry + country + \epsilon_{i,t} \tag{1}$$

In this model, $KD_{i,t}$ represents the cost of debt for firm i in year t . $Rgexpo_{i,t}$ denotes the level of exposure to climate change-related regulations for firm i in year t , where the values of this variable have been multiplied by 1000 for ease of interpretation. $Controls_{i,t}$ is a vector of the characteristics controlled in the model. In addition, year, firm, industry, and country fixed effects are included to control for unobserved heterogeneity. $\epsilon_{i,t}$ is the error term. Other types of fixed effects are also considered in the robustness tests to ensure the reliability of the findings.

Table 1
Distribution of sample by year.

Year	Obs.	Per(%)	Year	Obs.	Per(%)	Year	Obs.	Per(%)
2002	157	0.48	2009	935	2.86	2016	2050	6.27
2003	266	0.81	2010	1029	3.15	2017	2507	7.67
2004	384	1.17	2011	1091	3.34	2018	2902	8.88
2005	500	1.53	2012	1363	4.17	2019	3120	9.55
2006	561	1.72	2013	1478	4.52	2020	3284	10.05
2007	629	1.92	2014	1575	4.82	2021	3354	10.26
2008	782	2.39	2015	1767	5.41	2022	2951	9.03

4.3. Variables

4.3.1. Firms’ debt costs

The primary indicators commonly used to measure debt costs include interest expenses and the weighted average cost of debt. Interest expenses typically reflect only actual interest payments and may not comprehensively represent the cost of all debt. In contrast, the weighted average cost of debt accounts for both the interest rates and the amounts of debts of different types, offering a more comprehensive view of the overall debt profile. Therefore, in this study, firms’ debt costs are measured using the after-tax weighted average cost of debt, which provides a comprehensive representation of a firm’s debt burden.

4.3.2. Climate change-related regulation exposure

Previous research typically measured climate regulatory exposure using indicators such as carbon climate policies and environmental penalties. However, these indicators are often limited to regional or industrial levels and may not adequately capture the diverse regulatory factors faced by individual companies. This study employs the climate change-related regulatory exposure index developed by Sautner et al. (2023). This index is calculated based on the relative frequency of bigrams in the text of earnings calls related to climate change regulations. Earnings calls are crucial because they cover significant topics of concern to management and analysts. They enhance the availability of public information for analysts, enabling them to forecast earnings with greater accuracy (Aw et al., 2023). The innovative dataset based on earnings calls provided by Sautner et al. (2023) enables a detailed study of the impact of climate regulations on debt financing from a micro-level perspective, offering a fresh approach to assessing regulatory impacts.

4.3.3. Control variables

Based on previous research, this study incorporates several control variables that may influence firms’ debt costs. A widely used measure of firm size is the natural logarithm of total assets, which reflects a company’s market visibility and reputation, making it attractive to investors and improving credit availability. Moreover, the impact of financial structure on firms’ debt costs is examined using variables, including the debt-to-asset ratio, the proportion of long-term debt, the common stock share, and the external financing ratio, which provide insights into the firm’s leverage and external financing strategies. Furthermore, to explore the potential effects of growth and profitability on firms’ debt expenses, variables such as total asset growth rate, sales revenue to total assets ratio, and gross profit margin are added. Other included variables are cash ratio and shareholder score, which help evaluate a firm’s short-term debt-paying ability and performance concerning shareholder rights and interests. Finally, the industry-average Earnings Before Interest and Taxes (EBIT) is considered to reflect sectoral performance. A detailed description of the variables is provided in Table 3.

4.4. Descriptive statistics

In the sample, the average value of climate change-related regulation is 0.084, as detailed in Table 4. The relatively high standard deviation indicates significant variation in how management and market participants perceive the impact of climate change-related regulations on companies. For firms’ debt costs, the average value is 2.562. The negative values observed may be attributed to a low interest-rate environment and favorable tax policies in certain regions.

5. Empirical results

5.1. Correlation analysis

Table 5 presents the correlation matrix, which indicates that most of the correlation coefficients are below 0.5. Notably, the correlation coefficient between external financing sources and the annual growth rate

Table 2
Distribution of sample by country.

Country/Region	Obs.	Per (%)	Countr/Region	Obs.	Per (%)	Country/Region	Obs.	Per (%)
AE	28	0.09	FI	378	1.16	MX	277	0.85
AR	51	0.16	FR	997	3.05	MY	80	0.24
AT	168	0.51	GB	2475	7.57	NL	387	1.18
AU	1420	4.34	GR	70	0.21	NO	283	0.87
BE	220	0.67	HK	316	0.97	NZ	200	0.61
BM	118	0.36	HU	31	0.09	PE	46	0.14
BR	644	1.97	ID	72	0.22	PH	59	0.18
CA	1925	5.89	IE	373	1.14	PL	86	0.26
CH	682	2.09	IL	117	0.36	PT	91	0.28
CL	146	0.45	IN	664	2.03	QA	11	0.03
CN	268	0.82	IT	383	1.17	RU	217	0.66
CO	53	0.16	JE	33	0.10	SE	724	2.22
CY	10	0.03	JP	1438	4.40	SG	156	0.48
CZ	35	0.11	KR	218	0.67	TH	98	0.30
DE	1072	3.28	KY	33	0.10	TR	114	0.35
DK	299	0.91	LU	73	0.22	TW	218	0.67
EG	23	0.07	MC	20	0.06	US	14,014	42.88
ES	341	1.04	MT	15	0.05	ZA	415	1.27

of total assets is 0.542. Although this correlation coefficient exceeds 0.5, there is still considered to be no serious multicollinearity issue. It is generally believed that a correlation coefficient above 0.7 is the threshold for concern, as demonstrated by Muindi (2016), who treats 0.7 and 0.9 as critical values. Consequently, it can be concluded that multicollinearity is not a concern.

5.2. Main results

Table 6 displays the baseline regression results, with the cost of debt as the key variable of interest. The findings reveal that, after controlling for firm, year, industry, and country fixed effects, a one-standard-deviation increase in climate change-related regulation exposure corresponds to an average increase of approximately 0.018 units in firms' debt costs. Notably, after excluding U.S. companies from the sample, the regression coefficient for climate regulation exposure remains significantly positive. This finding suggests that the impact of climate change-related regulations is pervasive, significantly increasing debt costs across firms.

Most of the control variables exhibit the expected signs. Both leverage and debt maturity show a significant positive impact across all models, which is consistent with the findings of Lim (2011) and Bruche and Segura (2017). Because higher leverage and longer debt maturity increase financial risk, creditors demand higher interest rates for compensation. Sales revenue and gross profit margins significantly reduce debt costs because lenders may view earnings capacity and profitability as indicators of lower risk. This aligns with Muscettola and Naccarato (2016) and Santosuosso (2014), who highlight the positive role of firm profitability in debt financing. Moreover, it is observed that the higher the industry profitability, the lower the firm's debt costs. This finding suggests that firms in more profitable industries are perceived as having lower default risk and are, therefore, charged less for debt financing. This finding supports that of James and Kizilaslan (2014), who demonstrate that higher industry risks lead to higher interest rates from banks. Additionally, the significantly negative coefficient of the asset growth rate suggests that firms experiencing faster asset growth tend to incur lower debt costs. While some researchers argue that firms with growth options often incur higher debt costs owing to increased volatility and greater default risk during economic downturns (Arnold et al., 2013), the findings of this study align with those of Chen and Zhao (2006), who observe a negative correlation between firm growth and debt financing costs for most firms.

A significant positive coefficient for common stock share indicates that a firm's debt costs increase with greater reliance on common stock financing. These results could be due to the passive effects of common stock financing, such as deteriorating financial performance or signaling

financial distress (Achieng et al., 2018; Kim et al., 2019). The coefficient of external financing is insignificant and varies across the sample, indicating that the impact of external financing is uncertain. Shareholder protection significantly reduces debt costs for non-U.S. companies, consistent with Lins (2003) and Chi (2005), who emphasize the benefits of shareholder protection, including restraining managerial agency costs and enhancing firm value. The cash ratio is insignificant, suggesting an uncertain impact of cash holdings. Firm size was significantly positive, as observed by Fard et al. (2020). This result is unexpected because larger firms generally enjoy lower debt costs owing to better access to capital markets. These findings can be attributed to larger firms' greater sensitivity to business cycles in certain industries, as noted by Kumar and Yerramilli (2023). This sensitivity may increase risk during economic downturns, leading to higher debt costs. Finally, the significance of the coefficients for industry profitability, shareholder protection, and firm size changes when U.S. firms are excluded, likely due to the counteracting effect of differences in regional market structures and regulatory environments.

5.3. Robustness

5.3.1. Adding control variables and fixed effects

To address the potential omitted variable bias, this study includes control variables such as total financial sources and ESG performance in the main regression. The regression results in Models (1) to (4) of Table 7 show that climate change-related regulations raise firms' debt costs, with statistical significance at the 5% level. Furthermore, after controlling for various fixed effects, Table 8 shows that the main regression results remain robust.

5.3.2. Lagging the core explanatory variable

Additionally, this study enhances the analysis by incorporating the lagged value of climate change-related regulations, capturing the regulatory impact from the previous period. This lagged variable serves as the core explanatory factor in the regression models. The results from Model (5) in Table 7 confirm the consistent stability of the baseline regression outcomes.

5.3.3. Excluding special samples

In the spirit of Ma et al. (2023) and Cepni et al. (2024), this study sequentially excludes samples from the financial crisis period, the COVID-19 pandemic period, and firms with fewer than five and ten observations, as reported in Columns (1) to (4) of Table 9. Additionally, this study excludes samples corresponding to countries with five or fewer companies, as shown in Column (5) of Table 9. The results confirm the consistent stability of the baseline regression outcomes.

Table 3
Variable description.

Symbol	Variable	Description
KD	Cost of debt	After-tax weighted average cost of debt
Rgexpo	Exposure to climate change-related regulation exposure	Relative frequency with which bigrams representing regulatory shocks related to climate change within earnings call transcripts
Rgpos	Positive exposure to climate change-related regulations	Relative frequency with which bigrams related to climate change regulation are mentioned together with positive tone words
Size	Asset size	The natural logarithm of total assets
Lev	Leverage ratio	The ratio of total liabilities to total assets
Rlgdebt	Long-term debts	Long-term debts as a proportion of total debts
Rsales	Net sales or revenues	The ratio of gross sales and other operating revenue less discounts, returns, and allowances to total assets
Assetgr	Annual growth rate of total assets	(Current Year's total assets/Last Year's total assets - 1) * 100
Rstock	Common stock share	The ratio of common stock to total assets
Rexfinance	External financing	The ratio of outside financing sources to total assets
Gmargin	Gross profit margin	Total sales revenue minus the cost of goods sold, divided by the total sales revenue, expressed as a percentage
Rcash	Cash and equivalents	The ratio of cash and equivalents to total assets
Shareholders	Shareholder score	The score that evaluates a company's practices and performance related to shareholder rights and interests
indEBIT	Industry earnings before interest and taxes	The industrial average ratio of earnings before interest and taxes to total assets
Rtosource	Total sources	The ratio of the total funds generated by the company internally and externally to total assets
ESG1	Refinitiv's ESG score	A score based on the self-reported information in the environmental, social, and corporate governance pillars
ESG2	ESG controversies category score	Exposure to environmental, social, and governance controversies and negative events reflected in global media
ESG3	Refinitiv's ESG combined score	A score based on the reported information in the environmental, social, and corporate governance pillars with an ESG controversies overlay
ROA	Return on assets	12-month trailing return on assets (%)
Rcapital	Capital expenditure	The ratio of the funds used to acquire fixed assets other than those associated with acquisitions to total assets
Beta	The beta factor of a stock	The relative movement of the price against the market
EIS	Environmental innovation score	The capacity to reduce the environmental costs and burdens for its customers, thereby creating new market opportunities through new environmental technologies and processes or eco-designed products

5.3.4. IV regressions for endogeneity

To verify the causal relationship between climate change regulations and firms' debt costs, this study utilizes industry-average climate change regulation exposure as an instrumental variable. This variable is assumed to correlate with an individual firm's exposure to climate change-related regulations while remaining independent of the error

Table 4
Summary statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
KD	32,685	2.562	2.102	-0.113	9.963
Rgexpo	32,685	0.084	0.221	0.000	1.122
Size	32,685	15.343	1.552	11.996	18.692
Lev	32,685	0.577	0.202	0.158	1.094
Rlgdebt	31,813	0.801	0.233	0.005	1.000
Rsales	32,685	0.850	0.566	0.119	2.703
Assetgr	32,685	9.254	20.291	-24.310	91.740
Rstock	32,685	0.085	0.170	0.000	0.807
Rexfinance	32,685	0.004	0.087	-0.191	0.313
Gmargin	32,685	36.677	21.086	1.830	88.420
Rcash	32,685	0.135	0.132	0.004	0.605
Shareholders	32,685	53.464	28.465	2.640	98.370
indEBIT	32,685	0.067	0.039	-0.068	0.122

term. The findings from the two-stage IV regression displayed in Table 10 show that in the first stage, the instrumental variable is significantly positively correlated with the explanatory variable. By passing both the KP-LM test for under-identification and the Cragg-Donald test for weak identification, industry-average exposure is confirmed as a suitable instrumental variable. In the second stage, the instrumented regulatory exposure significantly increases the cost of debt, reinforcing the reliability of the initial findings.

5.4. Heterogeneity

Based on the degree of positive regulatory exposure, the sample is divided into groups experiencing lower and higher positive impacts, referred to as the low and high regulatory opportunity groups, respectively. Regressions conducted on these subsamples, as shown in Table 11, indicate that in samples with smaller regulatory opportunities, climate change-related regulation shocks increase firms' cost of debt. Conversely, the opposite effect is observed in samples with larger regulatory opportunities. This finding suggests that when companies engage in debt financing, the risk premium associated with climate regulation shocks may not necessarily be positive. In other words, if the market recognizes the opportunities brought about by climate change regulations, this may not necessarily lead to an increased debt burden for firms.

In addition, this study examines the impact of beta factors, asset tangibility, and environmental innovation performance on the relationship between firms' debt costs and climate change-related regulations. The results are presented in Tables 12–14. The findings indicate that while climate change-related regulation does not significantly affect debt costs in firms with lower beta values, it does significantly impact those with beta values above the median or 40th percentile. Investors may perceive these firms as facing greater uncertainty or risk, increasing their sensitivity to climate regulations. Furthermore, high-beta firms may encounter substantial financing challenges, causing the market to demand higher risk premiums.

Further analysis of the magnitude and significance of the coefficients of the key explanatory variables in the odd and even rows of Table 13 indicates that companies with higher asset tangibility are more affected by climate regulation. For these companies, the environmental compliance costs imposed by climate change-related regulations are relatively high. Restrictions on carbon emissions and energy usage may necessitate improvements in production processes, including updates to production equipment and assembly lines, as well as the adoption of more environmentally friendly raw materials to meet regulatory standards. Additionally, companies may need to enhance their infrastructure resilience and secure insurance coverage to mitigate potential losses. As environmental costs and regulatory pressures increase, companies may see a sharp decline in the value of existing tangible assets such as power generation facilities and factories, thereby increasing investment uncertainty for creditors and potentially leading to a higher required rate

Table 5
Correlation analysis.

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
KD (a)	1.000								
Rgexpo (b)	-0.007	1.000							
Size (c)	-0.028	0.146	1.000						
Lev (d)	0.020	0.030	0.184	1.000					
Rlgdebt (e)	0.058	0.031	0.070	0.197	1.000				
Rsales (f)	-0.049	-0.107	-0.161	0.112	-0.122	1.000			
Assetgr (g)	0.021	-0.007	-0.045	-0.076	0.001	-0.075	1.000		
Rstock (h)	0.081	0.020	-0.173	-0.178	-0.030	-0.094	-0.030	1.000	
Rexfinance (i)	0.019	0.002	-0.080	0.031	0.060	-0.205	0.542	0.021	1.000
Gmargin (j)	-0.020	-0.079	-0.081	-0.107	0.023	-0.313	0.115	-0.073	0.008
rcash2 (k)	-0.019	-0.104	-0.223	-0.137	-0.143	-0.039	0.139	-0.054	0.151
Shareholders (l)	-0.017	0.038	0.078	0.020	0.012	0.014	-0.024	0.028	-0.022
indEBIT (m)	0.093	-0.018	0.117	0.039	-0.062	0.212	0.014	-0.034	-0.142
	(j)	(k)	(l)	(m)					
Gmargin (j)	1.000								
rcash2 (k)	0.283	1.000							
Shareholders (l)	-0.061	-0.043	1.000						
indEBIT (m)	-0.064	-0.125	-0.003	1.000					

Table 6
Baseline regression.

	With U.S. Firms			Without U.S. Firms
	(1)	(2)	(3)	(4)
	KD	KD	KD	KD
Rgexpo	0.081** (0.04)	0.081** (0.04)	0.081** (0.04)	0.114** (0.05)
Size	0.104*** (0.03)	0.104*** (0.03)	0.104*** (0.03)	0.069 (0.05)
Lev	0.744*** (0.09)	0.744*** (0.09)	0.744*** (0.09)	0.668*** (0.15)
Rlgdebt	1.022*** (0.05)	1.022*** (0.05)	1.022*** (0.05)	1.047*** (0.07)
Rsales	-0.207*** (0.05)	-0.207*** (0.05)	-0.207*** (0.05)	-0.137*** (0.07)
Assetgr	-0.003*** (0.00)	-0.003*** (0.00)	-0.003*** (0.00)	-0.003*** (0.00)
Rstock	0.628*** (0.20)	0.628*** (0.20)	0.628*** (0.20)	0.685*** (0.25)
Rexfinance	0.055 (0.10)	0.055 (0.10)	0.055 (0.10)	-0.037 (0.15)
Gmargin	-0.008*** (0.00)	-0.008*** (0.00)	-0.008*** (0.00)	-0.008*** (0.00)
Rcash	-0.106 (0.13)	-0.106 (0.13)	-0.106 (0.13)	-0.124 (0.22)
Shareholders	-0.000 (0.00)	-0.000 (0.00)	-0.000 (0.00)	-0.001** (0.00)
indEBIT	-0.850** (0.34)	-0.850** (0.34)	-0.850** (0.35)	-0.514 (0.49)
Cons.	0.280 (0.54)	0.280 (0.54)	0.280 (0.54)	0.803 (0.82)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Industry FE	No	Yes	Yes	Yes
Country FE	No	No	Yes	Yes
Cluster by firm	Yes	Yes	Yes	Yes
Obs.	31,146	31,146	31,146	17,934
Adj. R2	0.817	0.817	0.817	0.850

Note: Standard errors are in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

of return.

Finally, according to the regression results in Table 14, companies with superior environmental innovation performance are less affected by climate regulations. This suggests that a firm’s environmental innovation efforts, which enhance its brand image, may be partially factored into financial market valuations, thereby reducing some of the debt financing burden in the context of climate regulations.

5.5. Mechanism

To further examine the impact of climate change-related regulations on firms’ debt costs, this study conducts a mechanism analysis focusing on profitability volatility and capital expenditures. Columns (1), (2), (4), and (5) in Table 15 report the impact of climate-related regulations on ROA volatility, which is calculated using the rolling standard deviation over a 5-year period. In Columns (1) and (4), the dependent variable is ROA volatility, whereas in Columns (2) and (5), it is the volatility of industry-adjusted ROA. The industry-adjusted ROA is calculated by subtracting the industry-average ROA from a firm’s ROA. The findings indicate that climate-related regulations tend to increase profitability volatility both in general and when adjusted for industry effects. Increased profitability volatility often raises concerns among investors and creditors regarding a firm’s financial stability, which can lead to higher risk premiums and, thus, higher debt costs. This finding suggests that profitability volatility can partially account for the mechanisms through which climate-related regulations affect debt costs.

Additionally, as shown in Column (3) of Table 15, firms reduce their capital expenditures in response to increased regulation, which could reflect a strategic decision to limit future investment under regulatory uncertainty. A reduction in capital expenditures typically signals that a company is scaling back its future expansion or investment, which may lead investors and creditors to question its long-term prospects. Such concerns can result in the demand for a higher risk premium, thereby increasing the cost of debt.

It is also notable that while the direction of the effects of climate change-related regulations on profitability volatility and capital expenditures remains consistent regardless of whether U.S. firms are included or excluded, the magnitude of the effects differs, with a less significant impact observed when U.S. firms are excluded. This might reflect the differences in market characteristics or regulatory environments between U.S. and non-U.S. companies. For companies headquartered outside the U.S., information asymmetry may be more pronounced, leading to a slower or inconsistent market response to profitability volatility, resulting in lower significance. These insights highlight that market responses to climate-related regulations can vary depending on location.

6. Conclusion and implications

Existing studies have predominantly focused on the impact of physical or transitional risks on corporate financing, with relatively few studies exploring the regulatory effects of climate change. Using a novel dataset from 54 countries and regions, this study examines the influence

Table 7
Robustness checks I.

	(1)	(2)	(3)	(4)	(5)
	KD	KD	KD	KD	KD
Rgexpo	0.080** (0.04)	0.081** (0.04)	0.081** (0.04)	0.081** (0.04)	
I.Rgexpo					0.076* (0.05)
Size	0.107*** (0.03)	0.101*** (0.03)	0.103*** (0.03)	0.105*** (0.03)	0.109*** (0.04)
Lev	0.728*** (0.09)	0.744*** (0.09)	0.742*** (0.09)	0.743*** (0.09)	0.768*** (0.10)
Rlgdibt	1.018*** (0.05)	1.022*** (0.05)	1.023*** (0.05)	1.023*** (0.05)	0.993*** (0.06)
Rsales	-0.214*** (0.05)	-0.209*** (0.05)	-0.207*** (0.05)	-0.206*** (0.05)	-0.202*** (0.05)
Assetgr	-0.003*** (0.00)	-0.003*** (0.00)	-0.003*** (0.00)	-0.003*** (0.00)	-0.003*** (0.00)
Rstock	0.625*** (0.20)	0.629*** (0.20)	0.627*** (0.20)	0.627*** (0.20)	0.724*** (0.22)
Rexfinance	0.049 (0.10)	0.054 (0.10)	0.054 (0.10)	0.055 (0.10)	0.178 (0.11)
Gmargin	-0.009*** (0.00)	-0.009*** (0.00)	-0.008*** (0.00)	-0.008*** (0.00)	-0.009*** (0.00)
Rcash	-0.091 (0.13)	-0.106 (0.13)	-0.105 (0.13)	-0.105 (0.13)	-0.089 (0.14)
Shareholders	-0.000 (0.00)	-0.000 (0.00)	-0.000 (0.00)	-0.000 (0.00)	-0.000 (0.00)
indEBIT	-0.868** (0.35)	-0.845** (0.34)	-0.852** (0.35)	-0.853** (0.35)	-0.432 (0.37)
Rtosource	0.136** (0.05)				
ESG1		0.001 (0.00)			
ESG2			-0.000 (0.00)		
ESG3				-0.000 (0.00)	
Cons.	0.218 (0.54)	0.296 (0.54)	0.318 (0.55)	0.275 (0.54)	0.103 (0.62)
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Cluster by firm	Yes	Yes	Yes	Yes	Yes
Obs.	31,146	31,146	31,146	31,146	25,245
Adj. R ²	0.817	0.817	0.817	0.817	0.825

Note: Standard errors are in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

Table 8
Robustness checks II.

	(1)	(2)	(3)
	KD	KD	KD
Rgexpo	0.081** (0.04)	0.081** (0.04)	0.081** (0.04)
Cons.	0.280 (0.54)	0.280 (0.55)	0.280 (0.54)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	No
Year FE	Yes	Yes	Yes
Industry FE	No	No	No
Country FE	Yes	No	Yes
Industry# country FE	No	Yes	No
Firm# industry FE	No	No	Yes
Cluster by firm	Yes	Yes	Yes
Obs.	31,146	31,146	31,146
Adj. R ²	0.817	0.815	0.817

Note: Standard errors are in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

of exposure to climate change regulation shocks on firms' debt costs. The key findings reveal that, on average, exposure to climate change regulations increases firms' debt costs. However, this trend is reversed in

Table 9
Robustness checks III.

	(1)	(2)	(3)	(4)	(5)
	KD	KD	KD	KD	KD
Rgexpo	0.088** (0.04)	0.090** (0.04)	0.087** (0.04)	0.090* (0.05)	0.078** (0.04)
Cons.	0.529 (0.53)	0.417 (0.58)	0.114 (0.57)	-0.169 (0.74)	0.338 (0.54)
Controls	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Cluster by firm	Yes	Yes	Yes	Yes	Yes
Obs.	28,465	27,872	27,219	16,726	30,999
Adj. R ²	0.830	0.804	0.811	0.801	0.817

Note: Standard errors are in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

firms that encounter greater opportunities under climate change regulations, suggesting that the climate change regulatory risk premium may not necessarily be positive.

The results further indicate that the unfavorable regulatory impact is more pronounced in corporations with a higher beta, greater asset

Table 10
Analysis for endogeneity concerns.

	First Stage rgexpo	Second Stage KD
Rgexpo		0.611*** (0.165)
Instru	1.090*** (0.051)	
Controls	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Industry FE	Yes	Yes
Country FE	Yes	Yes
Cluster by firm	Yes	Yes
Obs.	31,146	31,146
Adj. R ²	0.489	0.048
KP-LM	249.06	
p-value	0.000	
Cragg-donald wald	2215.15	

Note: Standard errors are in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

tangibility, and poorer environmental innovation performance. Additionally, the adverse effects on debt costs are partly attributable to the heightened profitability volatility and diminished growth prospects arising from reduced capital expenditures. These findings offer insights into refining climate regulation policies and facilitating corporate transitions toward environmentally sustainable practices. The key policy insights are threefold.

First, this study establishes that regulations associated with climate change generally tend to increase the pressure on corporate debt financing. To circumvent the potential vicious cycle of “aggravated

climate regulatory risks—escalating debt expenses—diminished green investment—further intensified climate regulatory risks,” it is crucial to promote a diverse array of financing channels for corporations. Harnessing green finance to stimulate environmental innovation and sustainable investment can enhance firms’ resilience to climate change risks, thereby mitigating part of the adverse effects of climate change regulations.

Second, establishing differentiated regulatory frameworks that prioritize the transitional nature and adaptability of various types of corporations is crucial. Policies must consider the diverse sensitivities and levels of adaptability of corporations to climate change-related regulations. Particularly when crafting and implementing regulations, policymakers need to account for the impact on firms with a higher beta value, greater asset tangibility, and weaker environmental innovation performance. By setting phased objectives and providing adaptive support measures, such as preferential financing and tax incentives, corporations may be encouraged to enhance their environmental performance, and transitional costs could potentially be alleviated.

Third, establishing a fair and transparent environmental performance evaluation system is of paramount importance. This study reveals that climate change-related regulations can reduce debt expenses for firms with greater opportunities, underscoring that effective climate policies may not only advance environmental conservation and sustainable growth but also provide economic advantages for businesses. However, owing to inadequate risk assessments and issues with information asymmetry, the market may misinterpret climate regulation as a risk rather than an opportunity. Therefore, governments need to promote the implementation of a fair and transparent environmental

Table 11
Heterogeneity analysis I.

	(1)	(2)	(3)	(4)	(5)	(6)
	KD	KD	KD	KD	KD	KD
	rgpos < Median	rgpos ≥ Median	rgpos < 60% percentile	rgpos ≥ 60% percentile	rgpos < 90% percentile	rgpos ≥ 90% percentile
Rgexpo	0.149** (0.07)	−0.166** (0.08)	0.149** (0.07)	−0.166** (0.08)	0.130** (0.06)	−0.177** (0.08)
Cons.	0.351 (0.57)	−2.306 (1.69)	0.351 (0.57)	−2.306 (1.69)	0.394 (0.56)	−2.885 (1.91)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Cluster by firm	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	27,396	2859	27,396	2859	27,861	2420
Adj. R ²	0.816	0.822	0.816	0.822	0.816	0.827

Note: Standard errors are in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

Table 12
Heterogeneity analysis II.

	(1)	(2)	(3)	(4)	(5)	(6)
	KD	KD	KD	KD	KD	KD
	Beta < Median	Beta ≥ Median	Beta < 40% percentile	Beta ≥ 40% percentile	Beta < 60% percentile	Beta ≥ 60% percentile
Rgexpo	0.018 (0.05)	0.100* (0.06)	0.042 (0.06)	0.136** (0.05)	0.026 (0.05)	0.094 (0.06)
Cons.	−0.776 (0.83)	1.245* (0.72)	−0.626 (0.95)	0.951 (0.68)	−0.474 (0.75)	1.526* (0.82)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Cluster by firm	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	15,209	15,126	12,074	18,275	18,412	11,944
Adj. R ²	0.847	0.796	0.855	0.799	0.841	0.793

Note: Standard errors are in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

Table 13
Heterogeneity analysis III.

	(1)	(2)	(3)	(4)	(5)	(6)
	KD	KD	KD	KD	KD	KD
	Tangi < Median	Tangi ≥ Median	Tangi < 40% percentile	Tangi ≥ 40% percentile	Tangi < 60% percentile	Tangi ≥ 60% percentile
Rgexpo	0.008 (0.05)	0.144** (0.06)	0.002 (0.06)	0.133** (0.05)	0.044 (0.05)	0.122* (0.07)
Cons.	-1.277 (0.82)	1.149 (0.87)	-0.994 (0.96)	0.775 (0.77)	-0.758 (0.72)	1.131 (1.01)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Cluster by firm	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	15,703	14,803	12,488	18,028	18,902	11,651
Adj. R ²	0.817	0.827	0.821	0.821	0.817	0.829

Note: Standard errors are in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

Table 14
Heterogeneity analysis IV.

	(1)	(2)	(3)	(4)	(5)	(6)
	KD	KD	KD	KD	KD	KD
	EIS < Median	EIS ≥ Median	EIS < 40% percentile	EIS ≥ 40% percentile	EIS < 60% percentile	EIS ≥ 60% percentile
Rgexpo	0.165** (0.07)	-0.013 (0.04)	0.154** (0.07)	-0.007 (0.04)	0.113** (0.06)	0.011 (0.05)
Cons.	1.274* (0.73)	-1.051 (0.86)	1.360* (0.74)	-1.069 (0.84)	1.052 (0.68)	-0.597 (1.00)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Cluster by firm	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	14,972	15,783	14,896	15,869	18,133	12,580
Adj. R ²	0.819	0.830	0.819	0.831	0.817	0.829

Note: Standard errors are in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

Table 15
Potential channels.

	With U.S. firms			Without U.S. firms		
	(1)	(2)	(3)	(4)	(5)	(6)
	vROA1	vROA2	rcapital	vROA1	vROA2	rcapital
Rgexpo	0.010*** (0.00)	0.008*** (0.00)	-0.003*** (0.00)	0.007* (0.00)	0.006* (0.00)	-0.002* (0.00)
Cons.	0.136*** (0.05)	0.111** (0.05)	0.077*** (0.01)	0.202*** (0.07)	0.153** (0.06)	0.108*** (0.02)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Cluster by firm	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	26,562	26,562	31,146	15,342	15,342	17,934
Adj. R ²	0.682	0.653	0.737	0.654	0.627	0.723

Note: Standard errors are in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

performance assessment system and establish unified standards for climate risk and opportunity reporting. Additionally, they should enhance the quality and consistency of climate-related financial disclosures to help investors and creditors identify opportunities presented by climate change-related regulations more accurately.

CRedit authorship contribution statement

Wenwen Jin: Conceptualization, Methodology, Writing – original

draft, Data curation, Funding acquisition. **Yu Wang:** Writing – original draft, Data curation, Funding acquisition.

Data availability

The authors do not have permission to share the data.

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No potential conflict of interest was reported by the authors.

Inclusion and diversity

The author list for this paper includes contributors from the location where the research was conducted who participated in the data curation, design, analysis, and interpretation of the work.

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