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Climate Risk Exposure and Bank Lending Terms in the United States: Evidence from Disaster-Based Regional Risk Indicators

Siamak Javadi[1] and Abdullah Al Masum[2]

[1]University of Texas Rio Grande Valley (Robert C. Vackar College of Business), United States
[2]University of Wisconsin–Oshkosh (College of Business), United States
[1]siamak.javadi@utrgv.edu, [2]amasum@uwosh.edu

Abstract

Climate change has emerged as a material source of financial risk, particularly through physical climate events that disrupt firm operations and increase credit uncertainty. This study examines whether U.S. banks incorporate regional physical climate exposure into corporate lending contracts. Using a panel dataset of publicly listed firms from 2012–2025, we construct a disaster-based Climate Exposure Index (CEI) by combining county-level disaster frequency and economic losses from the NOAA database. We merge these data with firm financial information from Compustat and syndicated loan contract data from Dealscan to analyze the impact of climate exposure on multiple dimensions of loan contracts. Employing panel fixed-effects regressions, we find that firms located in regions with higher climate exposure face significantly tighter lending conditions. A one-standard-deviation increase in CEI is associated with higher loan spreads, shorter maturities, greater collateral requirements, and reduced loan sizes. These results indicate that banks respond to climate risk through multidimensional adjustments to loan contract terms rather than solely through pricing. The effects are more pronounced for firms with lower asset tangibility and weaker financial performance, suggesting that borrower characteristics amplify the impact of environmental risk. This study contributes to the growing literature on climate finance by providing evidence that disaster-based measures of physical climate risk are systematically incorporated into credit contracting. The findings highlight the importance of integrating localized environmental risk metrics into credit risk assessment and financial decision-making frameworks.

Keywords: *Climate risk, Physical climate exposure, Bank lending, Loan contract design, Credit risk assessment, Disaster analytics, Smart financial risk management*

1. Introduction

Climate change has increasingly emerged as a critical source of systemic risk for the global financial system. In recent years, the frequency and severity of extreme weather events—including hurricanes, floods, wildfires, and heatwaves—have increased significantly, creating substantial economic disruptions across many regions. These physical climate events can

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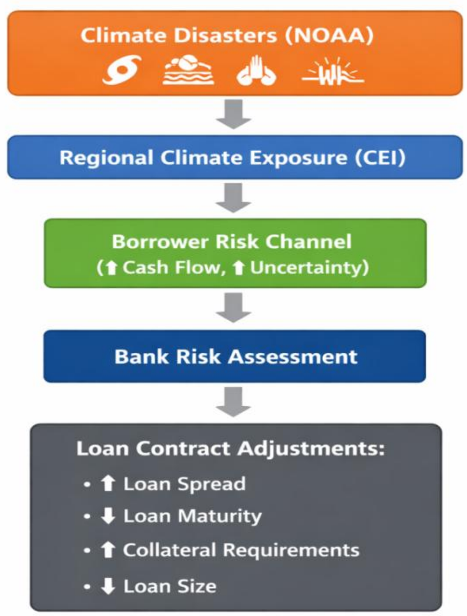
*corresponding author
[2]https://orcid.org/0009-0005-5084-6842

damage productive assets, interrupt supply chains, and increase uncertainty in corporate cash flows. As a result, climate-related shocks have become increasingly relevant for financial institutions that provide credit to firms exposed to geographically localized environmental risks. Banks, in particular, are vulnerable to climate-related shocks because the performance of loan portfolios depends heavily on the financial stability of borrowing firms and the economic resilience of the regions in which they operate.

A growing body of literature demonstrates that climate risk has important implications for financial markets and banking stability. Recent studies show that physical climate risk can increase default probabilities and reduce credit ratings for firms operating in climate-vulnerable regions, thereby influencing borrowing costs and credit access [1]. Empirical evidence further indicates that banks adjust lending conditions when borrowers face higher climate exposure, reflecting the incorporation of environmental risks into credit risk assessments [2]. In addition, climate-related shocks may increase overall credit risk within the banking system by raising the vulnerability of loan portfolios and weakening collateral values [3]. These findings suggest that climate risk is not merely an environmental concern but also a financially material factor affecting lending behavior and financial stability.

Despite the growing importance of climate-related financial risks, the mechanisms through which banks incorporate climate exposure into lending decisions remain an active area of research. Traditional credit risk models primarily focus on firm-level financial indicators such as leverage, profitability, and asset tangibility. However, climate change introduces a new dimension of risk that is geographically concentrated and often difficult to quantify using conventional financial indicators. As a result, financial institutions increasingly rely on environmental data and disaster-based risk metrics to assess the potential economic impact of climate-related shocks. Recent research suggests that banks may integrate climate risk into loan pricing models, capital allocation decisions, and portfolio management strategies [4].



Note: The figure illustrates how physical climate disasters contribute to regional climate exposure, which affects borrower risk and, in turn, influences bank risk assessment and loan contract adjustments, including loan spreads, maturity, collateral requirements, and loan size.

Figure 1. Conceptual Framework of Climate Risk Transmission to Loan Contracts

To illustrate the conceptual mechanism linking climate risk to lending outcomes, Figure 1 presents the transmission framework through which regional climate exposure influences bank loan contract design.

From a theoretical perspective, loan contracting models indicate that lenders can respond to increased borrower risk through multiple contractual channels. In addition to adjusting interest rate spreads, banks may shorten loan maturities, increase collateral requirements, or reduce loan sizes to manage potential credit losses. Empirical studies show that physical climate risk can influence not only loan pricing but also the broader structure of loan contracts, including collateralization and credit quantity adjustments [1]. These multidimensional responses highlight the importance of examining loan contract design rather than focusing solely on borrowing costs.

The United States provides an important empirical setting for studying climate risk and bank lending because it experiences significant regional variation in climate-related disasters. Coastal states are frequently affected by hurricanes and flooding, western states face increasing wildfire risk, and several inland regions experience severe droughts and extreme weather events. This geographic diversity creates substantial variation in climate exposure across firms headquartered in different regions. Such variation allows researchers to examine whether banks incorporate localized environmental risks into lending decisions.

This study investigates whether U.S. banks adjust corporate lending contracts in response to regional physical climate exposure. Using a panel dataset of publicly listed firms matched with county-level disaster data, this research constructs a Climate Exposure Index (CEI) capturing both disaster frequency and economic losses. The empirical analysis integrates firm-level financial data with syndicated loan contract information to examine how climate exposure affects loan spreads, maturity, collateralization, loan size, and loan renewal outcomes.

This study contributes to the emerging literature on climate finance in several ways. First, it provides new empirical evidence that banks respond to climate exposure through multiple loan contract dimensions rather than solely through interest rate pricing. Second, the study employs a disaster-based climate exposure index that captures realized physical climate shocks rather than relying solely on disclosure-based climate indicators. Third, the research highlights how environmental risk information can be incorporated into smart financial risk management systems, thereby improving financial institutions' ability to evaluate geographically concentrated climate risks.

Understanding how climate exposure affects bank lending is important for both financial stability and economic resilience. As climate-related disasters continue to intensify, banks and regulators will increasingly need to incorporate environmental risk metrics into credit risk models and financial supervision frameworks. The findings of this study, therefore, contribute to the growing policy discussion on climate stress testing, climate-aware lending practices, and the integration of environmental risk data into modern financial systems.

The remainder of the paper is organized as follows. Section 2 reviews the related literature and develops testable hypotheses. Section 3 describes the data sources and variable construction. Section 4 outlines the empirical methodology and presents the main results. Section 5 discusses the implications for climate-aware financial risk management. Section 6 concludes.

2. Literature Review and Theoretical Background

The relationship between climate change and financial systems has received growing attention in recent years, particularly as climate-related disasters increasingly affect economic productivity and financial stability. Physical climate risks—such as hurricanes, floods, droughts, and wildfires—can disrupt economic activity, damage physical infrastructure, and weaken firms' financial health. These disruptions may increase the likelihood of loan defaults and affect financial institutions' risk exposure. Consequently, researchers and policymakers have begun to examine how environmental risks influence credit markets, financial stability, and bank lending behavior.

Recent studies emphasize that climate change introduces both physical risk and transition risk into financial systems. Physical risks arise from direct environmental shocks that affect economic activity, whereas transition risks emerge from policy changes, technological shifts, and regulatory responses to climate change. Empirical evidence suggests that both forms of risk influence financial decision-making and asset pricing in modern markets [9]. For example, financial institutions increasingly incorporate climate-related indicators into their risk management frameworks to better assess long-term financial exposure and systemic vulnerabilities [10].

In the banking context, climate risk has important implications for credit allocation and lending behavior. Banks face exposure to climate-related shocks through their loan portfolios, as firms in vulnerable regions may experience operational disruptions and asset losses. These risks may reduce borrower repayment capacity and increase the probability of default. Empirical research demonstrates that climate-related disasters can negatively affect firm performance, leading to deteriorating financial conditions and reduced creditworthiness [11]. Consequently, banks may respond by tightening lending conditions, increasing loan spreads, or reducing credit supply to firms located in climate-exposed regions.

Another important dimension of the literature focuses on how climate risk affects the pricing of bank loans. Recent empirical evidence suggests that banks incorporate climate risk into lending decisions by adjusting interest rate spreads and loan contract terms. Firms with higher exposure to environmental risks often face higher borrowing costs because lenders require compensation for the increased probability of financial distress [12]. In addition, financial institutions may incorporate climate risk assessments into internal credit models to evaluate long-term borrower sustainability and environmental vulnerability [13]. These findings suggest that environmental factors are increasingly integrated into credit risk evaluation frameworks.

Beyond loan pricing, banks may also adjust non-price contract terms when responding to climate-related risks. Loan contracting theory indicates that lenders can modify various contractual features—such as loan maturity, collateral requirements, and loan size—to manage potential credit losses. When uncertainty increases, lenders may shorten loan maturities to allow for more frequent monitoring and repricing of credit risk. Similarly, requiring collateral can mitigate losses in the event of borrower default by providing lenders with additional recovery options. Empirical studies show that these non-price adjustments often accompany changes in loan spreads when banks respond to elevated borrower risk [14].

The role of regional exposure to climate disasters has also become a key focus in the climate finance literature. Firms located in areas frequently affected by environmental disasters may face higher financial risks due to supply chain disruptions, infrastructure damage, and increased insurance costs. Several studies find that firms operating in climate-vulnerable regions experience lower productivity and higher operating costs, which may translate into increased credit risk for lenders [15]. Consequently, banks may incorporate regional climate exposure into their lending decisions by adjusting loan conditions for borrowers operating in high-risk geographic areas.

Another emerging research stream examines how data analytics and digital risk assessment technologies can improve the evaluation of climate-related financial risks. Advances in financial technology and environmental data analytics have enabled financial institutions to integrate large-scale climate data into credit risk models. By combining Geographic Information Systems (GIS), disaster databases, and machine learning techniques, banks can more accurately evaluate borrower exposure to climate-related hazards. These data-driven approaches have been proposed as important tools for improving financial resilience and supporting climate-aware lending practices [16].

Despite these developments, several research gaps remain. First, much of the existing literature focuses primarily on loan pricing, while relatively fewer studies examine the broader structure of loan contracts and credit supply decisions [17]. Second, many empirical studies rely on firm-level environmental disclosures or carbon emissions data, which may not fully capture localized physical climate exposure [18]. Disaster-based measures of climate risk provide a more direct representation of environmental shocks affecting firm operations. Third, integrating climate risk metrics into smart financial risk management systems remains an emerging area of research, particularly regarding how banks incorporate environmental data into lending decisions.

Building on these insights, this study examines whether banks adjust multiple dimensions of loan contracts in response to regional physical climate exposure. By combining disaster-based climate exposure measures with detailed loan contract data, this research aims to provide a more comprehensive understanding of how climate risk influences bank lending behavior. The analysis contributes to the growing body of literature on climate finance by highlighting the importance of integrating environmental risk metrics into modern credit evaluation frameworks.

3. Research methodology

3.1. Data sources and sample construction

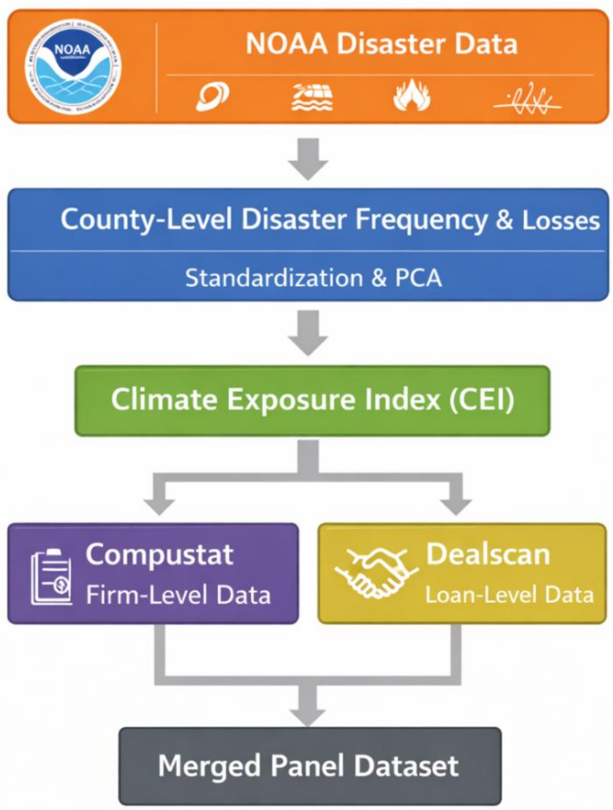
This study examines how regional physical climate exposure affects bank lending contracts in the United States. The empirical analysis integrates three primary datasets: syndicated loan data from the Dealscan database, firm financial information from Compustat, and regional disaster statistics from the National Oceanic and Atmospheric Administration (NOAA). Combining these datasets allows the study to link corporate borrowing conditions with geographically localized climate risk exposure.

Loan contract information is obtained from the Dealscan database, which provides detailed records of syndicated loan agreements between financial institutions and corporate borrowers. The dataset includes information on loan spreads, maturity, loan size, collateral requirements, and borrower identity. Dealscan is widely used in empirical banking research because it contains granular loan-level contract characteristics and lender–borrower relationships. Firm-level financial variables are collected from the Compustat database, which provides standardized accounting and financial information for publicly listed firms in the United States. These data include firm size, leverage, profitability, asset tangibility, and market-to-book ratios, which are commonly used as control variables in corporate finance research.

To measure regional climate exposure, this study uses disaster statistics from the NOAA Billion-Dollar Weather and Climate Disasters database. This dataset records major climate-related disasters in the United States, including hurricanes, floods, wildfires, droughts, winter storms, and severe weather events. For each event, NOAA reports the geographic location, year of occurrence, and estimated economic damages. By linking firms' headquarters locations to county-level disaster data, the study constructs a regional climate exposure measure that reflects the frequency and economic severity of environmental shocks affecting each firm's operating environment.

The initial sample includes all syndicated loans issued to publicly listed U.S. firms between 2012 and 2025. Financial institutions, utilities, and regulated industries are excluded because their capital structures and borrowing conditions are subject to different regulatory environments. Observations with missing information on key loan contract variables or firm financial characteristics are also excluded. To reduce the influence of extreme outliers, continuous variables are winsorized at the 1st and 99th percentiles. The final sample consists of firm–loan observations representing corporate borrowing relationships across multiple banks and geographic regions in the United States.

The data integration process and construction of the final panel dataset are illustrated in Figure 2.



Note: The figure illustrates the integration of NOAA disaster data, Compustat firm-level data, and Dealscan loan-level data. County-level disaster frequency and economic losses are standardized and combined using principal component analysis (PCA) to construct the Climate Exposure Index (CEI), which is then merged with firm and loan data to form the final panel dataset.

Figure 2. Data Pipeline for Constructing the Climate Exposure Index (CEI)

3.2. Measurement of climate exposure

The key explanatory variable in this study is the Climate Exposure Index (CEI), which captures the physical climate risk faced by firms from regional disaster events. The CEI is constructed using county-level disaster statistics derived from the NOAA database. Specifically, the index comprises two components: the frequency of climate-related disasters in a firm's geographic region and the total economic losses associated with those disasters.

To construct the index, disaster frequency and disaster-related economic losses are first standardized to ensure comparability across regions and years. The standardized variables are then combined using principal component analysis to generate a composite climate exposure index. This approach reduces measurement noise and captures the common variation underlying different dimensions of climate-related disasters. Each firm-year observation is assigned a CEI value based on the geographic location of the firm’s headquarters in a given year.

$$F^*_{c,t} = \frac{F_{c,t} - \mu F}{\sigma_F}, L^*_{c,t} = \frac{L_{c,t} - \mu L}{\sigma_L} \quad (1)$$

where $F^*_{c,t}$ and $L^*_{c,t}$ denote disaster frequency and economic losses in county c during year t, respectively. The standardized variables are then combined using principal component analysis (PCA) to construct the Climate Exposure Index (CEI):

$$CEI_{c,t} = \alpha_1 F^*_{c,t} + \alpha_2 L^*_{c,t} \quad (2)$$

where α_1 and α_2 represent the loadings of the first principal component. Each firm is assigned a climate exposure value based on its headquarters location:

$$CEI_{i,t} = CEI_{c(i),t} \quad (3)$$

This approach captures both the frequency and economic severity of climate-related disasters while reducing dimensionality and measurement noise.

As shown in Figure 2, the CEI is constructed by combining standardized measures of disaster frequency and economic losses derived from NOAA data.

The use of disaster-based exposure measures provides an objective representation of physical climate risk because it relies on realized environmental shocks rather than subjective environmental disclosures or forward-looking climate scenarios. As a result, the CEI reflects actual economic disruptions that may affect firms’ operating environments and credit risk.

3.3. Empirical model

To evaluate how climate exposure affects loan contract terms, this study estimates panel regression models linking the Climate Exposure Index to various loan outcomes. The baseline specification examines whether regional climate exposure is associated with changes in loan spreads, loan maturity, collateralization, and loan size.

The empirical model is specified as follows:

$$LoanContract_{i,t} = \alpha\, \beta \mathrm{CEI}_{i,t} + \gamma \mathrm{X}_{i,t-1} + \delta \mathrm{Z}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (4)$$

where $LoanContract_{i,t}$ represents the loan contract outcome for firm i in year t. Depending on the regression specification, this variable may represent loan spreads, loan maturity, collateralization indicators, or the logarithm of loan size. The variable $\mathrm{CEI}_{i,t}$ denotes the Climate Exposure Index assigned to the borrower based on their geographic location. The vector $\mathrm{X}_{i,t-1}$ represents firm-level control variables measured in the previous year, including firm size, leverage, profitability, asset tangibility, and market-to-book ratio. The vector $\mathrm{Z}_{i,t}$ includes loan-specific contract controls such as loan size, maturity, and collateralization when applicable.

Firm fixed effects (μ_i) are included to control for time-invariant borrower characteristics, while year fixed effects (λ_t) capture macroeconomic conditions affecting credit markets. Standard errors are clustered at the firm level to account for potential serial correlation in borrowing relationships over time.

For binary outcomes such as collateralization and loan renewal decisions, the study estimates linear probability models with the same fixed effects structure. This approach allows for consistent interpretation of coefficients while maintaining comparability with continuous outcome regressions.

3.4. Identification strategy

A key empirical challenge in studying loan contracts is distinguishing lender-side credit supply decisions from borrower demand for credit. Firms experiencing climate-related disruptions may demand different borrowing terms, which could confound the interpretation of observed lending outcomes. To address this issue, the empirical design incorporates fixed effects and control variables that isolate the impact of regional climate exposure on lending decisions.

First, firm fixed effects control for unobserved borrower characteristics that remain constant over time, such as managerial quality, industry characteristics, and long-term creditworthiness. Second, year fixed effects capture macroeconomic fluctuations affecting the entire credit market, including interest rate cycles and financial conditions. Third, the inclusion of detailed firm-level financial controls ensures that changes in borrower financial performance do not drive observed lending outcomes.

In addition, the study exploits geographic variation in climate exposure across U.S. regions. Because disaster events are largely exogenous to individual firm decisions, regional variation in environmental shocks provides a quasi-natural experiment for identifying the effect of climate exposure on lending conditions. By comparing firms located in regions with different levels of climate exposure over time, the analysis isolates the relationship between environmental risk and bank lending behavior.

3.5. Variable definitions

The dependent variables capture key dimensions of loan contract design. Loan spreads measure the difference between the contractual loan interest rate and the benchmark reference rate, reflecting the price of credit. Loan maturity represents the length of the loan contract in years. Collateralization is a binary indicator equal to one if the loan requires collateral or guarantees. Loan size is measured as the natural logarithm of the total principal amount of the loan.

The primary independent variable, the Climate Exposure Index, measures the intensity of climate-related disasters in the borrower's geographic region. Control variables include firm size (measured as the logarithm of total assets); leverage (total debt divided by total assets); profitability (return on assets); asset tangibility (tangible assets divided by total assets); and the market-to-book ratio, which captures firm growth opportunities.

Together, these variables allow the empirical analysis to examine how climate exposure influences multiple dimensions of bank lending contracts while controlling for borrower characteristics and macroeconomic conditions.

4. Empirical results and case analysis

4.1. Descriptive statistics

This section presents descriptive statistics for the primary variables used in the analysis. The dataset includes syndicated loans issued to publicly listed U.S. firms between 2012 and 2025. The descriptive statistics provide an overview of borrower characteristics, loan contract terms, and the distribution of the Climate Exposure Index (CEI).

The average loan spread in the sample is approximately 2.35 percentage points above the benchmark rate, with a standard deviation of 0.91 percentage points. This variation indicates substantial differences in borrowing costs across firms and lending relationships. The Climate Exposure Index is standardized with a mean close to zero and a standard deviation of approximately 0.97, suggesting significant variation in climate-related disaster exposure across U.S. regions.

Firm characteristics show patterns consistent with prior corporate finance research. The average firm size (log total assets) is 22.48, indicating that the sample comprises medium- to large-sized publicly listed firms. The average leverage ratio is 0.39, while the mean return on assets is 0.051. Asset tangibility averages 0.36, reflecting the availability of collateralizable assets in corporate borrowing.

Loan contract characteristics also exhibit meaningful variation. The average loan maturity is 3.10 years, and approximately 67% of loans require collateral or guarantees. These statistics suggest that lenders frequently rely on collateral arrangements and contract structure adjustments to manage credit risk.

Table 1 reports the summary statistics for all key variables used in the analysis.

Table 1. Descriptive statistics

Variable	N	Mean	Std. Dev.	Min	Max
Loan Spread (%)	8,942	2.35	0.91	0.40	6.10
CEI (Climate Exposure Index)	8,942	0.01	0.97	-2.21	2.85
Firm Size (log assets)	8,942	22.48	1.26	19.72	26.03
Leverage	8,942	0.39	0.18	0.02	0.84
ROA	8,942	0.051	0.067	-0.21	0.27
Tangibility	8,942	0.36	0.21	0.01	0.90
Market-to-Book	8,942	2.12	1.11	0.42	6.88
Loan Maturity (years)	8,942	3.10	1.74	0.25	10.00
Collateral (dummy)	8,942	0.67	0.47	0	1
Loan Size (log USD)	8,942	17.58	1.22	13.85	21.03

Note: Loan data are obtained from Dealscan, firm financial information from Compustat, and disaster exposure data from the NOAA Billion-Dollar Disaster Database.

4.2 Baseline regression results

Table 2 presents the baseline regression results examining the relationship between regional climate exposure and loan contract terms. The results show that climate exposure has statistically significant effects on multiple dimensions of lending contracts.

Column (1) reports the results when the loan spread is the dependent variable. The coefficient on the Climate Exposure Index is positive and statistically significant at the 1%

level, indicating that firms located in regions with higher climate exposure face higher borrowing costs. Economically, a one-standard-deviation increase in CEI increases loan spreads by approximately 9–11 basis points.

Column (2) examines loan maturity. The coefficient on CEI is negative and statistically significant, suggesting that lenders shorten loan maturities in regions with higher environmental risk. Shorter loan horizons allow lenders to reassess credit risk more frequently in uncertain environments.

Column (3) examines collateralization. The positive coefficient indicates that loans issued to firms in high climate-risk regions are more likely to require collateral. This finding is consistent with credit contracting theory, which suggests that collateral helps mitigate potential losses in the event of borrower default.

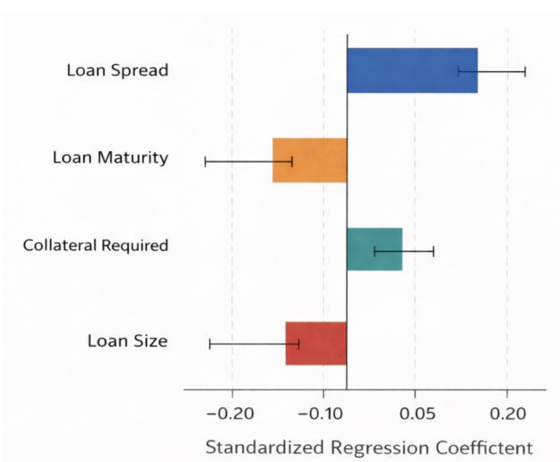
Column (4) examines loan size. The negative and statistically significant coefficient indicates that lenders reduce credit exposure when borrowers operate in climate-vulnerable regions. Finally, Column (5) examines loan renewal outcomes, showing that climate exposure slightly reduces the probability of loan renewal.

Table 2. Baseline regression results

Variables	(1) Spread	(2) Maturity	(3) Collateral	(4) Loan Size	(5) Renewal
Climate Exposure Index	0.102***	-0.081***	0.031**	-0.045***	-0.022*
Firm Size	-0.058***	0.185***	0.021***	0.792***	0.028***
Leverage	0.533***	-0.242***	0.116***	0.341***	-0.074***
ROA	-1.182***	0.392**	-0.082**	0.614***	0.147***
Tangibility	-0.142**	0.301***	0.218***	0.177***	0.041**
Market-to-Book	0.042*	-0.059**	-0.031***	0.052**	0.012
Firm Fixed Effects	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	8,942	8,942	8,942	8,942	8,942
Adjusted R^2	0.60	0.55	0.39	0.63	0.34

*Note: Standard errors clustered at the firm level. *, **, *** denote statistical significance at the 10%, 5%, and 1% levels.*

To provide a visual summary of the baseline results, Figure 3 presents the standardized coefficients of climate exposure across different loan contract dimensions.



Note: The figure displays standardized regression coefficients and 95% confidence intervals for the effect of the Climate Exposure Index (CEI) on loan spread, maturity, collateralization, and loan size. Positive coefficients indicate increases in contract terms, while negative coefficients indicate reductions in contract terms in response to higher climate exposure.

Figure 3. Relative Changes in Loan Contract Terms due to Climate Exposure

As shown in Figure 3, climate exposure increases loan spreads and collateral requirements while reducing loan maturity and loan size, consistent with a multidimensional tightening of credit conditions.

4.3 Robustness Analysis

Several robustness checks are conducted to ensure that the baseline results are not driven by model specification or omitted variable bias. First, alternative climate exposure measures are constructed using disaster frequency and disaster-related economic losses separately. The regression results remain consistent across these alternative measures.

Second, the model includes additional controls for regional economic conditions—such as state-level GDP growth and unemployment rates. These controls do not materially change the estimated coefficients on the Climate Exposure Index.

Third, the study estimates regressions using lagged climate exposure to address potential simultaneity between climate events and borrowing decisions. The results remain statistically significant under these alternative specifications, suggesting that climate exposure has a persistent impact on lending conditions.

4.4. Cross-sectional heterogeneity

The analysis further examines whether the impact of climate exposure varies across firm types. In particular, the study examines heterogeneity based on asset tangibility and financial performance.

The results indicate that climate exposure has stronger effects on firms with lower asset tangibility. Firms with fewer tangible assets have limited collateral available to secure loans, making them more vulnerable to tightening credit conditions in high-risk regions. As a result, lenders respond more aggressively to climate exposure when lending to these firms.

Similarly, firms with weaker financial performance experience larger increases in borrowing costs when operating in climate-exposed regions. These results suggest that environmental risk interacts with borrower financial characteristics to shape lending outcomes.

Table 3. Heterogeneity Analysis

Variables	(1) Spread	(2) Maturity	(3) Collateral	(4) Loan Size
Climate Exposure Index	0.051**	-0.039*	0.014	-0.022
CEI × Low Tangibility	0.068***	-0.052**	0.029**	-0.041**
CEI × Low Profitability	0.073***	-0.047**	0.021*	-0.034*
Controls	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Observations	8,942	8,942	8,942	8,942

Note: *Low tangibility and low profitability are defined relative to the sample median.*

4.5 Case analysis: Regional climate risk and lending behavior

To illustrate the mechanisms underlying the empirical results, the study examines case studies from different regions. Coastal regions in the southeastern United States—frequently affected by hurricanes—show higher Climate Exposure Index values. Firms headquartered in these regions face higher loan spreads and stricter collateral requirements than firms located in less-exposed inland areas.

Similarly, firms operating in Western states affected by wildfires exhibit noticeable adjustments in lending conditions following major disaster events. Banks respond by tightening credit supply and shortening loan maturities, reflecting increased uncertainty regarding long-term borrower stability.

These regional patterns illustrate how localized climate shocks influence financial decision-making and demonstrate the importance of incorporating environmental risk indicators into credit risk evaluation frameworks.

5. Discussion

The empirical findings are consistent with the conceptual framework presented in Figure 1, which illustrates how regional climate exposure translates into multidimensional adjustments in loan contract design through borrower risk and bank risk assessment channels.

The patterns observed in Figure 3 further confirm that banks respond to climate exposure through multiple contractual channels rather than relying solely on pricing adjustments.

The empirical findings presented in Section 4 provide strong evidence that regional climate exposure significantly influences bank lending decisions in the United States. The results indicate that financial institutions respond to environmental risks through multiple contractual channels, including loan pricing, maturity adjustments, collateral requirements, and credit quantity decisions. These findings reinforce the argument that climate risk is increasingly integrated into modern credit risk evaluation frameworks.

First, the positive relationship between climate exposure and loan spreads suggests that banks incorporate environmental risk into credit pricing mechanisms. Firms located in regions frequently affected by climate-related disasters face higher borrowing costs because lenders require compensation for increased uncertainty and potential financial distress. This result aligns with recent climate finance studies showing that environmental risks are reflected in corporate financing costs and credit conditions [17]. Importantly, the magnitude of the spread adjustment is economically meaningful, indicating that lenders actively incorporate regional disaster exposure into their risk assessments.

Second, the results demonstrate that banks adjust non-price contract terms in response to climate exposure. Loan maturity is significantly shorter for borrowers operating in high-risk regions, suggesting that lenders prefer shorter credit horizons when environmental uncertainty increases. Shorter maturities allow banks to reassess borrower risk more frequently and adjust lending conditions in response to evolving environmental conditions. This behavior is consistent with theoretical models of loan contracting, which predict that lenders will modify contract duration when facing elevated borrower risk [18].

Third, the analysis shows that collateral requirements increase for firms exposed to higher levels of climate risk. Collateral plays a critical role in mitigating expected losses when borrower default probabilities increase. In regions with frequent environmental disasters, the risk of asset damage or operational disruption may reduce borrower repayment capacity. By requiring collateral, lenders can protect themselves against potential credit losses and maintain the stability of their loan portfolios.

Fourth, the results indicate that banks reduce loan sizes for firms located in climate-vulnerable regions. This finding suggests that lenders actively manage exposure to environmental risk by limiting the quantity of credit extended to vulnerable borrowers. The reduction in loan size represents a form of credit rationing that allows banks to control portfolio risk while still maintaining lending relationships with borrowers.

The heterogeneity analysis further reveals that climate exposure has stronger effects for firms with lower asset tangibility and weaker financial performance. Firms with limited tangible assets have fewer collateralizable resources available to secure loans, making them more vulnerable to credit tightening. Similarly, financially weaker firms are more likely to experience increases in borrowing costs when operating in high-risk regions. These results highlight the interaction between environmental risk and borrower financial characteristics in shaping lending outcomes.

Overall, the findings suggest that climate risk affects bank lending behaviour through a combination of pricing adjustments and contract design modifications. Rather than relying solely on higher interest rates, lenders employ a multidimensional strategy that includes shorter loan maturities, stricter collateral requirements, and reduced credit supply. This comprehensive response reflects the complexity of environmental risks and their potential impact on borrower financial stability.

From a technological perspective, the results highlight the growing importance of data-driven climate risk analytics in financial decision-making. Advances in environmental data collection and disaster monitoring enable financial institutions to integrate climate risk indicators into credit evaluation models. By combining geographic information systems, disaster databases, and financial data, banks can better assess borrower exposure to environmental hazards and improve risk management strategies [18].

The findings also have implications for financial regulation and supervisory frameworks. Regulators increasingly encourage banks to conduct climate stress testing and incorporate environmental risk into prudential supervision. Understanding how climate exposure influences lending decisions provides valuable insights into how environmental shocks may propagate through the financial system. The results suggest that integrating climate risk metrics into supervisory models could enhance financial institutions' resilience and reduce systemic vulnerabilities.

To summarize the empirical evidence and theoretical implications, Table 4 presents a synthesis of the main findings and their relationship to the study's hypotheses.

Table 4. Synthesis of Empirical Findings

Hypothesis	Expected Relationship	Empirical Result	Interpretation
H1: Climate exposure and loan spreads	Positive	Supported	Banks charge higher spreads to compensate for climate-related credit risk
H2: Climate exposure and loan maturity	Negative	Supported	Lenders shorten loan horizons to reassess borrower risk more frequently
H3: Climate exposure and collateralization	Positive	Supported	Collateral requirements increase to mitigate potential credit losses
H4: Climate exposure and loan size	Negative	Supported	Banks reduce credit exposure to firms in high-risk regions
H5: Climate exposure and loan renewal	Negative	Partially Supported	Climate risk slightly reduces long-term lending relationships

Note: The table summarizes the empirical findings reported in Section 4 and their consistency with the theoretical hypotheses developed in the literature review.

In summary, the empirical analysis demonstrates that climate exposure is increasingly important in shaping bank lending behavior. The results highlight the need for financial institutions to integrate environmental risk metrics into credit risk evaluation frameworks and loan portfolio management strategies. As climate-related disasters intensify, the ability of banks to assess and manage environmental risks effectively will become increasingly important for maintaining financial stability and supporting sustainable economic growth.

6. Conclusion

This study examines how regional exposure to physical climate influences bank lending decisions in the United States. By integrating syndicated loan data from the Dealscan database, firm-level financial information from Compustat, and disaster statistics from the NOAA Billion-Dollar Disaster Database, the analysis provides new empirical evidence on how environmental risks affect corporate credit conditions. The results demonstrate that banks systematically adjust multiple dimensions of loan contracts in response to climate-related risks.

The empirical findings indicate that firms located in regions with higher climate exposure face significantly tighter credit conditions. In particular, lenders charge higher loan spreads, shorten loan maturities, increase collateral requirements, and reduce loan sizes for borrowers operating in disaster-prone areas. These adjustments suggest that banks actively incorporate environmental risk information into credit evaluation processes and loan contract design. Rather than relying solely on interest rate adjustments, lenders respond to climate exposure through a multidimensional strategy that combines pricing and non-price contractual mechanisms.

The heterogeneity analysis further reveals that the effects of climate exposure are more pronounced for firms with lower asset tangibility and weaker financial performance. Firms with limited collateralizable assets face tighter credit conditions when operating in environmentally vulnerable regions. These findings highlight the interaction between environmental risk and borrower characteristics in shaping lending outcomes.

From a theoretical perspective, this study contributes to the growing literature on climate finance by demonstrating that physical climate risk influences the broader structure of loan contracts rather than solely affecting borrowing costs. The findings extend existing research by showing that banks adjust multiple contractual margins—including loan maturity, collateralization, and credit quantity—when responding to environmental risks. This multidimensional response reflects the complex nature of climate-related financial risks and the need for lenders to manage uncertainty across several aspects of credit relationships.

The study also provides important implications for financial institutions and policymakers. As climate-related disasters become more frequent and severe, banks will increasingly need to incorporate environmental risk indicators into credit risk models and portfolio management strategies. Advances in data analytics and environmental monitoring technologies allow financial institutions to integrate climate risk metrics into lending decisions more effectively. The use of disaster-based exposure measures and geographic risk indicators may improve banks' ability to evaluate borrower vulnerability and maintain loan portfolio stability.

For regulators and policymakers, the findings highlight the importance of integrating climate risk considerations into financial supervision frameworks. Climate stress testing, environmental disclosure requirements, and climate-aware lending guidelines are increasingly being implemented across financial systems worldwide. Understanding how banks already respond to climate exposure provides valuable insights into how environmental risks may propagate through credit markets and affect financial stability.

Despite its contributions, this study has several limitations that provide opportunities for future research. First, the analysis focuses on publicly listed firms and syndicated loan markets, which may not fully represent borrowing conditions for smaller firms or private credit markets. Future research could examine how climate exposure affects lending behavior in small business or regional banking contexts. Second, the study focuses primarily on physical climate risks associated with disaster events. Additional research could explore the interaction between physical climate risk and transition risks arising from climate policies, technological changes, or environmental regulations.

Future studies may also benefit from incorporating advanced analytical methods, such as machine learning techniques and geospatial climate models, to further improve the measurement of environmental risk exposure. Integrating real-time environmental monitoring data with financial datasets may enable researchers and financial institutions to develop more sophisticated climate risk assessment frameworks.

In conclusion, this study's findings demonstrate that climate exposure is increasingly important in shaping bank lending behavior. As environmental risks continue to intensify, financial institutions must adapt their credit risk management strategies to account for geographically localized climate vulnerabilities. Incorporating environmental risk metrics into financial decision-making will be essential to maintaining financial stability and supporting sustainable economic development amid increasing climate uncertainty.

References

[1] K. Kempa, "Physical climate risk and the pricing of bank loans," Journal of Environmental Economics and Management, vol.137, pp.103280, (2026) DOI:10.1016/j.jeem.2025.103280

[2] M. Shikimi, "Firms' climate risks and bank lending: Evidence from the COVID-19 crisis," Finance Research Letters, vol.73, pp.106606, (2025) DOI:10.1016/j.frl.2024.106606

[3] I. Abinzano, P. Corredor, and J. M. Mansilla-Fernández, "Physical climate risk and banks' credit risk: Worldwide evidence," The North American Journal of Economics and Finance, vol.81, pp.102550, (2025) DOI:10.1016/j.najef.2025.102550

[4] S. Battiston, Y. Dafermos, and I. Monasterolo, "Climate risks and financial stability," Journal of Financial Stability, vol.54, pp.100867, (2021) DOI:10.1016/j.jfs.2021.100867

[5] N. Alsagr and N. Apergis, "Total climate change risk and banks' loan portfolios: Fresh evidence and extensions," Journal of Environmental Management, vol.394, pp.127460, (2025) DOI:10.1016/j.jenvman.2025.127460

[6] V. Peters, "How banks are impacted by and mediate the economic consequences of natural disasters and climate shocks: A review," De Economist, vol.173, pp.47–85, (2025) DOI:10.1007/s10645-024-09441-7

[7] Y. Zhang and H. Ming, "Climate risk exposure and bank risk-taking behavior: New evidence from China," Humanities and Social Sciences Communications, vol.12, no.1, pp.1865, (2025) DOI:10.1057/s41599-025-06232-6

[8] P. Bolton, M. Despres, L. Pereira da Silva, F. Samama, and R. Svartzman, "The green swan: Central banking and financial stability in the age of climate change," Bank for International Settlements, **(2020)**

[9] S. Battiston, Y. Dafermos, and I. Monasterolo, "Climate risks and financial stability," Journal of Financial Stability, vol.54, pp.100867, (2021) DOI:10.1016/j.jfs.2021.100867

[10] J. M. Addoum, D. T. Ng, and A. Ortiz-Bobea, "Temperature shocks and establishment sales," The Review of Financial Studies, vol.33, no.3, pp.1331–1366, (2020) DOI:10.1093/rfs/hhz126

[11] E. Ilhan, Z. Sautner, and G. Vilkov, "Carbon tail risk," The Review of Financial Studies, vol.34, no.3, pp.1540–1571, (2021) DOI:10.1093/rfs/hhaa071

[12] M. D. Delis, M. Iosifidi, and S. Ongena, "Being stranded with fossil fuel reserves? Climate policy risk and the pricing of bank loans," Financial Markets, Institutions & Instruments, vol.33, no.3, pp.239–265, (2024) DOI:10.1111/fmii.12189

[13] S. Giglio, B. Kelly, and J. Stroebel, "Climate finance," Annual Review of Financial Economics, vol.13, pp.15–36, (2021) DOI:10.1146/annurev-financial-102620-103311

[14] R. Ma, R. Yuan, and X. Fu, "Climate change opportunity and corporate investment: Global evidence," Journal of Climate Finance, vol.3, pp.100013, (2023) DOI:10.1016/j.jclimf.2023.100013

[15] I. Monasterolo and L. De Angelis, "Blind to carbon risk? An analysis of stock market reaction to the Paris Agreement," Ecological Economics, vol.170, pp.106571, (2020) DOI:10.1016/j.ecolecon.2019.106571
[16] V. Ivashina and D. Scharfstein, "Bank lending during the financial crisis of 2008," Journal of Financial Economics, vol.97, no.3, pp.319–338, (2010) DOI:10.1016/j.jfineco.2009.12.001
[17] E. Benmelech and N. K. Bergman, "Collateral pricing," Journal of Financial Economics, vol.91, no.3, pp.339–360, (2009) DOI:10.1016/j.jfineco.2008.03.003
[18] P. D'Orazio, "Climate risks and financial stability: Evidence on the effectiveness of climate-related financial policies," International Review of Financial Analysis, vol.105, pp.104304, (2025) DOI:10.1016/j.irfa.2025.104304