



Climate change and systemic risk: Evidence from financial intermediaries

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ABSTRACT

Climate change represents an escalating global challenge with profound implications for sustainability. This paper investigates the impact of climate-induced temperature shocks on systemic risk within the banking sector. Using a sample of 35 financial intermediaries across 13 countries and employing the ΔCoVaR methodology, we find that deviations from historical temperature averages—particularly temperature increases—are associated with heightened systemic risk. By integrating climate variables into risk assessment models, we demonstrate that climate volatility threatens financial stability by amplifying credit risk and reducing lending capacity. Our findings contribute to the growing discourse on climate finance and provide valuable insights for policymakers, regulators, and institutional risk managers seeking to safeguard financial stability in the face of increasing climate variability.

1. Introduction

Climate change, driven primarily by human activities, has led to significant and accelerating alterations in critical climate indicators—most notably, sustained increases in atmospheric temperature (NOAA, 2023). These changes pose serious threats to ecosystems, infrastructure, food and water security, and human health, with profound implications for economic and financial stability. The associated risks stem from the economic and social adjustments required to adapt to or mitigate climate change, encompassing financial, legal, technological, and market challenges inherent in the transition to a low-carbon economy (Billio et al., 2024). While this transition is essential, it is fraught with uncertainty and demands substantial investment in new technologies, infrastructure, and modernization of existing systems (Lundmark and Audretsch, 2024).

This paper investigates whether climate change, measured as gradual increases in temperature relative to historical norms, amplifies systemic risk in the European banking sector. This question is important because climate change represents not only an environmental and societal challenge but also an emerging source of financial risk that can undermine the stability of financial intermediaries and, through them, the broader economy (Curcio et al., 2023). Positioned as a paramount grand challenge (Doh et al., 2019) and a Tragedy on the Horizon

(Carney, 2015), climate change transcends environmental concerns to permeate the social, political, and economic fabric of global society. As the quintessential global externality (Nordhaus, 2019), it demands international cooperation and coordinated responses. While a growing body of literature has documented the effects of climate risks on firm-level performance, stock market returns, and credit risk (e.g., Balvers et al., 2017; Tzouvanas et al., 2019), less is known about how climate change influences the systemic risk posed by banks. Given their central role in credit provision and financial stability, understanding whether and how climate change increases banks' systemic risk is crucial for regulators, policymakers, and investors.

Our conceptual framework builds on two strands of literature. First, we draw on research highlighting the role of finance as a critical but constrained resource in entrepreneurial ecosystems (Lehmann, 2024; Roundy et al., 2017), emphasizing that resilient ecosystems depend not only on firms' ability to adapt but also on banks' ability to continue providing credit and managing risk under adverse conditions. Second, we build on studies showing how climate-related physical and transition risks impair firms' cash flows, reduce collateral values, and increase portfolio concentration in climate-sensitive sectors (Balvers et al., 2017; Tzouvanas et al., 2019; Ho et al., 2024). By focusing on the systemic dimension of these risks, our study extends this literature to examine how banks' intermediation role and interconnectedness contribute to

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broader financial instability.

Banks, as critical components of entrepreneurial ecosystems, influence economic and social sustainability through their financing decisions and risk management policies (Audretsch and Belitski, 2017). This focus is particularly relevant in Europe, where banks play a dominant role in financing entrepreneurial firms, while venture capital markets remain relatively underdeveloped. Climate-related risks in the banking system therefore have significant implications for the entrepreneurial ecosystem's resilience and innovation capacity. Credit rating agencies have begun to flag climate change as a potential risk to creditworthiness, underscoring the importance of effective risk assessment frameworks that map and quantify climate-related exposures and portfolio concentration.

Our key contribution lies in empirically demonstrating, using a panel of 35 banks across 13 European countries over the period 2016–2023, that rising temperatures are significantly associated with higher systemic risk in European banks, as measured by the ΔCoVaR metric. While prior research has examined the impact of climate risks on stock market returns, credit spreads, and firm-level vulnerabilities, the systemic implications for banks have remained underexplored. By addressing this gap, we contribute to the ongoing debate on climate-related financial stability and provide evidence relevant for policymakers, regulators, and institutional risk managers.

2. Institutional background and regulatory framework

Climate change is one of the most complex and consequential global challenges of the 21st century, demanding unprecedented international cooperation, scientific insight, and transformative policy responses (Billio et al., 2024). The evolution of global climate policy reflects a growing recognition of human-induced environmental transformations and their profound implications for economic, social, and ecological systems. From the initial wave of environmental awareness in the early 1970s to today's sophisticated regulatory frameworks, the international community has progressively developed more coordinated and ambitious approaches to address the multifaceted risks posed by climate change.

This trajectory has been marked by several key milestones that elevated environmental concerns from peripheral issues to central pillars of international governance. The United Nations Conference on the Human Environment in *Stockholm Declaration (1972)* was a pivotal moment of collective ecological awareness, establishing the foundational discourse on global environmental interdependence. This was followed by the creation of the Intergovernmental Panel on Climate Change (IPCC) in 1988, which institutionalized scientific assessment as a cornerstone of climate policymaking, emphasizing empirical evidence and rigorous research as the basis for effective governance.

A major transformation in the international regulatory framework came with the adoption of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, and later the Paris Agreement in 2015. These agreements marked a shift from declarative environmental statements to actionable, measurable commitments. The Paris Agreement, in particular, introduced an innovative model of nationally determined contributions, requiring countries to develop specific greenhouse gas reduction strategies within a flexible yet collaborative global framework.

Within the European context, the European Green Deal represents one of the most ambitious and comprehensive policy initiatives to date, placing the European Union at the forefront of global climate leadership. Launched in 2019, this strategy seeks to transform the EU economy into the world's first climate-neutral economic system by 2050, integrating environmental sustainability with economic growth and social inclusivity. The Green Deal exemplifies a holistic approach to climate policy, addressing not only emissions reduction but also a broader reimagining of economic and industrial paradigms.

This research contributes to the ongoing scholarly dialogue by

exploring the links between climate policy, systemic economic risk, and environmental transformation. Through advanced methodological approaches and comprehensive empirical analysis, we aim to shed light on the complex dynamics underpinning contemporary climate governance and its systemic implications for financial and economic stability.

3. Theory and hypotheses

Recent years have seen a surge in academic interest in the economic and financial implications of climate change. Climate risks are typically categorized as physical risks—arising from gradual or extreme weather-related damage to assets, infrastructure, and productivity—and transition risks, which stem from policy, market, and technological changes associated with the shift to a low-carbon economy (ESRB, 2016). Both types of risks can adversely affect firms' cash flows, asset values, and operational resilience, particularly in climate-sensitive sectors such as agriculture, energy, and real estate (Balvers et al., 2017; Tzouvanas et al., 2019).

Banks, through their unique position in financial intermediation, play a central role in supporting entrepreneurship and fostering economic dynamism within entrepreneurial ecosystems (Audretsch et al., 2019; Cantner et al., 2021; Deloof et al., 2025). Resilient ecosystems depend not only on firms' ability to adapt to environmental challenges but also on banks' capacity to supply credit and manage risks effectively as climate vulnerabilities increase. Disruptions to banks' balance sheets and lending capacity can impair credit provision, amplify systemic instability, and weaken entrepreneurial activity.

As primary intermediaries in capital allocation, banks facilitate access to finance for entrepreneurs, enabling the development of new ideas and technologies that might otherwise remain unrealized due to funding constraints. This role enhances economic development and competition, fostering productive entrepreneurship and sustainable growth aligned with the Sustainable Development Goals (SDGs) (Black and Strahan, 2002). Beyond traditional lending, banks contribute to entrepreneurial ecosystems by offering specialized financial products, promoting financial literacy, and supporting risk management—critical capabilities for navigating uncertainty and innovation. Institutions, therefore, shape both the quality and quantity of entrepreneurial activity (Chowdhury et al., 2019). Banks also act as gatekeepers of financial stability, maintaining investor confidence and attracting additional capital into ecosystems. By reducing information asymmetries and transaction costs, banks channel resources to high-potential firms, and through local relationships they help identify and nurture innovative startups (Audretsch and Belitski, 2017). Historical evidence shows that regions with more developed banking sectors experience higher rates of business formation and technological advancement, underscoring the symbiotic relationship between financial intermediation and economic vitality (Chowdhury et al., 2019; Audretsch et al., 2024).

Empirical research has begun to document how climate risks affect financial markets and firm performance. Early studies (Kamstra et al., 2003; Novy-Marx, 2014) show that weather and temperature deviations influence investor behavior and asset prices. More recent work emphasizes climate change's role in increasing systemic risk in the economy. For instance, Balvers et al. (2017) and Tzouvanas et al. (2019) find that higher temperatures raise systemic risk among firms through productivity losses and contagion effects. However, explicit evidence on how climate change affects systemic risk in the banking sector remains scarce. This paper addresses this gap by analyzing whether gradual climate change, proxied by sustained temperature increases, heightens banks' systemic risk. We build on the notion that banks play a dual role in entrepreneurial ecosystems: as providers of resilience through credit intermediation, and as amplifiers of instability when climate risks weaken their balance sheets and interconnectedness. Prior work on financial intermediation has shown how transparency and certification mechanisms influence market stability and investor confidence (Khurshed et al., 2014). In a similar vein, inadequate climate disclosure

can impair banks' ability to assess exposures, amplifying systemic risk. By empirically estimating the link between temperature changes and banks' contributions to systemic risk in Europe, we contribute to the growing literature on climate-related financial stability (Ho et al., 2024; Guan et al., 2025).

We conceptualize climate change as an exogenous driver of systemic banking risk through multiple channels. Physical risks—such as extreme weather events and rising temperatures—can damage assets, disrupt supply chains, and reduce productivity in climate-sensitive sectors, impairing borrowers' ability to service debt and reducing the value of banks' collateral. Transition risks—such as stricter climate policies and shifting consumer preferences—can accelerate the devaluation of “brown” assets, increase credit losses, and heighten portfolio concentration risks. As Balvers et al. (2017) argue, temperature deviations particularly affect sectors like agriculture and energy, which are often heavily represented in banks' loan portfolios. These dynamics increase interconnectedness among institutions and elevate the likelihood of contagion and systemic instability.

Building on this theoretical framework, we hypothesize that climate change—proxied by sustained increases in temperature relative to historical norms—elevates systemic risk in the banking sector through both direct channels, such as impaired borrower solvency and collateral devaluation, and indirect channels, including portfolio concentration and contagion effects among interconnected institutions.

Hypothesis 1. *Climate change, measured as increases in temperature relative to historical averages, is positively associated with banks' contribution to systemic risk.*

4. Research design

4.1. Sample and data

This study focuses on the European financial sector, employing a comprehensive sample of 35 banking intermediaries spanning 13 European countries, as detailed in Table 1. The selected institutions represent 93.6 % of the market capitalization attributed to the EURO STOXX 600 Banks Index, ensuring a robust and representative analysis of the sector's performance. The sample selection was guided by two primary criteria: (i) market capitalization, which guarantees the inclusion of the most significant financial institutions, and (ii) data availability and adequacy in terms of volume, periodicity, and compliance with banking information disclosure regulations.

The research period covers the timeframe from the first quarter of 2016 to the fourth quarter of 2023, with data collected daily and quarterly frequency. The selection of 2016 as the starting point is deliberate, aligning with the emerging financial market awareness of climate challenges following the Paris Agreement of December 12, 2015. The dynamic nature of the EURO STOXX 600 Banks Index is acknowledged, with the sample relying on the most recent information from the

Table 1

Countries considered in the reference sample.

Euro-zone		Non Euro-zone	
Country	Number of banks	Country	Number of Banks
Austria	1	Denmark	4
Belgium	1	Norway	1
Finland	1	Poland	3
France	3	Sweden	3
Germany	2	United Kingdom	4
Italy	5		
Netherlands	2		
Spain	5		
Total	20	Total	15

Note: The reference period for the sample is 2016Q1 – 2023Q4. Source: DataStream Refinitiv.

DataStream Refinitiv Dataset to provide an up-to-date representation of the European banking landscape.

Climate data was sourced from the European Climate Assessment & Dataset (ECA&D), a comprehensive repository of meteorological information. The data collection methodology involved a meticulous selection of 104 meteorological stations across the European territory, with the distribution of stations per country presented in Table 2. The station selection process prioritized two key objectives: (1) comprehensive geographical representation of the 13 countries in the sample, and (2) ensuring data availability. To guarantee a representative coverage of meteorological conditions, the station selection strategy ensured at least one station was chosen for each geographical reference coordinate (north, northeast, northwest, west, east, southwest, southeast, center) within each country, where possible. The data collection process involved the following key steps: (1) Daily temperature data collection for each meteorological station; (2) Calculation of quarterly average temperatures for each station; (3) Aggregation of station-level data to national and regional averages; (4) Computation of historical temperature norms across three temporal horizons: 50, 40, and 30 years. Temperature changes/variation in temperature were quantified by calculating the difference between observed quarterly average temperatures and their respective historical averages.

Table 3 presents the descriptive statistics of temperature changes across 50, 40, and 30-year time horizons. A preliminary analysis reveals a notable trend of increasing thermal variations across different temporal intervals. On average, temperature deviations at the 50-year interval are more pronounced compared to those at 40 and 30 years, suggesting an acceleration of climate change impacts over decadal scales. This observation is consistent with authoritative publications from the Intergovernmental Panel on Climate Change (IPCC), the National Oceanic and Atmospheric Administration (NOAA), and NASA. The data demonstrates a systematic increase in temperature fluctuations, with more frequent and marked positive thermal changes across all examined time intervals. This pattern underscores the importance of understanding the potential systemic implications of climate variability on financial systems.

4.2. Methodology

We define systemic risk as the potential for distress at one or more banks to propagate throughout the financial system, impairing the functioning of credit markets and threatening financial stability. This concept captures the externalities of banks' risk-taking beyond their individual exposures. We make use of the CoVaR measure of Adrian and Brunnermeier (2016), the most common measure of risk used in the literature. This tool is based on the understanding of the interdependence that characterizes the fabric of the financial system, highlighting

Table 2

Number of meteorological stations for each Country.

Country	Number of meteorological stations
Austria	9
Belgium	3
Denmark	8
Finland	8
France	9
Germany	10
Italy	6
Netherlands	8
Norway	9
Poland	9
Spain	8
Sweden	9
United Kingdom	8
Total	104

Note: Reference period 2016Q1- 2023Q4. Source: European Climate and Assessment&Dataset.

Table 3
Descriptive statistics of changes in temperature.

	Change 50	Change 40	Change 30
Obs.	1.120	1.120	1.120
Mean	0.89863	0.68395	0.36014
Median	0.83962	0.63939	0.34014
Std.Dev	0.65694	0.64382	0.63824

Note: Descriptive statistics of the quarterly temperatures deviating from the historical norms calculated for 50 years (Change 50), 40 years (Change 40), and 30 years (Change 30), respectively. The number of observations (Obs), the mean (Mean), the median (Median), and the standard deviation (Std.Dev) are highlighted. Source: European Climate Assessment&Dataset.

how the adversities faced by a single entity can propagate and impact the entire network. Unlike the Value-at-Risk (VaR), which quantifies the maximum potential predictable loss for a financial entity over a given period, assuming a specific probability q that such loss will exceed the estimate, CoVaR expands the vision limited to the single institution, opening up to the evaluation of the implications of a systemic scale disruption, distinguishing itself for its ability to offer an overall horizon of risk, considering both individual losses and the consequences of a crisis of an entity on other actors and on the system as a whole. Adrian and Brunnermeier (2016), through the introduction of CoVaR, have thus filled a methodological gap, allowing for a more precise capture of the dynamics of systemic risk and the interconnections existing between different intermediaries. The analysis implies as an essential starting point the definition of Value-at-Risk and then extends the concept and applies it to understanding the potential chains of adverse events and their repercussions.

$$Pr(X^i \leq VarX^i_q) = q \tag{1}$$

Where X^i is the variable of institution i for which the Var^i is defined and which in turn is characterized as the q -th quantile. The authors outline $CoVaR^{i/j}_q$ as the Value-at-Risk of the entire financial system conditioned on an event $C(X_i)$ of a generic institution i . Therefore, the $CoVaR^{i/j}_q$ is implicitly defined by the q -th quantile of the joint probability distribution, and is expressed as follows:

$$Prob(X_{system} / C(X_i) \leq (CoVaR^{system/C(X_i)}_q)) = q\% \tag{2}$$

Where X^i is the market-valued asset return of institutions i , and X^{system} is the return of portfolio, computed as the average of the X^i 's weighted by the lagged market value assets of the institutions in the portfolio. Adrian and Brunnermeier (2016) measure the contribution of each single institution to systemic risk by the $\Delta CoVaR$, namely the difference between CoVaR conditional on the institution being in distress and CoVaR in the median state of the institution.

As far as the estimation method is concerned, quantile regressions are employed to estimate CoVaR. First, one can estimate the predicted value of a quantile regression where the financial sector losses X^{system/X^i}_q is determined given losses of a particular institution i for the q %-quantile:

$$\widehat{X}^{system/X^i}_q = \widehat{\alpha}^i_q + \widehat{\beta}^i_q X^i \tag{3}$$

Where $\widehat{X}^{system/X^i}_q$ denotes the predicted value for a particular q %-quantile of the system conditional on a return realization X^i of institution i . From the definition of VaR, in Eq. (1) we have that:

$$Var^{system/X^i}_q = \widehat{X}^{system/X^i}_q \tag{4}$$

In practice, the predicted value from the quantile regression of the system losses on institution i losses gives the value at risk of the financial

system conditional on X^i , because the Var^{system/X^i}_q is simply the conditional quantile. Using the predicted value of $X^i = Var^i_q$ yields the $CoVaR^i_q$ measure. More formally, within the quantile regression framework, the $CoVaR^i_q$ measure is:

$$CoVaR^i_q = Var^{system/X^i=Var^i_q}_q = \widehat{\alpha}^i_q + \widehat{\beta}^i_q Var^i_q \tag{5}$$

The $\Delta CoVaR^i_q$ is therefore given by:

$$\begin{aligned} \Delta CoVaR^i_q &= CoVaR^i_q(q) - CoVaR^i_q(50\%) \\ &= \widehat{\beta}^{system/i}_q (Var^i_q(q) - Var^i_q(50\%)) \end{aligned} \tag{6}$$

In order to simplify the notation, in what follows q is always set to be 5 %, so that $CoVaR^i_q$ identifies the system losses predicted on the 5 % loss of institution i , while $\Delta CoVaR^i_q$ identifies the deterioration in the system losses, when the institution i moves from its median state to its 5 % worst scenario.

The measures are defined as time-varying, and in practice, in order to estimate the time-varying Var_t , as in the Eq. (3) and $CoVaR_t$, as in Eq. (5), have been included a set of state variables to capture the time variation in conditional moments of assets returns. With references to these specific market's factor, has been also followed the approached adopted by Lopez-Espinosa et al. (2012) and Bellavite Pellegrini et al. (2022) to consider the peculiarities of the European institutional environment. In practice, in this analysis the following variables have been used:

- 1) FTSE-Vol: The weekly price of the FTSE stock market volatility index ($FTSEVol_t$);
- 2) Liquidity Spread: calculated as the difference between the 3-month Euribor and the German Government Bond at 3 months. ($LiqSpread_t$);
- 3) Change T-Bill: the change in the rate of French Treasury bills in the secondary market at 3 months ($\Delta Tbill_t$);
- 4) Credit Spread: represented by the difference between the yields of Moody's BAA-rated corporate bonds and German government bonds at 10 years ($\Delta CreditSpread_t$);
- 5) Change Slope: the change in the yield curve slope, calculated as the difference between the interest rates on French government bonds at 5 years and at 3 months ($\Delta Slope_t$);
- 6) FTSE-Ret: the weekly stock returns of the European market index FTSE ($FTSERet_t$).

Table 4 and Table 5 report, respectively, the descriptive statistics of the state variables and the 95 %-risk measured, computed for the 35 banks on weekly data from the period 2016Q1-2023Q4 and the financial losses $X(i)$, calculated as:

$$X^i_t = \frac{ME^i_t \bullet LEV^i_t - ME^i_{t-1} \bullet LEV^i_{t-1}}{ME^i_{t-1} LEV^i_{t-1}} \tag{7}$$

Where ME^i_t is the market value of a money market fund and LEV^i_t is the ratio between total asset and common equity.

Table 4
Descriptive statistics of the state variables.

	Mean	Median	Min	Max	Std.Dev.
FTSEVol _t	0.00923	0.00770	0.00468	0.02651	0.00449
LiqSpread _t	0.31590	0.30537	0.09192	0.58789	0.12116
ΔTbill _t	0.00981	0.00085	-0.02243	0.09647	0.02831
ΔCreditSpread _t	1.45614	1.23673	0.12456	2.96763	0.78514
ΔSlope _t	-0.00462	0.00135	-0.07116	0.06193	0.02796
FTSEReturn _t	0.00472	0.00436	-0.22804	0.11562	0.06855

Note: variables used in the implementation of the $\Delta CoVaR$ calculation. Source: DataStream Refinitiv.

Table 5
Descriptive statistics of X(i), VaR, CoVaR, Δ CoVaR.

	Obs.	Mean	Min	Max	Std.Dev.
X(i)	1120	0.00171	-0.55056	0.98721	0.07197
VaR	1120	-0.02824	-0.38367	0.00000	0.06422
CoVaR	1120	-0.01625	-0.26398	-0.00147	0.00247
Δ CoVaR	1120	-0,01160	-0.08027	-0.00536	0.00181

Note: magnitudes of X(i), VaR, CoVaR, and Δ CoVaR, considered in the time range 2016Q1 to 2023Q4.

The analysis of the descriptive statistics for all risk measures reveals that these values are consistently negative. This finding is critical for interpreting subsequent results, as any variable exhibiting a negative coefficient contributes to an increase in systemic risk, whereas a positive coefficient corresponds to a reduction in systemic risk. This observation indicates an inverse relationship between the variables under examination and systemic risk: a decline in these variables (i.e., a more negative value) is associated with heightened systemic risk, whereas a less pronounced decrease (or an increase) signifies a reduction in systemic risk. This interpretation is fundamental to risk management, underscoring the necessity of closely monitoring these variables to anticipate and mitigate potential escalations in systemic risk within the financial system.

To investigate the relationship between climate change—and the systemic risk of the European banking sector, this study employs a statistical-econometric analysis methodology based on Fixed Effects regression on a balanced panel data sample. The choice of this specific technique is dictated by empirical evidence provided by robust statistical tests, such as the F-Test, the Lagrange-Multiplier Test, and the Hausman Test, which, demonstrating a level of significance of at least 1 %, highlight the superiority of the Fixed Effects model over alternative representations offered by pooled panel or random effects regressions, thereby solidifying the methodological foundation upon which the investigation rests.

The core of the analysis focuses on examining the interactions between climate change and systemic risk, according to an econometric setup that positions Δ CoVaR as the dependent variable, used as a proxy for systemic risk (Adrian and Brunnermeier, 2016) and the deviations from the average quarterly temperatures from their historical norms calculated over time intervals of 50, 40, and 30 years as a proxy measure for climate change that serve as the core explanatory variables. In this context, the study explores the different implications of deviations to capture the evolution of the ongoing climatic phenomenon. The aim of this analysis is twofold: (i) to evaluate the consequences of thermal changes, considering how temperature variations modulate their impact on the European financial and banking fabric over the decades, and (ii) to analyze the extent to which temporal differences lead to significant variations in the banking system's responses to the risk induced by such temperature deviations. According to these empirical approaches, each of the three regressions (based on change in temperature during time intervals of 50, 40, and 30 years) allows for a differentiated and comparative analysis that considers environmental changes and their repercussions on financial stability and the entrepreneurial ecosystem (Audretsch et al., 2019).

To capture the bank-specific effects of the thirty-five banks analyzed on systemic risk, a set of bank-level control variables is introduced, categorized into (I) corporate and (II) performance variables. Regarding the former, these focus on structural and operational aspects of the institutions, including indicators such as financial Leverage (Leverage), Institution Size (Size), Maturity Mismatch (Maturity Mismatch), Equity Return Volatility (Equity Return Volatility), Market Beta (Beta), and Market-to-Book Value (MBV). These metrics are selected in accordance with reference literature studies to reflect the intrinsic characteristics and financial configuration of the banks, offering insights into risk management strategies and structural elements that influence their

systemic vulnerability. Performance variables such as Return-on-Assets (ROA), Net Interest Margin (NIM), and the ratio between Total Loans and Total Deposits (LTD) provide further details on the strict operational results and financial health of the banks. The definitions and computational processes of these variables are provided in Table 6, while the descriptive statistics are reported in Table 7. These variables enable the examination of the intermediaries' core business efficiency and their capacity to absorb and mitigate external impact. Moreover, the macro-economic variable of GDP growth rate plays a crucial role as an indicator of the general economic trend of the countries considered, capturing economic fluctuations that may influence the stability and resilience of the banking system. All variables are lagged by one quarter.

The adoption of control variables leads to the formulation of two distinct models within the statistical-econometric analysis: (i) the first focuses exclusively on corporate regressors and the GDP growth rate (Eq. 8), while (ii) the second extends the investigation to include performance variables (Eq. 9). Both models incorporate a set of dummy variables to capture differences between country and year effects. Finally, in accordance with methodological guidelines proposed by Adrian and Brunnermeier (2016), Lopez-Espinosa et al. (2012), and Bellavite Pellegrini et al. (2022), both models consider lagged values of Δ CoVaR (Δ CoVaR(-1)) and VaR (VaR(-1)). This approach not only aligns with best methodological practices in economic research on systemic risk but also enhances the study's findings by providing insights into how previous risk conditions influence banks' current exposure. Eqs. 8 and 9 summarize the components of the models implemented in the investigation.

Table 6
Variables description.

Variables	Description
Leverage	as the ratio of the total assets (measured at book value) and shareholders' equity of generic financial institution "i" in time (t-1). This is a proxy of the magnitude with which the institution makes use of the Debt financing.
Size	Expresses in term of total assets in time (t-1).
Maturity Mismatch	as the ratio of the total debt to net of cash and equivalent, on the bank's total liabilities in time (t-1). This is a proxy for the interconnectedness of the financial institutions, allowing the potential for risk propagation to be assessed in the financial system.
Equity Return Volatility (ERV)	based on daily equity returns at time (t-1) for each institution. This metric highlights the uncertainty and riskiness associated with capital investments of the bank.
Beta (market Beta) (ERV)	from daily data for each bank in time (t-1), quantifies the degree of correlation between the institution's equity returns and those of the market, thus indicating the institution's exposure to fluctuations in the sector.
Market to Book value (MTB)	it represents the relationship between the market value and the book value of shareholders' equity, for each bank and for each previous time (t-1). It offers one the market's perception of the institution's valuation of its Book values.
Return on Assets (ROA)	it measures the efficiency with which the bank generates profit compared to the total assets in time (t-1) and provides an important measure of productivity and operational management of the institution.
Net Interest Margin (NIM)	which represents the percentage difference between the income from interest generated and interest spent on deposits, compared to profitable assets bank in time (T-1). Net interest margin provides an indication of success of the institution in its role as financial intermediary.
Loan to Deposit ratio (LTD)	It expresses the ratio between the total loans disbursed by the bank and total deposits collected in time (t-1). It is a critical metric that reflects liquidity of the institution and its ability to further finance lending activity.
GDP growth rate	it represents a percentage increase in Domestic Product Gross, in a given quarter (t) compared to the previous (t-1), serving as a fundamental macroeconomic indicator that reflects the overall economic health of a specific region.

Table 7
Descriptive statistics of control variables included in the model.

Variables	Obs.	Mean.	Std.Dev.	Min.	Max.
Lev	1.114	18.03852	5.19484	6.7876	36.0052
Size	1.114	23.305.130	1.259016	9.866.000	150.285.000
MM	1.114	0.17121	0.09184	-1.12721	0.88783
ERV	1.120	0.01972	0.00854	0.00667	0.0592785
Beta	1.120	1.28268	0.426156	-0.5064	2.3847
MVB	1.120	0.98450	0.87223	-3.132	7.7471
ROA	1.112	0.56814	0.47908	-1.3708	3.0249
NIM	1.003	1.7216	0.70858	0.4833	5.1689
LTD	1.112	0.67973	0.34951	0.37639	1.07434
GDP	1.101	0.00980	0.06190	-0.018229	0.29809

Note: Financial Leverage (*Lev*), Size (*Size*), Maturity Mismatch (*MM*), Equity Return Volatility (*ERV*), Market Beta (*Beta*), Market to Book Value (*MBV*), Return on Asset (*ROA*), Net Interest Margin (*NIM*), Loan to Deposit Ratio (*LTD*), Gross Domestic Product Growth Rate (*GDP*). The reference time horizon is 2016Q1 – 2023Q4. Source: DataStream Refinitiv.

$$\begin{aligned} \Delta CoVaR_{it} = & \beta_{i,0} + \beta_1 Shock_H + \beta_2 \Delta CoVaR_{it-1} + \beta_3 VaR_{it-1} + \beta_4 Lev_{it-1} \\ & + \beta_5 Size_{it-1} + \beta_6 MM_{it-1} + \beta_7 ERV_{it-1} + \beta_8 Beta_{it-1} \\ & + \beta_9 MBV_{it-1} + \beta_{10} GDP_{it-1} + \sum_{k=1}^7 \beta_k Year_k \\ & + \sum_{k=1}^{12} \beta_k Country_k + \varepsilon_{it} \end{aligned} \tag{8}$$

$$\begin{aligned} \Delta CoVaR_{it} = & \beta_{i,0} + \beta_1 Shock_H + \beta_2 \Delta CoVaR_{it-1} + \beta_3 VaR_{it-1} \\ & + \beta_4 Lev_{it-1} + \beta_5 Size_{it-1} + \beta_6 MM_{it-1} + \beta_7 ERV_{it-1} \\ & + \beta_8 Beta_{it-1} + \beta_9 MBV_{it-1} + \beta_{10} GDP_{it-1} + \beta_{11} ROA_{it-1} \\ & + \beta_{12} NIM_{it-1} + \beta_{13} LTD_{it-1} + \sum_{k=1}^7 \beta_k Year_k \\ & + \sum_{k=1}^{12} \beta_k Country_k + \varepsilon_{it} \end{aligned} \tag{9}$$

To address concerns about potential spurious correlations between systemic risk ($\Delta CoVaR$) and temperature shocks, we conducted panel co-integration tests using the approaches of Pedroni (1999, 2004), Kao (1999), and Westerlund and Edgerton (2007). These tests assess whether the variables share a long-term equilibrium relationship, thereby confirming that the observed associations are not merely the result of independent trending behavior. Table 8 presents the results of these co-integration tests. In all cases, the null hypothesis of no co-integration is rejected at conventional significance levels, supporting the existence of a stable long-run relationship between temperature shocks and systemic risk. Additionally, we re-estimated our models in first differences to eliminate potential non-stationary components and included year-fixed effects to control for unobserved macro-level shocks (e.g., geopolitical crises or macroeconomic cycles). The results remain consistent across these specifications, reinforcing the robustness of our findings and mitigating concerns that the main relationships are driven by coincident but unrelated trends.

5. Results

Tables 9, 10 and 11 present the regression results for changes in temperature of 50, 40, and 30 years, respectively, using both models.

Table 8
Panel Co-integration Test.

Test	Statistic	p-value	Conclusion
Pedroni Panel Co-integration	-3.12	0.0018	Reject H ₀ : No co-integration
Kao Panel Co-integration	-2.89	0.0042	Reject H ₀ : No co-integration
Westerlund Error Correction	-2.45	0.0079	Reject H ₀ : No co-integration

Table 9
Regression results on the impact of 50-year temperature changes.

	$\Delta CoVaR$ (1)	$\Delta CoVaR$ (2)
Change 50	-0.00104*** (0.0001801)	-0.000990*** (0.0001973)
$\Delta CoVaR(-1)$	0.136*** (0.029099)	0.129*** (0.0233847)
$VaR(-1)$	-0.0000428 (0.0005599)	-0.000393 (0.0005962)
Leverage	0.000545* (0.0001923)	0.000613* (0.0002591)
Size	-0.00575*** (0.0018313)	-0.00723*** (0.0022715)
Maturity Mismatch	-0.00893* (0.0039884)	-0.00914* (0.0061618)
Equity Return Volatility	0.0660* (0.0239974)	0.0571* (0.0259137)
Beta	-0.00143 (0.0015156)	-0.00164 (0.0016891)
MBV	-0.00118 (0.0007632)	-0.00135 (0.0009844)
GDP	-0.00116 (0.0024319)	-0.000842 (0.0025893)
ROA		0.000443 (0.0007493)
NIM		-0.000662 (0.0006381)
LTD		0.00000654 (0.000019)
Year and country dummies	Yes	Yes
Constant	0.0506** (0.024016)	0.0702** (0.028584)
Obs.	1100	1100
R-squared	0.2882	0.2935
Number of banks	35	35

Notes: The table presents regressions using alternative specification models. Model (i) serves as the reference benchmark, including 50-year temperature Changes (Change 50), lagged variables of $\Delta CoVaR(-1)$ and $VaR(-1)$, corporate variables (Leverage, Size, Maturity Mismatch, Equity Return Volatility, Beta, MVB), the macroeconomic indicator (GDP), and year (Year D.) and country (Country D.) dummy variables. Meanwhile, model (ii) adds to the variables the performance indicators (ROA, NIM, and LTD). Statistical significance at 1 %, 5 %, and 10 % are denoted by ***, **, * respectively. Robust standard errors in parentheses. The time frame covered is from 2016Q1 to 2023Q4.

Column (1) of each Table displays the results from the first model (Eq. 8), while Column (2) shows the results from the second model (Eq. 9). To accurately interpret the results, it is crucial to note that $\Delta CoVaR$ is consistently negative (Table 5). Consequently, a negative coefficient indicates an increase in systemic risk within the European banking sector, and conversely, a positive coefficient indicates a decrease.

The regression results provide empirical support for Hypothesis 1, which posits that temperature fluctuations deviating from historical norms increase systemic risk in the European banking sector. Specifically, the negative coefficients associated with changes temperature across all regressions demonstrate a statistically significant ($p < 0.01$) increase in systemic risk, highlighting the robust relationship between thermal volatility and systemic risk. Collectively, these findings provide novel empirical evidence that temperature deviations from historical averages significantly influence systemic risk in the banking sector across all change durations examined.

This relationship can be explained by empirical, economic, and academic evidence. First, climate change (measured through changes in temperature by the average) impacts the productivity of numerous sectors. In agriculture, deviations from historical temperature norms affect crop cycles, water resources, and the development of pests and diseases, reducing production. This instability then propagates through the value chain, affecting the food industry, distribution, and ultimately, the end consumer. In the industrial sector, temperature fluctuations lead to higher energy costs, with heatwaves or cold spells increasing demand for temperature control systems, impacting companies' operational budgets. Furthermore, climate volatility places significant pressure on infrastructure, necessitating greater investments in maintenance,

Table 10
Regression results on the impact of 40-year temperature changes.

	$\Delta\text{CoVaR (1)}$	$\Delta\text{CoVaR (2)}$
Change 40	−0.000793*** (0.0001377)	−0.000750*** (0.0001474)
$\Delta\text{CoVaR}(-1)$	0.137*** (0.0227967)	0.130*** (0.0232979)
$\text{VaR}(-1)$	−0.000168 (0.0005705)	−0.000511 (0.0006118)
Leverage	0.000552* (0.0001941)	0.000619* (0.0002609)
Size	−0.00573*** (0.0018356)	−0.00720*** (0.0022788)
Maturity Mismatch	−0.00884* (0.0039864)	−0.00914* (0.0061811)
Equity Return Volatility	0.0552* (0.0232165)	0.0465* (0.0253921)
Beta	−0.00141 (0.0015176)	−0.00162 (0.0016915)
MBV	−0.00121 (0.0007673)	−0.00139 (0.00099)
GDP	−0.00100 (0.0024528)	−0.000685 (0.002615)
ROA		0.000401 (0.0007559)
NIM		−0.000621 (0.0006387)
TLD		0.00000669 (0.0000191)
Year and country dummies	Yes	Yes
Constant	0.0500** (0.0240434)	0.0695** (0.286431)
Obs.	1100	1100
R-squared	0.2832	0.2888
Number of banks	35	35

Notes: The table presents regressions using alternative specification models. Model (i) is the reference benchmark, which includes 40-year temperature changes (Change 40), lagged variables of $\Delta\text{CoVaR}(-1)$ and $\text{VaR}(-1)$, corporate variables (Leverage, Size, Maturity Mismatch, Equity Return Volatility, Beta, MVB), the macroeconomic indicator (GDP), and year (Year D.) and country (Country D.) dummy variables. Model (ii) adds performance indicators (ROA, NIM, and LTD) to the variables. Statistical significance at 1 %, 5 %, and 10 % are denoted by ***, **, * respectively. Robust standard errors in parentheses. The time frame covered is from 2016Q1 to 2023Q4.

adaptation, and the construction of weather-resilient structures. These factors impair companies' ability to generate stable cash flows, thereby compromising their solvency and timely debt repayment. Consequently, lending institutions face an increase in non-performing loans, reflecting the financial difficulties of companies affected by temperature deviation. These issues adversely affect capital availability and the potential for enhancing sustainable finance instruments to support entrepreneurial ecosystem development and innovation (Buratti et al., 2023; Chowdhury et al., 2019; Audretsch et al., 2024).

An increased probability of non-performing loans significantly threatens to erode banks' capital bases, reducing their lending profitability and compromising market solvency (Dafermos et al., 2018). In the context of high non-performing loans, banks are compelled to increase capital allocations to loss reserves, thereby limiting resources available for new investments and lending. This not only restricts the bank's ability to expand its business but can also trigger a vicious cycle of credit restriction, negatively affecting the real economy, especially SME financing. Finally, the perceived increase in systemic risk due to climate change can influence investor behavior, contributing to market volatility. Investors may become more risk-averse, reallocating their portfolios towards safer assets, affecting capital flows and financial stability. Furthermore, the positive coefficient and statistical significance ($p < 0.01$) associated with the lagged ΔCoVaR variable underscore the importance of existing risk conditions.

This demonstrates that a financial system already under stress is better equipped to manage exposure to subsequent disturbances, including temperature risk. Additionally, the coefficient for firm size (Size) is negative, indicating a direct correlation with systemic risk. The

Table 11
Regression results on the impact of 30-year temperature changes.

	$\Delta\text{CoVaR (1)}$	$\Delta\text{CoVaR (2)}$
Change 30	−0.000511*** (0.0001021)	−0.000477*** (0.0000992)
$\Delta\text{CoVaR}(-1)$	0.138*** (0.0226831)	0.131*** (0.232093)
$\text{VaR}(-1)$	−0.000273 (0.0005818)	−0.000606 (0.0006272)
Leverage	0.000557* (0.0001953)	0.000623 (0.0002618)
Size	−0.00572*** (0.0018344)	−0.00718*** (0.00228)
Maturity Mismatch	−0.00878* (0.0039899)	−0.00915* (0.0062032)
Equity Return Volatility	0.0458* (0.0226702)	0.0373* (0.0250732)
Beta	−0.00139 (0.0015187)	−0.00160 (0.0016926)
MBV	−0.00123 (0.0007658)	−0.00141 (0.0009876)
GDP	−0.000966 (0.0024761)	−0.000647 (0.0026353)
ROA		0.000354 (0.0007625)
NIM		−0.000604 (0.0006411)
TLD		0.00000679 (0.0000191)
Year and country dummies	Yes	Yes
Constant	0.0497** (0.02401)	0.0691** (0.0286385)
Obs.	1100	1100
R-squared	0.2794	0.2854
Number of Banks	35	35

Notes: The table presents regressions using alternative specification models. Model (i) serves as the reference benchmark and includes 30-year temperature changes (Change 30), lagged variables of $\Delta\text{CoVaR}(-1)$ and $\text{VaR}(-1)$, corporate variables (Leverage, Size, Maturity Mismatch, Equity Return Volatility, Beta, MVB), the macroeconomic indicator (GDP), and year (Year D.) and country (Country D.) dummy variables. Model (ii) adds performance indicators (ROA, NIM, and LTD) to the variables. Statistical significance at 1 %, 5 %, and 10 % are denoted by ***, **, * respectively. Robust standard errors in parentheses. The time frame covered is from 2016Q1 to 2023Q4.

significance of larger institutions implies that any turbulence affecting them can have substantial repercussions on the entire financial system, amplifying systemic risk. In this context, size becomes a critical factor not only for the stability of the institution itself but also for the overall resilience of the banking system to climatic changes, aligning with the “too big to fail” doctrine. Leverage and Equity-Return-Volatility are statistically significant ($p < 0.10$), with positive coefficients, while Maturity Mismatch is a factor that increases systemic risk. Dummy variables exhibit significant statistical relevance, highlighting their role as essential control variables. In conclusion, all three models demonstrate R-squared values around 28 %–29 %, indicating a robust representation of the interconnected relationships between systemic risk and climate change.

Finally, our analysis reveals a progressively larger influence of changes in temperature on the systemic risk of banks, suggesting that this impact intensifies over longer time horizons. From the analysis of the evidence presented in Table 12, an intriguing finding emerges regarding the impact of variation in temperature on systemic risk within the European banking sector, assessed across three-time horizons using the second model. Specifically, Column (1) refers to 50-year temperature changes, Column (2) to 40-year temperature changes, and Column (3) to 30-year temperature changes. The empirical investigation demonstrates that higher average temperature changes correspond to larger absolute coefficients, all of which exhibit a negative sign, reflecting an increasing impact on systemic risk. Notably, increasing in temperature over a 50-year horizon exerts a more pronounced influence on systemic risk, followed by those at 40 and then 30 years, confirming that greater temperature fluctuations deviating from historical averages are

Table 12
Regression results on temperature changes over 50, 40, and 30 years.

	1 (50)	2 (40)	3 (30)
Change	−0.000990*** (0.0001973)	−0.000750*** (0.0001474)	−0.000477*** (0.0000992)
ΔCoVaR(−1)	0.129*** (0.0233847)	0.130*** (0.0232979)	0.131*** (0.232093)
VaR(−1)	−0.000393 (0.0005962)	−0.000511 (0.0006118)	−0.000606 (0.0006272)
LEVERAGE	0.000613* (0.0002591)	0.000619* (0.0002609)	0.000623* (0.0002618)
SIZE	−0.00723*** (0.00227115)	−0.00720*** (0.0022788)	−0.00718*** (0.00228)
MATURITY MISMATCH	−0.00914* (0.0061618)	−0.00914* (0.0061811)	−0.00915* (0.0062032)
ERV	0.0571* (0.0259137)	0.0465* (0.0253921)	0.0373* (0.0250732)
BETA	−0.00164 (0.0016891)	−0.00162 (0.0016915)	−0.00160 (0.0016926)
MBV	−0.00135 (0.0009844)	−0.00139 (0.00099)	−0.00141 (0.0009876)
GDP	−0.000842 (0.0025983)	−0.000685 (0.002615)	−0.000647 (0.0026353)
ROA	0.000443 (0.0007493)	0.000401 (0.0007559)	0.000354 (0.0007625)
NIM	−0.000662 (0.0006381)	−0.000621 (0.0006387)	−0.000604 (0.0006411)
TLD	0.00000654 (0.000019)	0.00000699 (0.0000191)	0.00000679 (0.0000191)
Year and country dummies	Yes	Yes	Yes
Constant	0.0702** (0.028584)	0.0695** (0.0286431)	0.0691** (0.0286385)
Obs.	1100	1100	1100
R-squared	0.2935	0.288	0.2854
Number of Bank	35	35	35

Note: The table presents the regressions using only model (ii) for temperature variations over 30, 40, and 50 years. The first column represents 50-year temperature changes, the second 40-year changes, and the third 30-year changes. The coefficients of the regressions for each time interval are then reported to allow for comparison between the various results. Statistical significance at 1 %, 5 %, and 10 % are denoted by ***, **, * respectively. Robust standard errors in parentheses. The time frame covered is from 2016Q1 to 2023Q4.

associated with sharper impacts on systemic risk for the European banking sector. Furthermore, the observation of a general trend towards rising temperatures, characterized by a predominance of positive thermal volatility over negative, leads to the conclusion that increasing temperatures, i.e., those indicating temperatures above historical averages, tend to amplify systemic risk, while negative fluctuations mitigate the impact on the financial stability of the banking sector. This analysis underscores the significance of climatic fluctuations as non-negligible risk factors for the financial system, highlighting how significant temperature variations, especially increases, can compromise the solidity and resilience of banking institutions, with potential impacts on entrepreneurial opportunities.”

6. Conclusion

This study examines the relationship between climate change and systemic risk in the European banking sector, with a particular focus on its implications for financial intermediation to entrepreneurial ventures. We address a novel and increasingly relevant question in the context of entrepreneurial ecosystem development: how gradual increases in temperature—defined as deviations from historical averages over 50-, 40-, and 30-year horizons—affect systemic risk in banking. Using a robust empirical framework based on the ΔCoVaR metric and a sample of 35 major European banks, which collectively account for most of the EURO STOXX 600 Banks index capitalization, we provide new evidence on the vulnerability of the financial system to climate-related risks.

Temperature data from the European Climate Assessment & Dataset (ECA&D) ensure comprehensive regional coverage.

Our empirical findings reveal statistically significant positive associations between sustained temperature increases and banks' contributions to systemic risk. Longer-term temperature deviations have a more pronounced effect, underscoring the escalating impact of climate change over time. These results highlight the growing vulnerability of financial intermediation to climate risks and support calls for integrating climate-related variables into risk assessment models. As climate risks intensify, banks' ability to manage them becomes crucial for preserving the flow of credit and sustaining entrepreneurial ecosystems (Roundy et al., 2017).

This study makes several important contributions to theory and practice. Theoretically, this study advances the literature on climate-related financial risks and systemic stability by demonstrating that climate change, conceptualized as a gradual, exogenous shock, propagates through banks' balance sheets, lending capacity, and interconnections—an underexplored systemic dimension (Balvers et al., 2017; Billio et al., 2025; Tzouvanas et al., 2019). We also contribute to the entrepreneurial ecosystem resilience perspective (e.g. Audretsch and Belitski, 2024; Hess et al., 2025) by showing how climate risks threaten access to finance, a critical but fragile resource for entrepreneurial activity (Colombo et al., 2019). In this sense, our findings also extend the entrepreneurial ecosystem literature by showing how systemic financial fragilities induced by climate change can constrain ecosystem resilience. Banks thus play a dual role—as enablers of resilience through credit provision and as amplifiers of instability when climate risks materialize.

For policymakers, regulators, and institutional risk managers, our findings carry several implications. Regulators should advance climate-sensitive stress testing, strengthen disclosure of banks' climate exposures, and adjust prudential requirements to account for systemic climate risks—aligning with initiatives by the Basel Committee. Institutional risk managers should proactively rebalance portfolios, monitor exposures to climate-sensitive sectors, and adapt credit policies and collateral valuation practices to reflect climate risks more accurately. These measures will be key to maintaining financial stability and supporting entrepreneurial ecosystems as climate challenges intensify.

This study also has limitations. First, our analysis focuses exclusively on banks as financial intermediaries, reflecting their systemic importance and central role in providing credit in Europe. However, other intermediaries, including crowdfunding (Cumming et al., 2024; Farè et al., 2024; Vismara, 2019; Vismara and Wirtz, 2025) are also vital for financing environmentally-sustainable entrepreneurial firms. Future research could extend our framework to assess how climate change impacts systemic risk and opportunities across a broader spectrum of financial actors. Second, while our findings emphasize the risks posed by climate change, it is also important to note that climate-related policy shifts and consumer preferences can create positive opportunities for banks and entrepreneurial firms that innovate in sustainable and low-carbon sectors. These offsetting dynamics merit further investigation. Third, the banks in our sample are heterogeneous and, in some cases, may only represent a portion of their respective national banking systems. While we mitigate this limitation by including banks that collectively account for over 90 % of the EURO STOXX 600 Banks Index capitalization, the representativeness of our sample at the country level remains imperfect. Finally, our study period coincides with several major macroeconomic and geopolitical crises—including the global financial crisis, the Eurozone sovereign debt crisis, the COVID-19 pandemic, and the war in Ukraine—that could influence both systemic banking risk and climate-related exposures.

Taken together, these limitations highlight avenues for further research, but they also underscore the timeliness and relevance of our contribution. By shedding light on the intersection of climate risk, financial stability, and entrepreneurial opportunity, this study provides a foundation for future work that can inform both scholarly inquiry and policy responses to the challenges and opportunities of the green transition.

CRedit authorship contribution statement

Carlo Bellavite Pellegrini: Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Laura Pellegrini:** Writing – original draft, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Silvio Vismara:** Writing – original draft, Supervision, Project administration, Methodology, Investigation, Conceptualization.

Authors contribution

All authors contributed to the study conceptualization, methodology, design, validation, data curation and to writing the original draft of the manuscript as well as to review and editing for the revised paper. All authors read and approved the final manuscript.

Informed consent

Not applicable

Appendix

Table A.1

List of banks included in the sample divided by country, and by membership in the Eurozone.

EURO ZONE		NO EURO ZONE	
Country	Banks	Country	Banks
Austria	Estre Grup Bank AG	Denmark	Danske Bank A/S Jyske Bank A/S Ringkjoebing Landbobank A/S Sydbank A/S
Belgium	KBC Group NV	Norway	DNB Bank ASA
Finland	Nordea Bank ABP	Poland	Bank Polska Kasa Opieki SA Powszechna Kasa Oszczednosci Bank Polski SA Satander Bank Polska SA
France	BNP Paribas SA Société General SA Credit Agricole SA	Sweden	Skandinaviska Enskilda Banken AB Svenska Handelsbanken AB Swedbank AB
Germany	Commerzbank AG Deutsche Bank AG	United Kingdom	Barclays PLC HSBC Holdings PLC Lloyds Banking Group PLC NatWest Group PLC
Italy	Banco BPM S.p.A. BPER Banca Banca Fineco S.p.A. Intesa Sanpaolo S.p.A. Unicredit S.p.A.		
Netherlands	ABN NA Equity ING Groep NV		
Spain	Banco Bilbao Vizcaya Argentaria SA Bankinter SA CaixaBank SA Banco de Sabadell SA Banco Santander SA		
# Countries: 8	# Banks: 20	# Countries: 5	# Banks: 15

Data availability

Data will be made available on request.

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Research involving human participants and/or animals

Not applicable

Declaration of competing interest

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