The Impact of Climate Risk on Corporate Leverage: Evidence from Chinese A-Share Listed Companies

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Abstract— This paper examines how climate risk influences corporate leverage decisions using a comprehensive panel dataset of Chinese A-share listed companies. By combining firm-level financial information with regional climate-risk indicators, we document a robust and economically meaningful negative relationship between climate risk and corporate leverage. The effect persists after controlling for firm- and year-fixed effects, addressing potential endogeneity through lagged climate exposures and propensity score matching, and conducting extensive robustness checks using alternative climate and leverage measures. Furthermore, heterogeneity analyses reveal that the deleveraging effect is more pronounced among non-state-owned firms, firms with concentrated ownership, and those more exposed to transition risk rather than physical climate threats. We also find that cash holdings significantly moderate this relationship; specifically, firms with higher liquidity reduce leverage more strongly in response to climate risk, suggesting that internal funds facilitate precautionary adjustments in capital structure.

Keywords: climate risk, corporate leverage, transition risk, cash holdings, Chinese A-share firms

I. INTRODUCTION

Climate change has emerged as one of the most profound and persistent sources of systemic risk confronting modern economies. The accelerating frequency and intensity of extreme weather events—including heatwaves, floods, droughts, and wildfires—have already begun reshaping global patterns of production, investment, and financial stability. According to the World Meteorological Organization (WMO, 2023), the global average near-surface temperature has reached a historic high of 1.45 ± 0.12°C above pre-industrial levels, underscoring the urgency of assessing climate-related vulnerabilities. Moreover, Germanwatch's Climate Risk Index reports more than 9,400 extreme climate events between 1993 and 2022, causing over 763,000 deaths and USD 4.2 trillion in economic losses (Adil et al., 2025). Despite the clear macroeconomic ramifications, comparatively less is known about how climate risk shapes corporate financial decisions—particularly firms' capital structure choices, which serve as core mechanisms for managing risk exposure. Therefore, understanding how climate risk affects leverage is essential not only for corporate resilience but also for safeguarding financial system stability in an era of escalating climate uncertainty.

China constitutes a uniquely informative context for such an inquiry. As the world's largest carbon emitter and a major global economy, China's corporate sector faces a dual burden of acute climate risks and intensifying transition pressures. In recent years, recurrent floods in the south, droughts in the north, extreme heat, and sandstorms have caused significant operational disruptions, reduced asset values, and destabilized supply chains. Simultaneously, to advance the national goals of carbon peaking and carbon neutrality, the Chinese government has expanded its carbon-trading system, strengthened green credit policies, and mandated broader environmental disclosures. These regulatory developments have intensified transition risks for firms (NGFS, 2019; Li et al., 2024; Giglio et al., 2021). A-share listed companies, situated at the forefront of both climate-related hazards and policy-driven transition pressures, offer an ideal empirical setting for assessing how environmental risks are incorporated into corporate leverage decisions.

Although a rich body of literature has examined climate risk from the perspectives of profitability, productivity, asset pricing, financing costs, and cash-flow sensitivity (Hong et al., 2019; Brown et al., 2021; Karydas & Xepapadeas, 2022; Li & Wan, 2024; Pankratz et al., 2023), research specifically linking climate risk to corporate leverage remains limited. Studies on the U.S. context find that firms exposed to natural disasters tend to maintain lower leverage (Elnahas & Kim, 2018; Nguyen et al., 2022), while carbon-intensive firms facing transition pressures often reduce debt financing in favor of equity (Ginglinger & Moreau, 2023; Nguyen & Phan, 2020). However, other works suggest that transition policies—particularly those that expand access to green credit—can increase firms' leverage by easing financing constraints (Reboredo & Ugolini, 2022; Sharfman & Fernando, 2008). Meanwhile, extensive literature on the determinants of leverage reveals that factors such as firm size, internal financing capacity, profitability, and ownership structure play central roles in shaping capital structure (Frank & Goyal, 2009; Korajczyk & Levy, 2003; Wang et al., 2014; Khan et al., 2024). Yet, the interaction between these financial determinants and climate-related risks has not been systematically analyzed in the Chinese context. This gap is particularly striking given that climate risk, as a long-lasting and pervasive external shock, is likely to reshape firms' risk-management preferences, cost of capital, and leverage adjustments.

This study addresses these gaps by investigating how climate risk shapes the leverage decisions of Chinese A-share listed companies. Specifically, it uses textual analysis of annual reports from 2008–2024 to construct a firm-level proxy for climate risk, measured as the frequency of climate-related keywords relative to total word count (Li et al., 2024; Du et al., 2023; Li & Wan, 2024). Using this granular measure, the study empirically examines whether firms with higher climate risk tend to reduce leverage to mitigate the threat of operational disruptions and rising financing costs, or whether they increase leverage due to heightened dependence on external funding during periods of climate-induced financial pressure. Furthermore, given that firms often accumulate precautionary cash reserves to buffer against climate-related uncertainty (Javadi et al., 2023; Yu et al., 2022; Zhang et al., 2023), this study tests whether cash holdings moderate the relationship between climate risk and leverage, thereby shedding light on firms' joint liquidity-leverage adjustment behavior under climate stress.

Overall, this paper contributes to the literature in three ways. First, it incorporates climate risk into the analysis of corporate financial behavior, offering micro-level evidence on how systemic environmental shocks influence capital structure. Second, it provides new empirical insights into how Chinese firms respond to both physical and transition risks during the national low-carbon transition, which is of growing interest to regulators, investors, and policymakers. Third, by employing a textual analysis-based measure of climate risk, the study captures firm-specific climate concerns more accurately than traditional region-based climate indicators, thereby enhancing explanatory power in identifying the financial consequences of climate risk. Collectively, these contributions offer practical implications for corporate leverage management under climate uncertainty and for regulators seeking to safeguard financial stability in the context of China's green transition.

II. HYPOTHESIS DEVELOPMENT

The trade-off perspective asserts that capital structure choices result from balancing the tax advantages of debt with the expected costs linked to potential financial distress (Kraus & Litzenberger, 1973; Myers, 1984). When climate risk heightens the probability of insolvency and instability, the expected distress cost rises, prompting firms to cut back on debt usage and reduce leverage. In addition, the pecking order theory asserts that under information asymmetry, companies prioritize internal funds, then turn to debt financing, and view equity issuance as the least preferred option (Myers and Majluf, 1984). Climate risk heightens the difficulty for external investors to assess firms' future cash flows and profitability, reinforcing firms' cautious attitude toward external financing and further encouraging them to reduce leverage. In addition, the precautionary saving theory suggests that under heightened uncertainty, firms tend to increase cash holdings and reduce debt to guard against potential future shocks (Bates et al., 2009). Therefore, in the presence of climate risk, firms may prefer to retain earnings and reduce reliance on external debt financing, thereby decreasing their overall leverage. Building on these theoretical considerations, the study formulates the following hypothesis:

H_1: Climate risk is negatively correlated with the leverage of Chinese A-share listed companies.

Furthermore, this study also examines the moderating role of corporate cash holdings within this mechanism. According to the Precautionary Savings Theory, when external environmental uncertainty increases, firms tend to hold liquid assets—such as cash—as a buffer against the potential impact of external risks on their capital structure (Bates et al., 2009). From this perspective, cash holdings function as a "risk buffer," and are thus expected to mitigate the negative impact of climate risk on corporate leverage.

However, the Financial Flexibility Theory posits that cash not only serves as a buffer against risk but also operates as a tool for firms to actively adjust their financial structure. Enterprises maintaining substantial cash reserves are inclined to reduce leverage proactively under heightened climate risk, aiming to curb prospective financing expenses and mitigate default risk (Yuan et al., 2025). This implies that cash reserves could strengthen the adverse impact of climate risk on leverage. Accordingly, the following hypothesis is advanced:

H_{2a}: Cash holdings weaken the negative effect of climate risk on corporate leverage.

H_{2b}: Cash holdings strengthen the negative effect of climate risk on corporate leverage.

III. METHODOLOGY AND DATA

III.I. DATA AND SAMPLE

This research investigates how climate risk influences the leverage decisions of Chinese A-share firms, covering the period 2008–2024. For sample selection, we follow established approaches in prior literature, first excluding companies in the financial sector as classified under the Shenwan industry standard. This is due to the distinct risk profiles and accounting standards applied to financial firms, which may compromise data consistency; (2) Firms under special treatment (ST) or facing delisting risk (marked with 'ST' or '*ST' in the stock abbreviation) are removed; (3) Observations with missing values for key variables are also excluded; (4) To mitigate the impact of outliers on empirical outcomes, continuous variables are winsorized at the 1st and

99th percentiles. After data screening and quality control, the resulting dataset comprises 15,266 firm-year observations drawn from 898 Chinese A-share firms.

The key variables include climate risk and corporate leverage. Consistent with Du et al. (2023), climate risk is quantified as the frequency of 96 predefined climate risk keywords relative to the total word count in a firm's annual report, multiplied by 100. Leverage is measured as total liabilities divided by total assets. Following Rajan and Zingales (1995), Devos et al. (2017), Li and Wan (2024), Yu et al. (2022), and Yuan et al. (2025), control variables encompass firm size, return on assets, growth potential, ownership concentration, and the level of regional economic development. Detailed definitions appear in Table 1.

Table 1: Model Variables and Data Sources

Variables		Symbol	Definition	Source
Dependent Variable	Corporate Leverage	Leverage	Total Liabilities/Total Assets	CSMAR Database
Independent Variable	Climate Risk	ClimateRisk	(96 keywords frequency/Total words in the Company's annual reports) x 100	Annual Reports of A-Share Listed Companies
Moderator Variable	Corporate Cash Holdings	CashHold	Cash and cash equivalents/Total Assets	CSMAR Database
Control Variables	Corporate Size	Size	The natural logarithm of total assets	
	Return on Assets	ROA	Net Profit/Total Assets	
	Corporate Growth Capacity	CGC	(Current operating revenue - Previous operating revenue)/Previous operating revenue	
	Degree of Equity Concentration	Top1	The shareholding ratio of the largest shareholder.	
	Regional Economic Development Level	LnGDP	The natural logarithm of GDP per capita in the province where the corporation is located	National Bureau of Statistics of China

In terms of Climate Risk, this study follows the approach of Du et al. (2023) and identifies 96 keywords related to climate risk, as shown in Table 2. We construct a firm-specific climate risk index via Python-based textual analysis. Specifically, annual reports for Chinese A-share firms from 2008–2024 are obtained from CNINFO and converted from PDF to Chinese TXT format (in Chinese). (2) We apply the "Jieba" library to segment the Chinese text in each annual report. (3) We count the occurrences of the 96 climate-related keywords and calculate the total number of words in each report. (4) The climate risk index is calculated as the ratio of keyword frequency to total word count, multiplied by 100, where larger values denote greater climate risk exposure. This keyword dictionary has been validated in prior research and is regarded as an effective proxy for measuring firm-level climate risk. Moreover, it has been widely applied in empirical studies on Chinese A-share listed firms, which ensures the reliability and credibility of the constructed climate risk index. In addition, to further validate the robustness of our results, alternative climate risk measures will be employed for robustness checks.

Table 2: Climate Risk Word Sets

Climate Risk Category		Representative Keywords (Translated from Chinese)
Physical Risk	Acute Risk	Typhoon, flood disaster, snow disaster, hail, tornado, drought, frost, earthquake, mudslide, sandstorm, flood and waterlogging, flooding, heavy rainstorm, freezing, dust storm, intense rainfall, severe weather, blizzard, drought disaster, hurricane, icebound, drought and flood, disaster, severe cold, strong wind, storm, frost damage, sleet, drought situation, tsunami, extreme climate, waterlogging, landslide, water disaster (34)

	Chronic Risk	Winter, rainy season, temperature, humidity, precipitation, climate, cooling, rainy conditions, rainfall, flood season, extreme cold, water level, water shortage, rainfall situation, cold weather, surface, sunlight, high humidity, air temperature, overcast weather, flood condition, water situation, water storage, alpine cold, subsidence, groundwater, rainwater, cold wave, weather, rainfall patterns (30)

Table 2: Climate Risk Word Sets (Continued)

Climate Risk Category	Representative Keywords (Translated from Chinese)
Transition Risk	Green, energy saving, consumption reduction, clean energy, renewable, transition, photovoltaic, upgrading, recycling, water saving, nuclear power, intensive use, low-carbon, fuel, oil consumption, fuel oil, energy consumption, wind power, efficiency improvement, transformation, efficiency, environment, natural gas, energy efficiency, utilization rate, environmental protection, solar energy, electricity consumption, energy, performance, emission reduction, high efficiency (32)

III.II. MODEL DESIGN

To rigorously identify the causal relationship between climate risk and corporate leverage, this study constructs a series of panel-data regression models grounded in both theoretical considerations and empirical requirements. Given the structure of the dataset—comprising 15,266 firm-year observations for 898 A-share listed firms from 2008 to 2024—we adopt a two-way fixed effects (TWFE) framework. This choice is justified not only by the need to control for unobservable firm heterogeneity and time-specific macroeconomic shocks, but also by the results of the Hausman test and F-test, which jointly indicate that the fixed-effects specification is superior to pooled OLS and random-effects alternatives.

We begin by estimating the baseline model designed to examine Hypothesis 1, which posits that climate risk exerts a negative impact on the leverage of Chinese A-share firms. Accordingly, the empirical specification is expressed as:

$$Leverage_{it} = \alpha_0 + \alpha_1 ClimateRisk_{it} + \alpha_2 Size_{it} + \alpha_3 ROA_{it} + \alpha_4 CGC_{it} + \alpha_5 Top1_{it} + \alpha_6 LnGDP_{it} + \delta_i + \gamma_t + \varepsilon_{it} \quad (1)$$

Where i indexes individual firms, t denotes time periods, and the data intervals are annual. *Leverage* is the leverage of Chinese A-share listed companies, and *ClimateRisk* represents climate risk at the firm level. *Size, ROA, CGC, Top1,* and *LnGDP* denote corporate size, return on assets, corporate growth capacity, the shareholding ratio of the largest shareholder and regional economic development level, respectively. δ_i represents the individual fixed effect. γ_t denotes year fixed effects. $\mathcal{E}_{it}$ is the error term.

After establishing the baseline relationship, we further investigate the potential moderating mechanism through which cash holdings influence the impact of climate risk on leverage. This corresponds to Hypotheses 2a and 2b, which propose that cash holdings may either attenuate or amplify the negative effect of climate risk on leverage. To evaluate this channel, we augment the baseline model by incorporating an interaction term between climate risk and corporate cash holdings:

$$\begin{aligned} \text{Leverage}_{it} = {} & \beta_0 + \beta_1 ClimateRisk_{it} + \beta_2 CashHold_{it} + \beta_3 \left(ClimateRisk \times CashHold\right)_{it} + \beta_4 Size_{it} + \beta_5 ROA_{it} \\ & + \beta_6 CGC_{it} + \beta_7 Top1_{it} + \beta_8 LnGDP_{it} + \delta_i + \gamma_t + \varepsilon_{it} \end{aligned} \quad (2)$$

Here, *CashHold* represents the firm's cash holdings, and the coefficient β_3 captures whether internal liquidity buffers alter the sensitivity of leverage to climate risk. A statistically significant and negative interaction term would support Hypothesis 2a, indicating a weakening effect, whereas a positive coefficient would suggest reinforcement, consistent with Hypothesis 2b. As in the baseline model, all control variables and fixed effects remain included to mitigate omitted variable bias.

Furthermore, following the estimation of the baseline and moderating models, we conduct a battery of robustness checks to ensure the stability of the results. Specifically, we re-estimate the baseline model using an alternative sample period (2009–2019) to exclude potential structural distortions arising from the global financial crisis recovery years and the COVID-19 period. In addition, we replace the dependent variable with a market-based leverage measure (total liabilities divided by the market value of equity) to verify whether the findings remain consistent under alternative capital structure specifications. Moreover, we replace the main explanatory variable by employing a climate risk proxy constructed from the absolute deviation of annual average temperature from the 50-year rolling mean, thereby capturing long-term climate anomalies independent of firm disclosure patterns. In addition, we implement heterogeneity tests by grouping firms according to ownership type (state-owned vs. non-state-owned), ownership concentration (largest shareholder's shareholding ratio(Top1) above vs. below the median), and the

nature of climate risk (physical vs. transition risk). These extensions not only enhance the explanatory depth of the study but also provide richer insights into the differentiated pathways through which climate risk influences corporate financing decisions.

IV. EMPIRICAL RESULTS

IV.I. DESCRIPTIVE STATISTICS

Table 3 reports the descriptive statistics for the main variables used in the analysis. The average leverage ratio among Chinese A-share listed firms is approximately 0.486, indicating a moderate level of indebtedness in the sample period. ClimateRisk exhibits a mean value of 0.258 and substantial variation (SD = 0.250), suggesting pronounced cross-firm heterogeneity in climate exposure. Furthermore, firm size (Size) shows a relatively wide distribution, with a mean of 22.79, while profitability (ROA) averages 3.8%. The ownership concentration indicator (Top1) averages 35.8%, reflecting the generally high degree of controlling shareholder influence in Chinese listed firms. Lastly, lnGDP displays moderate variation across regions. Overall, the descriptive patterns provide an informative foundation for subsequent estimations, as they indicate sufficient variability in both dependent and explanatory variables.

Table 3: Descriptive Statistics

Variable	N	Mean	p50	SD	Min	Max
Leverage	15266	0.486	0.496	0.187	0.077	0.863
ClimateRisk	15266	0.258	0.174	0.250	0.030	1.379
Size	15266	22.792	22.659	1.398	20.089	26.688
ROA	15266	0.038	0.032	0.048	-0.114	0.195
CGC	15266	0.128	0.081	0.326	-0.497	1.916
Top1	15266	0.358	0.338	0.151	0.093	0.752
lnGDP	15266	11.066	11.102	0.581	9.651	12.287

IV.II. UNIT ROOT TEST

Table 4 presents the panel unit root results based on LLC, IPS, and Fisher-ADF tests. Except for Top1, all variables reject the null hypothesis of non-stationarity at the 1% significance level, implying that the series are stationary. Although Top1 appears non-stationary in LLC, IPS, and Fisher-ADF tests, this variable is widely adopted as a control variable in existing empirical studies, and its economic significance may be weakened after difference-in-differences analysis. Therefore, this paper retains the variable in its original form while controlling for individual fixed effects and annual effects, thereby enhancing the comparability and interpretability of the empirical results.

Table 4: Unit Root Test

Variable	LLC t^*	IPS Z-bar	Fisher-ADF P stat	Stationary?
Leverage	-19.4726^{***}	-6.1409^{***}	2658.4453^{***}	YES
ClimateRisk	-32.0432^{***}	-23.8433^{***}	3519.3859^{***}	YES
Size	-29.3568^{***}	-9.8097^{***}	2880.6522^{***}	YES
ROA	-23.2341^{***}	-24.0226^{***}	3694.2029^{***}	YES
CGC	-51.0289^{***}	-52.8185^{***}	7112.8657^{***}	YES
Top1	11.0691	10.1133	1755.7025	NO
lnGDP	-74.6054^{***}	-9.0307^{***}	2854.3893^{***}	YES

Note: *** p<0.01, ** p<0.05, * p<0.1

IV.III. CORRELATION ANALYSIS

Table 5 presents the pairwise correlation coefficients. Leverage displays a positive and significant correlation with ClimateRisk, Size, CGC, and Top1, yet a negative relationship with ROA, consistent with expectations that more profitable firms rely less on external financing. Importantly, the correlation between ClimateRisk and other regressors remains below 0.35, suggesting that multicollinearity is not a major concern. This observation is corroborated by the subsequent VIF test.

Table 5: Correlation Analysis

	Leverage	ClimateRisk	Size	ROA	CGC	Top1	lnGDP
Leverage	1.000						
ClimateRisk	0.130^{***}	1.000					

Size	0.408***	0.327***	1.000				
ROA	-0.379***	-0.065***	-0.004	1.000			
CGC	0.059***	-0.014*	0.023***	0.217***	1.000		
Top1	0.053***	0.084***	0.219***	0.074***	0.038***	1.000	
lnGDP	-0.032***	0.159***	0.297***	-0.078***	-0.093***	0.017**	1.000

Note: *** p<0.01, ** p<0.05, * p<0.1

IV.IV. MULTICOLLINEARITY TEST

Table 6 reports the VIF values, all of which lie within the range of 1.06 to 1.26, with a mean VIF of 1.12. These results indicate that multicollinearity is minimal and will not bias the coefficient estimates. Consequently, the explanatory variables can be simultaneously included in the regression without concerns of inflated standard errors.

Table 6: Multicollinearity Test

Variable	VIF	1/VIF
ClimateRisk	1.13	0.885231
Size	1.26	0.793117
ROA	1.06	0.941426
CGC	1.06	0.944447
Top1	1.06	0.943955
lnGDP	1.12	0.892897
Mean VIF	1.12	

IV.V. BASELINE ESTIMATION RESULTS

Table 7 summarizes the baseline fixed-effects estimates examining the relationship between climate risk and corporate leverage. Column (1) indicates that ClimateRisk significantly reduces leverage at the 1% level, with a coefficient of −0.027. This negative effect persists when using a one-period lag of ClimateRisk in column (2), providing further evidence that the relationship is not driven by contemporaneous feedback or short-term adjustments.

Among the control variables, Size is positively associated with leverage, consistent with the argument that larger firms enjoy greater borrowing capacity. Conversely, ROA is strongly negatively related to leverage, suggesting that more profitable firms rely more on internal financing. Corporate governance quality (CGC) and ownership concentration (Top1) exhibit positive associations with leverage, while lnGDP enters negatively, implying that firms in more developed regions tend to carry less debt.

Taken together, the baseline results indicate that climate risk is significantly negatively correlated with corporate leverage, supporting the hypothesis H_1.

Table 7: Baseline results

Variables	Leverage (1)	Leverage (2)
ClimateRisk	-0.027***	
	(0.006)	
L.ClimateRisk		-0.027***
		(0.006)
Size	0.068***	0.068***
	(0.002)	(0.002)
ROA	-0.924***	-0.906***
	(0.021)	(0.021)
CGC	0.036***	0.034***
	(0.002)	(0.002)
Top1	0.034***	0.039***
	(0.009)	(0.009)
lnGDP	-0.031***	-0.034***
	(0.011)	(0.012)
Constant	-0.647***	-0.617***
	(0.117)	(0.134)
Year FE	YES	YES

Firm FE	YES	YES
Observations	15,266	14,368
Within R-squared	0.216	0.213

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

IV.VI. ENDOGENEITY ANALYSIS

Although leverage is unlikely to influence climate conditions directly, potential omitted variables or selection bias may still impact the estimates. To address possible endogeneity concerns, this study employs Propensity Score Matching (PSM), following Du et al. (2023). As a first step, firms with ClimateRisk values above the upper quartile are coded as "treated", while those below the lower quartile serve as the "control" group. A Logit model is then estimated using Size, ROA, CGC, Top1, and lnGDP as matching covariates.

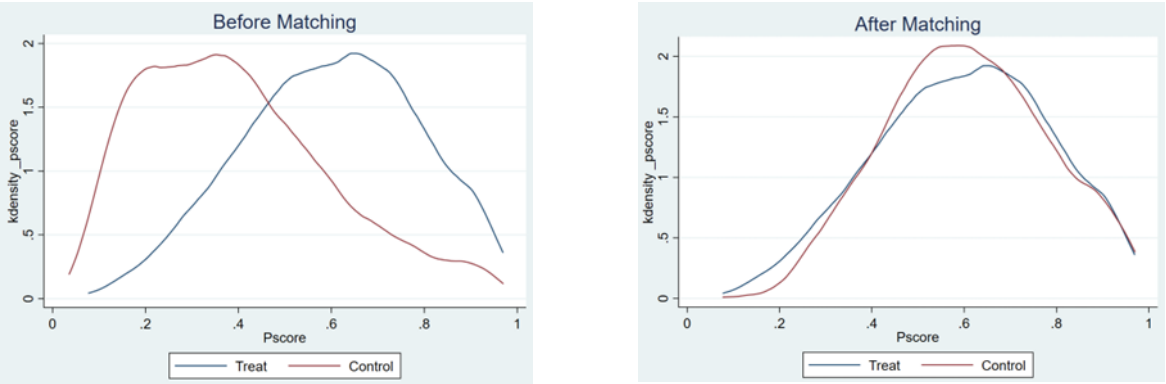
Table 8 reports the Logit results, showing that firm size and ownership concentration significantly increase the likelihood of high climate risk, whereas ROA and regional economic development (lnGDP) reduce such likelihood. All coefficients are highly significant and align with theoretical expectations.

Table 8: Logit results

Variables	Coef. and significance	z value	p value
Size	0.425***	18.69	0.000
ROA	-3.239***	-4.97	0.000
CGC	0.076	0.90	0.369
Top1	1.337***	6.98	0.000
lnGDP	-0.757***	-11.20	0.000
Constant	-3.215***	-3.93	0.000

Note: *** p<0.01, ** p<0.05, * p<0.1

After performing one-to-one nearest-neighbor matching (caliper = 0.05), the ATT remains significant at the 1% level, indicating that the difference in leverage between high-risk and low-risk firms persists even after mitigating self-selection bias. The standardized mean differences of all covariates fall below 10%, confirming the balance and validity of the matching process. The kernel density plot further illustrates strong overlap between the treated and control groups after matching.



PSM PSM

Figure 1. kernel density plot

Table 9 displays the post-matching regression results. ClimateRisk remains significantly negative (−0.023), indicating that regression results are robust to selection corrections.

Table 9: PSM regression results

Variables	Leverage (1)
ClimateRisk	-0.023***
	(0.008)
Size	0.072***
	(0.002)
ROA	-0.891***
	(0.029)

CGC	0.034***
	(0.003)
Top1	0.040***
	(0.013)
lnGDP	-0.072***
	(0.015)
Constant	-0.308*
	(0.166)
Year FE	YES
Firm FE	YES
Observations	7,633
Within R-squared	0.233

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

IV.VII. ROBUSTNESS CHECKS

To further verify the stability of the results, several robustness tests are conducted, as shown in Table 10.

First, following Yuan et al. (2025), we replace the climate-risk indicator with the 50-year rolling window absolute deviation of annual average temperature at the provincial level. This measure captures long-term climate fluctuations and mitigates concerns that short-term climate indicators may be subject to measurement noise or cyclical effects. The regression results are shown in column (1) of Table 10.

Next, we replace the dependent variable to test whether the climate–leverage relationship is sensitive to different capital-structure definitions. Following Bowman (1980) and Obreja (2013), the dependent variable is redefined as the ratio of total liabilities to the market value of equity, instead of the book-value measure (total liabilities/total assets) used in the baseline regressions. The regression results are shown in column (2) of Table 10.

Finally, to eliminate potential distortions caused by extraordinary macroeconomic events—such as the 2008 global financial crisis and the COVID-19 pandemic—we re-estimate Model (1) using a restricted sample from 2009 to 2019, thereby excluding 2008 and 2020–2022. This adjustment ensures that the results are not confounded by extreme credit-cycle shocks, abrupt liquidity contractions, or policy interventions that may obscure the true effect of climate risk. The regression results are shown in column (3) of Table 10.

Across all specifications, ClimateRisk or its alternative measure remains significantly negative at conventional levels, with coefficients showing consistent magnitude and direction. Although the significance varies slightly when alternative climate risk measures are used, the overall pattern remains stable. These results reinforce the robustness of the main conclusion that climate risk reduces corporate leverage.

Table 10: Robustness Checks

Variables	Leverage (1)	Leverage1 (2)	Leverage (3)
ClimateRisk1	-0.004**		
	(0.002)		
ClimateRisk		-0.287***	-0.038***
		(0.051)	(0.007)
Size	0.067***	0.679***	0.071***
	(0.002)	(0.014)	(0.002)
ROA	-0.960***	-4.673***	-0.969***
	(0.021)	(0.169)	(0.023)
CGC	0.035***	0.124***	0.029***
	(0.002)	(0.020)	(0.003)
Top1	0.032***	0.925***	0.021*
	(0.011)	(0.076)	(0.011)
lnGDP	-0.027**	-0.507***	-0.042***
	(0.011)	(0.088)	(0.012)
Constant	-0.680***	-8.345***	-0.587***
	(0.117)	(0.962)	(0.133)
Year FE	YES	YES	YES
Firm FE	YES	YES	YES

Observations	14,108	15,266	11,977
Within R-squared	0.233	0.263	0.239

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

IV.VIII. HETEROGENEITY ANALYSIS

To further explore whether the impact of climate risk on corporate leverage varies across different firm characteristics, this section conducts a series of heterogeneity analyses. The grouping criteria reflect structural differences in financing environments, governance structures, and exposure to climate-related policy transitions.

IV.VIII.I. OWNERSHIP TYPE: STATE-OWNED VS. NON-STATE-OWNED ENTERPRISES

Chinese state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs) differ fundamentally in terms of financing constraints, government support, and risk-taking incentives. SOEs are typically larger in scale, more profitable, and possess stronger financial resources. Compared to non-SOEs, SOEs have greater internal financing capabilities and lower external financing needs. Furthermore, SOEs have consistently been a key focus of the Chinese government's "deleveraging" efforts. Prior studies show that SOEs generally face softer budget constraints, easier access to credit, and stronger policy backing (Li et al., 2008). In contrast, non-SOEs typically rely more heavily on external financing markets and are more vulnerable to regulatory and environmental uncertainties (Geng and Pan, 2024).

Given these structural distinctions, the reaction to climate-related uncertainty may also diverge. Table 11 shows that although climate risk significantly reduces leverage for both groups, the effect is more pronounced for non-SOEs. Specifically, non-state firms exhibit a coefficient of −0.034, compared with −0.030 for SOEs. This pattern is consistent with the expectation that non-SOEs, facing tighter financing constraints and higher marginal borrowing costs, are more sensitive to climate-related risks. Consequently, they tend to adjust their capital structures more aggressively by reducing debt.

Table 11: Heterogeneity analysis I

Variables	Leverage State-owned (1)	Leverage Non-state-owned (2)
ClimateRisk	-0.030*** (0.007)	-0.034*** (0.011)
Size	0.063*** (0.002)	0.079*** (0.003)
ROA	-1.035*** (0.026)	-0.771*** (0.034)
CGC	0.034*** (0.003)	0.038*** (0.004)
Top1	0.027** (0.011)	0.025 (0.017)
lnGDP	-0.045*** (0.012)	0.005 (0.023)
Constant	-0.394*** (0.136)	-1.258*** (0.243)
Year FE	YES	YES
Firm FE	YES	YES
Observations	10,047	4,993
Within R-squared	0.226	0.210

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

IV.VIII.II. OWNERSHIP CONCENTRATION: HIGH VS. LOW CONTROL

Next, firms are classified into high and low ownership-control groups based on the shareholding of the largest shareholder. Ownership concentration shapes corporate governance quality, managerial incentives, and risk preferences. Firms with highly concentrated ownership often exhibit more conservative financial policies, stronger monitoring, and quicker responses to external shocks (La Porta et al., 1999). Moreover, large controlling shareholders are more likely to internalize financial risks and therefore adjust leverage to safeguard firm value.

Consistent with this theoretical intuition, the estimation results reveal that climate risk exerts a stronger negative impact on leverage among high-control firms. This finding suggests that controlling shareholders respond to climate-related uncertainty by

actively reducing financial leverage, possibly to mitigate long-term exposure to environmental and policy risks. By contrast, firms with lower ownership concentration exhibit milder responses, likely due to dispersed monitoring and weaker alignment between ownership and risk management.

Table 11: Heterogeneity analysis II

Variables	Leverage High Ownership Control (1)	Leverage Low Ownership Control (2)
ClimateRisk	-0.025*** (0.009)	-0.021** (0.010)
Size	0.076*** (0.003)	0.062*** (0.003)
ROA	-1.010*** (0.030)	-0.798*** (0.028)
CGC	0.033*** (0.003)	0.035*** (0.004)
Top1	0.049*** (0.018)	0.072*** (0.027)
lnGDP	0.012 (0.016)	-0.062*** (0.016)
Constant	-1.289*** (0.171)	-0.214 (0.171)
Year FE	YES	YES
Firm FE	YES	YES
Observations	7,633	7,633
Within R-squared	0.252	0.181

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

IV.VIII.III. TYPES OF CLIMATE RISK: PHYSICAL VS. TRANSITION RISK

Finally, we distinguish between physical risk and transition risk, reflecting the growing emphasis in climate finance research on differentiating between acute climate events and low-carbon policy transitions (NGFS, 2019; Li et al., 2024; Giglio et al., 2021). Physical risks—including extreme weather, chronic temperature increases, and environmental degradation—tend to unfold gradually and may not immediately affect financing decisions. Transition risks, however, arise from regulatory adjustments, carbon-reduction policies, technological shifts, and investor expectations, which can directly alter firms' costs, operational flexibility, and financing capacity.

The regression results in Table 12 support this theoretical distinction. Physical risk does not exert a statistically significant effect on leverage, suggesting that Chinese listed firms may perceive physical climate threats as long-term structural issues with limited short-term balance-sheet implications. Conversely, transition risk significantly reduces leverage, with a coefficient of –0.028, indicating that firms respond more strongly to uncertainties associated with carbon-reduction policies, regulatory pressure, and market restructuring. This aligns with evidence from Krueger et al. (2020), who find that firms adjust financial decisions primarily in response to transition-related climate expectations.

Table 12: Heterogeneity analysis III

Variables	(1) Leverage	(2) Leverage
PysicalRisk	-0.004 (0.128)	
TransitionRisk		-0.028*** (0.006)
Size	0.066*** (0.002)	0.068*** (0.002)
ROA	-0.929*** (0.021)	-0.924*** (0.021)
CGC	0.036*** (0.002)	0.036*** (0.002)
Top1	0.034***	0.034***

	(0.009)	(0.009)
lnGDP	-0.034***	-0.031***
	(0.011)	(0.011)
Constant	-0.593***	-0.649***
	(0.116)	(0.117)
Year FE	YES	YES
Firm FE	YES	YES
Observations	15,266	15,266
Within R-squared	0.215	0.216

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

IV.VIII.IV. MODERATING EFFECT OF CASH HOLDINGS

To further examine whether firms' internal liquidity conditions alter the relationship between climate risk and capital structure decisions, this section investigates the moderating role of cash holdings. As discussed in the theoretical framework, the direction of moderation is theoretically ambiguous, giving rise to two competing hypotheses.

H_{2a} posits that cash holdings weaken the negative effect of climate risk on leverage. The rationale is that firms with abundant internal liquidity may be less financially constrained and therefore less pressured to reduce debt when confronted with climate-related uncertainty. In such cases, cash reserves act as financial buffers that cushion climate-induced operational and regulatory risks, thereby mitigating the need for deleveraging.

Conversely, H_{2b} predicts that cash holdings strengthen the negative effect of climate risk on leverage. Under this mechanism, firms with higher cash balances possess greater flexibility to substitute internal funds for external borrowing. When climate risk increases financing costs or raises uncertainty about future cash flows, these firms may more readily adjust toward lower leverage by relying on their liquid assets, resulting in an amplified negative effect.

Table 13 presents the moderating-effect regressions. In Column (3), the interaction term ClimateRisk×CashHold is statistically significant and negative at the 10% level. This finding indicates that the deleveraging response to climate risk becomes more pronounced when firms hold higher levels of cash. In other words, firms with abundant cash reserves respond to climate-related uncertainty by reducing their reliance on debt to an even greater extent than firms with lower cash buffers.

Table 13: Moderating effect results

Variables	Leverage (1)	Leverage (2)	Leverage (3)
ClimateRisk	-0.027***	-0.028***	-0.020***
	(0.006)	(0.006)	(0.008)
CashHold		-0.217***	-0.201***
		(0.010)	(0.013)
ClimateRisk×CashHold			-0.078*
			(0.043)
Size	0.068***	0.065***	0.066***
	(0.002)	(0.002)	(0.002)
ROA	-0.924***	-0.832***	-0.832***
	(0.021)	(0.021)	(0.021)
CGC	0.036***	0.034***	0.034***
	(0.002)	(0.002)	(0.002)
Top1	0.034***	0.033***	0.033***
	(0.009)	(0.009)	(0.009)
lnGDP	-0.031***	-0.036***	-0.036***
	(0.011)	(0.011)	(0.011)
Constant	-0.647***	-0.517***	-0.518***
	(0.117)	(0.115)	(0.115)
Year FE	YES	YES	YES
Firm FE	YES	YES	YES
Observations	15,266	15,266	15,266
Within R-squared	0.216	0.240	0.240

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

These results provide clear empirical support for H_{2b}, rather than H_{2a}. The evidence suggests that cash-rich firms prefer to conserve financial flexibility and reduce exposure to external financing risks when climate uncertainty rises. This behavior aligns with the precautionary motive and the substitution effect documented in prior studies, whereby firms choose to rely on internal liquidity and avoid costly external financing under heightened uncertainty. Furthermore, the inclusion of the moderating term substantially increases the explanatory power of the model (within R^2 rising from 0.216 to 0.240), indicating that cash holdings constitute an important mechanism through which climate risk affects corporate leverage decisions.

V. CONCLUSION

This paper offers comprehensive empirical evidence on how climate risk shapes the capital structure decisions of Chinese A-share listed companies. By integrating firm-level climate vulnerability indicators with detailed financial and governance data, the study demonstrates that climate risk exerts a consistently negative effect on corporate leverage. This deleveraging response persists across multiple robustness checks, alternative variable constructions, and heterogeneity analyses, thus reinforcing the interpretation that climate-related uncertainty fundamentally alters firms' financing choices. Moreover, the moderating effect of cash holdings reveals that internal liquidity amplifies firms' sensitivity to climate risk, as cash-rich firms substitute more aggressively away from debt financing. Collectively, these findings deepen the understanding of how climate-related risks propagate through corporate balance sheets and contribute to the broader literature linking environmental uncertainty to financial policy.

Nevertheless, several constraints should be acknowledged. First, although the study employs an extensive dataset and adopts rigorous econometric strategies, climate-risk measures may still contain latent measurement noise due to regional data aggregation or limited historical availability. Second, the analysis focuses exclusively on Chinese listed firms, and therefore, institutional characteristics—such as state ownership, bank-centered financing, and policy-driven environmental regulation—may shape the findings in ways that differ from other markets. Consequently, future research could extend this framework to cross-country settings or explore more granular climate indicators derived from satellite-based environmental monitoring.

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