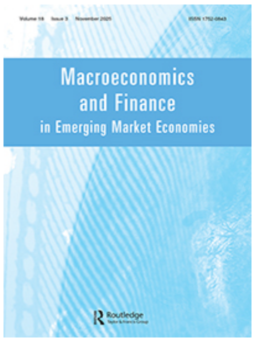

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Physical climate risk and bank lending: empirical evidence from emerging markets

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Physical climate risk and bank lending: empirical evidence from emerging markets

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ABSTRACT

This research is an attempt to look at the potential impacts of climate change derived from extreme weather events on banking activities. The study focuses on studying the impact of climate change vulnerability and adaptability on credit behaviour of banks located in emerging countries over a 10-year period. Results suggest that vulnerability to physical climate risk negatively affects loan supply. Additionally, countries' adaptability to this risk can enhance credit supply. By shedding light on these relationships, our analysis offers insights to regulators and professionals.

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Climate vulnerability; adaptability; credit supply; banks

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Introduction

Climate change is the greatest challenge facing humanity in this century. The first decade has been the hottest ever recorded, accompanied by an intensification of floods, droughts, heatwaves, and water shortages, with immense social and economic impacts, the new decade seems to have the same characteristics if not worse (FAO 2021). Climate risk is recognized as the most significant global menace, having substantial impact on economic performance, disrupting the operations of numerous institutions and increasing systemic risk across countries.

The financial sector is not immune to the repercussions of climate change; it is affected directly, but above all, indirectly by the damage caused by natural disasters. By financing risky projects and businesses, banks can find themselves in unstable situations if these borrowers suffer damage as a result of disasters and fail to honour their commitments. Therefore, banks are at risk from climate change, which may impair economic activity in other sectors and lead to suboptimal investment. Changes in the frequency and severity of natural disasters stemming from climate change may result in higher insurance payouts and lower credit ratings for disaster-affected countries. Climate change could redefine the mission of the financial industry, and further research is required to identify specific vulnerabilities, quantify potential damages, analyse implications for both private and public finance and identify potential ways to reduce these impacts. Assessing the impacts of climate change on banking activities and evaluating the needed conditions to mitigate this effect is a necessary first step to build policy for the industry. This research seeks to contribute towards the aforementioned research gap by focusing specifically on the

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implications of climate risk vulnerability and adaptability on lending activity of banks in emerging countries.

Our research is linked to at least two literature strands. First, it contributes to the growing empirical literature on climate risk with a particular focus on physical risk. It is widely recognized that natural disasters entail adverse effects including direct costs such as deaths, building destruction and aggregate physical damages (Lazzaroni and Van Bergeijk 2014), as well as indirect costs, notably GDP recession (Klomp and Valckx 2014). More precisely, our study is related to the burgeoning literature documenting the impact of climate risk on the banking industry. In this vein, recent studies have documented that physical climate risk affects banking performance (Caby, Ziane, and Lamarque 2022), asset valuation (Campiglio et al. 2023) and financial stability (Nieto 2019). Another field of the literature has focused on how banks react to climate change by integrating this risk into their management strategy (Capasso, Gianfrate, and Spinelli 2020). Second, our research is closely linked to the literature on credit supply determinants. Previous studies have shown that macroeconomic factors have a significant impact on the granting of bank loans (Pham 2015). In addition, specific bank characteristics – particularly bank capital – determine their lending strategy. This strand of the literature is developed after the banking crisis of 2008, which put credit strategy back on both regulators' and researchers' agenda since crises and economic uncertainty affect banks' decisions (Swamy and Sreejesh 2012).

Three major differences distinguish us from previous studies. Firstly, our research sheds light on the impact of the country's climate risk on the banking sector without considering a specific natural disaster. Second, whereas previous studies have largely focused on mitigation (Kates 2000), our research emphasizes adaptability, which has received limited attention. In fact, as defined by the fourth assessment report of the IPCC as 'adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities', it better addresses urgent issues like climate variability. We note that as public authorities have recently increased their focus on adaptation, academic research has also started to explore strategies for adapting to climate change and examining the impacts of these approaches. However, the banking sector remains absent from these studies. Thirdly, we refine our study by focusing on the bank's core business, while the majority of studies focus on financial performance. Hence, the fundamental objective of our research is to address the effect of countries' vulnerability and adaptability to climate change on banks' lending behaviour. We analyse banks' level data, addressing an important gap in the finance and banking academia, which currently has limited empirical evidence regarding the effect of countries' vulnerability and adaptability to climate change for banks.

We have chosen a study duration spanning a decade, from 2010 to 2019, primarily because it provides a comprehensive dataset of financial and climate information for numerous banks. Second, the exclusion of the years 2020 and 2021 from our analysis is attributed to the substantial impact of the coronavirus on banks' lending. Finally, this decade witnessed various extreme climate events, influencing the economies of emerging countries. Examining this specific time-frame allows for an in-depth investigation into how these events have affected banks' lending behaviour. Over the course of this period, there has been a notable increase in awareness regarding climate risks, prompting banks to implement necessary measures. In this context, we have examined the effect of physical climate vulnerability and adaptability on banks' lending by covering a broad sample of 114 banks from 10 emerging countries, classified as newly industrialized countries by the World Bank.

There are two major results from this empirical study. First, findings show that vulnerability to physical climate risk has a significant negative impact on bank lending; this conclusion remains unchanged after considering endogeneity and some sensitivity robustness tests. Second, the country's adaptability has a positive impact on bank lending; banks located in more adapted countries to climate risk have significantly higher loans in their assets. Specifically, these relations are stronger after the Paris Agreement and after controlling the acquisition and merger effects.

By understanding how these institutions manage the consequences of climate events, valuable insights can be gained into the financial resilience of the entire economy. Furthermore, emerging markets are generally characterized by rapid integration into the global economy, both from a trade perspective and a financial standpoint. However, financial institutions in emerging markets may be more vulnerable than those in advanced market economies, notably due to weaker banking regulations. Banks of emerging countries may face specific challenges in terms of adaptation and financial resilience, given their limited economic and institutional capacities. Studying the impact of climate risk in these contexts can provide crucial insights into how banks navigate through often more complex and volatile economic environments. Finally, the choice to focus on emerging countries stems from the increasing recognition of their central role in the global economy and the need to understand how the financial institutions serving them can contribute to overall sustainability. In essence, concentrating research on emerging countries offers a unique perspective on the specific challenges these nations encounter in the face of climate risks and allows for targeted recommendations to enhance financial stability in these regions.

The remainder of this paper is organized as follows. Section 2 presents the literature review and the hypothesis. Section 3 explains the methodology of the empirical study and the data used. Section 4 exposes the results and Section 5 conclude.

Literature review and hypothesis development

The scientific community affirms that climate change exacerbates natural disasters by increasing the frequency and intensity of extreme weather events, such as powerful hurricanes, prolonged droughts and intense heatwaves. The extent to which net climate change may harm a particular organization is referred to as vulnerability, which implies a state of weakness or powerlessness of the system (O'Brien et al. 2007).

Predominantly focused on the macroeconomic implications of climate change, prior research affirmed that climate change is adverse to economic growth. In a related vein, it is well documented that increasing the frequency and severity of natural disasters affects economic development (Loayza et al. 2012) and reduces the accumulation of human capital (Cuaresma 2010). Recently, Cevik and Jalles (2022) present evidence indicating that climate change vulnerability is already exerting a statistically and economically noteworthy influence on sovereign borrowing costs, credit ratings, and the risk of debt default, with a pronounced impact observed in low-income countries. Climate change increases the banking crisis and public debts (Lamperti et al. 2019) and negatively affects private credit supply, especially for high-income countries (Li, Li, and Lu 2022).

Focusing on specific natural catastrophes, several empirical studies prove that banks, affected by deposit withdrawals, lower their credit supply in response to natural disasters such as hurricanes on the Eastern Caribbean Island (Brei, Mohan, and Strobl 2019) and the Indian Ocean Tsunami (Nguyen and Wilson 2020). This effect can be attributed to the worsening balance sheets and disruption of bank stability due to the climate catastrophe. However, the surging demand for recovery and reconstruction funds may stimulate more bank lending; local German banks increased their corporate recovery lending after the Elbe flood (Koetter, Noth, and Oliver 2020), community American banks enhance their lending to assist corporates affected by natural disasters (Barth et al. 2022). Furthermore, multi-market banks reallocate capital after natural disasters (Cortés and Strahan 2017) and adjust their asset structure in response to natural disasters; Bos, Li, and Sanders (2022) demonstrate that US commercial banks increase total loans and particularly real estate lending after disasters by selling government bonds to finance such a disaster-driven demand surge.

It is commonly recognized that climate change significantly impacts firm infrastructure, production processes and supply chains due to the tangible effects of physical impacts on operations and resource access. This is still true for financial institutions, natural disasters affect banks' proper activity by at least three ways. Firstly, natural disasters can weaken the loan processing capacity of banks by harshly affecting both physical and human capitals. On the one hand, physical capital such as proprietaries, branches, equipment and data centres can be severely affected by disasters. These losses are likely to hamper their activity and reduce their ability to grant loans. This effect may be temporary, but it can also be longer-term, due to a regulatory capital decline. As this capital acts as a buffer against potential loan losses, its reduction can lessen lending. On the other hand, climate change disturbs human capital by severely harming health and reducing their productivity (X. Cai, Lu, and Wang 2018). Following natural disasters, some inhabitants may lose their lives or suffer health problems, which will reduce their productivity. Banks will find themselves with fewer human resources and sometimes less productive. Second, banks are affected by the serious ramifications of climate change since they have loan portfolios tied to sectors particularly sensitive to climate risks, such as agriculture, construction and real estate. Physical climate risk affects borrowers' operational performance (Pankratz, Bauer, and Derwall 2023) and profitability which lower their credit standing and increases default risk (Capasso, Gianfrate, and Spinelli 2020). Extreme events reduce firms' revenues and enhance their costs, which results in lower margins and probably the incapacity of credit repayment. This increase in credit risk may prompt banks in the most vulnerable countries to tighten credit conditions or limit new lending. More interestingly, climate risk can damage the collateral value; disasters have harmful effects on buildings, factories which destroy their value and increase the solvency risk of borrowers. Facing these situations, commercial banks may reduce loan supply to avoid default losses (Ginglinger and Moreau 2023; Li and Wu 2023). Third, firms located in more vulnerable countries prefer holding liquidity (Huang et al. 2022); banks may reduce their loans to enhance liquidity, ensuring that they have readily available funds to meet short-term obligations. If the bank faces massive deposit withdrawals or a drop in its funding sources as a result of the disaster, it could be forced to limit lending. Moreover, climate risks reduce local employment and consumer demand (Jin et al. 2021), which negatively affect bank lending. Focusing on natural disasters, Álvarez Román et al. (2024) affirm that outsider banks significantly reduce lending following climate-driven events in Spain. Likewise, Conlon et al. (2024) prove that American banks reduce lending and loan loss provisions subsequent to an unexpected climate shock.

Based on the literature reviewed above, we suggest that, faced with greater uncertainty and risks due to climate vulnerability, banks tend to reduce their lending. Hence, we formulate the following research hypothesis:

H_1. *Vulnerability to climate change negatively affects lending behaviour*.

Controlling climate risk impacts is becoming a necessity for economies, where both local and international level adaptation strategies are required. Adaptability can affect bank lending through three channels. First, high adaptability reduces the economic disruption caused by climate events, thus lowering the financial risks associated with lending in climate-sensitive areas. Banks, recognizing the reduced likelihood of widespread loan defaults, may respond by increasing credit availability to businesses and households in these regions. Countries' practices towards ESG aspects could be significant for sustaining a favourable investment climate since sustainability performance is positively associated with the volume of domestic credit extended by banks to the private sector and negatively associated with the prevalence of nonperforming loans (Sol Murta and Gama 2024). Second, adaptability also reflects the role of government policies and infrastructure development in stimulating and concreting a stable lending environment, encouraging banks to finance growth even in sectors vulnerable to climate change. Countries' sustainability significantly reduces market friction distortions (Dai and Zhang 2019) and government bond spread (Capelle-Blancard et al. 2019; Zhang, Zhao, and Lau 2022). In this way, greater adaptability not only mitigates risk but may also serve as an incentive for banks to support long-term investments, including those that foster further climate resilience. Finally, national-level factors are essential for corporate social management, as firms tend to exhibit higher corporate social performance in countries with high social and governance ratings (Y. Cai, Pan, and Statman 2016). Banks are becoming increasingly aware of climate change consequences on their operations, with its management being a strategic topic at the broad level. Banks are becoming more aware about climatic risk, they will have less procyclical lending behaviour (Abdelsalam et al. 2023) and less decline in lending during crises (Danisman and Tarazi 2024).

Adaptability to climate risk encompasses a country's capacity to anticipate, prepare for, and mitigate the effects of climate change through robust infrastructure, effective policy frameworks, and technological innovation. High adaptability reduces the economic disruption caused by climate events, thus lowering the financial risks associated with lending in climate-sensitive areas. Banks, recognizing the reduced likelihood of widespread loan defaults, may respond by increasing credit availability to businesses and households in these regions. This positive relationship implies that banks view investments in adaptable economies as safer and more resilient, as these countries are better equipped to manage climate-induced shocks. It also reflects the role of government policies and infrastructure development in creating a stable lending environment, encouraging banks to finance growth even in sectors vulnerable to climate change.

Adaptability at the national level stimulates a conducive business climate, fosters confidence, attracts sustainable investments and encourages banks to be more responsible; we posit that lending behaviour is positively affected by country adaptability. We formulate the following research hypothesis:

H_2. *Adaptability to climate change positively affects lending behaviour*

Methodology and data measurements

Description of the sample

We use a balanced panel dataset of 114 banks in 10 Newly Industrialized Countries, covering the period from 2010 to 2019. NICs are a group of emerging countries that have experienced accelerating economic growth in recent years; they have transitioned from economies largely based on agriculture to those focused on manufacturing and services. These countries are typically in an intermediate phase between developing and developed nations. Data on bank loans, financials, are sourced from the Data stream, and macroeconomic indicators are sourced from World Bank databases. The main independent variables are represented by the Vulnerability index and adaptability index calculated by the ND-Gain University. Table 1 offers a concise overview of how banks are distributed across countries.

List of variables

Dependent variables

Following Li and Wu (2023), the bank loan supply level is calculated using two indicators:

The ratio of total loans to total assets: $LOAN = Loans/Total\ assets$.

The growth rate of loans: $GLOAN = \Delta\text{loans}/\text{loans}$.

Independent variables

We take into consideration two principal measures: vulnerability and adaptability as calculated and published by ND-Gain University. These indexes, characterized by a transparent methodology (Grant et al. 2023), and a comprehensive coverage (Cevik and Jalles 2022) has stimulated recent research. Vulnerability and adaptability scores are

Table 1. Distribution of banks by country.

Country	N. banks	N. observation	%
South Africa	8	80	7,02%
India	12	120	10,53%
China	15	150	13,16%
Brazil	13	130	11,40%
Indonesia	10	100	8,77%
Malaysia	13	130	11,40%
Mexico	6	60	5,26%
Philippines	12	120	10,53%
Thailand	12	120	10,53%
Turkey	13	130	11,40%
Total	**114**	**1140**	100%

Table 2. Variable measurement.

	Variable	Definitions	Data Source
Dependent Variables	LOAN	Loans × 100/Total assets	Refinitiv Datastream
	GLOAN	Δ Loans/Loans	Refinitiv Datastream
Independent Variables	VUL	Vulnerability index	ND-Gain University
	ADAP	NDG index	ND-Gain University
Specific Control Variables	SIZE	Ln (Total assets)	Refinitiv Datastream
	DEBT	Debt × 100/Total assets	Refinitiv Datastream
	DEPO	Deposit × 100/Total assets	Refinitiv Datastream
	NPL	Non-performing loans × 100/Total loans	Refinitiv Datastream
	ROA	Net Result × 100/Total assets	Refinitiv Datastream
	CAR	Tier1 Capital/Risk Weighted Assets	Refinitiv Datastream
Macroeconomic Control Variables	INF	Consumer price index	World Bank data
	INT	Interest rate	World Bank data
	PCGDP	Private credit/GDP	World Bank data
	GDPG	GDP growth	World Bank data

Dependent and specific control variables are collected from Refinitiv Database. Independent variables are collected from ND-Gain University date. Macroeconomics control variables are collected from World Bank data.

built through a structured process based on composite index method using min-max normalization and arithmetic aggregation.

The vulnerability (VUL) is defined as the propensity or predisposition of human societies to be negatively impacted by climate hazards. It is a measure of the degree to which a system is susceptible to, and unable to cope with, the adverse effects of climate change. The Vulnerability index is composed of 36 indicators. It is broken down into exposure, sensitivity and adaptive capacity across six life-supporting sectors: Food, Water, Health, Ecosystem services, Human habitat and Infrastructure.

ND-GAIN assesses the country's adaptability to the climate risk by considering its readiness and vulnerability. The adaptability (ADAP) describes a country's capacity or potential to adapt to climate risks. It encompasses the underlying qualities or resources that make it possible to implement adaptive strategies effectively. Adaptability includes factors like economic resilience, technological advancement, institutional strength and social flexibility. ND-GAIN assesses adaptability as the difference between vulnerability and readiness indices, the latter being composed of nine indicators.

Control variables

Following prior research (Beutler et al. 2020; Li and Wu 2023; Sánchez Serrano 2021; Vo 2018), we include several bank-specific and macroeconomic control variables (Table 2). Bank-specific controls consist of: (1) bank size (SIZE), represented by the natural logarithm of a bank's total assets; (2) DEBT specifies banks' reliance on debt, (3) the deposit-to-total-assets ratio (DEPO), which reflects a bank's capacity for deposit absorption; (4) nonperforming loan ratio (NPL) reflects asset quality; (5) ROA indicates bank profitability and (6) the Tier 1 ratio (CAR) which represents capital adequacy. Macroeconomic controls include: (1) inflation rate (INF) which reflects the annual percentage change in the cost to the average consumer; (2) the interest rate (INT) reflecting the lending interest rate; (3) private credit to GDP (PCGDP) assesses financial development and (4) real GDP growth rate (GDPG), indicating the general economic environment.

Empirical models

The study focuses on the impact of climate risk on the lending behaviour in emerging countries by adopting dynamic panel method estimation. The use of GMM is supported by the dynamic nature of lending behaviour, which exhibits significant persistence over time as well as the potential endogeneity of explanatory variables.

Our Model (1) is built as follows:

$$LOAN_{ijt} = a_0 + a_1 LOAN_{ijt-1} + a_2 VUL_{jt} + a_3 \sum SCV_{ijt} + a_4 \sum MCV_{jt} + \varepsilon_{ijt} \tag{1}$$

$$GLOAN_{ijt} = a_0 + a_1 GLOAN_{ijt-1} + a_2 VUL_{jt} + a_3 \sum SCV_{ijt} + a_4 \sum MCV_{jt} + \varepsilon_{ijt} \tag{2}$$

To test if adaptability to climate risks impact bank lending, we build the Model (2):

$$LOAN_{ijt} = a_0 + a_1 LOAN_{ijt-1} + a_2 ADAP_{j} + a_3 \sum SCV_{ijt} + a_4 \sum MCV_{jt} + \varepsilon_{ijt} \tag{3}$$

$$GLOAN_{ijt} = a_0 + a_1 GLOAN_{ijt-1} + a_2 ADAP_{j} + a_3 \sum SCV_{ijt} + a_4 \sum MCV_{jt} + \varepsilon_{ijt} \tag{4}$$

Where the indices i, j and t, respectively, denote the bank, country and year.

VUL represents an index-measuring climate risk vulnerability, ADAP represents an index of adaptability, SCV is used to describe specific control variables that impact bank lending and MCV is used to describe macroeconomic variables of each country. We run our estimation by adopting a two step System Generalized Method of Moments (Vo 2018) using density of population, collected from The World Bank database, as instrument variable because it is likely to be highly correlated with climate risk and not with our dependent variables (Huang, Kerstein, and Wang 2018).

Table 3. Descriptive statistics.

Variable	N	Mean	Std. dev.	Min	Max
LOAN	1140	63.9203	14.5347	10.0574	97.9006
GLOAN	1026	12.6710	10.8828	−6.3475	37.2109
VUL	1140	42.1169	4.7543	34.7999	52.1786
ADAP	1140	50.6070	5.0590	39.1462	59.2955
SIZE	1140	20.3478	2.6174	12.9932	27.9768
DEBT	1140	19.1984	15.2564	0	88.6214
DEPO	1140	63.2305	18.3183	0	91.2977
NPL	1140	3.3241	3.4320	0	46.13
ROA	1140	1.8488	1.3971	−4.5561	12.0549
CAR	1140	16.1233	5.1099	8.46	80
INF	1140	4.5561	3.1094	−0.9	16.3
INT	1140	7.2416	9.5131	−2.1	41.7
PCGDP	1140	83.8556	43.6650	24.6	165.4
GDPG	1140	4.9403	2.7511	−3.5	11.2

Dependent variables (LOAN and GLOAN), specific control variables (SIZE, DEBT, DEPO, NPL, ROA and CAR) are collected from Refinitiv Database. Independent variables (VUL and NDG) are collected from ND-Gain University date. Macroeconomics control variables (INF, Int, PCGDP and GDPG) are collected from World Bank data. The Table describes variables by calculating mean, standard deviation, minimum and maximum.

Descriptive statistics

Table 3 supplies descriptive statistical outcomes for the studied variables. Firstly, the average ratio of loans to bank assets is about 63.92%, indicating that loans are an important part of bank assets and growth of loans has an average of 12.67%. Second, the average of the vulnerability score is 42.11, with a minimum of 34.79 and a maximum of 52.17, which shows that NICs are climate risk vulnerable since the global average vulnerability is 43.54. The average of the adaptability score is 50.60 which is higher than the global average (48.91), with a minimum of 39.14 and a maximum of 59.29. NICs have a greater capacity to adapt on an average than the rest of the world. However, the high variability indicates that some of them have not yet adapted to this risk.

As expected, the correlation matrix presented in Table 4 shows that some variables are highly correlated. Loans levels and growth are positively related; specific banks' characteristics are correlated with each other, larger banks tend to be not only a less performant but also less risky. Macroeconomic variables are also correlated, and growth is negatively correlated with inflation, interest rates and private credit. However, the FIV test indicates acceptable values of 2.38 and 2.48 for the respective models 1 and 2.

In order to gain a better understanding of vulnerability and adaptability concepts in the studied countries, we conduct a comparative study of score levels by averaging each score across countries. Turkey is the least vulnerable country (34.89), while India is the most vulnerable of all (51.38). In terms of adaptability, Philippines records the lowest adaptability score (42.98), whereas Malaysia emerges as the most climate-resilient country with a score of 56.46 (Figure 1). This is largely attributed to Malaysia's climate readiness which surpasses that of other countries. Malaysia's strength is primarily driven by robust economic performance (58.94) and strong governance (57.14).

Next, we test the difference between vulnerability and adaptability over countries over a 10 year period, and we adopt a non-parametric test since for small sizes per group, the assumptions of normality are hard to test. The Kruskal-Wallis test (Table 5) confirms that there are statistically significant differences between at least some of countries in terms of vulnerability and adaptability.

Empirical results and discussion

Main results

For the effect of vulnerability lending behaviour (Model 1), as expected for lagged dependent variables, the estimation result presents a significant positive coefficient and all control variables are significant. More interestingly, estimation results show that the coefficient of climate risk vulnerability (VUL) is negative and significant at the 1% level, indicating that the rise of vulnerability reduces bank loan supply (Table 6, column 1). Results indicate that banks located in more vulnerable regions adopt a more conservative lending strategy; banks are more cautious about expanding their loan portfolio due to concerns about credit risk, as physical climate risks – such as floods, hurricanes, droughts and other extreme weather events – become more pronounced; banks reduce their lending (Conlon et al. 2024; Li and Wu 2023). The results of the first estimation indicate a significant second-order autocorrelation coefficient which may indicate inappropriateness of the lag structure chosen. Including the dependent variable delayed by two periods

Table 4. Correlation matrix.

	LOAN	GLOAN	VUL	ADAP	SIZE	DEBT	DEPO	NPL	ROA	CAR	INF	INT	PCGDP	GDPG
LOAN	1													
GLOAN	0.0679*	1												
VUL	−0,0334	0.0574	1											
ADAP	0.0955*	−0.0330	−0.7690*	1										
SIZE	0,1172*	−0.0995*	0,4556*	−0.2045*	1									
DEBT	−0,1278*	0.1196*	−0,3874*	0.2417*	−0,3099*	1								
DEPO	0,2197*	−0.0476	0,3766*	−0.1647*	0,3583*	−0,8790*	1							
NPL	−0,2006*	−0.1851*	0,0045	−0.2061*	−0,1690*	0,0321	−0,0756*	1						
ROA	−0,0223	0.1871*	−0,0891*	−0.0174	−0,1899*	0,2459*	−0,3952*	−0,0037	1					
CAR	0,0661*	−0.0330	−0,0111	−0.1075*	−0,1195*	0,0081	−0,1232*	0,0983*	0,3168*	1				
INF	0,0137	0.1987*	−0,1111	0.0239	−0,1872*	0,2412*	−0,2522*	0,2248*	0,1720*	0,0152	1			
INT	−0,2712*	−0.1288*	−0,2068*	−0.0600*	−0,3020*	0,3481*	−0,4674*	0,2509*	0,1978*	0,0416	0,3119*	1		
PCGDP	0,1071*	−0.1942*	−0,3558*	0.5025*	0,0096	0,0363	0,0806*	−0,1786*	−0,2186*	−0,1771*	−0,4269*	−0,2534*	1	
GDPG	0,0403	0.2548*	0,1515*	0.0609*	0,2374*	−0,1876*	0,3647*	−0,1861*	−0,2289*	−0,1069*	−0,1305*	−0,5062*	−0,0178	1

*$p < 0.05$.

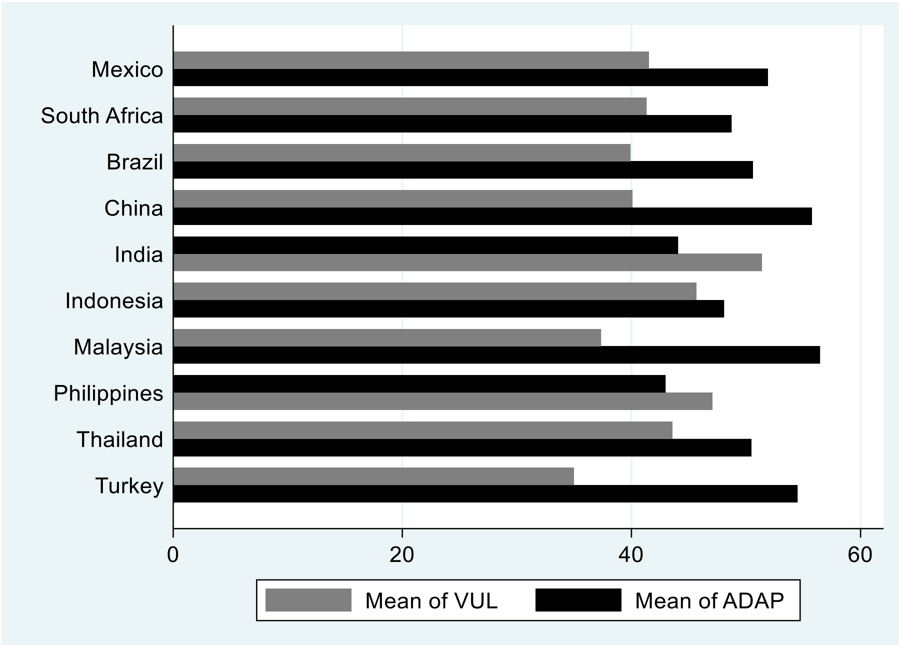

Figure 1. Vulnerability and adaptability across countries.

Table 5. Differences in vulnerability and adaptability distributions.

		Rank Sum	
Countries	Obs	VUL	ADAP
Mexico	60	37494.00	39515.00
South Africa	80	47736.00	28744.00
Brazil	130	50505.00	67496.00
China	150	61875.00	136770.00
India	120	129660.00	20010.00
Indonesia	100	85050.00	3770.00
Malaysia	130	25415.00	127712.00
Philippines	120	115260.00	15139.00
Thailand	120	88860.00	66996.00
Turkey	130	8515.00	11018.00
Kurskal-Wallis test	Chi2 (9)	1111.726	930.519
	Prob	0.0001	0.0001

does not change results, the coefficient of vulnerability to climate risk remains negative (column 2). Additionally, as indicated in Columns 3 and 4, including the year and country effects in the model, the results do not change. The same conclusions can be drawn from the estimated growth rate of borrowing in relation to the country's climate vulnerability (Table 6, columns 5 and 6); the coefficient of climate risk is significantly negative. Our first hypothesis is confirmed, vulnerability to physical climate risk negatively affects lending behaviour.

To test our second hypothesis, we run the same model by taking into consideration the adaptability to climate change measured by the overall ND-Gain index. Results, presented in Table 7, show that the coefficient of adaptability to climate change is positive and

Table 6. Results relative to the effect of vulnerability on loan supply.

	(1) LOAN	(2) LOAN	(3) LOAN	(4) LOAN	(5) GLOAN	(6) GLOAN
L1.LOAN	0.762***	0.540***	0.457***	0.268***		
	(0.0018)	(0.0017)	(0.0026)	(0.0036)		
L2.LOAN		0.181***	0.206***	0.0545***		
		(0.0012)	(0.0019)	(0.0016)		
L1.GLOAN					0.0171***	0.0599***
					(0.00232)	(0.00290)
VUL	**−0.0045*** **	**−0.0078*** **	**−0.0074*** **	**−0.0203*** **	**−0.00425*** **	**−0.00538*** **
	(8.91e-05)	**(9.81e-05)**	**(0.0009)**	**(0.0036)**	**(0.0002)**	**(0.00163)**
SIZE	0.0040***	0.0057***	0.0076***	−0.0182***	−0.0082***	−0.0053***
	(0.0001)	(0.0001)	(0.0002)	(0.0008)	(0.0002)	(0.0003)
DEBT	−0.0919***	−0.144***	−0.276***	−0.151***	0.753***	0.646***
	(0.0033)	(0.0072)	(0.0091)	(0.0106)	(0.0109)	(0.0184)
LOAN					−0.153***	−0.205***
					(0.0057)	(0.0074)
DEPO	−0.161***	−0.205***	−0.384***	−0.254***	0.361***	0.236***
	(0.0044)	(0.0085)	(0.0107)	(0.0133)	(0.0112)	(0.0193)
NPL	−0.0077***	−0.0104***	−0.0137***	−0.0093***	−0.0147***	−0.0130***
	(7.51e-05)	(0.0001)	(0.0002)	(0.0003)	(0.0001)	(0.0002)
ROA	−0.0099***	−0.0140***	−0.0203***	−0.0067***	0.0487***	0.0328***
	(0.0001)	(0.0001)	(0.0003)	(0.0001)	(0.0003)	(0.0004)
CAR	−0.0010***	−0.0014***	−0.0038***	−0.0031***	−0.0007***	0.0028***
	(1.77e-05)	(3.59e-05)	(6.89e-05)	(6.44e-05)	(8.27e-05)	(0.0001)
INF	−0.0001***	−0.0005***	0.0002	0.0006	−0.0023***	4.73e-05
	(3.20e-05)	(4.51e-05)	(0.0004)	(0.0005)	(0.0001)	(0.0011)
INT	−0.0009***	−0.0007***	−0.0005	−0.0001	0.0001**	−0.0006
	(1.92e-05)	(3.67e-05)	(0.0005)	(0.0005)	(6.38e-05)	(0.0009)
PCGDP	−0.0004***	−0.0005***	−0.0006***	−0.0008***	−0.0012***	−0.00111***
	(2.23e-05)	(3.86e-05)	(6.51e-05)	(0.0002)	(5.15e-05)	(0.0001)
GDPG	−0.0033***	−0.0032***	−0.0040***	−0.0006	0.0053***	0.0051***
	(0.0001)	(0.0003)	(0.0010)	(0.0010)	(0.0004)	(0.0015)
Constant	0.503***	0.704***	0.876***	1.975***	0.246***	0.303***
	(0.0058)	(0.0081)	(0.0511)	(0.153)	(0.0194)	(0.0912)
YEARS	No	No	Yes	Yes	No	Yes
COUNTRIES	No	No	No	Yes	No	No
AR (1)	−2.93***	−3.22***	−4.63***	−2.88***	−6.36***	−6.55***
AR (2)	2.05**	−0.02	−0.67	1.35	−0.71	0.17
Sargan Test	0.997	0.919	0.973	0.984	0.689	0.956
Hansen Test	0.319	0.288	0.181	0.081	0.055	0.068
Observations	1,026	912	912	912	912	912

Standard errors in parentheses and ***$p < 0.01$, **$p < 0.05$.
This table focuses on the regression of lending behavior on climate risk. LOAN and GLOAN are dependent variables, while VUL which assesses a country's vulnerability, is the explanatory variable. s. AR (1) and AR (2) check the autocorrelation in the residuals. Saragn and Hansen assess the validity of instruments used in the model.

significant at 1% level for the two dependent variables, indicating that the country's adaptability enhances loan supply; hence, our second hypothesis is confirmed. As a country becomes more capable of managing climate-related challenges, banks are more willing to extend credit. In this way, greater adaptability not only mitigates risk but may also serves as an incentive for banks to support long-term investments, including those that foster further climate resilience.

Sensitivity tests

To check the robustness of our results, we run some sensitivity tests. First, to ensure that our results do not exclusively depend on the considered variables, we use alternative

Table 7. Results relative to the effect of adaptability to loan supply.

	(1) LOAN	(2) GLOAN
L1.LOAN	0.227***	
	(0.0034)	
L2.LOAN	0.0082***	
	(0.0020)	
L1.GLOAN		0.0577***
		(0.0028)
ADAP	**0.0044*** **	**0.0040*** **
	(0.0007)	**(0.0008)**
SIZE	−0.0252***	−0.0073***
	(0.0008)	(0.0003)
DEBT	−0.312***	0.741***
	(0.0125)	(0.0159)
DEPO	−0.457***	0.296***
	(0.0155)	(0.0180)
LOAN		−0.174***
		(0.0075)
NPL	−0.0051***	−0.0092***
	(0.0002)	(0.0002)
ROA	−0.0004**	0.0378***
	(0.0002)	(0.0004)
CAR	−0.0027***	0.0044***
	(6.44e-05)	(0.0001)
INF	−0.0007*	−0.00035
	(0.0004)	(0.0010)
INT	−7.68e-05	−0.0007
	(0.0003)	(0.0009)
PCGDP	−0.0008***	−0.0011***
	(0.0002)	(0.0001)
GDPG	−0.0006	0.0055***
	(0.0008)	(0.0017)
Constant	1.217***	−0.198***
	(0.0598)	(0.0465)
YEARS	Yes	Yes
COUNTRIES	Yes	No
AR (1)	−2.07**	−6.50***
AR (2)	1.39	0.01
Sargan Test	0.999	0.959
Hansen Test	0.189	0.101
Observations	912	912

Standard errors in parentheses and ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

This Table focuses on the regression of lending behaviour in adaptability. LOAN and GLOAN are dependent variables while ADAP which assess country's adaptability is the explanatory variables. AR (1) and AR (2) check the autocorrelation in the residuals. Saragn and Hansen assess the validity of instruments used in the model.

measures of interest variables. We use the Climate Risk Index (CRI) and Sensitivity Score for physical climate risk. Moreover, we focus on the readiness score of the country and its components for country's adaptability. Then, to alleviate the endogeneity issue, we run additional estimations. On the one hand, we lag our explicative variables and, on the other hand, we use the linear instrumental regression as an alternative econometric method. Finally, to ensure that our results are not dependent on specific events, we have found it useful to eliminate banks that are likely to be involved in mergers and acquisitions and have studied the two sub-periods before and after the Paris Agreement.

Alternative measures of interest variables

Alternative measures of climate risk. We use other indicators to measure the physical climate risk. First, we adopt the Climate Risk Index (CRI). County indexes are manually collected from annual reports published by the Germanwatch Association. Although the two indicators focus on the physical climate risk of the countries, they have different approaches. While vulnerability is measured through the state of the sectors and their exposure, sensitivity and capacity to adapt to the risk of climate change, the CRI measures this risk through the impact of natural disasters, whether economic, material or human. We note that higher CRI values indicate lower climate risk. Second, we adopt the sensitivity score developed by the ND-Gain University, which assesses the degree to which people and the sectors they depend upon are affected by climate-related disruptions.

Alternative measures of country's adaptability. To verify the effect of countries' adaptability on banks' lending behaviour, we use other indicators related to the climate adaptability of the country. First, we adopt the Readiness score calculated by ND-Gain University. Since there is a possible correlation between vulnerability and readiness score, we test the effect of readiness index on the lending behaviour. Second, we focus on the social and governance scores as a correlation between economic development and the economic pillar may occur.

Regression results are reported in Table 8, and we find that the coefficients of CRI are significantly positive (Columns 1 and 2) and the coefficient of sensitivity is significantly negative (Columns 3 and 4). This suggests that higher climate risk, reflected by lower CRI and higher sensitivity, has a negative effect on lending activities. Similarly, the effects of the countries' readiness (Columns 5 and 6) and especially social and governance scores (Columns 7 and 8) are significantly positive. Banks are more likely to lend in environments with stronger social stability and governance quality, which conforms with our main results.

Model specification

Lagged variables. To determine whether GMM estimators handle endogeneity by using internal instruments, which are useful in panels, we include lagged explanatory variables as regressors to mitigate endogeneity issues for the two equations. Results are presented on Table 9, the coefficient of vulnerability to climate risk is significantly negative, which supports our previous findings.

Estimation method. We run our model using the two-stage least-squares regression to account for the potential endogeneity in the model. We use the Density of the Population as an instrumental variable of physical vulnerability. We specifically use the Generalized Method of Moment to account for the potential heteroskedasticity in the error. The Durbin-Wu-Hausman test affirms the exogeneity of the variables considered in the two models. The coefficient of the vulnerability score remains significantly negative in the first model (Table 10, Columns 1 and 2) reinforcing our findings as the result holds regardless of the estimation method employed.

Table 8. Alternative measures of climate risk and adaptability.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	LOAN	GLOAN	LOAN	GLOAN	LOAN	GLOAN	LOAN	GLOAN
L1.LOAN	0.230***	–	0.500***		0.508***	0.0233***	0.573***	
	(0.0036)		(0.0034)		(0.0018)	(0.0021)	(0.0022)	
L2. LOAN	0.0553***	–	0.228***		0.236***		0.193***	
	(0.0017)		(0.0026)		(0.0012)		(0.0010)	
L1.GLOAN	–	−0.0451***		0.0825***	–			−0.0096***
	–	(0.0034)		(0.0031)				(0.0023)
CRI	**0.0002*** **	**0.0003*** **			–			
	(5.92e−05)	**(0.0001)**						
SEN			**−0.0082*** **	**−0.0037** **	–			
			(0.0011)	**(0.0018)**				
READ					**0.148*** **	**0.232*** **		
					(0.0009)	**(0.0034)**		
SOCIAL							**0.116*** **	**0.0005*** **
							(0.0103)	**(0.0001)**
GOV							**0.140*** **	**0.0057*** **
							(0.0048)	**(0.0001)**
SIZE	−0.0225***	0.0204***	0.0037***	−0.0079***	0.0036***	−0.0089***	0.0023***	−0.0087***
	(0.0008)	(0.0006)	(0.0002)	(0.0003)	(0.0001)	(0.0003)	(0.0001)	(0.0002)
DEBT	−0.348***	0.469***	−0.191***	0.702***	−0.0045	0.748***	−0.0909***	1.113***
	(0.0118)	(0.0281)	(0.0106)	(0.0199)	(0.0058)	(0.0112)	(0.0055)	(0.0113)
DEPO	−0.486***	0.0675*	−0.421***	0.230***	−0.0137***	0.238***	−0.0030***	0.637***
	(0.0143)	(0.0383)	(0.0123)	(0.0212)	(0.0002)	(0.0119)	(0.0001)	(0.0108)
LOAN	–	0.275***		−0.144***	–	−0.205***		−0.0562***
	–	(0.0111)		(0.0073)		(0.0075)		(0.0076)
NPL	−0.0085***	−0.0163***	−0.0157***	−0.0122***	−0.231***	−0.0123***	−0.221***	−0.0145***
	(0.0002)	(0.0003)	(0.0002)	(0.0003)	(0.0071)	(0.0001)	(0.0064)	(0.0002)
ROA	−0.0036***	0.0053***	−0.0294***	0.0304***	−0.0074***	0.0460***	−0.0079***	0.0570***
	(0.0002)	(0.0004)	(0.0003)	(0.0005)	(0.0001)	(0.0003)	(0.0001)	(0.0003)
CAR	−0.0037***	0.0024***	−0.0037***	0.0031***	0.0005***	0.0009***	−0.0017***	−0.0019***
	(8.35e−05)	(0.0001)	(8.01e−05)	(0.0001)	(3.05e−05)	(8.74e−05)	(3.83e−05)	(8.62e−05)
INF	0.0018***	0.0001	0.0007	0.0005	0.00150***	−0.0016***	0.0008***	−0.0013***
	(0.0005)	(0.0012)	(0.000510)	(0.0010)	(3.58e−05)	(0.0001)	(0.0001)	(0.0002)
INT	−0.0006	0.0005	−1.22e−05	−0.0005	−0.0019***	−0.0006***	−0.0018***	0.0013***
	(0.0004)	(0.0011)	(0.0005)	(0.0009)	(4.03e−05)	(6.38e−05)	(8.51e−05)	(0.0001)
PCGDP	−0.0005***	0.0005	−0.0004***	−0.0009***	−0.0004***	−0.0014***	−0.0005***	−0.0012***

(*Continued*)

Table 8. (Continued).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	LOAN	GLOAN	LOAN	GLOAN	LOAN	GLOAN	LOAN	GLOAN
	(0.0002)	(0.0005)	(7.40e–05)	(0.0001)	(2.08e–05)	(7.50e–05)	(2.75e–05)	(6.80e–05)
GDPG	0.0003	0.00762**	−0.0026***	0.0061***	−0.0032***	0.0038***	−.00040***	0.0057***
	(0.0010)	(0.0031)	(0.0008)	(0.0017)	(0.0003)	(0.0007)	(0.0005)	(0.0010)
Constant	1.355***	0.0377	0.870***	0.160**	0.280***	0.0945***	0.292***	−0.512***
	(0.0523)	(0.0331)	(0.0422)	(0.0652)	(0.0088)	(0.0206)	(0.0134)	(0.0217)
YEARS	Yes	Yes	Yes	Yes	No	No	No	No
COUNTRIES	No	No	No	No	No	No	No	No
AR (1)	−2.58***	−5.36***	−4.81***	−6.53***	−2.54***	−5.91***	−2.63***	−6.48***
AR (2)	1.14	−0.73	−0.70	0.38	−1.53	−1.29	−0.69	−0.56
Sargan Test	0.989	0.970	0.994	0.951	0.888	0.771	0.862	0.791
Hansen Test	0.198	0.517	0.154	0.068	0.214	0.047	0.194	0.119
Observations	912	912	912	912	912	912	912	912

Standard errors in parentheses and ***$p < 0.01$, **$p < 0.05$.

This table focuses on the regression of alternative measures of explanatory variables. Dependent variables are LOAN and GLOAN, explanatory variables are CRI and Sensitivity for climate risk; Readiness, social and governance performance of the country for adaptability. AR (1) and AR (2) check the autocorrelation in the residuals. Saragn and Hansen assess the validity of instruments used in the model.

Table 9. Lagged variables.

	(1)	(2)
VARIABLES	LOAN	GLOAN
L.LOAN	0.268***	
	(0.00256)	
L.GLOAN		0.764***
		(0.0022)
L.VUL	**−0.0151*** **	**−0.0029** **
	(0.00416)	**(0.0003)**
L.SIZE	−0.0166***	0.0066***
	(0.0002)	(0.0002)
L.DEBT	−0.0392***	−0.0403***
	(0.0067)	(0.0051)
L.DEPO	−0.187***	−0.171***
	(0.0072)	(0.0043)
L.ROA	−0.0056***	−0.0105***
	(0.0002)	(0.0001)
L.CAR	−0.0017***	−0.0022***
	(2.47e-05)	(1.90e-05)
INF	−0.0004	−0.0004
	(0.0003)	(0.0003)
INT	−0.0004	−0.0020***
	(0.0003)	(0.0003)
PCGDP	−0.0004**	−0.0003***
	(0.0002)	(3.12e-05)
GDPG	−0.0041***	−0.0023***
	(0.0008)	(0.0006)
Years	Yes	Yes
Countries	No	No
AR (1)	−2.14	−6.70***
AR (2)	0.207	1.29
Sargan Test	0.998	0.915
Hansen Test	0.270	0.238
Observations	1,026	1,026

Standard errors in parentheses and ***$p < 0.01$, **$p < 0.05$.
This Table focuses on the regression of Loan and Gloan on CRI, Sensitivity, Readiness, social and governance performance of the country. AR (1) and AR (2) check the autocorrelation in the residuals. Saragn and Hansen assess the validity of instruments used in the model.

Specific events

Effects of mergers and acquisitions of banks. We note that asset growth rates are quite high, and we are seeing merger and acquisition activity at certain banks. Given that this rate may affect our main measure of bank leverage, we have chosen to eliminate observations where the rate is greater than 20% and to re-estimate the base model. The results (Table 10, Column 3) confirm our initial conclusions that the coefficient remains significantly negative for the rest of the sample, indicating that this effect is not sensitive to merger and acquisition operations.

Effect of the COP21. The 2015 Paris Agreement is a commitment by 195 countries to limit global warming to 2°C by 2100. It is considered as an exogenous shock affecting managerial decisions. Ginglinger and Moreau (2023) find that, following the Paris Agreement, firms facing higher climate risk reduce their leverage, and creditors increase interest rates for these high-risk firms. We suppose that banks are taking into account the

Table 10. Alternative estimation methods.

	(IV)	(IV)	GRA<20%	2010–2014	2015–2019
VARIABLES	(1) LOAN	(2) GLOAN	(3) LOAN	(4) LOAN	(5) LOAN
L.LOAN			0.631***	0.381***	0.766***
			(0.0059)	(0.110)	(0.116)
VUL	−0.0024*	−0.0025**	**−0.0072*** **	−0.0064	**−0.0152*** **
	(0.0014)	(0.0011)	**(0.0004)**	(0.0062)	(0.0022)
SIZE	0.0035*	−0.0078***	0.0092***	0.0012	0.0043
	(0.0019)	(0.0014)	(0.0007)	(0.0061)	(0.0027)
DEBT	0.338***	0.190***	−0.458***	1.347***	0.577***
	(0.0812)	(0.0551)	(0.0331)	(0.355)	(0.195)
ROA	0.00561	0.0161***	−0.550***	0.0031	0.0098
	(0.0058)	(0.0034)	(0.0300)	(0.0259)	(0.0090)
DEPO	0.448***	0.114**	−0.0063***	0.926***	0.385*
	(0.0674)	(0.0516)	(0.0005)	(0.333)	(0.202)
LOAN		0.0055			
		(0.0266)			
NPL	−0.0076***	−0.0056***	−0.0037***	−0.0161**	0.0018
	(0.0016)	(0.0008)	(0.0002)	(0.0071)	(0.0022)
CAR	0.0036***	−0.0013	−0.0008***	−0.0082***	0.0022
	(0.0013)	(0.0008)	(0.0001)	(0.0029)	(0.0023)
INF	0.0078***	0.0067***	7.85e-05	−0.0049	−0.0119***
	(0.0014)	(0.0012)	(8.80e-05)	(0.0035)	(0.0015)
INT	−0.0039***	−0.0013***	−0.0003***	0.0077***	−0.0002
	(0.0006)	(0.0004)	(9.85e-05)	(0.0027)	(0.0006)
PCGDP	7.81e-05	−0.0002***	0.0008	−0.0022***	−0.0008***
	(0.0001)	(0.0001)	(0.0010)	(0.0005)	(0.0001)
GDPG	−0.0119***	0.0098***	0.631***	−0.0026	−0.0012
	(0.0022)	(0.0015)	(0.0059)	(0.0066)	(0.0023)
Constant	0.330***	0.0399	0.923***	0.134	0.406**
	(0.0880)	(0.0691)	(0.0350)	(0.405)	(0.200)
YEARS	Yes	Yes	Yes	Yes	Yes
Durbin-Wu-Hausman	2.3827	0.1964			
	(p = 0.1227)	(p = 0.6576)			
Observations	1,140	1026	912	456	456
R-squared	0.203	0.307			

Standard errors in parentheses and *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
This table assesses alternative estimation method and specific situations and events. The Durbin-Wu-Hausman test affirms the exogeneity of the explanatory variables.

country's vulnerability to climate risk, mainly after 2015. Awareness of climate risk following COP21 has raised banks' awareness of this major risk, which is in line with Aslan et al. (2022). Climate vulnerability is becoming a key factor in the banks' lending after the Paris Agreement, banks are more cautious in offering loans (Table 10, Columns 4 and 5), reinforcing our main results.

Conclusion

Physical risk is particularly significant for the financial sector, especially because its role as an intermediary for savings and investments makes it potentially capable of amplifying the negative impact of adverse events. Climate-related risks directly impact banks' activity through physical damage, loan losses due to climate-sensitive borrower solvency, property value risks in high-risk weather zones, increased insurance costs and liquidity constraints from economic disruptions. Results confirm that lending behaviour is negatively affected by physical climate risk. Moreover, it has been documented that countries' adaptability enforces lending behaviour.

This research offers several practical recommendations. Considering adaptability enhances the precision of climate risk management and contributes to more robust, forward-looking lending strategies. Incorporating economic, social and governance dimensions guides contingency planning and supports climate-related scenario analysis, enabling banks to account for both vulnerability and capacity to respond. At the country level, governments should intensify efforts to combat climate change and implement robust policies supporting low-carbon industries. These initiatives will create opportunities for banks to develop sustainable credit products and expand lending.

Due to the data limitation data, this paper focuses on the impact of climate physical risk on the overall credit supply, and we suggest that future research explores its effect on the loan structure. In addition, we can consider the diversification of the banking activity as an alternative to mitigate this risk. Finally, we may consider the difference in the structure of the banking market and extend our research over other countries.

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No potential conflict of interest was reported by the author(s).

Notes on contributor

Soumaya Maztoul currently works as an assistant professor of finance at the Higher School of Commerce. Her research interests focus on banking, climate risk, and sustainability, with a particular emphasis on understanding how financial institutions adapt their operations to environmental challenges.

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