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When climate risk hits corporate value: The moderating role of financial constraints, flexibility, and innovation

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ABSTRACT

This study examines the relationship between firms' exposure to climate risk and their market value using global data from 2002 to 2022. A significant negative relationship between climate risk and firm value is identified, with geographic variation in impact severity. Asia faces the highest risk, followed by Europe, North America, and others. Policy events like the Stern Review and the Paris Agreement influence this relationship. Financial constraints exacerbate the negative effects of climate risk, while financial flexibility and R&D mitigate them. Firms in environmentally sensitive sectors and outside the United States are more vulnerable, and non-G20/non-OECD countries face greater climate challenges.

1. Introduction

Climate change has become a critical global challenge with significant implications for businesses and economies. The increasing frequency of climate events and stricter regulations have reshaped the business landscape, making it essential for investors, policymakers, and corporate strategists to understand how climate risks affect firm value. This study addresses a key gap in the literature by exploring how climate change risks impact firm value across different regions and economic contexts. The economic literature on climate risk dates back to Nordhaus (1977) and has evolved with key events like the "*Kyoto Protocol*", the "*Stern Review*", the "*Paris Accord*", and the "*Task Force on Climate-related Financial Disclosures (TCFD)*", culminating in the 2023 IFRS S1 and S2[1] standards. These developments link climate risk exposure (CREXP) to firm value, underscoring the importance of finance and management theories in analysing this relationship.

While research on the impact of CREXP on firms' financial decisions is growing (Berkman et al., 2024; Huang et al., 2018; Krueger et al., 2020), there is limited understanding of how company-specific CREXP affects operational decisions (Kim et al., 2023). This gap may stem from the difficulty in evaluating the full impact of CREXP on individual firms. Traditionally, companies assessed vulnerability through metrics like carbon emissions and extreme weather events (Farajzadeh et al., 2023; Hsiang and Jina, 2014). However, as Giglio et al. (2021) note, determining how specific firms are impacted by climate change is complex. To address this, Sautner et al. (2023a) developed time-varying metrics that capture how management and analysts perceive CREXP, offering a more nuanced view of

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[1] The "International Sustainability Standards Board (ISSB)" has issued its inaugural standards, IFRS S1 and IFRS S2, marking a new era of sustainability-related disclosures in global capital markets. These standards aim to enhance trust in company disclosures and inform investment decisions, providing a unified framework for reporting the impact of climate-related risks and opportunities on a company's prospects. Details available at https://www.ifrs.org/news-and-events/news/2023/06/issb-issues-ifrs-s1-ifrs-s2/.

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firms' exposure to climate-related concerns.

Existing literature has explored various dimensions of CREXP and its economic consequences.[2] However, a comprehensive analysis integrating geographic distribution, financial flexibility (FF), and innovation strategies remains scarce. This study addresses this gap by investigating the relationship between CREXP and firm value, focusing on the moderating roles of financial constraints (FCON), FF and R&D intensity (RDI).

The novelty of this research lies in its multifaceted approach. First, it examines the geographic distribution of CREXP and its impact on firm value across North America, Europe, Asia, and the Southern Hemisphere. CREXP vary by region, with developed regions like North America and Europe facing transition risks due to stringent climate policies but benefiting from strong economic structures. In contrast, Asia and the Southern Hemisphere are more exposed to physical risks, such as extreme weather and sea-level rise, due to their geographic locations and rapid industrialisation. This study highlights the need for tailored policy interventions, as strategies effective in one region may not work in another.

Second, this study explores country-level mechanisms through which technological readiness, socioeconomic development, regulatory environment, and institutional factors moderate CREXP impacts on firms. This multifaceted approach provides a thorough understanding of the complex relationship between national-level factors and firm-level responses to CREXP. Third, this study examines how FF, FCON, and RDI moderate the relationship between CREXP and firm value. FF, representing a firm's ability to access and deploy financial resources, enables firms to invest in climate risk mitigation and withstand economic shocks. In contrast, FCON firms face challenges in addressing climate risks due to limited internal cash flow and restricted external capital access. Similarly, R&D-intensive firms are better positioned to develop technologies for climate risk adaptation and mitigation.

Finally, to enrich the analysis further, this study conducts quasi-natural experiments using the Stern Review and the Paris Agreement as exogenous shocks. These landmark events, the Stern Review highlighting climate change's economic implications and the Paris Agreement setting global temperature targets, provide insights into how policy interventions shape the relationship between CREXP and firm value.

The remainder of this paper is structured as follows. Section 2 describes research methods. Section 3 empirical results and discussion. Finally, Section 4 concludes the paper.

2. Research methods

2.1. Data and variables

We analyse a global sample of 7,416 firms from 2002 to 2022, yielding 59,740 firm-year observations. The unavailability of climate risk proxy data prior to 2002 determines our dataset's starting point. We exclude financial and utility firms due to their distinct regulatory environment and capital structure characteristics. Our dependent variable is the firm value measured through Tobin's Q. The key independent variable is the CREXP measure developed by Sautner et al. (2023b) .[3] Following the existing norm of corporate finance and especially studies of climate risk (Agoraki et al., 2024; Feng et al., 2024; Ferdous et al., 2024; Hossain et al., 2023; Javadi et al., 2023; Sautner et al., 2023c) we employ size, leverage (LEVER), sales growth (SAGR), asset tangibility (ASTA) and capital expenditure (CAEX) as control variables.

We employ FF, FCON, and RDI as moderating variables. Whited-Wu Index (WWI) utilised to measure FCON. We measure FF with two indicators: "cash holdings" and "debt levels." RDI is measured as R&D expenses to total assets ratio. The measurement of variables is provided in Appendix Table A1.

2.2. Model setting

The study employs several empirical models to examine the relationship between CREXP and firm value, as well as the moderating roles of FCON, FF and RDI. Our baseline model specification is in Eq. (1).

$$Firm's\ Value_{i,t} = \alpha_1 + \beta_1 CREXP_{i,t} + \gamma_1 \sum Controls_{i,t} + \varepsilon_{i,t} \tag{1}$$

For quasi-natural experiments, we explore the Stern Review and the Paris Agreement. The model includes interaction terms between CREXP and event dummies Eq. (2).

$$Firm's\ Value_{i,t} = \alpha_1 + \beta_1 CREXP_{i,t} + \beta_2 SEvent\_Dummy_{i,t} + \beta_3 \left(CREXP_{i,t} \times Event\_Dummy_{i,t} \right) + \gamma_1 \sum Controls_{i,t} + \theta_i + \varepsilon_{i,t} \tag{2}$$

We employ FF, FCON, and RDI as moderating variables, which provide a multi-faceted view of how a firm's financial health and strategic priorities interact with climate risks. This approach allows for a more differentiated analysis of the impacts of climate change on firm value by considering the dual role of financial health (through FF and FCON) in enabling or hindering a firm's response to

[2] For example, impact of climate risk on bank loan pricing (Ge et al., 2024), market efficiency (Hong et al., 2019), institutional investors (Ilhan et al., 2023), stock market/prices (Khalfaoui et al., 2022; Liesen et al., 2017; Sautner et al., 2023), firm value (Bagh et al., 2024; Li et al., 2024; Lucas & Mendes, 2018; Sato et al., 2024), CSR performance (Mbanyele & Muchenje, 2022), volatility (Zhao et al., 2024; Naseer et al., 2024), and stock price informativeness (Wang & Li, 2023).

[3] Data is available at https://doi.org/10.17605/OSF.IO/FD6JQ.

climate risks. And the innovation capability (via RDI) as a strategic asset in climate risk mitigation and adaptation strategies. The following Eq. (3) empirical model is specified to study the moderating relationships.

$$Firm's\ Value_{i,t} = \alpha_1 + \beta_1 CREXP_{i,t} + \beta_2 M_{i,t} + \beta_3 \left(CREXP_{i,t} \times M_{i,t}\right) + \gamma_1 \sum Controls_{i,t} + \theta_i + \varepsilon_{i,t} \tag{3}$$

CREXP is a firm climate change risk and control variables, including size, LEVER, SAGR, ASTA and CAEX. $M_{i,t}$ represents the moderating variable (e.g. either FF, FCON and RDI), θ_i represents firm-specific fixed effects, ε is the error term, i for firm and t for year.

Robustness tests include re-estimating models excluding the financial crisis, subsample analyses, using alternative measures of firm value and CREXP, performing quantile regressions and GMM estimations.

3. Analysis and results

3.1. Summary and correlation statistics

Table 1 provides descriptive statistics of variables for the sample companies and provides insights into data variation and distribution, essential for econometric analysis. Firm value has a mean value of 2.010 with a standard deviation of 1.510, suggest considerable variability in firm values across sample firms globally. The CREXP minimum value is 0, and the maximum is 5.560 with a 0.118 mean value and 0.282 standard deviations. Table 2 presents the correlation matrix for the variables, offering an initial view of their interrelationships. Notably, CREXP exhibits a significant negative correlation with firm value. Among the control variables, LEVER, ASTA, and CAEX show negative correlations, whereas SIZE and SAGR are positively correlated with firm value. To assess multicollinearity, we conducted a Variance Inflation Factor (VIF) test. The results show an average VIF of 1.26 for all variables, with individual VIFs below 10, indicating no concerns of multicollinearity in our analysis.

3.2. Baseline analysis

After the initial descriptive statistics, we performed the stepwise regression analysis using OLS with robuststandard error. The results are presented in Table 3. All models have a negative CREXP coefficient, demonstrating a significant association between CREXP and firm value.

3.3. Endogeneity concerns and further analysis

To ensure robustness, we conducted additional analyses using alternative fixed effects, year, country and industry. Results in Table 4 confirm the consistency of our findings across model specifications. To address potential simultaneity between CREXP and firm value, we reanalysed the primary model using one-year lagged values for both variables. We also applied propensity score matching (PSM) to mitigate selection bias, and to handle zero CREXP values, we repeated the analysis excluding firms with zero CREXP, confirming consistent results. We tested for bias from the 2008–2009 global financial crisis (GFC) by including a GFC dummy and excluding these years, with results in Table 4 remains robust. Additionally, separate analyses provided in Table 5 for U.S. and non-U.S. firms revealed consistent results with minor differences (p-value<0.1). Industry-specific effects showed a stronger negative relationship between CREXP and firm value in environmentally sensitive sectors, supported by a significant coefficient equivalence test (p-value<0.01), in line with legitimacy theory.

3.4. Changes in investors' awareness

To address potential endogeneity concerns and establish a causal link between CREXP and firm value, we use the Stern Review[4,5] as an exogenous shock to CREXP, we hypothesise that post-Stern, investors and regulators became more aware of climate risks, making CREXP more influential on firm value. We test this by creating an indicator variable, *Post_Stern*, for the years 2007–2008 and an interaction term *CREXP* × *Post_Stern*. Analysis in Table 6 reveals that after the Stern Review, firms with higher CREXP were viewed more favourably due to increased awareness of climate-related opportunities.

The *Paris Agreement*[6] with enforceable commitments, represents a major milestone in climate risk management. We hypothesise that this agreement significantly impacts the relationship between CREXP and firm value. Using the *Post_Paris* indicator (2017–2019)

[4] The Stern Review, a comprehensive UK Government-sponsored analysis spanning over 700 pages, is widely regarded as the first in-depth economic study detailing the profound impact of climate change on the global economy.

[5] Published 30 October 2006 "This Review has assessed a wide range of evidence on the impacts of climate change and on the economic costs and has used a number of different techniques to assess costs and risks. From all of these perspectives, the evidence gathered by the Review leads to a simple conclusion: the benefits of strong and early action far outweigh the economic costs of not acting."

[6] As stated by the United Nations Climate Change (UNCCC) website, the Paris Agreement is a legally binding international treaty on climate change, adopted by 196 Parties at COP 21 in Paris on December 12, 2015, and entered into force on November 4, 2016, with the primary objective to limit global warming to well below 2 degrees Celsius, preferably 1.5 degrees, compared to preindustrial levels. To achieve this, countries aim to peak greenhouse gas emissions as soon as possible and strive for a climate-neutral world by mid-century.

Table 1
Descriptive statistics.

Variables	N	Mean	SD	Min	Q25	Median	Max
Firm value	59,740	2.010	1.510	0.527	1.140	1.520	10.700
CREXP	59,740	0.118	0.282	0.000	0.012	0.034	5.560
SIZE	59,740	7.757	2.470	0.000	3.027	7.105	70.700
LEVER	59,740	0.281	0.156	0.001	0.182	0.299	0.900
SAGR	59,740	0.972	0.371	−8.100	−0.077	0.944	7.050
ASTA	59,740	0.270	0.250	0.000	0.071	0.175	0.931
CAEX	59,740	0.049	0.056	0.000	0.014	0.031	0.367
FF	59,740	0.023	0.209	−1.270	−0.041	0.000	1.760
FCON	59,740	0.030	0.364	−6.760	−0.010	0.000	4.500
RDI	59,740	0.050	0.092	0.000	0.000	0.002	0.455

The table presents the descriptive statistics for study variables. The sample spans from 2002 to 2022 and includes 7416 firms globally. Measurement of variables provided in appendix Table A1.

and its interaction term with CREXP, we find that firms with higher CREXP experience changes in market value due to heightened regulatory and societal pressures. The coefficients equivalence test shows a significant difference ($p = 0.032$), indicating that Post_-Paris, firm value responds differently to CREXP as firms adapt to new regulations and investor expectations.

3.5. *Geographic distribution and economic development*

We analysed the geographic distribution of CREXP and its impact on firm value across four regions: North America, Europe, Asia, and Southern Hemisphere countries (Table 7). CREXP negatively affects firm value in all regions, with the strongest impact in Asia (−0.718***), followed by Europe (−0.634***), North America (−0.155***), and the Southern Hemisphere (−0.092). Asia's high impact suggests greater exposure to physical risks and challenges in transitioning to a low-carbon economy. G20 countries show a milder negative relationship (−0.191***) compared to non-G20 developing countries (−0.321***), while OECD countries experience a lower impact (−0.176***) than non-OECD countries (−0.372***), reflecting stronger economies and better climate policies. These findings highlight the disproportionate challenges faced by developing nations in managing climate risks.

3.6. *Alternative measures and estimators*

To ensure the robustness of our findings, we supplement our primary model with alternative measures[7] of firm value (Table 8). Additionally, we use GHG emissions as an alternative measure of climate risk, confirming that the negative impact on firm value remains consistent (Table 9). To further explore the relationship, we employ quantile regression analysis across multiple quantiles, revealing that the negative effect of CREXP persists at all levels of firm value distribution (Table 10). We employ the dynamic system GMM estimator following Wintoki et al. (2012) to address potential dynamic endogeneity from changes in CREXP, using a two-step approach that manages dynamic and simultaneous endogeneity and unobservable heterogeneity. We incorporate the lag of the dependent variable and other endogenous controls as regressors, treating the lags of these variables as instruments per (Arellano and Bover, 1995; Blundell and Bond, 1998) to mitigate biases from omitted variables. Our results, detailed in Table 10, show that the coefficients of climate change risk are negative and statistically significant.

3.7. *Moderation analysis*

We examine country-level moderators through which CREXP affects firm value, focusing on technological, socioeconomic, regulatory, and reputational risks. Technological readiness, such as renewable energy adoption, and socioeconomic factors like development level influence resilience and the ability to address climate risks. Regulatory policies, including governance quality, affect climate regulation predictability. Our analysis in Table 11 shows that economic development factors (e.g., per capita GDP, manufacturing-share) and renewable energy transition have limited impact. However, institutional and socio-political factors, particularly the rule of law and civic participation, positively influence firm value. The interaction of CREXP with strong governance (rule of law and voice) suggests that firms in stable, democratic countries are viewed as less exposed to climate risk, enhancing investor confidence. Thus, while economic and energy factors are less influential, strong governance and socio-political stability significantly mitigate CREXP's negative impact on firm value.

Financially constrained firms with limited cash flow and capital access struggle more with climate-related risks, making it harder to absorb carbon costs and invest in emission-reducing technologies. We hypothesise that CREXP has a stronger negative impact on the value of these firms. Using the WWI, firms above the median are classified as constrained. Results in Table 12 show a larger negative coefficient for constrained firms. A seemingly unrelated regression (SUR) approach confirms the distinct effects of CREXP on firm value

[7] Alternative measures of firm value including Return on Assets (ROA), Return on Equity (ROE), Sustainable Growth Rate (SGR), Earnings Per Share (EPS), and Stock Prices.

Table 2
Pairwise correlations and VIF.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	VIF
(1) Firm value	1.000***										–
(2) CREXP	−0.081***	1.000									1.04
(3) SIZE	0.080***	0.025***	1.000								1.01
(4) LEVER	−0.132***	0.030***	−0.029***	1.000							1.07
(5) SAGR	0.126***	−0.003	0.014***	−0.009**	1.000						1.01
(6) ASTA	−0.243***	0.176***	−0.008*	0.235***	−0.016***	1.000					1.79
(7) CAEX	−0.060***	0.057***	0.057***	0.053***	0.050***	0.615***	1.000				1.66
(8) FF	0.036****	0.000	−0.005	−0.129***	−0.040***	−0.031***	−0.048***	1.000			–
(9) FCON	−0.012***	−0.004	0.023***	0.011***	0.114***	0.017***	0.010**	−0.012***	1.000		–
(10) RDI	0.332***	−0.081***	−0.048***	−0.158***	−0.001	−0.352***	−0.197***	0.011***	−0.031***	1.000	–
Mean VIF											1.26

Measurement of variables provided in appendix Table A1. Asterisks ***, **, and * denote significance levels of 1 %, 5 %, and 10 %, respectively.

Table 3
Baseline regression analysis.

Dependent variable = Firm value Variables	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) OLS
CREXP	−0.432***	−0.452***	−0.459***	−0.439***	−0.434***	−0.236***	−0.202***
	(0.022)	(0.022)	(0.022)	(0.021)	(0.021)	(0.021)	(0.021)
SIZE			0.043***	0.041***	0.040***	0.040***	0.034***
			(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
LEVER				−1.277***	−1.271***	−0.799***	−0.679***
				(0.039)	(0.038)	(0.038)	(0.038)
SAGR					0.498***	0.491***	0.461***
					(0.016)	(0.016)	(0.016)
ASTA						−1.271***	−1.801***
						(0.024)	(0.031)
CAEX							3.669***
							(0.134)
Constant	2.061***	1.700***	1.682***	2.031***	2.029***	2.251***	2.182***
	(0.007)	(0.035)	(0.035)	(0.036)	(0.036)	(0.035)	(0.035)
Observations	*59,740*	*59,740*	*59,740*	*59,740*	*59,740*	*59,740*	*59,740*
Year Fixed	*No*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Adj. R-squared	*0.007*	*0.035*	*0.040*	*0.057*	*0.072*	*0.112*	*0.123*

This table presents the results of our baseline regression analysis, where we sequentially introduce year-fixed effects and control variables across seven models. Model 1 serves as the baseline. Model 2 adds the direct impact of CREXP on firm value with year-fixed effects. Subsequent models incrementally introduce additional controls: Model 3 incorporates SIZE alongside year-fixed effects, continuing through Model 7, which includes all control variables with year-fixed effects. The sample spans from 2002 to 2022 and includes 7416 firms globally. Measurement of variables provided in appendix Table A1. Below the coefficients, the standard errors are presented in parentheses and asterisks ***, **, and * denote significance levels of 1 %, 5 %, and 10 %, respectively.

Table 4
Treatment of zero values and GFC.

Dependent variable = Firm value	(1)	(2)	(3)	(4)	(5)	(6)	(7)
CREXP × GFC							**0.379*** **
							(0.059)
GFC_dummy						**−0.459*** **	**−0.505*** **
						(0.160)	**(0.162)**
CREXP	**−0.188*** **	**−0.221*** **	**−0.203*** **	**−0.175*** **	**−0.215*** **	**−0.188*** **	**−0.232*** **
	(0.039)	**(0.034)**	**(0.049)**	**(0.039)**	**(0.037)**	**(0.044)**	**(0.043)**
SIZE	0.042***	0.032***	0.046***	0.041***	0.042***	0.040***	0.040***
	(0.009)	(0.008)	(0.010)	(0.009)	(0.009)	(0.010)	(0.010)
LEVER	−0.697***	−0.477***	−0.743***	−0.695***	−0.737***	−0.651***	−0.650***
	(0.119)	(0.120)	(0.143)	(0.119)	(0.123)	(0.113)	(0.113)
SAGR	0.451***	0.471***	0.438***	0.501***	0.450***	0.437***	0.437***
	(0.042)	(0.057)	(0.044)	(0.048)	(0.045)	(0.039)	(0.038)
ASTA	−1.715***	−1.453***	−1.717***	−1.649***	−1.795***	−1.739***	−1.735***
	(0.108)	(0.106)	(0.106)	(0.111)	(0.102)	(0.109)	(0.110)
CAEX	3.714***	2.891***	3.904***	3.413***	3.870***	3.122***	3.110***
	(0.417)	(0.385)	(0.403)	(0.427)	(0.439)	(0.450)	(0.451)
Observations	*59,740*	*43,837*	*45,642*	*49,458*	*53,636*	*59,740*	*59,740*
Year Fixed	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Country Fixed	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Adj. R-squared	*0.140*	*0.145*	*0.131*	0.146	0.134	0.103	0.104

The table presents the fixed effect regression estimates. Model 1 estimates the direct impact of variables using fixed effect regression. Model 2 incorporates one-year lagged values of firm-level CREXP and control variables to analyse delayed effects. Model 3 presents PSM sample analysis, Model 4 presents the treatment of zero values of climate risk exposure (CREXP), Model 5 excludes GFC from the sample period, and Model 6 GFC_dummy is included as a control variable, while Model 7 presents the interaction effect of GFC_dummy between CREXP and firm value. We added country and year-fixed effects in all models. The sample spans from 2002 to 2022 and includes 7416 firms globally. Measurement of variables provided in appendix Table A1. Below the coefficients, the standard errors are presented in parentheses and asterisks ***, **, and * denote significance levels of 1 %, 5 %, and 10 %, respectively.

between constrained and unconstrained groups (p-value$<$0.01). The interaction term is negative and significant, showing that FCON exacerbates the impact of CREXP on firm value, highlighting the role of FCON in this relationship.

Table 13 shows that firms with higher-FF are better able to mitigate the negative impact of CREXP on firm value. Firms were classified into low and high-FF based on the median value, with results indicating a more pronounced negative effect of CREXP in low-FF firms. The positive and significant interaction term suggests that higher-FF buffers the adverse effects of CREXP. Using a SUR approach and a coefficients equivalence test (p-value$<$0.01), we find significant differences between the two groups. This supports the

Table 5
Sub-sample analysis.

Dependent variable = Firm value	Non-USA (1)	USA (2)	CREXP × USA (3)	Env. Sensitive (4)	Others (5)	CREXP × Env. Sensitive (6)
CREXP × USA			**−0.089***			
			(0.048)			
CREXP × Env. Sen						**0.284*****
						(0.047)
USA			−0.270***			
			(0.015)			
Env. Sensitive						−0.169***
						(0.028)
CREXP	**−0.284*****	**−0.142*****	−0.168***	**−0.245*****	**−0.093*****	−0.310***
	(0.035)	**(0.026)**	(0.024)	**(0.028)**	**(0.021)**	(0.028)
Controls	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Coefficient Equi. Test			*0.063*			*0.000*
Observations	*14,704*	*45,036*	*59,740*	*5,764*	*53,976*	*49,247*
Adj. R-squared	*0.104*	*0.091*	*0.101*	*0.085*	*0.082*	*0.106*

Note: This table shows the results for firm value. Column (1) presents findings for firms excluding those based in the USA, while Column (2) focuses on USA firms. Column (3) provides the interaction results for the USA dummy variable (where USA = 1 and non-USA = 0). Column (4) shows the results for firms in environmentally sensitive industries, and Column (5) presents the results for firms outside these industries. Column (6) reports the interaction results for the environmentally sensitive industries dummy variable. Coefficient equivalence test = test _b[1.CREXP × USA or Env. Sensitive] = _b[0.CREXP × USA or Env. Sensitive]. Measurement of variables provided in appendix Table A1. Below the coefficients, the standard errors are presented in parentheses and asterisks ***, **, and * denote significance levels of 1 %, 5 %, and 10 %, respectively.

Table 6
Exogenous shocks.

Dependent variable = Firm value	(1)	(2)
CREXP × Post Stern	**0.220***	
	(0.115)	
CREXP × Post Paris		**0.110****
		(0.052)
Post Stern	−0.421***	
	(0.025)	
Post Paris		−0.098***
		(0.016)
CREXP	−0.128	−0.035
	(0.098)	(0.078)
Controls	*Yes*	*Yes*
Coefficient Equi. Test	*0.055*	*0.032*
Observations	11,226	16,647
Adj. R-squared	0.113	0.744

This table is based on quasi-natural experiments, using two significant historical events during the sample period as external shocks: the release of the Stern Review in 2006 and the enactment of the Paris Agreement in 2016. Column (1) reflects the impact of the Stern Review, while Column (2) captures the effects of the Paris Agreement. Coefficient equivalence test = test _b[1.CREXP × Post Stern or Post Paris] = _b[0.CREXP × Post Stern or Post Paris]. Measurement of variables provided in appendix Table A1. Below the coefficients, the standard errors are presented in parentheses and asterisks ***, **, and * denote significance levels of 1 %, 5 %, and 10 %, respectively.

idea that FF enables firms to invest in climate risk mitigation, improve resilience, and adapt to environmental changes, ultimately protecting firm value.

Table 14 shows the moderating effect of RDI on the relationship between CREXP and firm value. Firms were classified into low and high-RDI subgroups based on the median RDI. The negative impact of CREXP on firm value is more pronounced for low-RDI firms. A coefficients equivalence test (p-value<0.01) reveals significant differences between the two groups. The results indicate that high-RDI helps firms better mitigate the negative effects of CREXP, leading to a less severe decline in firm value.[8] The positive interaction term

[8] The moderating effect of R&D intensity is analysed through dynamic capabilities theory (Teece et al., 1997), which argues that high R&D intensity equips firms to innovate and adapt in dynamic environments, including climate change impacts. Supporting this, Flammer and Ioannou (2021) observed that firms with substantial R&D investments demonstrated greater resilience during the COVID-19 crisis. Similarly, Cooper et al. (2022) found that high R&D intensity correlates with reduced stock price crash risk, suggesting that R&D-driven innovation contributes to firm stability. Further, Kong et al. (2023) reported that innovation efficiency significantly boosts firm market valuation, particularly when aligned with high-tech industry affiliation and robust intellectual property rights, underscoring the value of efficient R&D processes.

Table 7
Climate risk across geographic distribution.

Dependent variable = Firm value	North America	Europe	Asia	Others
	(1)	(2)	(3)	(4)
Variables	Firm value	Firm value	Firm value	Firm value
CREXP	**−0.155*****	**−0.634*****	**−0.718*****	**−0.092**
	(0.022)	**(0.083)**	**(0.141)**	**(0.089)**
Controls	*Yes*	*Yes*	*Yes*	*Yes*
Observations	*52,935*	*3598*	*1858*	*1379*
Adj. R-squared	*0.126*	*0.131*	*0.130*	*0.163*
Year FE	*Yes*	*Yes*	*Yes*	*Yes*
	G20	Developing	OECD	Others
	(5)	(6)	(7)	(8)
CREXP	**−0.191*****	**−0.321*****	**−0.176*****	**−0.372*****
	(0.020)	**(0.049)**	**(0.020)**	**(0.053)**
Controls	*Yes*	*Yes*	*Yes*	*Yes*
Observations	*53,914*	*5,826*	*55,867*	*3,873*
Adj. R-squared	*0.119*	*0.177*	*0.121*	*0.192*
Year Fixed	*Yes*	*Yes*	*Yes*	*Yes*

This table is based on regional distribution, North America, Europe, Asia, and others for the sample firms. Models 1–4 represent the regions where the firm is based. Model 5–8 represents economic development levels, G20, other than G20, OECD, and non-OECD for the sample firms, and the regional economic development level where the firm is based. Measurement of variables provided in appendix Table A1. Below the coefficients, the standard errors are presented in parentheses and asterisks ***, **, and * denote significance levels of 1 %, 5 %, and 10 %, respectively.

Table 8
Other measures for financial performance.

	(1)	(2)	(3)	(4)	(5)
Variables	ROA	ROE	SGR	EPS	Stock Prices
CREXP	**−0.008*****	**−0.007*****	**−0.013****	**−0.366*****	**−6.078*****
	(0.003)	**(0.002)**	**(0.006)**	**(0.080)**	**(1.349)**
Controls	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Country Fixed	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Year Fixed	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	*37,475*	*56,095*	*20,491*	*56,095*	*56,095*
Adj. R-squared	*0.076*	*0.144*	*0.144*	*0.258*	*0.275*

This table is based on alternative measures dependent on the variable firm value. We employed returns of assets (ROA), returns on equity (ROE), sustainable growth rate (SGR), earnings per share (EPS) and Stock Prices to capture the firm value. Measurement of variables provided in appendix Table A1. Below the coefficients, the standard errors are presented in parentheses and asterisks ***, **, and * denote significance levels of 1 %, 5 %, and 10 %, respectively.

Table 9
Alternative measures for climate risk.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Firm value	ROA	ROE	SGR	EPS	Stock Price
GHG Emission	**−0.099*****	**−0.002*****	**−0.002**	**0.002**	**−0.004**	**−0.301*****
	(0.006)	**(0.001)**	**(0.001)**	**(0.001)**	**(0.003)**	**(0.042)**
SIZE	0.063***	0.002***	0.001***	0.005***	0.248***	0.568***
	(0.010)	(0.000)	(0.000)	(0.001)	(0.020)	(0.063)
LEVER	−0.423***	−0.054***	−0.019***	0.152***	−0.779***	−2.719***
	(0.082)	(0.005)	(0.003)	(0.022)	(0.196)	(0.638)
SAGR	0.382***	−0.004	0.008***	0.062***	0.508***	3.732***
	(0.031)	(0.010)	(0.001)	(0.010)	(0.048)	(0.356)
ASTA	−0.905***	−0.031***	−0.012**	−0.076***	−0.187	1.950***
	(0.099)	(0.006)	(0.005)	(0.018)	(0.233)	(0.592)
CAEX	3.255***	0.079***	0.064***	0.364***	2.541***	−20.351***
	(0.278)	(0.017)	(0.017)	(0.057)	(0.701)	(2.421)
Constant	3.301***	0.122***	0.048***	0.037**	1.645***	5.090***
	(0.080)	(0.009)	(0.001)	(0.015)	(0.083)	(0.510)
Observations	*39,752*	*25,870*	*31,342*	*14,773*	*24,810*	*33,243*
Country Fixed	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Year Fixed	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Adj. R-squared	*0.245*	*0.0809*	*0.153*	*0.164*	*0.297*	*0.106*

This table is based on alternative measures of independent variable climate risk exposure. We employed GHG emission in tons for climate risk. Measurement of variables provided in appendix Table A1. Below the coefficients, the standard errors are presented in parentheses and asterisks ***, **, and * denote significance levels of 1 %, 5 %, and 10 %, respectively.

Table 10
Quantile regression results.

Dependent variable = Firm value Variables	(1) q10	(2) q25	(3) q50	(4) q75	(5) q90	(6) q95	(7) GMM
Lagged Tobin's Q							0.202*** (0.057)
CREXP	**−0.024*** (0.009)**	**−0.035*** (0.010)**	**−0.083*** (0.012)**	**−0.157*** (0.014)**	**−0.254*** (0.023)**	**−0.356*** (0.028)**	**−0.195*** (0.031)**
SIZE	0.027*** (0.001)	0.033*** (0.002)	0.046*** (0.002)	0.071*** (0.002)	0.109*** (0.010)	0.124*** (0.012)	0.035*** (0.006)
LEVER	0.130*** (0.012)	−0.079*** (0.014)	−0.364*** (0.026)	−0.769*** (0.033)	−1.060*** (0.075)	−1.181*** (0.160)	−0.450*** (0.071)
SAGR	0.141*** (0.008)	0.218*** (0.010)	0.355*** (0.015)	0.503*** (0.029)	0.590*** (0.057)	0.704*** (0.071)	0.392*** (0.041)
ASTA	−0.272*** (0.009)	−0.428*** (0.015)	−0.872*** (0.019)	−1.756*** (0.029)	−3.288*** (0.055)	−4.829*** (0.090)	−1.077*** (0.109)
CAEX	0.163*** (0.048)	0.587*** (0.049)	1.683*** (0.069)	3.010*** (0.126)	4.461*** (0.294)	6.085*** (0.384)	2.025*** (0.330)
Constant	0.952*** (0.004)	1.257*** (0.006)	1.790*** (0.010)	2.788*** (0.013)	4.412*** (0.032)	5.974*** (0.069)	1.596*** (0.146)
Observations	*59,740*	*59,740*	*59,740*	*59,740*	*59,740*	*59,740*	*59,740*
Year Fixed	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Pseudo R2	*0.027*	*0.029*	*0.051*	*0.078*	*0.100*	*0.119*	
AR2 P value							*0.486*
Sargan P Value							*0.226*

This table is based on alternative estimation technique quantile regression at 10, 25, 50 75, 90 and 95 percentiles and dynamic system GMM. Measurement of variables provided in appendix Table A1. Below the coefficients, the standard errors are presented in parentheses and asterisks ***, **, and * denote significance levels of 1 %, 5 %, and 10 %, respectively.

Table 11
Technological, socioeconomic and regulatory policy mechanism analysis.

Dependent variable = Firm value	GDP	Manufacturing/GDP	Renewable Energy	Rule of Law	Voice
	(1)	(2)	(3)	(4)	(5)
Variables	Firm value	Firm value	Firm value	Firm value	Firm value
CREXP × GDP	**0.032 (0.092)**				
CREXP × Man_GDP		**0.018* (0.009)**			
CREXP × Renewables			**0.001 (0.005)**		
CREXP × Rule of law				**0.299*** (0.104)**	
CREXP × Voice					**0.261** (0.112)**
CREXP	−0.303 (1.004)	−0.156 (0.107)	0.038 (0.077)	−0.389** (0.159)	−0.212* (0.121)
GDP	0.086 (0.184)				
Man_GDP		−0.014 (0.010)			
Renewables			0.031** (0.013)		
Rule of law				0.012 (0.152)	
Voice					−0.652*** (0.193)
Constant	1.284 (1.985)	2.392*** (0.136)	1.950*** (0.137)	2.195*** (0.237)	2.921*** (0.226)
Controls	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	*55,170*	*52,485*	*52,603*	*55,208*	*54,965*
Country Fixed	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Industry Fixed	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Year Fixed	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Adj. R-squared	*0.218*	*0.225*	*0.225*	*0.218*	*0.218*

This table is based on country-level mechanisms of climate risk exposure. The Independent variable is CREXP (climate risk exposure), and the dependent variable is the firm's value (measured with Tobin's Q). GDP, manufacturing/GDP, renewable energy, rule of law and voice are country-level mechanisms. Measurement of variables provided in appendix Table A1. Below the coefficients, the standard errors are presented in parentheses and asterisks ***, **, and * denote significance levels of 1 %, 5 %, and 10 %, respectively.

Table 12
Financial constraints mechanism.

Dependent variable = Firm value Variables	Financially Constrained (1)	Financially Unconstrained (2)	CREXP × FCON (3)
CREXP	**−0.273******	**−0.146******	−0.037**
	(0.032)	**(0.028)**	(0.017)
FCON			−0.018*
			(0.011)
CREXP × FCON			**−0.070*****
			(0.031)
Constant	2.292***	2.543***	2.020***
	(0.024)	(0.018)	(0.027)
Controls	*Yes*	*Yes*	*Yes*
Observations	*20,456*	*39,284*	*40,357*
Adj. R-squared	*0.104*	*0.093*	*0.067*
Country Fixed	*Yes*	*Yes*	*Yes*
Year Fixed	*Yes*	*Yes*	*Yes*
Coefficient Equi. Test		*0.000*	

This table is based on the financial constraints' mechanism of climate risk exposure. The Independent variable is CREXP (climate risk exposure), and the dependent variable is the firm's value (measured with Tobin's Q). Financial Constraints (FCON) is moderator measured using the Whited-Wu (WW) index, firms above the median are classified as constrained, and those below as unconstrained. Coefficient equivalence test = test [Model1_mean] = [Model2_mean]. Measurement of variables provided in appendix Table A1. Below the coefficients, the standard errors are presented in parentheses and asterisks ***, **, and * denote significance levels of 1 %, 5 %, and 10 %, respectively.

Table 13
Financial flexibility mechanism.

Dependent variable = Firm value Variables	Low FF (1)	High FF (2)	CREXP × FF (3)
CCEXP	**−0.273******	**−0.146******	−0.194***
	(0.021)	**(0.027)**	(0.039)
FF			0.128**
			(0.057)
CREXP × FF			**0.218*****
			(0.085)
Constant	2.543***	2.292***	2.434***
	(0.018)	(0.024)	(0.054)
Controls	*Yes*	*Yes*	*Yes*
Observations	*39,284*	*20,456*	*59,740*
Adj. R-squared	*0.104*	*0.093*	*0.140*
Country Fixed	*Yes*	*Yes*	*Yes*
Year Fixed	*Yes*	*Yes*	*Yes*
Coefficient Equi. Test		*0.000*	

This table is based on the financial flexibility mechanism of climate risk exposure. The Independent variable is CREXP (climate risk exposure), and the dependent variable is the firm's value (measured with Tobin's Q). Financial flexibility (FF) is the moderator; firms above the median are classified as High FF, and those below as Low FF. Coefficient equivalence test = test [Model1_mean] = [Model2_mean]. Measurement of variables provided in appendix Table A1. Below the coefficients, the standard errors are presented in parentheses and asterisks ***, **, and * denote significance levels of 1 %, 5 %, and 10 %, respectively.

further supports the hypothesis that higher-RDI buffers against CREXP.

4. Conclusion

This study demonstrates a robust negative relationship between CREXP and firm value, with significant variations across geographic regions and firm characteristics. Our findings reveal that Asian firms face the most potent negative impacts, while developed markets show greater resilience, highlighting the importance of institutional frameworks in climate risk management. The analysis of the Stern Review and the Paris Agreement as exogenous shocks indicates that policy interventions can significantly influence the market pricing of climate risks. Moderation analysis reveals that FCON amplifies negative CREXP effects while RDI serves as a buffer, suggesting that innovation capability enhances climate resilience. These findings have important implications for corporate strategy, emphasising the need for robust financial management and technological innovation in addressing climate risks. Our study

Table 14
Research and development mechanism.

Dependent variable = Firm value Variables	Low RDI (1)	High RDI (2)	CREXP × RDI (3)
CREXP	**−0.315***** **(0.039)**	**−0.167***** **(0.018)**	−0.048** (0.024)
RDI			2.970*** (0.167)
CREXP × RDI			**2.054***** **(0.470)**
Constant	2.741*** (0.025)	1.919*** (0.016)	2.002*** (0.022)
Controls	*Yes*	*Yes*	*Yes*
Observations	*29,870*	*29,870*	*46,571*
Adj. R-squared	*0.062*	*0.086*	*0.273*
Country Fixed	*Yes*	*Yes*	*Yes*
Year Fixed	*Yes*	*Yes*	*Yes*
Coefficient Equi. Test		*0.000*	

This table is based on research and development mechanisms of climate risk exposure. The Independent variable is CREXP (climate risk exposure), and the dependent variable is the firm's value (measured with Tobin's Q). Research and development intensity (RDI) is the moderator; firms above the median are classified as High RDI, and those below as Low RDI. Coefficient equivalence test = test [Model1_mean] = [Model2_mean]. Measurement of variables provided in appendix Table A1. Below the coefficients, the standard errors are presented in parentheses and asterisks ***, **, and * denote significance levels of 1 %, 5 %, and 10 %, respectively.

highlights the capability of R&D-intensive firms to effectively develop climate risk adaptation and mitigation technologies, with our broad focus presenting a limitation. Future research should examine forward-looking measures of climate risk and additional moderating factors like corporate governance and stakeholder engagement, as well as investigate how different industries implement these strategies effectively.

CRediT authorship contribution statement

Mirza Muhammad Naseer: Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Yongsheng Guo:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization. **Xiaoxian Zhu:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Conceptualization.

Declaration of competing interest

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

Appendix

Table A1

Table A1
Variable Measurement.

Variable	Measure	Data Sources
Firms' value	To measure firms' value, we used Tobin's Q, defined by Brainard and Tobin (1968) and Tobin (1969) as the ratio of a "*firm's market value*" to the "*replacement cost of its capital stock*". This metric reflects a firm's incentive to finance capital investments. Hayashi (1982) showed conditions where "average Q" equals "marginal q." Abel and Eberly (1994) expanded this into a amalgamated investment theory. Several scholars, including Chung and Pruitt (1994), simplified "*Tobin's Q*", suggesting the "*book value of assets*" as a proxy for "*replacement cost*". We adopt approximation: $\text{Tobin's}Q_{i,t} = (PRCC_{Fi,t} {*} CSHO_{i,t}) + AT_{i,t} - CEQ_{i,t}/\text{AT}_{i,t}$ Where PRCC_F is the "annual closing share price", CSHO is "common shares outstanding", CEQ indicates total ordinary equity or common equity, AT indicates total assets, t is year and i is for each company in the sample.	Compustat/CRSP
CREXP	This measure is derived from analysing quarterly earnings conference call transcripts of publicly listed firms, capturing managers' perceptions of their firm's vulnerability to climate change. Sautner et al. (2023b) apply a machine learning algorithm to identify climate change-related bigrams in these transcripts. The climate change exposure variable, "CREXP", is defined as the proportion of climate-related bigrams to the total bigrams in a firm's transcript, multiplied by 100 for expositional clarity. $CREXP_{i,q} = \frac{1}{B_{i,q}} \sum_{b=1}^{B_{i,t}} D(b) \times 100$ Here, $b = 0,.,B_{i,q}$ represents the total bigrams for firm i in quarter q, and D(b) is a dummy variable equal to 1 if bigram b is climate-related, and 0 otherwise.	(Sautner et al., 2023).

(*continued on next page*)

Table A1 (*continued*)

Variable	Measure	Data Sources
Size	Natural log of Market Capitalisation = Common Shares Outstanding (csho item of Compustat) × closing price (prcc_f item of Compustat)	Compustat
Leverage (LEVER)	To measure leverage, I use the ratio of corporate total debt (dltt+dlc items of Compustat) to the firm's total assets at book value (at the item of Compustat).	Compustat
Sales growth (SAGR)	$SAGR_{i,t} = \ln[sale_{i,t} / sale_{i,\ t\text{-}1}]$ (sale item of compustat)	Compustat
Assets Tangibility (ASTA)	ASTA is the ratio of property plant and equipment (ppent item of Compustat) in firm's total assets at book value (at item of Compustat).	Compustat
Capital Expenditure (CAEX)	CAEX is the value of capital expenditure (capx item of Compustat) scaled with the firm's total assets at book value (at item of Compustat).	Compustat
Financial constraints (FCON)	WW index. $WWI = -0.091\left(\frac{ib_{i,t}+dp_{i,t}}{at_{i,t}}\right) - 0.062\left(I\left(dvc_{i,t}+dvp_{i,t}>0\right)\right) + 0.021\left(\frac{dltt_{i,t}}{at_{i,t}}\right) - 0.044\left(l\left(at_{i,t}\right)\right) + 0.102\ (ISG_{s,t}) - 0.035(SAGR_{i,t})$. Where ib is income before extraordinary items, dp is depreciation, at is total assets, dvc and dvp are dividends on common and preferred stock, dltt is long-term debt, ISG is industry sales growth and SAGR is firm sales growth calculated annually.	Compustat
Financial flexibility (FF)	We measure FF with two indicators: "cash holdings" and "debt levels." FF = CHF + DTF Where CHF (Cash flexibility) refers to a firm's ability to utilise internal funds, calculated as $\frac{Cash\ \&\ cash\ equivalent_{i,t}}{Total\ Assets_{i,t}}$, while DTF (debt flexibility) refers to a firm's ability to obtain external financial resources, calculated as 1-corporate debt ratio.	Compustat
R&D Intensity (RDI)	Research and development (xrd item of Compustat data) expenses to firm's annual total assets (at)	Compustat
GFC_dummy	The dummy variable equals 1 for the years 2008–2009 and 0 otherwise.	Compustat
USA	Dummy variable equalling 1 for firms located in USA and 0 otherwise.	Compustat
Env. Sen	The dummy variable equals 1 for the environmentally sensitive sector SIC 4-digit code 1000–1399 and 4900–4999 and 0 otherwise.	Compustat
Post Stern	The dummy variable equals 1 for the years 2007–2008 and 0 for the years 2004–2005 (A 2-year window).	Compustat
Post Paris	The dummy variable equals 1 for the years 2017–2019 and 0 for the years 2013–2015, (A 3-year window).	Compustat
GHG Emission	Total GHG emission in tonnes reported by a firm across scope 1 and scope 2.	LSEG workspace
ROA	Return on Assets = Net income before extraordinary items divided by total assets.	Compustat
ROE	Return On Equity = (Compustat item: EBIT) Earnings before interest and tax divided by (Compustat item: CEQ) book value of equity	Compustat
SGR	Sustainable growth rate Robert C. Higgins (2018)	Compustat
EPS	Earnings per share = (epspx*csho/cshoq)	Compustat
Stock Prices	Stock Prices = Stock price at fiscal year-end (prcc_f)	CRSP
GDP	GDP measures a country's GDP per capita in current dollars in a given year	World bank WDI
Manufacturing/GDP	Manufacturing/GDP is the percentage of a country's GDP that is produced in a given year in the manufacturing sector.	World bank WDI
Renewable Energy	"Renewable energy measures a country's share of electricity generated by renewable power plants in total electricity generated by all types of plants in a given year".	World bank WDI
Rule of Law	"Rule of law measures a country's perceptions in a given year of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence. Estimate gives the country's score on the aggregate indicator, in units of a standard normal distribution".	World bank WGI
Voice	"Voice captures perceptions in a given year of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and free media. Estimate gives the country's score on the aggregate indicator, in units of a standard normal distribution".	World bank WGI

Note. We winsorised all continuous control variables at the 1 % and 99 % levels.

Data availability

Data will be made available on request.

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