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Spotlight on physical risk: Assessing the banks' stock reaction to the ECB climate stress test ¹

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Using an event study approach, this paper examines the impact of the ECB's 2022 climate stress test on the share prices of European banks. We provide novel evidence that investors reacted negatively to both the announcement of the stress test and the publication of the results, even though there was no direct impact on regulatory capital and no detailed disclosure for individual institutions. Our unique dataset combines granular information on bank branch locations with geospatial data on several physical risks (landslides, floods and extreme temperatures) and shows that banks with branches in areas most exposed to physical risks had lower abnormal returns relative to their peers. We also examine the role of being signatory of the Principles for Responsible Banking, finding different results for the announcement and the results' disclosure dates. These results show that investors are pricing in both banks' physical risk exposure and their commitment to responsible banking, even though the regulatory framework for climate risk management is still evolving. Our findings have important implications for investors in assessing climate-related risks in their portfolios, for banks that should develop strategies to manage and mitigate these risks, not only to meet regulatory requirements, but also to preserve their market value and stakeholders' trust, as well as for policymakers in designing effective climate risk disclosure and management frameworks for the banking sector.

Keywords: Physical risk; Europe; Banks; Climate stress test; Event study

JEL Codes: G14, G21, N24, Q54

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“The awareness that sound Climate and Environmental risk management in the financial sector is of crucial importance can now be considered mainstream [...] And you – the banks – are in the lead when it comes to translating this awareness into mainstream practices by designing and implementing specific, practical tools to adequately manage these risks.”

Frank Elderson, Member of the Executive Board of the ECB and Vice-Chair of the Supervisory Board of the ECB, 3 February 2023, Frankfurt am Main

1. Introduction

Climate change creates new sources of financial risk (Monasterolo, 2020; Rudebusch, 2021). Successful implementation of climate policies that guide the transition to a low-carbon economy and prevent extreme climate disasters requires substantial and rapid transformations in developed and developing economies. Institutional investors believe climate risks have financial implications for their portfolios (Krueger et al., 2020), and their climate sentiments can play a role in avoiding a disorderly low-carbon transition (Dunz et al., 2021b). Climate change and environmental factors have unpredictable and undiversifiable features (e.g., Battiston et al., 2021; Ai and Gao, 2023) that create potential risks and opportunities in the financial sector. Climate awareness is gaining attention, particularly in Europe, due to recent instances of devastating floods and wildfires that have caused significant economic losses and human casualties. In 2020 alone, natural disasters caused \$210 billion of damages¹.

Not surprisingly, policymakers are developing rules to incentivise banks to lend while accounting for environmental risks and the physical effects of climate change (Mueller and Sfrappini, 2022), as well as developing hedging strategies for climate risk (Ouazad and Kahn, 2022). Banks have worked to integrate climate risks into their lending processes, but banks still largely lend to brown borrowers (Giannetti et al., 2023). Looking at the policymaker's actions, there is a wide range of interventions ranging from recommendations (i.e., to screening borrowers via an exhaustive assessment of both financial and climate risks) to running regular climate stress test exercises (i.e., to assess the financial system's vulnerability to climate

¹ Source: MunichRe.

change). In 2022, the European Central Bank (ECB) conducted a stress test to assess climate-related risks. The exercise aimed to identify vulnerabilities and provide banks with best practices for the green transition, incorporating both physical and transition risks. In this study, we focus on the former for several reasons. First, while transition risks have been extensively studied in the literature (e.g., Huang et al., 2021; Nguyen et al., 2023; Alessi et al., 2024), the analysis of physical risks has often been hampered by the lack of detailed data on the geographical location of bank assets exposed to these risks. This limit has made the topic difficult to study and, consequently, underrepresented in existing research. We believe that our approach may represent a significant step in this direction: by using granular data on branch location and combining it with geospatial information, we are able to provide a more accurate assessment of banks' exposure to physical climate-related risks. Furthermore, the ECB stress test scenarios for physical risks have a time horizon of one year, whereas the projections for transition risks have horizons of three and thirty years. This difference in time horizons makes the analysis of physical risks particularly suitable for our event study approach, which focuses on short-term market reactions. Finally, since transition risks are more dependent on the evolution of sustainability regulations, there is more uncertainty in projections. In contrast, physical risks are more tangible and can be assessed more accurately based on existing geographic and climate data. Thus, by focusing on physical risks, we aim to fill an important gap in the existing literature and provide new insights into a crucial but under-researched aspect of climate risk in banking.

This leads us to the following questions: Did the 2022 ECB climate stress test provide valuable information to investors? Did investors penalise banks with higher physical risk? If so, is the negative effect mitigated when a bank is committed to responsible banking? By running an event study around the key dates of the 2022 ECB climate stress test, we show that the ECB's stress test provided valuable information to investors. Specifically, investors reacted negatively both when the climate stress test was announced and when the results were published. The difference in abnormal returns between the bank with the lowest and highest

exposure to physical risk ranged from -4.48% to -6.53% across the (-3; +3) event window. Moreover, banks with branches in geographical areas more exposed to the aggregated physical risk experienced lower abnormal returns. While signing the Principles for Responsible Banking (hereafter PRB) was able to generate a mitigating effect at the announcement date, this is not the case at the results date, when risky banks that adopted the PRB experienced a worse market reaction than non-signatories, probably indicating a loss of confidence in this type of formal alliance.

Stress testing represents one of the key risk management's instruments to know the resilience of an exposure to deteriorating conditions by different sensitivities or scenarios. These exercises, especially conducted for financial risks, enable more informed risk management decisions and help maintain financial stability (Orlov et al., 2023). However, the importance of stress tests goes far beyond the mere assessment of capital at risk under several conditions. In particular, macro-prudential stress test programmes fulfil at least two critical functions. First, to provide a credible assessment of the soundness of the tested institutions; second, to outline a credible strategy for market participants to safeguard the financial system by filling any identified gaps (Schuermann, 2014). While various types of stress tests have been employed to evaluate the impacts of economic downturns, market disruptions, and modelling assumption violations, the emergence of climate-related stress tests represents a significant evolution in this field (Acharya et al., 2023). Thus, the 2022 ECB climate stress test stands out as an insightful initiative in this context: although there were no direct consequences in terms of regulatory capital, the 2022 climate stress test was part of a wider ECB action plan to include climate risk in prudential requirements.

It is also important to outline the peculiarities of this climate assessment. In contrast to traditional EU-wide stress tests², the ECB did not disclose individual banks' results for the climate stress test. Instead, it provided banks with an overall impact of the transition and

² <https://www.eba.europa.eu/risk-and-data-analysis/risk-analysis/eu-wide-stress-testing>.

physical risks in different scenarios. The absence of immediate regulatory consequences and individual disclosure poses an empirical question: on the one hand, the ECB stress test could impact investors' decisions by providing new information on banks' exposure to climate risk, although individual results were not disclosed. On the other hand, investors may not be able to properly assess and compare the resilience of different banks due to the lack of disclosure of individual results and the fact that only aggregated findings were published. By analysing this particular stress test, our study contributes to the growing body of knowledge on climate risk in finance, offering a unique perspective on how markets interpret and react to such comprehensive climate risk assessments in the banking sector.

Thus, our contribution to the existing literature is multifaceted. To the best of our knowledge, this is the first paper showing that the 2022 ECB climate stress test provided novel information in financial markets, even though a disclosure of the results for each institution did not accompany it. Furthermore, we created a unique dataset on banks' exposure to physical risk, which - as suggested by the ECB (2022) - is closely tied to the geographical location of their lending activities, with significant spatial concentration and high heterogeneity across Europe (as shown in Figure 1 for flood risk). We exploited granular information on the location of bank branches and collected data on the exposure to different types of natural disasters (flood, landslide and high temperature) from public databases (i.e., DRMKC and EUROSTAT). Using this original database, we can assess whether investors price the level of physical risks faced by banks and to what extent they are able to differentiate between institutions that are more or less exposed, even though the regulatory framework for climate risk is still in its infancy. Finally, we also examine whether investors consider banks' commitment to responsible banking when pricing exposure to natural disasters. This adds to the literature that demonstrates how environmental engagement can reduce downside risk (Fiordelisi et al., 2023).

[INSERT FIGURE 1 HERE]

The remainder of the paper is structured as follows. Section 2 presents the literature review and Section 3 describes data and methodology. The main results are discussed in Section

4. Section 5 provides further evidences, Section 6 presents some robustness checks, and Section 7 concludes.

2. Literature review

Our paper contributes to two main research streams: the first one is related to the pricing of physical risk in the banking industry, while the second one is devoted to stock market reactions to banking stress tests.

First, natural disasters lead to greater credit constraints (Baltas et al., 2022), as extreme climate events increase acute physical risks due to the deterioration of firms' creditworthiness and ability to borrow from banks. Thus, financial consequences of natural catastrophes may negatively affect borrowers' solvency (Klomp, 2014; Walker et al., 2023) and liquidity creation (Lee et al., 2022), supporting the hypothesis that natural disasters decrease bank stability because total deposit and equity become more volatile and the bank is prone to increase lending margins, as well as loan loss provisions (Do et al., 2023). Moreover, while banks play a role in mitigating post-disaster impacts (e.g., Nguyen and Wilson, 2020), they may also bear the consequences of their actions to support their communities. They can therefore act as shock absorbers for local economies, responding to changes in credit demand by increasing real estate lending (Bos et al., 2022), especially if they are highly concentrated within a city (Celil et al., 2022). As Horvath (2021) demonstrates, large-scale natural catastrophes can severely undermine financial deepening, particularly in developing economies. This exposure is further complicated by the dynamics observed by Berg and Schrader (2012), where disaster events like volcanic activity increase credit demand while simultaneously restricting credit access. However, established bank-borrower relationships can mitigate these lending restrictions. Abedifar et al. (2024) highlight the crucial role of local branches in bridging the gap between disasters and governmental aid by immediately increasing lending in the aftermath of events like floods. Apart from credit and liquidity risks, physical risks can propagate to affect market risks on value of banks' financial asset holdings. As Brei et al. (2024) point out, systemic climate shocks can lead to a drop in market capitalization. From an investor's perspective, this decline

is particularly concerning. As Wachter (2013) notes, damaging natural disasters can result in both negative price shocks and higher financial market volatility, adversely affecting banks with large exposures. This can create a gap between market capitalization and book values, potentially making banks reluctant to issue stocks. Consequently, investors must consider not only the direct impact of physical risks on assets, but also banks' ability to manage post-disaster credit demand and maintain financial stability in increasingly volatile climate contexts, even making recourse to insurance coverage (Zanin et al., 2024).

According to the review of Venturini (2022), climate change could be considered as an additional source of market risk. Interestingly, only a limited number of papers investigate whether investors price climate risks, including both physical and transition risks. In addition, at our knowledge, the evidence specifically focusing on financial institutions is even smaller. For instance, Zhang (2022) provides evidence that global stock prices react negatively to perceived changes in climate risk (both physical and transition risks, measured with newspaper attention), with a weaker effect for “green firms”, for which the negative impact is moderated by their environmental commitment. Gong et al. (2022) outlines that firms more exposed to climate risk (measured with the frequency of climate related words in earning calls) are more sensitive to political uncertainty. At our knowledge, the only paper focusing on the sensitivity of banks stock returns to climate risk is the one by Bounou and Urom (2023), documenting a negative impact on stock prices. However, the authors measure climate change with a textual and narrative analysis of Reuters climate-change related news (as proposed by Faccini et al., 2023) and consider wide stock banking indices at the country level. In a paper focused on physical risk and mortgage lending, Schubert (2021) find that banks with large shares of loans in affected areas experience lower profits and capital ratios following flood disasters, implying that exposure to flood is not fully priced.

Overall, there are several reasons to believe that banks are strongly affected by physical risks: natural disasters are already damaging property and disrupting trade, harming the solvency and leverage of financial institutions (e.g., Lamperti et al., 2021). Nevertheless, the

empirical evidence on the extent to which physical risk is priced in bank stock returns is still limited. At our knowledge, the existing finance literature is more concentrated on the pricing of transition risk, especially linked to the bank lending activity. For example, Kacperczyk and Peydró (2022) find that banks are more likely to reallocate credit from the most polluting firms to the greenest firms than to lend to polluting firms to get them to invest in reducing their carbon emissions. Such a credit reallocation seems to be evident after the 2015 Paris Agreement (e.g., Reghezza et al., 2022; Martini et al., 2024). Moreover, banks that signed environmental commitment's principles reduce their exposures to the riskiest industries compared to non-signatories (Jung et al., 2023). Our paper aims to contribute to the existing literature by constructing a unique dataset allowing us to focus on physical risk at a granular level, exploiting data on branch locations and regional exposure to landslides, floods and extreme temperatures.

With respect to the second literature stream observed, several papers find that stress test's results caused price adjustments and were considered relevant by investors (e.g., Petrella and Resti, 2013; Fernandes et al., 2020). The use of macro stress tests to assess bank solvency has rapidly developed in recent years. These tests have proven to be useful in identifying potential vulnerabilities within the banking sector and gauging its resilience to adverse developments (Henry et al., 2013). However, they are not suitable as early warning devices to identify vulnerabilities in apparently quiet times and to trigger corrective actions (Borio et al., 2014). Alves et al. (2015) find that during the recent sovereign debt crisis, two stress tests conducted by the European Banking Authority conveyed new information to the stock market and had a stronger impact on the stock prices of riskier financial institutions. More in details, the outcomes were not anticipated by the stock market, but were partially anticipated by the credit default swap market. Later, the 2014 Comprehensive Assessment conducted by ECB surprised the market revealing an unexpected harsher ECB policy stance (Lazzari et al., 2017), with a negative stock reaction for banks under direct ECB supervision at the official launch of the Single Supervisory Mechanism (Carboni et al., 2017).

Focusing on climate issues, we have several papers showing that ESG-related events provide new information to market participants (e.g., Capelle-Blancard and Petit, 2019; Glück et al., 2021).

However, to our knowledge, there are no papers investigating the impact of 2022 ECB climate stress test on the stock price of European banks, apart from Torricelli and Ferrari (2021) who analyse market reaction from another exercise conducted by ECB in 2021, called economy-wide climate stress test, which has been developed to assess the resilience of both non-financial corporations and euro area banks to climate risks, as well as highlighting that an orderly transition is less costly than delaying action (Dunz et al., 2021a). Our contribution is the focus on the 2022 climate exercise, specifically devoted to the banking industry, considering stock reaction in the light of banks' exposure to physical risk.

Overall, more research is required in order to better understand and incorporate bank-lending responses to climate risks, as well as assess the adequacy of climate risk pricing in financial markets (Acharya et al., 2023).

3. Data and methodology

The purpose of this section is to describe the data collection process and the methodology used for the event study and the second-stage regression analysis.

We consider two key dates relevant for the 2022 climate risk stress test conducted by ECB, which evaluated the ability of banks to deal with climate-related risks using a bottom-up approach. On the 18th of October 2021, the ECB corresponded with banks' CEOs requesting the submission of a complete set of templates that encompass a minimum of two modules and respective calculations, as part of their ongoing climate risk assessments. This date may be considered as the "launch" of the climate stress test. The nature of the exercise has been defined as "exploratory" and the results, published on the 8th of July 2022, do not have any direct capital

implications for the supervised institutions, but are intended to feed into the annual SREP assessment in an indirect and qualitative way only³.

To build our dataset, we retrieve financial and geographical information from several different sources. First, we use Datastream to collect stock price series for listed European banks. For banks having a commercial specialisation, we also draw information on headquarters locations and bank balance sheet items from Moody's Analytics BankFocus. Furthermore, we integrate branches' locations for each European bank by using the Orbis dataset in order to match them with their respective climate risks at larger spatial scales (Carter et al., 2018).

Second, we consider data on climate risk drivers by collecting information from other two sources. The European Commission Disaster Risk Management Knowledge Centre (EC DRMKC) integrates existing scientific multi-disciplinary knowledge and co-develops innovative solutions for existing needs (e.g., Antofie et al., 2019; Faiella et al., 2020). The risk data hub is a web platform for disaster risk assessment and provides climate indicators based on asset exposure, year projection, and aggregation. Indeed, each risk is measured as a function of hazard, exposure and vulnerability and is calculated at the scale of NUTS3 regions, which are defined as small regions according to nomenclature of territorial units for statistics (NUTS). NUTS3 regions are part of a system that subdivides the economic territory of Europe to support statistical data gathering, socio-economic analysis and the framing of European policies. There are 1,379 NUTS3 regions in Europe. This mapping allows us to have a set of climate indicators at a geospatial scale, indicating whether regions are above or below the European average for the selected NUTS3. Specifically, from this database, we can assess the grade of physical hazards in terms of flood and landslide risk and average indicators for all branches to obtain an indicator at the bank level. Since the ECB climate stress test also consider drought and heat risk, we also need information on temperatures, which we draw from another source. In details, heat risk data is obtained from EUROSTAT⁴ using the Cooling Degree Day (CDD) measure, a

³ <https://www.bankingsupervision.europa.eu/press/pr/date/2022/html/ssm.pr220127~bd20df4d3a.en.html>.

⁴ https://ec.europa.eu/eurostat/databrowser/view/NRG_CHDDR2_A__custom_7482300/default/table?lang=en.

weather-based technical index that describes the need for the cooling (air-conditioning) requirements of buildings and it represents the severity of the heat in a specific time period taking into consideration outdoor temperature and average room temperature. CDD is derived from meteorological observations of air temperature, aggregated and presented at the NUTS3 level.

Thus, since several information are retrieved from different sources, we need to correctly manipulate data input in order to measure physical riskiness at the bank level. This process mainly consists of four steps. First, we start from banks with an available ISIN code and we extract information from location-related columns, such as addresses, postal codes, and cities⁵. In this way, for each bank we take geographical data on its head office and branches, when provided by either BankFocus or Orbis. Second, we map postal codes to NUTS3, based on ISO country information in order to avoid mismatching due to duplicate postal codes, by using correspondence tables⁶ from EUROSTAT. Third, after we also retrieve NUTS3 codes from other geographical information (i.e., city or zip code), integration with DRMKC (for flood and landslide risks) and EUROSTAT (for heat risk) is developed for each bank location. Then, we calculate climate risk averages at both head office and branch levels, when at least one value is available. As we have three different measures of physical risk at the bank level, based on branches' locations (or those of headquarters when no branches are available), we combine them into a single overall measure of physical risk, which is calculated by first ranking each individual risk (i.e., flood, landslide, and heat) across banks, and then normalising these ranks to a scale of 0-1. The final measure is an average of the normalised ranks for specific physical risks⁷, which is then itself normalised to a scale of 0-1.

After merging and processing the data, we drop nationalised banks that are under government control, following Véron (2017), as well as checking for the Global Ultimate Owner

⁵ We manually integrate some important cities (especially French ones) when postal codes are missing.

⁶ <https://ec.europa.eu/eurostat/web/nuts/correspondence-tables/postcodes-and-nuts>.

⁷ We thank the anonymous referee for suggesting this aggregation procedure.

(GUO) from BankFocus. Thus, our final sample consists of 85 unique banks over the two date announcements (Table A.1 shows the country distribution).

We define the methodology used for the event study and for the subsequent regression analysis, in order to assess whether European banks that are more exposed to the overall physical risk experience lower abnormal stock returns, around both the announcement and the results' disclosure of the ECB climate stress test.

We measure the stock price reaction for European banks by estimating Abnormal Returns (ARs), which are the forecast error of a specific normal return-generating model. Regarding the estimation procedure, we estimate the AR adopting a standard market model (MacKinlay, 1997). As in Ricci (2015), market model parameters are obtained with daily log returns of each bank and a broad reference index (i.e., EUROSTOXX 600⁸) able to represent the market portfolio over a 252-day estimation period, ending 20 days before the announcement (Fiordelisi and Ricci, 2015). We also test with an alternative reference index (i.e., MSCI EMU Financials Index) and results are very similar. ARs are calculated as the difference between the observed and expected returns, cumulated over different short event windows (i.e., [-1, +1], [-3, +3], [-5, +5]), consistently with other studies (e.g., Graziano et al., 2020).

As a second step, we investigate the cross-sectional determinants of different banks' stock price reaction by running an OLS regression for each key date around the ECB climate stress test, as shown in the following baseline specification:

$$CAR_i[t1, t2] = \alpha + \beta_1 Physical_{Risk} + \sum_k \gamma_k Bank + \varepsilon_i \quad (1)$$

where CAR is the cumulated abnormal return for the i -th bank over the event window ($t1, t2$). $Physical Risk$ represents the aggregate physical risk measure. It consists of an average of the normalised ranks for individual physical risks (i.e., flood, landslide, and heat) at the bank level. $Bank$ represents a vector of standard control variables (Ramelli and Wagner; 2020) and it includes $Size$ (i.e., the logarithm of the total assets), MTB (i.e., the book value of the equity

⁸ We also consider MSCI EMU Financials Index (EUR) as alternative market proxy.

divided by market evaluation), and *ROA (%)* which is the gross return on assets in percentage. Standard errors are based on the robust variance estimator. All the independent variables are standardised and winsorised at the first and ninety-ninth percentiles.

In a further specification, we also investigate the cross-sectional effect of physical risk exposure and commitment to the Principles for Responsible Banking (PRB). Due to the high heterogeneity across ESG measures of different providers (Berg et al., 2022; Christensen et al., 2022), we decide to consider an elective commitment rather than using external ESG scoring as proxy for assessing green awareness performance, as already done in some previous studies (Degryse et al., 2023). Specifically, we create four binary variables: (1) low-risk banks without PRB membership; (2) high-risk banks without PRB membership; (3) high-risk banks with PRB membership; (4) low-risk banks with PRB membership. We run the following regression model:

$$CAR_i[t1, t2] = \alpha + \beta_1 LowPRwithoutPRB + \beta_2 HighPRwithoutPRB + \beta_3 HighPRwithPRB + \sum_k \gamma_k Bank + \varepsilon_i \quad (2)$$

where *LowPRwithoutPRB* is a binary variable which takes the value of 1 when the bank has exposure to physical risk (PR) below the sample median and it is not committed to the PRB, and 0 otherwise. *HighPRwithoutPRB* represents a dummy variable which is defined as equal to 1 when the bank has exposure to PR above the sample median value and it is not a PRB signatory, and 0 otherwise. *HighPRwithPRB* is a binary variable when bank signed the PRB and its exposure to PR is above the sample median, and 0 otherwise. The fourth variable (i.e., *LowPRwithPRB*) is regarded as the reference category. The remaining regressors are the same as in our baseline model shown in Equation (1).

All the independent variables used in our empirical analyses are described in Table 1, while the main summary statistics are presented in Table 2, where Panels A and B represent the two key dates, respectively. Since flood and landslide risks have the same unit of measurement, we note that banks' branches present a higher average value of flood rather than landslide risk. The variables describing exposure to the different types of physical risks are time-invariant, given the availability of cross-sectional data, in line with the proximity of the

two event dates. With regard to the sample considered, 30 banks have signed up to the PRB. MTB ratio shows significant variability, with an average value lower than one. Conversely, size shows less variability, indicating a consistent size distribution of banks. Profitability is also quite heterogeneous across banks, with both positive and negative values, highlighting a strong heterogeneity in profitability. Overall, we observe similar ranges to other studies which analyse market reactions in banks (Fiordelisi et al., 2020; Onali et al., 2021).

[INSERT TABLE 1 HERE]

[INSERT TABLE 2 HERE]

4. Results

First, we comment the main results from our event study analysis conducted on European banks with reference to the announcements of the ECB climate stress test. We begin by graphically analysing whether and to what extent investors reacted to the 2022 ECB climate stress test. Figures 2 and 3 illustrate the market reactions surrounding the two key event dates. Specifically, Figure 2 presents the cumulative raw returns for banks⁹ and the market index, while Figure 3 depicts the cumulative abnormal returns for banks from three working days before to three days after the dates, following De Vito et al. (2023). We find that the worst effect was caused by the publication of results (i.e., 08 July 2022), with a sharp decline in both raw and abnormal cumulative returns around the announcement. This is consistent with the main results of the ECB stress test: the exercise revealed many deficiencies, data gaps and inconsistencies across institutions, still at a very early stage in the measurement and management of climate risks, which are able to produce non-negligible losses in each relevant scenario. More in details, for physical risks the ECB concluded that significant institutions are, to varying degrees, exposed to the materialisation of acute physical risks in Europe, namely drought and heat events and flood risk (ECB, 2022).

[INSERT FIGURE 2 HERE]

⁹ Equally weighted average value from our sample of banks (i.e., 85).

[INSERT FIGURE 3 HERE]

Table 3, Panel A shows cumulated average abnormal returns (CAARs) and the relative level of statistical significance. The index chosen to run our market model is the EUROSTOXX 600. Results remain substantially unaltered when using the narrower MSCI EMU Financials index¹⁰. For the longest event windows (-5; +5) and (-3; +3), the average market reaction is negative and statistically significant at least at the 5% level, with a stronger magnitude for the results date, reaching almost -7% over the 11-day window and -4% over the 7-day window. As suggested by Kolari and Pynnönen (2010), since the event dates are the same for all banks, we adjust the Z-statistics for possible cross-sectional correlation among abnormal returns. Also with this adjustment, CAARs remain statistically significant at least at the 10% level only for the results date in both event windows. This is consistent with the published ECB report (i.e., aggregated results' presentation) in which the ECB states that banks do not yet sufficiently incorporate climate risk into their stress-testing frameworks and internal models¹¹.

To provide more details around the average reaction, in Panel B of Table 3 we test the difference in mean between CARs in the two dates and across the three event windows. The difference is negative and statistically significant for both the (-3; +3) and the (-5; +5) event windows, while it is not distinguishable from zero in the interval (-1; +1), confirming that banks reacted more negatively to the disclosure of results rather than to the announcement of the exercise. This result is also confirmed in Panel C of Table 3 where we show the number of banks registering positive or negative Cumulated Abnormal Returns (CARs) over our three different event windows and for both event dates. The portion of banks experiencing negative abnormal returns is higher than the number of peers with positive abnormal returns in 5 out of 6 cases, consistently with the evidence shown in Panel A. The prevalence of negative returns is stronger for the results date, especially for the longest event window (-5; +5), where 72 out of 85 banks

¹⁰ Results are available from the authors upon request.

¹¹ “Euro area banks must urgently step up efforts to measure and manage climate risk, closing the current data gaps and adopting good practices that are already present in the sector” said Andrea Enria, Chair of the ECB’s Supervisory Board.

show a decrease in their stock price. Panel D of Table 3 provides details on the consistency of market reactions across the two key dates of the 2022 ECB climate stress test, indicating that market's negative reaction to the climate stress test was more pronounced and consistent over longer periods, particularly for both the (-5; +5) and the (-3; +3) event windows. The shorter window (i.e., [-1, +1]) shows more varied responses, possibly reflecting immediate market uncertainty or the need for more time to fully incorporate the information and understand the implications of this exercise.

We also investigated asymmetric event windows to assess possible anticipatory effects (i.e., [-5, -1], [-3, -1], and [-1, -1]). We find no significant anticipatory effects for the launch date, while the market reaction was negative and significant in the wider event windows (i.e., [-5, -1] and [-3, -1]) before the publication of results. This suggests that investors began to incorporate potentially negative outcomes prior to the official release. Following the announcement of the results, we do not find any compensation for negative abnormal returns, but the market - on average - continued to penalise banks.

Finally, in Panel E of Table 3 we also conduct a comparative analysis of CAARs and we divide our sample into two groups according to exposure to the aggregate physical risk: above and below the median value. With respect to the launch date, banks experienced a CAAR of -2.18% from three trading days before to three trading days, as shown in Panel A. However, in Panel E, we also see that the most exposed banks had a CAAR of -4.39%, while the least exposed banks reported a CAAR of -0.03%. The findings are even more negative along the results date, where the CAAR was -3.84% (see Panel A of Table 3) and from Panel E, the most exposed banks had a CAAR equals to -5.94%, compared to -1.79% for others. This comparison allows us to observe two main insights. Firstly, both groups experienced negative CAARs on both event dates, underscoring the overall market reaction to the climate stress test. Secondly, there is a marked difference in the magnitude of these negative returns between banks with high and low physical risk exposure, with highly exposed banks experiencing significantly larger negative

CAARs. These findings highlight the evolving nature of market reactions to climate-related disclosures and stress tests in the banking sector.

[INSERT TABLE 3 HERE]

As a second step in our analysis, we run a multivariate regression analysis to assess the main determinants of CARs, including the aggregated measure of physical risk. As baseline results, we focus on the event windows from three trading days before to three trading days after each date. Results are reported in Table 4, for both a more parsimonious model (odd columns) and for a specification including balance sheet control variables (even columns). While Columns 1 and 2 are referred to the first date, Columns 3 and 4 show the regression models for the second date when 2022 ECB climate stress test were published. Around the announcement date, we find that the difference between the bank with the lowest and highest physical risk is 6.53% in the absence of additional financial controls, or 5.34% when bank balance sheet variables are taken into account. With regard to the period on which results were published, similar findings were revealed. The difference between the bank with the lowest and highest exposure to physical risk is either 6.25% in the absence of other controls or 4.48% with the inclusion of financial variables, respectively. Thus, all the coefficients associated with physical risk indicators show a negative relationship with CARs, reaching statistical significance at least at the 10% confidence level. While profitability and MTB ratio have not statistically significant effects on abnormal returns, the market reaction is on average worst for large banks (the coefficient for size is negative and statistically significant at the 10% level when considering results date).

[INSERT TABLE 4 HERE]

We also observe similar findings when considering our longest event window (i.e., [-5, +5]). Results are shown in Table A.2. In 3 out of 4 cases, we find a negative association between aggregated physical risk and CARs, statistically significant at least at the 5% confidence level. When we consider financial control variables, the magnitude of the coefficients of interest decreases, but still remains statistically significant, except for the announcement date. For

other control variables, the market reaction is on average worst for larger banks and better for more profitable ones, while MTB ratio has not statistically significant effects on abnormal returns.

In Table 5, we explore which category of physical risks contributes more to the previous findings. In order to avoid possible multicollinearity problems in our regression analyses, we focus on the three risk measures separately due to the positive correlations among them (i.e., ranging from 0.28 to 0.45). Except for the flood risk, we find that landslide and heat risks have a negative and statistically significant association with CARs at the 10% level, when we consider financial controls. The most significant indicator in results appear to be the landslide risk: specifically, a one-standard-deviation increase in the average landslide risk affecting bank branches is associated with a decrease in abnormal returns equals to 1.52% (or 1.68% without considering other variables).

[INSERT TABLE 5 HERE]

One may question the definition of our main risk indicator variables. Since they are based on a simple average of all branches, it is possible that some branches have extreme risk exposures, but these are smoothed by the average across many branches and are then no longer relevant in the indicator. For this reason, we extend our analysis by including an alternative risk indicator that is not based on the average risk across all branches, but takes into account the median and 75th percentile of each bank's risk exposure derived from its branches. The results remain qualitatively unchanged and continue to indicate that investors have some perception of physical risk and price this risk into their assessment of bank value.¹²

Furthermore, one might claim that investors do not have easy access to data about the exact location of all bank branches, but are more likely to consider only the headquarter. To address this issue, we run a robustness check that focuses solely on the physical risk associated with the NUTS3 code where the bank's headquarters is located, rather than using averages

¹² Results are available from the authors upon request.

across branch locations. Our analysis confirms that our main findings remain consistent even under this alternative specification¹³. Moreover, the coefficients for our risk indicator have a lower level of statistical significance. This may be an indication that investors are able to consider the overall exposure of banks to physical risks, although it is likely that they obtain this information from publicly available reports and information, rather than specifically mapping all branches in NUTS3 regions as done in this paper.

Overall, we find that the ECB climate stress test was able to produce relevant information for the market, despite the decision not to disclose individual results and the exploratory nature of the exercise. This is consistent with the finding of significant abnormal returns. The negative sign is probably due to the expectations of new compliance costs and capital burden to manage and cover climate risks. In fact, even though the ECB climate stress test was designed not to have immediate consequences on capital regulation, participating banks are expected to draw on their individual reports and further improve their climate risk stress-testing capabilities. In addition, the ECB climate stress test is part of a greater strategy about climate risk, obviously finalised to include them in the prudential regulation of banks.

Our second-stage regression analysis revealed a strong heterogeneity across banks, partially explained by their geo-localisation and consequent exposure to climate risk. Hence, we provide preliminary evidence that investors incorporate the exposure to climate physical risks in the pricing of banks stocks, despite the fact that the regulatory framework for managing climate risk is still evolving.

5. Further findings: The role of responsible banking

While banks are potentially more exposed to physical risks due to the location of their offices, it is interesting to examine whether the proactive adoption of responsible banking principles can have a mitigating effect on the risk perceived by investors.

¹³ Results are available from the authors upon request.

Table 6 presents the results of a regression model examining the relationship between physical risk and the cumulative abnormal returns of European banks around the climate stress test announcements, controlling not only for being exposed to physical risk but also for being a signatory of the Principles for Responsible Banking. The subscription of PRBs has already been used in the literature as a proxy of banks commitment to consider environmental factors when assuming loan decision (Degryse et al., 2023). The idea is that a more responsible conduct is linked to a higher awareness and then a more effective management of climate risks, for both physical and transition components. With respect to the announcement date of climate stress test across the (-3; +3) event window, we find a confirmation of the idea that the adherence to PRB plays a mitigating role: non-PRB banks with higher physical risk result to be the worst category, with lower cumulative abnormal returns (i.e., -5.49%) compared to the reference category (less risky and PRB member institutions), with statistical significance at the 1% level. This evidence is consistent across both the flood risk and heat risk drivers, suggesting that investors have a good perception about the adherence to PRB risk as a driver of more risk awareness and better risk management. This is also consistent with past papers showing that the stock price of green banks is less exposed to variations in climate risk with respect to the peers (e.g., Zhang, 2022). However, with respect to the second results date, when climate stress test was disclosed, the analysis reveals different results. In this case, banks more exposed to physical risk have a worse market reaction with respect to the base category, but the stock response is more negative for those adhering rather than not to PRB. In this case, there is no monitoring effect, but a sort of mistrust effect, that may be due to some events occurring between the two dates. In particular, we refer to the reinforced standards of the Race to Zero campaign and the Glasgow Financial Alliance for Net Zero, which were implemented in June 2022. These tightened standards prompted critical reflection on the credibility and actual effectiveness of such alliances, leading to notable institutional withdrawals in the following year. In our case, at the results date, when published results reveal that banks are largely exposed (and unprepared) to the consequences of physical risk, investors may be particularly upset by banks

taking part in this kind of alliances, being doubtful about their effectiveness and credibility. Control variables (MTB, Size, and profitability) do not show significant differences in signs with respect to the previous models.

[INSERT TABLE 6 HERE]

6. Robustness checks

As a first robustness check, to further validate our findings and address potential concerns about omitted variables, we incorporate macroeconomic controls in our baseline model, following previous studies on banks' market reaction to regulatory or policy announcements (e.g., Onali et al., 2021). Table A.3 presents these results. The coefficient for the aggregated physical risk remains negative across all specifications and statistically significant at the 5% level only for the results date (Column 2). The persistence of the negative relationship between physical risk and CARs confirms our baseline results, even after controlling for macroeconomic factors, and strengthens our conclusion that the market's reaction to the climate stress test is driven by bank-specific physical risk exposure rather than broader economic conditions.

As a second robustness check, we consider the possibility that a previous announcement related to the ECB climate policy impacted on investors' perception about physical risks before the launch of the climate stress test. To overcome this issue, we consider the first relevant date of the ECB specific strategy on climate risk. We refer to the disclosure of the ECB's guidance on climate-related and environmental risks, published on 27 November 2020, containing supervisory expectations on banks prudent management and transparent disclosure of climate risks. In an event study analysis, we find that - on this first date - the average reaction of banks was positive rather than negative, which probably indicates that investors were expecting a stricter approach or were somehow relieved by a reduction in uncertainty about the ECB's climate policy. However, we try to include this further date in our regression analysis to see whether the negative relationship between abnormal returns and physical risks still holds. Our independent variables are the same. Results are shown in Table 7 and are in line with our baseline model presented in Table 4. Specifically, we find that the difference in abnormal

returns between the bank with the lowest and highest exposure to the aggregated physical risk is equivalent to 7.43%, even if statistically significant at the 10% level. This indicates persistent investors' concerns about the negative impact of physical risks on bank performance, both at the announcement of supervisory expectations and at the dates relative to the climate stress test.

[INSERT TABLE 7 HERE]

7. Conclusions

Climate change and its associated financial risks have become crucial issues in the modern global economic landscape. Delaying action would inevitably lead to higher short-term costs, highlighting the importance of investing in transition mechanisms and sustainable technologies to mitigate risks in the long term. Thus, policy action to deal with climate change is accelerating, especially in Europe (Lagarde, 2021), where regulators have prioritised addressing climate and environmental risks to a large extent, as well as integrating them into the business models and governance frameworks of financial institutions¹⁴.

Indeed, a first relevant result of our study is that the ECB climate stress test produced a significant market reaction, even though it was an exploratory study, without the publication of individual results and direct consequences in terms of regulatory capital. This indicates that, at the time of this learning exercise, investors already expected a future increase in compliance costs and capital requirements. This is consistent also with some statements by ECB representatives. For example, in a March 2022 speech, Frank Elderson (Member of the Executive Board of the ECB and Vice-Chair of the Supervisory Board of the ECB) said: “[...] *we are gradually integrating C&E risks into our regular supervisory methodology, and how banks manage these risks will ultimately impact their Pillar 2 capital requirements*”.

Second, our findings show that European banks with higher exposure to physical risks experience decreased abnormal stock returns during significant dates of the climate stress test

¹⁴ <https://www.bankingsupervision.europa.eu/press/pr/date/2020/html/ssm.pr201127~5642b6e68d.en.html>

conducted by ECB in 2022. This is an indication that investors assessing the value of banks price physical risk, even if they are not able to have complete and perfect information and despite regulatory uncertainty. At the same time, we also find that less risky banks committed to the Principles for Responsible Banking exhibit a moderate effect on their stock returns at the announcement date, consistent with past literature showing that the market rewards green companies in situations of increasing risk and uncertainty (e.g., Zhang, 2022; Gong et al., 2022). However, at the result date, the moderator effect of PRB is reversed, probably for the decrease in the perceived effectiveness and credibility of this kind of formal alliances.

Our research provides early insights into the implications of climate risk stress testing in the context of European banks, offering significant takeaways with important policy implications. The findings demonstrate that financial markets are increasingly sensitive to climate-related risks, as evidenced by the negative abnormal returns experienced by banks following the climate stress test announcements and results. This market reaction underscores the effectiveness of such regulatory measures in raising awareness and promoting transparency about climate-related financial risks, supporting the case for continued and potentially expanded use of climate stress tests as a supervisory tool. The differentiated market response based on banks' physical risk exposure highlights the urgent need for financial institutions to enhance their climate risk management capabilities, suggesting that regulators should consider mandating more robust climate risk assessment and disclosure practices. Furthermore, our results emphasise the importance of coordinated policy actions between financial regulators and environmental policymakers, as integrating climate considerations into financial supervision could accelerate the transition to a low-carbon economy by influencing capital allocation decisions. Lastly, our results have implications for banks in their assessment and pricing of climate-related financial risks. In particular, it indicates that these exercises could serve as crucial analytical instruments, requiring financial institutions to quantify, assess and strategically manage their climate-related financial vulnerabilities. By identifying potential weaknesses in banks' current risk management frameworks, these tests incentivise the

implementation of a proactive adaptation strategy, which may result in significant changes to lending strategies, investment portfolios and risk mitigation approaches. Yet, market reactions to climate stress test indicate that banks are not only subject to regulatory pressure but also face significant investor and stakeholder expectations to preserve its market value and credibility in investors. Consequently, banks may need to develop more sophisticated climate risk assessment methodologies, as well as integrate climate considerations into their strategic planning in order to minimise potential future financial losses associated with climate-related risks.

Overall, our research contributes to the growing literature on the increasing importance of climate risk for financial institutions. Our main findings provide a small piece of evidence that investors are already paying close attention to banks' exposure to climate risk, and that market discipline may be able to anticipate regulation, even if the path to prudential regulation is still some time away.

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Table 1: Variables description

Variable	Source	Description
Physical risk	DRMKC, EUROSTAT	It consists of an average of the normalised ranks for individual physical risks (i.e., flood, landslide, and heat) at the bank level, which is then itself normalised to a scale of 0-1
Flood risk	DRMKC	It represents a measure of flood risk at the bank level, obtained as an average of the risk across all branches, based on geo-locations (where branches are not available, the head office is used). Each risk is based on asset (i.e., buildings), year projection (i.e., 2 years), and aggregation (i.e., NUTS3). It is estimated with an indicator varying from 1 to 10 and is calculated as a function of hazard, exposure and vulnerability
Landslide risk	DRMKC	It represents a measure of landslide risk at the bank level, obtained as an average of the risk across all branches, based on geo-locations (where branches are not available, the head office is used). Each risk is based on asset (i.e., buildings), year projection (i.e., 2 years), and aggregation (i.e., NUTS3). It is estimated with an indicator varying from 1 to 10 and is calculated as a function of hazard, exposure and vulnerability
Heat risk	EUROSTAT	It represents the logarithm of a measure of heat risk at the bank level, obtained as an average of the risk across all branches, based on geo-locations (where branches are not available, the head office is used). Each risk is a weather-based technical index that describes the need for the cooling (air-conditioning) requirements of buildings and it represents the severity of the heat in a specific time period taking into consideration outdoor temperature and average room temperature
PRB	UNEP-FI	Dummy variable indicating which bank is a signatory of the Principles for Responsible Banking (as of October 2021)
MTB	BankFocus	The book value of the equity divided by market evaluation
Size	Orbis	The logarithm of the total assets
ROA (%)	Orbis	The ratio between net income and total assets, in percentage
Inflation (%)	World Bank Database	It is measured by the consumer price index which reflects the annual percentage change in the cost to the average consumer of acquiring a basket of goods and services
GDP growth (%)	World Bank Database	It represents the annual percentage growth rate of Gross Domestic Product (GDP) at market prices based on constant local currency

This table reports, respectively, variables name, source and description, used in our empirical analyses.

Table 2: Summary statistics

Panel A – Announcement date								
Variables	Obs	Mean	SD	p1	p25	Median	p75	p99
CAR [-5, +5]	85	-0.0176	0.0633	-0.1440	-0.0592	-0.0154	0.0262	0.1732
CAR [-3, +3]	85	-0.0218	0.0550	-0.1637	-0.0594	-0.0193	0.0055	0.1371
Physical risk	85	0.4576	0.2709	0.0000	0.2636	0.4922	0.6855	1.0000
Flood risk	85	4.2391	3.044	0.0000	0.4545	4.8936	6.5049	9.9392
Landslide risk	85	2.6836	2.8224	0.0000	0.0000	2.0225	5.0000	9.8812
Heat risk	85	1.7253	3.6559	-4.6052	-0.4005	2.6685	5.0868	5.9931
PRB	85	0.3529	0.4807	0.0000	0.0000	0.0000	1.0000	1.0000
MTB	80	0.7042	0.6894	0.1000	0.3600	0.5600	0.8100	4.3100
Size	80	24.019	2.2505	19.1081	22.3406	23.8232	25.3587	28.1269
ROA (%)	85	0.6461	0.6906	-0.8430	0.2255	0.6290	0.9595	2.6360
Inflation (%)	85	0.7418	1.2558	-1.2480	-0.1377	0.4207	1.1999	3.3745
GDP growth (%)	85	-4.8000	3.8474	-11.1673	-8.5204	-3.8268	-2.4245	6.6172
Panel B – Results date								
Variables	Obs	Mean	SD	p1	p25	Median	p75	p99
CAR [-5, +5]	85	-0.0674	0.0729	-0.2618	-0.0960	-0.0570	-0.0096	0.0682
CAR [-3, +3]	85	-0.0384	0.0545	-0.2083	-0.0535	-0.0274	-0.0084	0.0699
Physical risk	85	0.4576	0.2709	0.0000	0.2636	0.4922	0.6855	1.0000
Flood risk	85	4.2391	3.0440	0.0000	0.4545	4.8936	6.5049	9.9392
Landslide risk	85	2.6836	2.8224	0.0000	0.0000	2.0225	5.0000	9.8812
Heat risk	85	1.7253	3.6559	-4.6052	-0.4005	2.6685	5.0868	5.9931
PRB	85	0.3529	0.4807	0.0000	0.0000	0.0000	1.0000	1.0000
MTB	85	1.0609	0.8816	0.1800	0.5500	0.8600	1.2700	5.5500
Size	80	24.1139	2.2316	19.1705	22.5073	23.9755	25.6064	28.1269
ROA (%)	80	0.9307	1.0249	-3.9920	0.4955	0.9360	1.4600	2.8800
Inflation (%)	85	2.7045	1.2025	1.2238	1.8530	2.1632	3.0931	5.1110
GDP growth (%)	85	7.2302	2.6139	2.8382	6.2847	6.8445	8.3102	15.1252

This table presents the summary statistics for variables used in regression analyses. Panel A represents the announcement date (i.e., 18/10/2021). Panel B indicates the results date (i.e., 08/07/2022). The sample consists of 85 unique banks from 23 countries.

Table 3: Market reaction to the ECB climate stress test - Descriptive statistics of CAARs

Panel A: Event study analysis						
Date	18/10/2021		08/07/2022		Aggregated dates	
Event windows	CAARs	Z-stat	CAARs	Z-stat	CAARs	Z-stat
[-5, +5]	-0.0176	-2.3157**	-0.0674	-9.1187***	-0.0425	-7.5571***
[-3, +3]	-0.0218	-3.2453***	-0.0384	-6.4341***	-0.0301	-6.6688***
[-1, +1]	0.0021	0.5354	-0.0019	-1.2429	0.0001	-0.1061

Panel B: Differences in mean for CAARs in distinct dates				
Event windows	Obs	CAARs (18/10/2021)	CAARs (08/07/2022)	Difference
[-5, +5]	170	-0.0176	-0.0674	0.0498***
[-3, +3]	170	-0.0218	-0.0384	0.0166*
[-1, +1]	170	0.0021	-0.0019	0.0040

Panel C: CARs signs				
Date	18/10/2021		08/07/2022	
Event windows	<0	>0	<0	>0
[-5, +5]	57	28	72	13
[-3, +3]	59	26	68	17
[-1, +1]	41	44	51	34

Panel D: Variation in CARs signs across distinct dates				
CARs signs (1 st date, 2 nd date)	[-5, +5]	[-3, +3]	[-1, +1]	
(-, -)	51	53	25	
(-, +)	6	6	16	
(+, -)	21	15	26	
(+, +)	7	11	18	

Panel E: Comparative analysis of CAARs for physical risk exposure								
Date	18/10/2021				08/07/2022			
Physical risk	Low		High		Low		High	
Event windows	CAARs	Z-stat	CAARs	Z-stat	CAARs	Z-stat	CAARs	Z-stat
[-5, +5]	-0.0012	0.2360	-0.0343	-4.0535***	-0.0377	-5.4179***	-0.0977	-8.5023***
[-3, +3]	-0.0003	0.3110	-0.0439	-5.9836***	-0.0179	-2.7716***	-0.0594	-6.5357***
[-1, +1]	0.0094	1.9491*	-0.0055	-1.5410	0.0005	-0.1524	-0.0043	-1.6916*

Panel A reports the descriptive statistics of cumulated abnormal returns estimated over various event windows. Daily Abnormal Returns are obtained using the market model with a 252-day estimation period. The market portfolio is represented by the EUROSTOXX 600. CAARs in bold are those that remain statistically significant also with the adjustment suggested by Koları and Pynnönen (2010) in order to account for possible cross-sectional correlation of abnormal returns. ***, **, * denote that estimates are statistically significant at the 1, 5, and 10% levels. Panel B reports the sample distribution by CAARs (on rows) and differences in mean between two dates (on columns). Difference indicates the differential value between the first and second date. The null hypothesis is represented by equality between the two averages. Panel C of this table reports the sample distribution by CARs (on rows) and dates (on columns), respectively. The values are represented in absolute terms. Panel D reports the count of banks in terms of CARs variation across the two main dates (on rows) for different event windows (on columns), respectively. The values are represented in absolute terms. Panel E reports the descriptive statistics of cumulated abnormal returns estimated over various event windows by splitting into two groups according to physical risk exposure (i.e., above and below the median value). CAARs in bold are those that remain statistically significant also with the adjustment in order to account for possible cross-sectional correlation of abnormal returns.

Table 4: Determinants of CARs – Baseline results on the aggregate measure of physical risk along the event window [-3, +3]

Variables	<i>Announcement date</i>		<i>Results date</i>	
	(1) CAR [-3, +3]	(2) CAR [-3, +3]	(3) CAR [-3, +3]	(4) CAR [-3, +3]
Physical risk	-0.0653*** (0.0225)	-0.0534** (0.0255)	-0.0625*** (0.0233)	-0.0448* (0.0236)
MTB		0.0162 (0.0128)		0.0138 (0.0085)
Size		-0.0100 (0.0093)		-0.0127* (0.0076)
ROA (%)		0.0901 (0.0874)		0.0709 (0.0553)
Constant	0.0080 (0.0117)	0.0475 (0.0303)	-0.0098 (0.0096)	0.0116 (0.0166)
Number of banks	85	80	85	80
Observations	85	80	85	80
R-squared	0.1034	0.2276	0.0963	0.2557

This table illustrates empirical results from Eq. (1). The main interest variable consists of the aggregate measure of physical risk. All the variables and data sources are defined in Table 1. Columns 1 and 2 represent the announcement date (i.e., 18/10/2021). Columns 3 and 4 indicate the results date (i.e., 08/07/2022). Standard errors are based on the robust variance estimator. Physical risk is normalised between 0 and 1. Other independent variables are standardised and winsorised at the 1% level. ***, **, * denote that estimates are statistically significant at the 1, 5, and 10% levels.

Table 5: Determinants of CARs – Further evidences on the individual physical risks

Variables	<i>Announcement date</i>			<i>Results date</i>		
	(1) CAR [-3, +3]	(2) CAR [-3, +3]	(3) CAR [-3, +3]	(4) CAR [-3, +3]	(5) CAR [-3, +3]	(6) CAR [-3, +3]
Flood risk	-0.0027 (0.0067)			-0.0007 (0.0063)		
Landslide risk		-0.0168*** (0.0062)			-0.0152* (0.0078)	
Heat risk			-0.0151** (0.0075)			-0.0120* (0.0066)
MTB	0.0135 (0.0136)	0.0102 (0.0133)	0.0146 (0.0130)	0.0099 (0.0081)	0.0091 (0.0075)	0.0123 (0.0080)
Size	-0.0170* (0.0090)	-0.0148* (0.0081)	-0.0094 (0.0098)	-0.0175** (0.0076)	-0.0167** (0.0076)	-0.0122 (0.0082)
ROA (%)	0.0797 (0.0798)	0.0925 (0.0808)	0.1036 (0.0904)	0.0865 (0.0534)	0.0724 (0.0608)	0.0861 (0.0544)
Constant	0.0231 (0.0232)	0.0259 (0.0228)	0.0371 (0.0277)	-0.0017 (0.0139)	-0.0052 (0.0157)	0.0034 (0.0149)
Number of banks	80	80	80	80	80	80
Observations	80	80	80	80	80	80
R-squared	0.1751	0.2396	0.2162	0.2191	0.2719	0.2467

This table illustrates empirical results from Eq. (1). The main interest variables consist of the individual physical risks. All the variables and data sources are defined in Table 1. Columns 1, 2 and 3 represent the announcement date (i.e., 18/10/2021). Columns 4, 5 and 6 indicate the results date (i.e., 08/07/2022). Standard errors are based on the robust variance estimator. Independent variables are standardised and winsorised at the 1% level. ***, **, * denote that estimates are statistically significant at the 1, 5, and 10% levels.

Table 6: Mitigation role of commitment to responsible banking

Variables	<i>Announcement date</i>				<i>Results date</i>			
	(1) CAR [-3, +3]	(2) CAR [-3, +3]	(3) CAR [-3, +3]	(4) CAR [-3, +3]	(5) CAR [-3, +3]	(6) CAR [-3, +3]	(7) CAR [-3, +3]	(8) CAR [-3, +3]
Low PR without PRB	-0.0260 (0.0217)				-0.0243 (0.0165)			
High PR without PRB	-0.0549*** (0.0198)				-0.0358** (0.0147)			
High PR with PRB	-0.0348 (0.0216)				-0.0637*** (0.0205)			
Low FR without PRB		-0.0358 (0.0260)				-0.0220 (0.0237)		
High FR without PRB		-0.0364 (0.0236)				-0.0131 (0.0219)		
High FR with PRB		-0.0154 (0.0235)				-0.0281 (0.0252)		
Low LR without PRB			-0.0201 (0.0197)				-0.0129 (0.0178)	
High LR without PRB			-0.0442** (0.0207)				-0.0270 (0.0200)	
High LR with PRB			-0.0061 (0.0222)				-0.0343 (0.0233)	
Low HR without PRB				-0.0509** (0.0210)				-0.0185 (0.0172)
High HR without PRB				-0.0513*** (0.0184)				-0.0307* (0.0161)
High HR with PRB				-0.0382* (0.0215)				-0.0490** (0.0211)
MTB	0.0107 (0.0128)	0.0079 (0.0139)	0.0069 (0.0129)	0.0074 (0.0139)	0.0121 (0.0088)	0.0100 (0.0081)	0.0096 (0.0080)	0.0132 (0.0081)
Size	-0.0179 (0.0126)	-0.0263** (0.0129)	-0.0253** (0.0123)	-0.0239* (0.0137)	-0.0090 (0.0095)	-0.0177* (0.0092)	-0.0137 (0.0095)	-0.0110 (0.0097)
ROA (%)	0.0873 (0.0779)	0.1024 (0.0774)	0.1068 (0.0769)	0.1131 (0.0835)	0.0727 (0.0450)	0.0853* (0.0498)	0.0816 (0.0522)	0.0830* (0.0486)
Constant	0.0560* (0.0292)	0.0590* (0.0328)	0.0538* (0.0297)	0.0769*** (0.0286)	0.0223 (0.0174)	0.0150 (0.0238)	0.0149 (0.0211)	0.0230 (0.0192)
Number of banks	80	80	80	80	80	80	80	80
Observations	80	80	80	80	80	80	80	80
R-squared	0.2687	0.2127	0.2357	0.2415	0.3262	0.2450	0.2561	0.2805

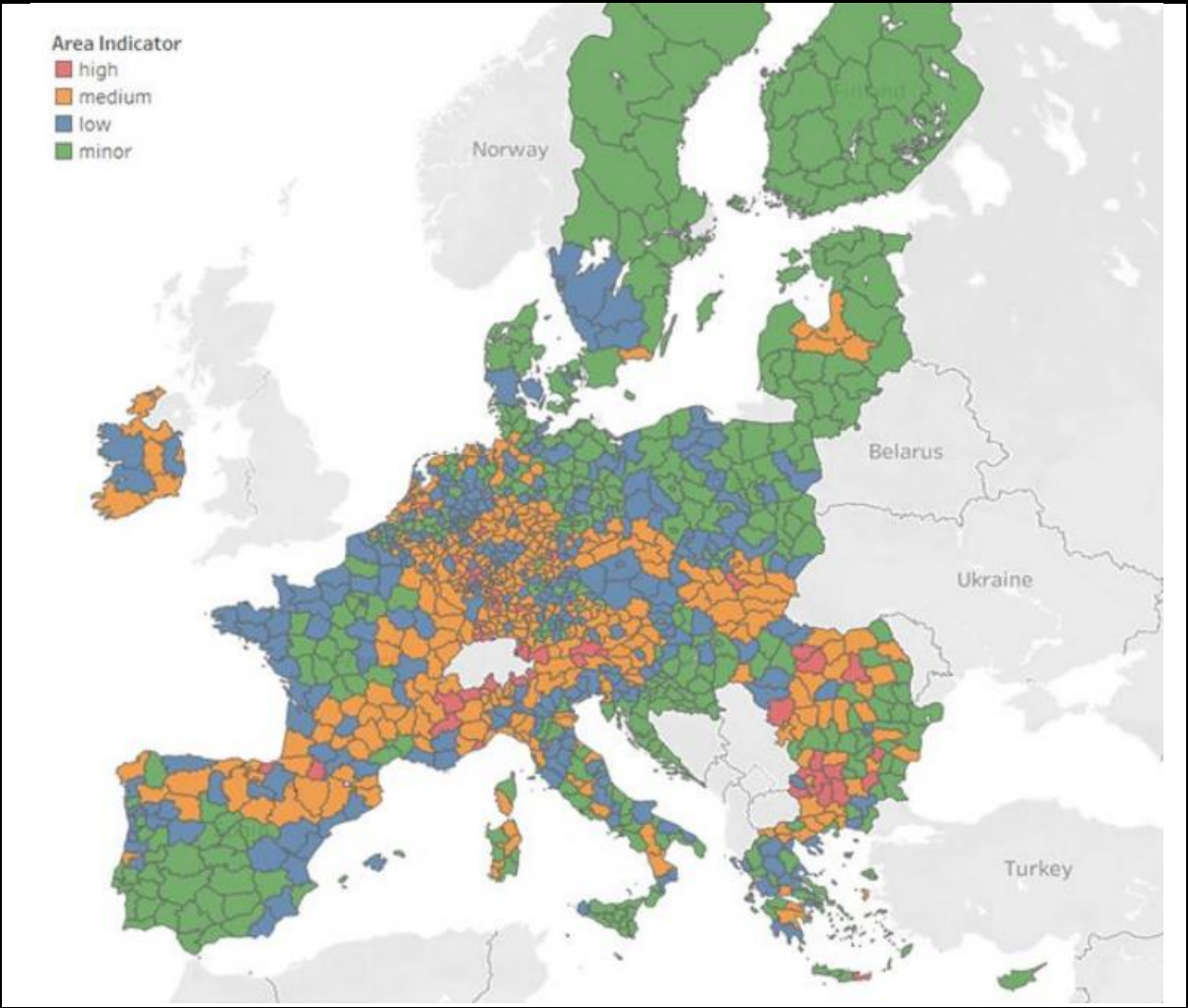
This table illustrates empirical results from Eq. (2). The types of physical risk considered are the aggregated physical risk (PR), flood risk (FR), landslide risk (LR), and heat risk (HR). PRB stands for signatory of the Principles for Responsible Banking. Columns 1, 2, 3, and 4 represent the announcement date (i.e., 18/10/2021). Columns 5, 6, 7, and 8 indicate the results date (i.e., 08/07/2022). Standard errors are based on the robust variance estimator. Independent variables are standardised and winsorised at the 1% level. ***, **, * denote that estimates are statistically significant at the 1, 5, and 10% levels.

Table 7: Anticipation effect from ECB guide on climate-related and environmental risks

Variables	(1) CAR [-3, +3]	(2) CAR [-3, +3]	(3) CAR [-3, +3]	(4) CAR [-3, +3]
Physical risk	-0.0743* (0.0392)			
Flood risk		-0.0142 (0.0093)		
Landslide risk			-0.0208* (0.0116)	
Heat risk				-0.0228** (0.0113)
MTB	-0.0139 (0.0139)	-0.0187 (0.0126)	-0.0183 (0.0121)	-0.0172 (0.0125)
Size	0.0112 (0.0093)	0.0077 (0.0097)	0.0052 (0.0096)	0.0121 (0.0090)
ROA (%)	-0.0402 (0.0675)	-0.0206 (0.0702)	-0.0520 (0.0708)	-0.0073 (0.0574)
Constant	0.0422** (0.0175)	0.0202 (0.0137)	0.0083 (0.0141)	0.0338** (0.0130)
Number of banks	74	74	74	74
Observations	74	74	74	74
R-squared	0.1275	0.0837	0.1125	0.1237

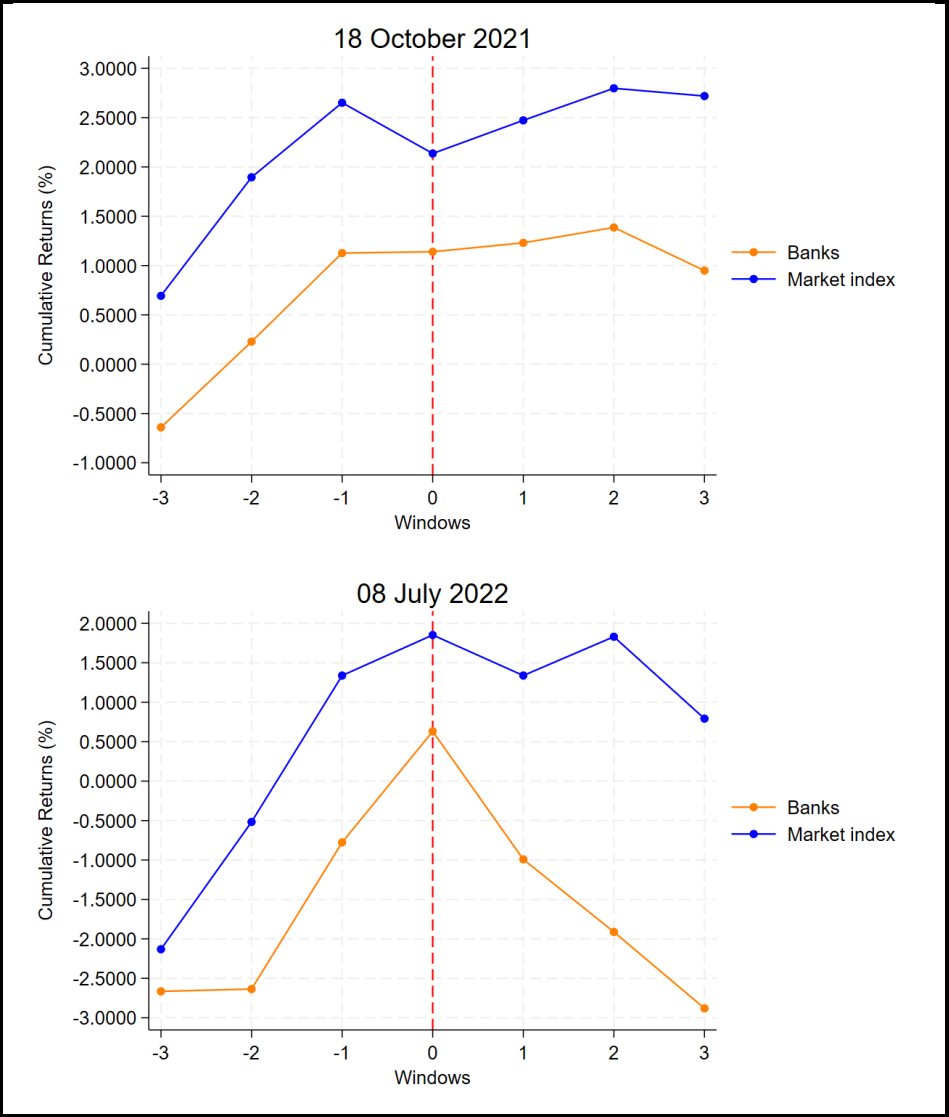
This table illustrates empirical results from Eq. (1). All the variables and data sources are defined in Table 1. All the columns show the empirical results only considering the date when ECB published guide on climate-related and environmental risks (i.e., 27/11/2020). Standard errors are based on the robust variance estimator. Physical risk is normalised between 0 and 1. Other independent variables are standardised and winsorised at the 1% level. ***, **, * denote that estimates are statistically significant at the 1, 5, and 10% levels.

Figure 1: Flood risk map



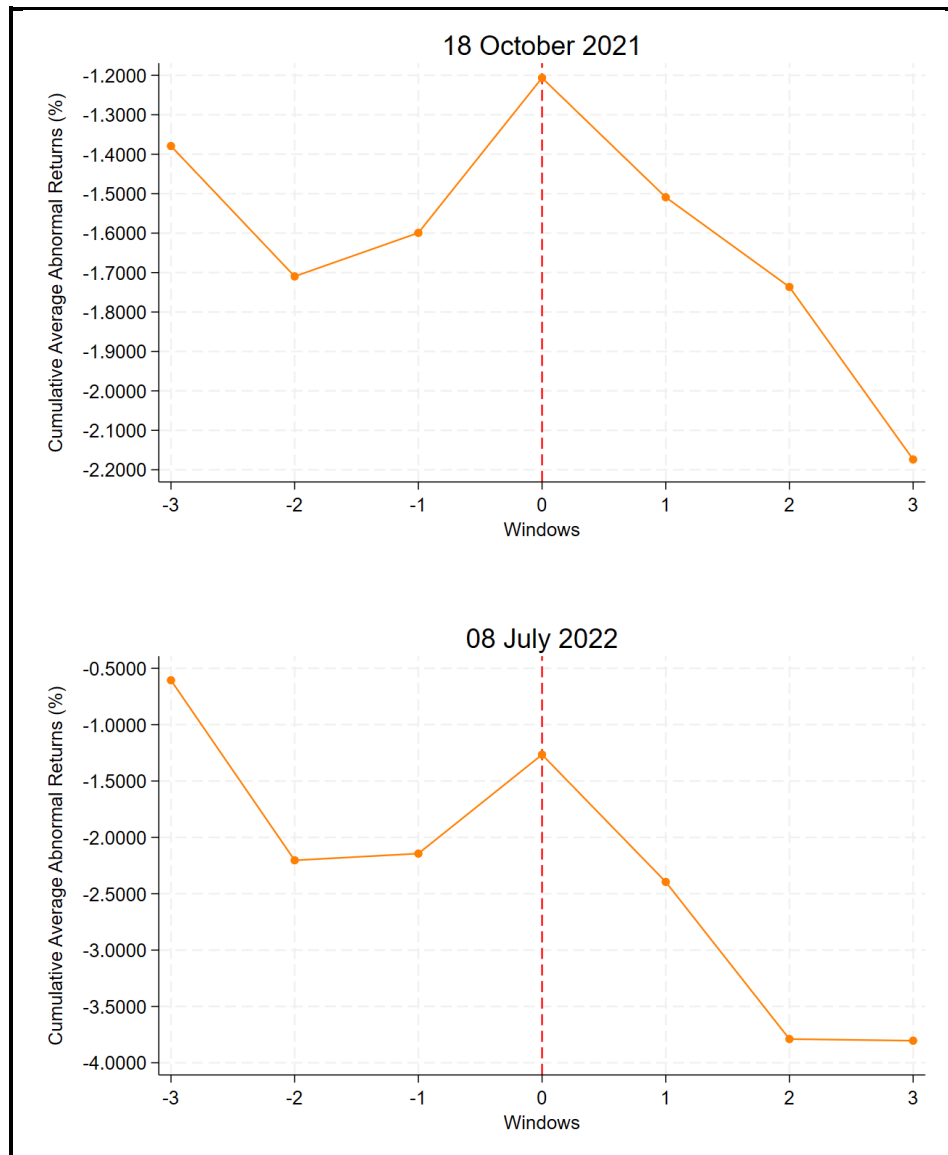
Source: ECB. Available at the following link:
https://www.bankingsupervision.europa.eu/ecb/pub/pdf/ssm.climate_stress_test_report.20220708~2e3cc0999f.en.pdf.

Figure 2: Returns around the key dates of the 2022 ECB climate stress test



This figure shows the cumulative average raw returns for banks and the cumulative raw returns for reference index from three trading days before to three trading days after each date.

Figure 3: CARs around the key dates of the 2022 ECB climate stress test



This figure shows the cumulative abnormal returns (CARs) for banks from three trading days before to three trading days after each date.

Additional tables

Table A.1: Country distribution

Country	Number of banks
Austria	3
Bulgaria	2
Croatia	3
Cyprus	1
Czech Republic	2
Denmark	16
Estonia	1
Finland	3
France	3
Germany	4
Greece	2
Hungary	1
Ireland	3
Italy	14
Lithuania	1
Malta	2
Netherlands	1
Poland	9
Portugal	1
Romania	3
Slovenia	1
Spain	5
Sweden	4
Total	85

This table reports the sample distribution by country (on rows) and count of unique banks (on column), respectively.

Table A.2: Determinants of CARs – Robustness checks on the aggregate measure of physical risk along the event window [-5, +5]

Variables	<i>Announcement date</i>		<i>Results date</i>	
	(1) CAR [-5, +5]	(2) CAR [-5, +5]	(3) CAR [-5, +5]	(4) CAR [-5, +5]
Physical risk	-0.0482** (0.0238)	-0.0429 (0.0286)	-0.1008*** (0.0284)	-0.0681** (0.0296)
MTB		0.0237 (0.0144)		0.0039 (0.0111)
Size		-0.0114 (0.0103)		-0.0239*** (0.0086)
ROA (%)		0.0484 (0.1006)		0.1174* (0.0606)
Constant	0.0045 (0.0125)	0.0346 (0.0354)	-0.0212* (0.0118)	0.0098 (0.0167)
Number of banks	85	80	85	80
Observations	85	80	85	80
R-squared	0.0427	0.1430	0.1403	0.3489

This table illustrates empirical results from Eq. (1). All the variables and data sources are defined in Table 1. Columns 1 and 2 represent the announcement date (i.e., 18/10/2021). Columns 3 and 4 indicate the results date (i.e., 08/07/2022). Standard errors are based on the robust variance estimator. Physical risk is normalised between 0 and 1. Other independent variables are standardised and winsorised at the 1% level. ***, **, * denote that estimates are statistically significant at the 1, 5, and 10% levels.

Table A.3: Additional control for macro-economic variables

Variables	<i>Announcement</i>	<i>Results</i>
	<i>date</i>	<i>date</i>
	(1)	(2)
	CAR [-3, +3]	CAR [-3, +3]
Physical risk	-0.0213 (0.0264)	-0.0500** (0.0234)
MTB	0.0111 (0.0124)	0.0166* (0.0085)
Size	-0.0074 (0.0087)	-0.0133* (0.0071)
ROA (%)	0.1420* (0.0831)	0.0670 (0.0554)
Inflation (%)	-0.0188*** (0.0070)	-0.0182*** (0.0068)
GDP growth (%)	0.0259* (0.0153)	-0.0238** (0.0113)
Constant	-0.0074 (0.0087)	-0.0133* (0.0071)
Number of banks	80	80
Observations	80	80
R-squared	0.2986	0.3262

This table illustrates empirical results from Eq. (1). All the variables and data sources are defined in Table 1. Column 1 represents the announcement date (i.e., 18/10/2021). Column 2 indicates the results date (i.e., 08/07/2022). Standard errors are based on the robust variance estimator. Physical risk is normalised between 0 and 1. Other independent variables are standardised and winsorised at the 1% level. ***, **, * denote that estimates are statistically significant at the 1, 5, and 10% levels.