Climate Risk and Bank Capital Structure

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Abstract

We study the role of climate risk exposure in the dynamic behavior of banks' regulatory capital adjustment using a large European sample from 39 countries during the 2006–2021 period. We find that banks facing high exposure to climate risk opt for higher target (regulatory) capital adequacy ratio and make faster adjustment to their optimal capital structure, especially if they are more exposed to carbon pollution. Such banks boost their adjustment during the post Paris Agreement period. These banks move to their target capital adequacy ratio by mainly adjusting their risk-weighted assets or by reallocating them more promptly than other peers, but without necessarily altering assets, particularly, lending. This paper lends support to the importance of the climate change-related risks into prudential supervision to protect the financial system's resilience and contributes to the debate on climate-related capital requirements.

JEL codes: G21, G28, Q53, Q54.

Keywords: Dynamic capital structure, Speed of adjustment, Climate change, Paris Agreement, Balance sheet composition.

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1.Introduction

In this paper, we examine how does climate change affect bank capital structure by investigating the extent to which climate change-related risks are constraining the speed of convergence to optimal capital structure and the mechanisms for capital adequacy adjustments across a large panel of banks and countries. The ratification of the Paris Agreement on climate (COP21) in 2015 had triggered the commitment of 98% of global carbon emitter economies to taking action to limit abnormal warming to below 1.5°C.[1] Immediately after that, in 2017, the G20 Financial Stability Board (FSB) released the Task Force on Climate-related Financial Disclosures (TCFD) aimed to provide institutions with recommendations for the disclosure of climate-related financial risks (TCFD, 2017). Like other firms, many banks become aware of the financial risks tied to climate change and the prospect of regulatory interventions on climate policy and disclosure requirements.[2] Additionally, consistent with the trend that climate change is high on the policy-makers agenda, banking regulators have started designing new climate risk buffer requirements and climate risk weight policies in response to unaddressed systemic climate risk to the banking industry (see ECB, 2022a, 2022b; ECB, 2020) and requiring specific procedures for promoting sustainable lending practices (see EBA, 2020; BCBS, 2020). Most notably, Mark Carney (2015), the head of the Bank of England, Campiglio et al. (2018) and Giglio et. (2021) linked such climate change-related risks to financial stability.

As any environmental threat, climate change-related risk refers to sources of uncertainty surrounding external environment and the transition to a low carbon economy (Batten et al., 2016; Roncoroni et al., 2021; Barnett et al., 2020). According to NGFS (2020), the global financial sector faces two types of climate risks: (i) *physical risk* (e.g., abnormal temperature, among others), and (ii) green *transition risk* (i.e., carbon-dioxide emissions, transition to a low-carbon economy). Much of the difficulties in managing climate risks are attributed to the uncertain and endogenous future policy shocks that eventually determine the transition path to a low-carbon economy (Campiglio et al., 2018; Carbone et al., 2021; Degryse et al., 2023) as well as the regulatory costs and uncertainty about future regulations (Krueger et al., 2020; Karpoff et al., 2005).

There is mounting body of empirical research showing the adverse impact of climate change on the financial system (e.g., Fard et al., 2020; Roncoroni et al., 2021; Degryse et al., 2023) and providing support for the environmentally sensitive banks' lending decisions via the pricing of climate risk into their loans (Delis et. 2020; Reghezza et al., 2021). Other work have studied the relationship between climate finance, regulation, financial stability and

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[1] The Paris Agreement is a legally binding international treaty on climate change. It was adopted by 196 parties, including the European Union, representing over 98% of global greenhouse gas emissions, at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015. It aims to keep global warming at 1.5°C - 2°C, in accordance with the recommendations of the Intergovernmental Panel on Climate Change.

[2] More than hundred global financial institutions have announced that they will no longer allocate funding to coal-related activities or coal power companies. See: http://ieefa.org/wp-content/uploads/2019/02/IEEFA-Report_100-and-counting_Coal-Exit_Feb-2019.pdf

credit risk (see e.g., Campiglio et al., 2018; Giglio et al., 2021) and pointed out that exposure to climate risk leads to reduce bank loans to firms with the greatest risk, debts and leverage (Ginglinger and Moreau 2022), adversely affects bank performance (Dafermos and Nikolaidi, 2021), cost of bank loans (Javadi and Masum, 2021), market efficiency (Hong et al., 2019), corporate earnings (Addoum et al., 2020), corporate cost of capital (Chava, 2014), and increases probability of default and credit risks (Aiello and Angelico, 2022) and regulatory-related costs and uncertainty about future regulations (Krueger et al., 2020). While the environmental, social, and governance (ESG) performance may act as climate risk hedge (Engle et al., 2020) and provides essential information to efficiently price and manage climate risk.

However, despite the recently growing attention on the financial impacts of climate change, the existing literature addressing the role of climate risk on capital decisions are relatively recent but burgeoning. Previous studies suggest that firms with greater exposure to environmental risks confront lager costs of capital (Sharfman and Fernando, 2008; Chava, 2014) and cost of equity (Delis et al., 2020). Ginglinger and Moreau (2022) examine the impact of climate risk on corporate capital structure and find that physical climate risk lowers the firms' leverage. A close result is given by Nguyen and Phan (2020), who find that firms located in areas more vulnerable to carbon risk bear higher financial distress, which leads them to decrease their financial leverage. Nonetheless, whether and how climate risk affects bank capital management and adjustments remain under-researched.

To contribute to the debate, we exploit the main climate change-related risks faced by banks as well as a major climate regulatory change (i.e., COP21), to explore how climate risk relate to the regulatory capital structure of European banks, and investigate how such climate risk affects the speed and adjustment choices with which banks converge to their optimal capital ratios.

In this paper, we focus on two distinguishing aspects of climate risk, which are abnormal hot temperatures (Choi et al., 2020; Addoum et al., 2020) and carbon emission intensity (Nguyen and Phan, 2020; Zhu and Zhao, 2022). We also construct a composite climate risk index based on the quintiles of these indicators. In our analysis, we examine the effect of climate risk on the speed of adjustment for capital adequacy ratio (i.e., total regulatory capital over risk-weighted assets) of an exhaustive sample of 4,606 banks located in 39 European states selected for the 2006–2021 period. For our initial step, we follow the literature and estimate a partial adjustment model of bank capital towards an optimal capital ratio in a dynamic panel setting (see e.g., Öztekin and Flannery, 2012; Lepetit et al., 2015; Gilani et al., 2021). The partial adjustment model assumes that banks do have a target (or optimal) capital ratio, but that there might be frictions (such as adjustment costs) that prevent them from instantaneously adjusting towards the target (De Jonghe and Öztekin, 2015; Bakkar et al., 2019). This first part is essential to estimate a bank-specific and time-varying target capital ratio and to quantify the distance of banks from their target. Subsequently, we implement an empirical setting based on the drivers of the adjustment process. The relation between climate risk and capital structure is unclear ex ante. On the one hand, one could expect a higher adjustment for the capital adequacy ratio because of the regulatory focus of this measure and also given that higher exposure climate risk can enhance banks' governance, decreasing its agency costs and thereby reducing its adjustment costs (Nguyen and Phan, 2020; Krueger et al., 2020). On the other hand, the opposite could also be found as climate risk reduces market efficiency (Hong et al., 2019) and leads to a larger increase in regulatory costs and uncertainty (Çolak et al., 2017; Ginglinger and Moreau, 2022).

Our results provide strong evidence that European banks highly exposed to climate risk (abnormal hot temperature and/or carbon pollution) make faster capital structure adjustments, in particular, during the post-COP21 period. More specifically, a one standard deviation increase in the composite climate risk-index leads to an increase the average speed of adjustment of 19% which corresponds to a higher half-life, i.e. less time required for banks to halve the gap between their actual capital adequacy ratio and their target. These findings are consistent with the view that banks with the rising awareness about climate change concerns and environmental threats are more likely to take proactive actions to reach their regulatory capital target and achieve a capital management that aligns to the climate uncertainty and regulatory objective of enhancing stability.

In the second part, we attempt to identify how climate risk influences the capital choices. That is, the adjustments that banks rely on to close their regulatory gap between the target and the actual capital adequacy ratio. The dynamic adjustment depends on the trade-off between the adjustment costs, the costs of operating with suboptimal capital and the extent of information asymmetry (Öztekin and Flannery, 2012; Flannery and Rangan, 2006). Our analyses reveal that banks exposed to climate risk adjust their regulatory capital downward by expanding more risk-weighted assets. Asymmetrically, such banks do not issue equity to adjust upward. Instead, they are more prone to rely on shrinking their expansion (downsizing) and reshuffling risky assets, particularly cutting lending. These results are consistent with Reghezza et al. (2021), who argue that climate risks interact with the organizational decisions and policies of banks, notably capital decisions. Overall, our findings highlight the importance of "bridging" climate risk to the capital adjustment decisions of banks. From a policy perspective, our results based on the capital adequacy ratio might be helpful in understanding and fine-tuning the new climate risk capital requirements.

Our contribution is threefold. First, the study adds to the recent banking literature on how environmental-based threats affect bank capital decisions and responds to the call for better understanding of the climate risk implication for banking industry. We relax the homogeneity assumption in the speed of adjustment and provide novel evidence on (i) the role of exposure to climate risk on bank capital management, (ii) whether the speed of adjustment and the adjustment process differ across banks before and after the COP21, and (iii) how climate risk affect the financing choices to upward and downward adjustments to capital adequacy ratio. Our analyses shed light on the ongoing debate of whether and how firms and banks manage their capital structure under climate change uncertainty. Second, unlike previous studies on climate risk that focus on one specific aspects of climate risk (Nguyen and Phan, 2020; Fard, et al., 2020; Choi et al., 2020; Degryse et al., 2023), this research relates to the literature on physical, transition and regulatory climate risks and their impacts on capital decisions. We add to this strand of literature by providing novel evidence on the role of climate risk exposure (as measured by abnormal hot temperatures, carbon emission intensity and aggregated climate risk–index) and reveal plausible differences in banks' capital structure dynamics. In addition to the different outcomes investigated, however, we employ a significantly larger sample of European banks and a longer time period that is not confined to the COP21 period. Third, our study contributes to the ongoing debate on types of banking regulations on climate-related capital requirements and financial disclosures (see e.g., Campiglio et al., 2018; NGFS, 2020; Ilhan et al., 2021). Our work addresses the concerns raised by the European Central Bank that banks might not anticipate the effects of climate change, and that this could endanger financial stability (Reghezza et al, 2021; ECB, 2020, 2022a, 2022b) and opens future research on how banking industry may contribute to the transition to low-carbon economy and green financial system (Dafermos and Nikolaidi, 2021; Degryse et al., 2023).

The remainder of the paper is organized as follows: Section 2 describes our data sources, defines the climate risk and capital variables and provides some statistics. Section 3 develops the methodology and layouts the econometric approach. Section 4 presents and discusses estimations results, provides policy implications and shows robustness checks. Section 5 concludes.

2. Data and summary statistics

2.1. Sample construction

Our paper conducts analyses on a sample of banks established in 39 European countries spanning over the 2001–2021 period. The sample period covers the pre-COP21 and the post-COP21. The post-COP21 corresponds to the subperiod ranging from 2016 to 2021, when European countries governments ratified the Paris Agreement and committed to take part of the legally binding international accords on climate change. We exclude firms (non-banks) operating in the financial industries from the sample since these firms may adopt fundamentally different capital structure choices in comparison with banks. We further restrict the sample to banks (i) having more than USD500 million, (ii) involved in lending by requiring the bank to have a ratio of loans to total assets above 10% and a ratio of customer deposits to total assets above 25%[3], and (iii) bank-year observation to have more than 70% of non-missing data for the main variables of interest. After eliminating the adverse effects of outlier bank-year observations and misreported data for the main variables (by winsorizing at their 1% lowest and highest percentile values), we end up with a final sample of 32,506 annual observations corresponding to 4,606 unique banks.[4]

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[3] Eikon defines as financial institutions that are mainly active in a combination of retail, wholesale, and private banking. The broad definition implies that some banks considered (especially investment banks) may exhibit very low loans to total assets ratios and deposits to total assets ratios. In Europe, small cooperative and mutual banks with total assets less than USD 500 million may have a different core business activity. Because our aim is to analyze banks' lending behavior, among others, we need to further restrict our sample (see Bakkar et al., 2020).

[4] Our sample includes banks that become inactive/delisted or are acquired/merged during the period under investigation to eliminate potential survivorship bias.

We retrieve bank-level accounting data and GICS industry classification from Thomson Reuters Eikon and bank-level market data from Bloomberg. Thomson Reuters Eikon reports balance sheet and income statement information for both listed and unlisted banks and covers over 90% of the total banking assets in a given country. Bloomberg provides high frequency market data for both active and delisted banks accounting for 98% of the global stock market capitalization. Starting from the matched accounting and market data, we collect climate-related indicators. We obtain state-level temperature information from the World Bank (Bank Climate Change Knowledge Portal) and carbon emissions data from Asset 4 (Refinitiv) and the Climate Watch Data. We collect macroeconomic data from World Development Indicators (World Bank) and World Economic Outlook (WEO).

To gauge the representativeness of the sample, Table 1 reports the distribution of the sample per country and per bank specialisation over 16 year study period. Our sample consists of 4,606 banks, 553 (12%) of which are listed. More than 47% are commercial banks, about 33% are cooperative banks and fewer than 20% are saving, investment and others (mostly mortgage) banks. In terms of total assets, our sample conveniently represents the European banking industry. On average, it covers about 91% of banks' total assets in the considered countries recorded in Thomson Reuters Eikon. Finally, large number of German and Italian bank observations do not heavily skew the sample, since our main measures of interest are not affected by the number of bank observations in each country-year. A similar observation was made by Psillaki and Daskalakis (2009) and Mc Namara et al. (2017) in terms of French and Italian observations.[5]

[Insert Table 1 about here]

2.2. Bank capital and climate-related risk

In this section, we turn to the climate-specific aspects of bank capital and discuss our key measures of climate risk. The aim is to identify the implications of climate risk on bank capital dynamics towards optimal regulatory capital.

Our variable of interest is the bank regulatory capital ratio known as a capital adequacy ratio (CAR). Imposed by the Basel Committee on Banking Supervision (BCBS), this ratio is defined as the sum of Tier 1 capital and Tier 2 capital, divided by total risk-weighted assets (RWA). For robustness checks, we use an alternative measure of bank regulatory capital. We consider Tier 1 capital ratio, defined by the BCBS as Tier 1 capital over total RWA. Under the Basel III accords, the CAR must be no lower than 8% and the Tier 1 RWA must equal at least 6%.

According to NGFS (2020), the global banking industry faces two types of climate change risk: (i) *physical risk,* which emerges from a changing climate (i.e., a long-term shift in the

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[5] In robust checks, we also checked that our results are robust to excluding those countries and filter out countries with fewer bank observations.

mean and variance of temperatures and magnitude of weather events) and (ii) *transition risk,* which stem from the transition to a low-carbon economy. According to this classification, we calculate climate risk measures.

First, we classify banks as either highly or low exposed to the abnormal hot temperature[6] by empirically exploiting the occurrence of an abnormally temperature in the close vicinity of the bank's location. Following the common approach in the literature (e.g., Addoum et al., 2020; Brown et al., 2021), we approximate the bank's location by the country where the bank is headquartered. Temperature measures the monthly average temperature that was observed every day between 7am and 7pm local time, expressed in degree Celsius (°C), in all the weather stations of the country.[7] Following the approach described by Choi et al. (2020), we decompose the local temperature-related data into three components that account for seasonal, predictable, and abnormal patterns. In particular, for each country j in month m, we calculate the monthly actual $\text{Temperature}_{j,m}$ by taking the average of daily average temperatures in our data. Then we define:

$$\text{Temperature}_{j,m} = \text{AvgTemp}_{j,m} + \text{MonTemp}_{j,m} + \text{AbTemp}_{j,m}, \tag{1}$$

where $\text{AvgTemp}_{j,m}$ is the average monthly local temperature for a given country j over the 120 months (10 years) prior to m, $\text{MonTemp}_{j,m}$ is the average deviation of this month's temperature from the average, i.e., the average temperature in country j in the same calendar month over the last 10 years minus $\text{AvgTemp}_{j,m}$, and $\text{AbTemp}_{j,m}$ is the remainder, which represents unusual abnormal deviations from this month actual temperature in country j. As abnormal temperatures require 10 years of data to calculate, we use the period from 1996 to 2021. Finally, we standardize these abnormal deviations, which is usually known as the standardized anomaly (see Kim et al., 2021). In our analyses, we focus on the average annual abnormal hot temperature denoted $\text{AbTemp}_{j,t}$ for each year t.

Second, we classify banks as either highly or low exposed to the carbon dioxide emission intensity. As many countries in Europe have no comprehensive and authoritative firm-level carbon emission data, our method quantifies carbon emission intensity as total carbon emissions scaled by country's economy size, to account for carbon-intensive economies (e.g., Jung et al., 2018; Nguyen and Phan, 2020; Javadi and Masum, 2021; Zhu and Zhao, 2022) as follows:

$$\text{CEI}_{j,t} = \frac{\text{KtCO2e}_{j,t}}{GDP_{j,t}} \tag{2}$$

where $KtCO2e_{j,t}$ is the total emission expressed in kilotons of carbon dioxide (CO_2) equivalent for a given country j in year t. They include carbon dioxide produced during

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[6] The terms "abnormal hot temperatures" and "abnormal temperatures" are used interchangeably. Following Choi et al., (2020), we use the term "abnormally hot" to refer to cases in which a country's temperature is significantly higher than the historical average temperature at the same point in the year.

[7] For each country, temperature data is collected from World Bank Group, Weather Data Portal: Climate Change Knowledge Portal (CCKP). The data requires that the weather stations need to have at least 10 years of historical data prior to 2006, the starting year of the study, to match it with financial data.

consumption of solid, liquid, and gas fuels and gas flaring. $GDP_{j,t}$ is the gross domestic product.

We also construct a composite climate risk–index that covers in an equally-weighted way these two abovementioned dimensions of climate risk. More specifically, for each of the two climate risk metrics, we divide the sample in quintiles and give a score of one to banks in the lowest quintile, two in the second quintile and so on, with five for the highest. Subsequently, we take the sum of the scores associated to each of these quintiles of the two climate risk aspects to obtain an index that ranges from two to ten, with the highest value representing the highest level of climate risk that an individual bank can be exposed to. This equally-weighted index of two risks provides a summary statistic of country's environmental threats as it combines two important measures of climate risk (i.e., AbTemp and CEI) in one metric.
Importantly, our data does not allow to control for country year fixed effects. Thus, the climate risk indicators, especially for CEI, might pick up country-year economic factors.

Table 2 provides summary statistics, definitions and sources of all the bank and country level variables used in the empirical analyses. The average capital adequacy ratio is 19.92%, and its twenty fifth percentile suggests that total regulatory capital ratio is well above the Pillar 1 minimum requirement for the majority of banks throughout the sample period. Besides, an average bank in the sample has log total assets value of 14.35, retail funding ratio of 81.98%, credit risk of 9.23%, liquidity ratio of 5.24%, tangibility ratio of 1.48%, cost income ratio of 68.87%, return on assets of 2.39%, and non-interest income share of 82.51%. These numbers are comparable to those in previous studies in the literature. Evidence from this table also suggests that the average bank-year exposure to abnormal hot temperature is 0.38°C, whereas the average exposure to carbon emission into the atmosphere (kilotons per unit value of GDP) into the atmosphere is 12.35. Table 3 reports the *pearson* correlation coefficients for the main variables employed in the analysis. The findings suggest positive and significant correlations between capital adequacy ratio and the two climate risk measures. The correlations between all the control variables do not suggest the presence of a high correlation (coefficients are below 50%) and therefore indicate no multicollinearity concerns.

[Insert Tables 2 and 3 about here]

Table 4 compares key financial characteristics for the subsamples of banks with high versus low exposure to climate risk. We adopt the two above-defined climate risk measures. Banks with high (with respect to less) exposure to climate risk (either abnormal temperatures or carbon emissions intensity) are relatively small sized and hold higher regulatory capital (higher capital adequacy ratio and regulatory Tier 1 capital). They are more reliant on retail market funding (higher proportions of customer deposit over total funding and total deposits over total assets) and are more profitable (high returns on assets). The table also shows that banks with higher exposure to environmental challenges are less likely lending-oriented (and thus less liquid) and have poorer loan quality (higher credit risk and proportion of nonperforming loans).

[Insert Table 4 about here]

We gauge the relationship between climate risk and bank regulatory capital in Figure 1. This figure provides information on the time series evolution of the capital adequacy ratio (CAR) and each of the climate risk measures, the abnormal hot temperature (AbTemp) and carbon emission intensity (CEI), between 2006 and 2021. To give equal weight to every single country, the variables are first averaged by country and then across countries on a yearly basis. The plotted lines correspond to the yearly averages of these cross-country averages. The values of the CAR are measured at the left-hand axis, while the values of the climate risk on the right-hand axis. The CAR has been drastically increasing since 2006, suggesting that banks are well capitalized and complying with the post global financial crisis (GFC) stringent capital regulations. As expected, the figure shows that the CAR exhibits an increasing pattern as a function of increasing climate risk. There is a close correspondence between the time series pattern of the CAR and the abnormal hot temperature (right-hand panel), which documents that capital and climate risk are positively correlated over time. The right-hand panel, which plots the CAR and the carbon emission intensity, confirms this finding.

[Insert Figure 1 about here]

3. Dynamic capital structure of banks: partial adjustment model

The paper tests whether and how climate risk causes cross-country differences in the speed and the way banks adjust their capital adequacy to the target levels, in response to capital shock. Our objective enforces two features on our methodology. First, we need to estimate our models for banking data that was generated prior to the implementation of the climate-related capital requirements. This is easily satisfied by using annual data on a large sample of European banks over the 2006–2021 period, as the European Central Bank is still examining climate risk buffers and related weight policies in response to climate-related risks.[8] Second, we must identify negative changes in bank regulatory capital that are plausibly exogenous within our dataset. This is problematic, notably in the absence of a natural experiment in which capital exogenously becomes deficient at some but not all banks (allowing a difference-in-differences test) or sudden and exogenous bank-specific reductions in capital that occur at different times (allowing an event study test). Our solution to this later issue constitutes the key part of our methodology and represents a potential contribution to the literature.

In this section, we discuss the econometric methodology. It involves three steps. Using adopted estimation techniques (see e.g., Gropp and Heider, 2011; De Jonghe and Öztekin, 2015; Nguyen and Phan, 2020; Gilani et al., 2021), we first calculate the bank's internal capital adequacy ratio target. We then estimate the effects of climate risk on the speed of adjustment of capital adequacy toward the desired target. Addressing this issue is paramount

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[8] For more insight, see: https://greencentralbanking.com/2021/10/22/ecb-climate-related-capital-requirements/

to investigate the way banks react to an exogenous capital shock depending on their exposure to environmental threats. Particularly, Nguyen and Phan (2020) and Ginglinger and Moreau (2022) show that climate risk is a source of heterogeneity that drive firm's capital structure and thus affects firm financial policies to adjust towards their desired target. Lastly, we assess the role of climate regulation and regulatory pressures in banks' adjustment speed.

3.1. Estimating the capital target and observing the regulatory capital deviations

We follow the empirical capital structure literature and model the target capital adequacy ratio using a partial adjustment model, in each year of the 2006–2021 data (see e.g., Gropp and Heider, 2011; De Jonghe and Öztekin, 2015; Lepetit et al., 2015; Gilani et al., 2021). We begin by assuming that each bank has a target capital ratio that can be expressed as a function of observable (lagged) characteristics, as written below:

$$CAR^{*}_{\mathrm{ij,t}} = \beta \mathrm{X}_{\mathrm{ij,t-1}} + \delta Y_{\mathrm{ij,t-1}} + \mathrm{u_i} + \mathrm{v_t}, \tag{3}$$

where $\mathrm{i, j, t}$ indicates bank i from country j in year t. $CAR^{*}_{\mathrm{ij,t}}$ is the target capital adequacy ratio defined as total capital divided by risk-weighted assets. $\mathrm{X}_{\mathrm{ij,t-1}}$ is a vector of bank-specific explanatory variables. We follow Gilani et al. (2021) and Bakkar et al. (2019) and includes: bank size (diversification benefits), funding (reliance on insured retail deposits), credit risk (trade-off theory), liquidity (exposures to counterparty risk), tangibility (collateral), efficiency (cost of external finance), profitability (pecking order theory), revenue mix (growth opportunities) and a dummy variable for listed banks. $\mathrm{Y}_{\mathrm{ij,t-1}}$ is a vector of the other controls: climate risk measures (AbTemp and CEI), a dummy variable for the period posterior to the Paris agreement (COP21), the natural logarithm of a country's surface, and growth rate of real GDP. Definitions of all variables and correlations among them are listed in Tables 2 and 3. Following De Jonghe and Öztekin (2015) and Bakkar et al. (2019), we account for two sources of unobserved heterogeneity: bank fixed effects ($\mathrm{u_i}$), which subsume country fixed effects, and year fixed effects ($\mathrm{v_t}$) for an unbiased estimation of targets.

In a frictionless world, banks would always maintain their capital ratio at its target level. However, if adjustment costs are significant, the bank's decision to adjust its capital structure depends on the trade-off between the adjustment costs and the costs of operating with suboptimal capital (see e.g., Flannery and Rangan, 2006). In practice, banks need time to adjust their capital and assets to move to the target ratio. Hence, to account for adjustment costs, we consider a partial adjustment framework (Eq.(4)) where the speed of adjustment λ is initially assumed to be the same across banks: $\lambda \in [0;1]$ is a scalar adjustment speed, with higher values indicating faster adjustment and less capital rigidity (Gropp and Heider, 2011; De Jonghe and Öztekin, 2015; Gilani et al., 2021). To capture the adjustment process, we assume that banks close a constant proportion λ of the gap between actual (observed) $CAR_{\mathrm{ij,t-1}}$ and desired (unobserved) $CAR^{*}_{\mathrm{ij,t}}$ each year as follows:

$$CAR_{\mathrm{ij,t}} - \mathrm{CAR}_{\mathrm{ij,t-1}} = \lambda\left(CAR^{*}_{\mathrm{ij,t}} - \lambda CAR_{\mathrm{ij,t-1}}\right) + \eta_{\mathrm{ij,t}}, \tag{4}$$

where λ is the speed of adjustment toward the target $CAR^{*}_{\mathrm{ij,t}}$ between $t-1$ and t and its complement $(1-\lambda)$ is the portion of capital that is inertial. The closer λ is to 0, the slower the bank capital adjustment process and the longer the time a bank takes to achieve its target after a shock to bank capital. $\eta_{ij,t}$ is a random shock. Substituting Eq. (3) into Eq. (4) and rearranging gives an estimable partial adjustment model:

$$(5) \qquad CAR_{ij,t} = (1-\lambda)CAR_{ij,t-1} + \lambda(\beta X_{ij,t-1} + \delta Y_{ij,t-1} + u_i + v_t) + \eta_{ij,t}.$$

We can recover $\hat{\lambda}$ directly from the estimated parameter $(\widehat{1-\lambda})$, after which we can then recover β by dividing the estimated parameter $\widehat{\lambda\beta}$ by $\hat{\lambda}$. We replace $\hat{\lambda}$ in Eq. (3) to compute a fitted value of the target capital adequacy ratio for each bank i at time period t $(\widehat{CAR}^{*}_{ij,t})$. Next, we use the difference between this target ratio and the actual ratio in year $t-1$ to compute capital adequacy ratio deviation, hereinafter called "regulatory gap": $RegGap_{ij,t-1}$, as follows:

$$(6) \qquad RegGap_{ij,t-1} = \widehat{CAR}^{*}_{ij,t} - CAR_{ij,t-1}.$$

To test how climate risk may affect banks adjustment processes, specifically whether bank rely on issuing new equity, or rather they are reluctant to issue new equity and therefore prefer to downsize (selling assets) by refraining loan policy and/or lowering risk-weighted assets (substituting riskier assets for safer ones), we detangle the cases in which banks are below the target (U*ndercapitalized,* $RegGap^{+}_{ij,t-1}$) and above the target (*Overcapitalized,* $RegGap^{-}_{ij,t-1}$):

$$(7) \qquad \begin{aligned} RegGap^{+}_{ij,t-1} &= 1 \text{ if } \widehat{CAR}^{*}_{ij,t} > CAR_{ij,t-1} \text{ and } zero\ otherwise, \\ RegGap^{-}_{ij,t-1} &= 1 \text{ if } \widehat{CAR}^{*}_{ij,t} < CAR_{ij,t-1} \text{ and } zero\ otherwise. \end{aligned}$$

We estimate Eq. (5) using Blundell and Bond's (1998) generalized method of moments (GMM) estimator and allowing variation in the target due to bank and country characteristics as well as bank and year fixed effects. This estimator addresses endogeneity by combining the moment conditions from the first-difference and level equations. Bank-level variables are modelled as endogenous covariates and we choose a set of instruments that fulfils two conditions: exogeneity and explanatory power (see Wintoki et al., 2012). We check the validity of the GMM instruments using the Hansen test and the Arellano and Bond test.

3.2. Initial findings: climate risk and bank capital management

The estimation results of Eq. (5) are reported in Panel A of Table 5. Column (1) reports the estimated coefficients, while column (2) shows the coefficients for the target capital adequacy equation that we have obtained by dividing the coefficients in column (1) by the speed of adjustment (λ). We find that the estimated speed of adjustment is 0.48 for our European sample of banks over the 2006–2021 period, that is banks adjust their capital adequacy ratio at an approximately yearly rate of 48.3%. In economic terms, this speed of adjustment corresponds with half-live of 1.10 implying that adjustment to target capital adequacy ratio is partial, on average, banks require more than 13 months to halve the gap between the target and the actual capital adequacy ratio. The half-life is computed as log(0.5)/log(1– speed of adjustment). This conclusion lies in the range obtained for large banks (0.47, in the U.S. and 15 European countries, Gropp and Heider (2011)), systemically important banks (0.33, listed banks in 28 OECD countries, including 15 European economies, Bakkar et al. (2019)) and commercial banks (0.34, across 17 European countries, Lepetit et al. (2015)). At the bottom of Panel A, we report test statistics documenting the validity of the instruments. The Hansen J test (a test of exogeneity of all instruments as a group) cannot reject the null of joint validity of all GMM instruments (lagged values) and the Arellano and Bond AR(2) test confirms the absence of second-order residual autocorrelation.[9]

Panel B of Table 5 reports summary statistics for the estimated target capital adequacy ratio and the deviation from the target derived from our estimates in Eq. (6) and Eq. (7). The average target adequacy ratio is 20%, while the average deviation from the target is 0.6%.[10] In terms of economic impact, the finding implies that banks in Europe are concerned about readjusting quickly towards optimal capital adequacy. Two key arguments can be rationalized to explain this result. First, it could indicate that deviations from optimal capital adequacy ratios are more costly for bank shareholders, as the target capital has to be chosen such to maximize banks' return on capital to satisfy investors and comply with the regulatory capital constraints. Second, it could also be that developed capital markets in Europe are more conducive to easy access to equity markets and greater financial flexibility, which should decrease the transaction costs associated with external financing and lower banks' rebalancing costs, implying faster adjustment. Overall, banks might have more (and less costly) adjustment options that contribute to a faster bank recapitalization via more complex financing choices.

Furthermore, we find that high exposure to abnormally hot temperature (AbTemp) and carbon emissions (CEI) increases the target regulatory ratio. This suggests that climate risk is critical in shaping banks' preference on capital management. This finding is consistent with the existing related studies, based on a static framework, arguing that exposure to environmental risks affects the capital structure (Nguyen and Phan, 2020; Ginglinger and Moreau, 2022) and allows for more leverage (Chava, 2014; Sharfman and Fernando, 2008).

The results are not only statistically significant but also economically telling. An increase of one standard deviation in abnormal temperature (carbon emission intensity) produces an increase in the observed capital adequacy ratio of 99 (48) basis points, equal to about 9.93% (4.84%) of the sample mean. The impact on the target capital (see Column 2) is thereby significantly larger being equal to an increase of 205 (100) basis points equivalent to 20.56% (9.98%) of the mean target ratio. By and large, under stronger regulatory scrutiny, banks

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[9] The System GMM estimator yields higher levels of both consistency and efficiency than other estimators proposed by Arellano and Bond (1991).

[10] The average observed capital ratio of banks below (above) target capital is 19.0% (21.8%). The difference between the mean values of the two groups is statistically significant at the 5% level.

exposed to the climate-related hazards have active capital management; that is, they tend to increase their target capital adequacy ratio and accelerate their adjustment process.[11]

[Insert Table 5 about here]

We also estimate the partial adjustment model in Eq. (5) on a country-by-country basis. Using a uniform methodology for all European countries, we find that the estimated bank adjustment speeds vary substantially across countries. Fig. 2 depicts the heterogeneity in the speed of adjustment of bank adequacy capital across 39 European countries during the 2006–2021 period.[12]

Based on these estimations, the average adjustment speed across all the European countries is 43.9%, this complies with the pooled full sample estimate of 48.3%. The standard deviation of these country-specific estimates is 22%, with a minimum of 0.03% in Lichtenstein and a maximum of 80.10% in Lithuania. In addition, 75% of the country distribution ranges in the interval of 10–60% (25th and 75th percentiles, respectively). The UK, Germany and France have adjustment speeds of about 15%, Switzerland shows 24%, while Turkey exhibits 53%, which is slightly above the cross-country average. In Belgium and Hungary, the adjustment speeds exceed 55% and 74%, respectively. Such differences in the adjustment speeds are not entirely driven by a Western *vs*. Eastern (or Northern *vs*. Southern) country distinction. For example, a significant dispersion in the adjustment speed estimates occurs even among the Nordic countries (47% in Norway and 15% in Denmark), Western Europe (35% in the Netherlands and 8% in Ireland), Southern Europe (33% in Italy and 9% in Greece) and Eastern Europe (66% in Slovakia and 21% in the Czech Republic). The economic magnitude of this dispersion is quite considerable; on average, the half-life is approximately eighteen months. Overall, our European data confirm that the banks' adjustment speed to their target capital adequacy is partial and heterogeneous. Such stylized facts are by and large consistent with the bank-individual analyses.

It is important to note that previous works (e.g., Hovakimian and Li, 2011) have found that the estimation of Eq. (5) could lead to evidence in favor of adjusting toward the target with random financing. These works argue that tests based on the financing behaviour only (instead of capital changes) have the power to reject alternatives. Our empirical set-up and data would lend support to the importance of the partial adjustment of capital adequacy ratio if adjustment patters are manifested in bank balance sheets and adjustment speeds vary plausibly with environmental threats such as climate risk (see e.g., Chava, 2014; Nguyen and

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[11] We also report the coefficient estimates and the significance levels of bank-specific characteristics and macroeconomics drivers of the target capital adequacy ratio. Our findings present similar evidence as in the existing literature (Gropp and Heider, 2011; Bakkar et al., 2019). Succinctly, the bank target capital adequacy increases with bank risk (De Jonghe and Öztekin, 2015; Berger et al., 2008), whereas it decreases with the bank size (Berger et al., 2008), retail funding (Bakkar et al., 2019), asset liquidity (Berger et al., 2008; Lepetit et al., 2015), efficiency (De Jonghe and Öztekin, 2015), ROA (Berger et al., 2008) and revenue diversification (Gilani et al., 2021). Besides, banks show larger target capital adequacy ratio during the period post-COP21, in small countries and during good economic conditions (De Jonghe and Öztekin, 2015; Gilani et al., 2021).

[12] We follow a similar methodology as in Öztekin and Flannery (2012) and De Jonghe and Öztekin (2015) who compare firms' and banks' capital structure adjustments across countries in a uniform setting.

Phan, 2020; Ginglinger and Moreau, 2022). These will be examined in the following sections.

[Insert Figure 2 about here]

3.3. Adjustment mechanisms

We now turn to an analysis of various balance sheet patters through which banks alter their regulatory capital to achieve their long-term desired level when examining banks' exposure to climate risk. Specifically, these actions necessitate either capital adjustment (equity issues or repurchases) or assets adjustment (expanding or shrinking assets, particularly loans and risk-weighted assets). We follow the approach of Lepetit et al. (2015), De Jonghe and Öztekin (2015) and Gilani et al. (2021) and examine how banks adjust their capital structure to close their regulatory deviation (RegGap) from the desired target. We then evaluate the percentage growth rates in various balance sheet components for three quintiles of the gap (first, middle and fifth). To do this, we first allocate banks to quintiles based on their gap at the end of year. Subsequently, we compute the yearly change in the relevant variable in the following year. We then average these growth rates across all bank-year observations in that quintile.

How exposure to climate risk affect banks' balance sheet adjustments? To address this question, we draw generalizations about banks with high *vs*. low exposure to climate risk and explore the extent to which they differ in terms of capital management. These results are presented in Table 6. Our focus here is mainly on the risk-shifting, asset sales and equity adjustments, and thus for brevity, we only documents information for these variables.

In Table 6, we split the sample in two blocks of banks based on their exposure to climate risks: abnormal hot temperature (Panel A) and carbon emission intensity (Panel B). We use the median values to cutoff the two blocks (the values are 0.39 for the former measure and 12.84 for the later measure). For each block, we look at the average growth rates of the main balance sheet items (scaled by total assets) allocated to the first quintile, the third quintile and the fifth quintile based on their $RegGap_{ij,t-1}$.[13] The first quintile (Q1) represents the most overcapitalized banks with a negative regulatory gap, which should reduce their adequacy capital ratio to arrive at their target. The third quintile (Q3) represents banks with a negligible regulatory gap. The fifth quintile (Q5) represents the most undercapitalized banks with a positive regulatory gap that need to increase their adequacy capital ratio to reach their target. We then report the p-values of difference in means tests using the middle quintile (banks close to their target) as the benchmark.

First, we investigate adjustments made by overcapitalized banks (Q1) highly exposed to abnormal hot temperature (Panel A of Table 6). The growth rate of their capital adequacy ratio is significantly negative compared with the change rate of the third quintile (−2.13% *vs*.

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[13] On average, the difference between an overcapitalized (undercapitalized) bank's regulatory capital and its target, defined as $RegGap_{ij,t-1} = \widehat{CAR}^{*}_{\mathrm{ij,t}} - CAR_{\mathrm{ij,t-1}}$is −2.65% (2.58%) as reported in Panel B of Table 5.

0.21%). Facing high opportunity costs, banks have no incentives to remain above their desired target. Accordingly, bank managers actively decrease their regulatory capital to converge to their desired target and thus reduce the ongoing costs of capital surplus. How does this negative capital growth occur? The results indicate that when banks are overcapitalized, they expand significantly and roughly similar their loan growth (6.87%) and total asset growth (6.34%), but considerably at a larger (economic) extent their RWA (10.94%). In the same line, such banks significantly slow down their external funding (Tier 1 capital) growth (2.79%). Our results suggest that such banks tend to reduce their regulatory capital (lever up) by engaging more in risky activities, pursuing aggressive loan strategy and engaging significant reduction in the regulatory capital level.

Second, we investigate the adjustments made by undercapitalized banks (Q5) highly exposed to abnormal hot temperature. The results show that the capital adequacy ratio of these banks is significantly larger and positive than the third quintile (2.7% *vs*. 0.21%), implying that managers of these banks make also proactive actions to reach to their desired target. In this case, facing regulatory constraints and market pressures, such banks are more inclined to increase their regulatory capital ratio in order to bridge the regulatory gap and coverage to their desired target. But how does this recapitalization result? Analyzing the mechanisms through which those banks recapitalise, results show that the loan growth is significantly lower (1.11%) as well as the asset growth (2.36%), whereas the average RWA expansion is significantly negative (−5.67%) than the growth rate of the benchmark. We do find that the regulatory capital (Tier 1 capital) growth is significantly higher (7.13%) than the growth rate of the benchmark. Overall, we observe a mix of asset liquidation and recapitalization. Though, most of the increase in the regulatory capital ratio is realized by downsizing the bank (especially selling risky assets and reducing lending) rather than recapitalizing. This translates into a rationalized capital adjustment for these banks to reach their target and thus may be more cost-efficient as injecting external equity is more costly due to the financial frictions and governance problems. With respect to the second blocks of banks, i.e., banks less exposed to abnormal hot temperature, the patterns on asset and equity growth mimic the results discussed above for the first block of banks.

Now, we explore the extent to which these two blocks of banks differ in terms of capital management. For brevity, in each block, we focus on the extreme quintiles of the regulatory gap (i.e., quintile 1 *vs*. quintile 5). The results are reported in the rightmost columns in Table 6. Banks highly (*vs*. less) exposed to abnormal hot temperature exhibit higher capital ratio growth (in absolute value), regardless of whether they are over- or undercapitalized. The main disparity between these two blocks of banks is the pronounced difference in risk-weighted assets (10.94% when overcapitalized and –5.76% when undercapitalized for banks highly exposed to abnormal temperature *vs*. 8.31% when overcapitalized and –4.02% when undercapitalized for banks less exposed to abnormal temperature). Subsequently, overcapitalized banks highly (*vs*. less) exposed to abnormal temperature do not prefer to alter the Tier 1 capital to make the adjustment, the growth rate differential between Q1 and Q5 is about 4% (*vs*. 6%). Whereas undercapitalized banks highly (*vs*. less) exposed to abnormal temperature seem to rely more on downsizing (selling assets), the growth rate of total assets differential between the two quintiles is about 6% (*vs*. 5%). The assets' growth rates across the two blocks of banks are negligible when they are over- and undercapitalized.

In Panel B of Table 6, we expose the results and capital management patterns by splitting the sample in two groups of banks based on carbon emission intensity. For brevity, we only focus on the discrepancies in the capital structure adjustment patterns for banks highly (*vs*. less) exposed to carbon pollution and discuss the first and the fifth quintiles of the regulatory gap as reported in the rightmost columns. Consistent with the above reported results, for the banks highly exposed to carbon emission, the growth rates of the capital adequacy ratio are higher (in absolute value) compared to the less exposed ones, both for the over- and undercapitalized. Similarly, we find that this mainly due to the reallocation of the RWA (10.51% when overcapitalized and –9.28% when undercapitalized for banks highly exposed to carbon emission *vs*. 8.77% when overcapitalized and –2. 02% when undercapitalized for banks less exposed to carbon emission). An important caveat, in comparison of Panel A, is that banks highly exposed to carbon emission may differ sharply from the other peers less exposed to carbon emission in terms of the other mechanisms for making capital adjustments. Thus, overcapitalized banks highly (*vs*. low) exposed to carbon exhibit lower total assets growth (4.92% *vs*. 7.27%) and net loan growth (4.82% *vs*. 8.57%), whereas when they are undercapitalized, banks highly (*vs*. low) exposed to carbon seem to considerably rely on cutting their assets and especially their lending, i.e., total assets growth (–0.63% *vs*. 2.98%) and net loan growth (–1.81% *vs*. 2.93%). Furthermore, when overcapitalized the slower expansion of real assets in banks highly (*vs*. less) exposed is likely driven by moderate growth of the Tier 1 capital of 2.77% (*vs*. 1.29%), whereas when undercapitalized, the (forced) sale of real assets in banks highly (*vs.*) exposed to carbon emission is likely driven by their lower external financing capacity: the growth rate of Tier 1 regulatory capital is only 5.43% (*vs*. 9.73%).

Furthermore, natural questions that arises are (i) whether the Paris Agreement (COP21) is a watershed moment that would invoke a change in banks' balance sheet behavior and (ii) whether countries with existing resolutions or strong environmental stringency would distort their capital management. For that purpose, we examine capital structure adjustment patterns for banks before and after the Paris agreement and report the results in the Panel C of Table 6. In this panel, we split the sample into a sample before and after the COP21. The patterns on capital and asset growth mirror our results documented in Panels A and B. Important to note is that, after the Paris Agreement, capital adequacy rate growths of over- and undercapitalized banks (–2.11% for Q1 and 2.75% for Q5, respectively) are significantly larger (about 1.5 times) than the growths during the post Paris Agreement (–1.55% for Q1 and 1.86% for Q5, respectively). These results also indicate that after the ratification of the Paris Agreement, bank managers actively rebalance their risk-weighted asset items to a larger significant extent (14.75% for Q1 and –2.51% for Q5, respectively) to converge faster to their target compared with the change rates before the Paris Agreement. However, in the post–

Paris Agreement period, they use Tier 1 capital to a lesser extent (2.80% for Q1 and –7.02% for Q5, respectively) compared to the pre–Paris Agreement period.[14]

In sum, this analysis is informative and relevant for policymakers seeking to tackle climate risk. We find that the exposure to climate risk, or not, determines the mechanisms banks use to adjust upward and downward their capital adequacy ratio. On the one hand, we find that banks highly exposed to climate risk adjust their regulatory capital downward by expanding more risk-weighted assets (by substituting riskier assets for safer ones), but with some moderate extent of their asset expansion strategy and their loan policy, while new equity issuance continue to grow. On the other hand, asymmetrically, these banks do not issue equity to adjust upward. Instead, they are more prone to rely on shrinking sharply their expansion (downsizing via fire sales) and reshuffling risky assets (extensively reducing risk-weighted assets), particularly cutting lending. In addition, putting climate change on the agenda through the Paris Agreement has also fostered the speed of capital structure adjustment by reshuffling, particularly, their risk-weighted assets.

[Insert Table 6 about here]

4. Climate risk and bank capital dynamics

Previous theory and empirical works document that the country context and institutional environment affect banks' (or firms) financing policies and thus speed of adjustment by restricting the access to equity and debt markets and limiting the financial flexibility of their capital structure. See e.g., Bancel and Mittoo (2004), Frank and Goyal (2009), Cook and Tang T. (2010), Öztekin and Flannery (2012), De Jonghe and Öztekin, (2015), Dyck et al. (2019), among others. In addition, the speed of adjustment is the result of the trade-off between the benefits and costs of adjustment, and this varies substantially across banks deviating from the desired equilibrium capital (see e.g., Öztekin and Flannery, 2012; Lepetit et al., 2015). Therefore, if banks confront a set of costs and benefits when adjusting toward the desired capital level, their adjustment speed is endogenous. To the degree that country context and institutional features affect adjustment costs and benefits, variations in these factors should influence the capital adjustment. Against this background, we hence hypothesize that as costs and benefits of rebalancing the capital structure might be affected by banks' exposure to climate risk (see, Nguyen and Phan, 2020), so does the speed with which banks adjust regulatory capital to reach their targets.

This section involves three steps. We first describe the approach we take to estimate the effects of climate risk on the speed of adjustment of capital adequacy ratio. We then exploit the impact of climate risk on banks' capital structure and balance sheet adjustments. Lastly, we examine the role of climate regulation and financial regulatory pressures in banks'

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[14] It may be more cost-efficient for banks to improve their capital ratios through asset adjustment rather than capital injection if raising new capital is costly. However, shrinking their assets depends on the number of assets maturing in the current period or the capital losses that might result from selling off illiquid or non-maturing assets.

adjustment channels. Addressing this issue is paramount to draw policy-makers awareness of climate-related risks and the importance of an effective enforcement of climate policy.

4.1. Climate risk effects on capital structure adjustment speed

4.1.1. Climate risk as source of heterogeneity in speed of adjustment

The Eq. (5) constitutes a standard partial adjustment model for capital structure in which the estimation of target ratio is bank- and time-varying $CAR^{*}_{\mathrm{ij,t}}$, while the estimation of speed of adjustment is homogeneous across all banks and over time. More realistically, banks have unique capital adjustment processes that vary with their own fundamentals as well as with the country context and other external conditions. We now relax the simplification of this assumption and conjecture that the speed with which banks adjust their capital adequacy ratio depends on several environmental characteristics. Specifically, we analyze whether or not climate risk (i.e., abnormal temperature and carbon intensity) affects the speed of adjustment. We therefore re-specify the partial adjustment model (in Eq. (5)) such that the adjustment speed can vary over time, banks and countries. In particular, we follow the approach of Gilani et al. (2021) to adjust the model and express λ more flexibly as formalized below:

$$\lambda_{ij,t} = \lambda_0 + \Lambda \mathrm{Z}_{jt-1}. \tag{8}$$

where $\lambda_{ij,t}$ is the bank-specific, time-varying speed of adjustment, Λ is a vector of coefficients to be estimated and $Z_{i,j,t-1}$ is a vector of climate risk covariates that could affect the adjustment speeds. Now, substituting Eqs (6 and 8) into Eq. (5) yields for the *Variable Speed of Adjustment* model with heterogeneous the speed of adjustment:

$$\Delta CAR_{\mathrm{ij,t}} = \left(\lambda_0 + \Lambda \mathrm{Z}_{jt-1}\right) RegGap_{ij,t-1} + \eta_{\mathrm{ij,t}}. \tag{9}$$

where $\Delta CAR_{\mathrm{ij,t}}$ is $CAR_{\mathrm{ij,t}} - \mathrm{CAR}_{\mathrm{ij,t-1}}$, $RegGap_{ij,t-1}$ is the regulatory gap, λ_0 can be interpreted as the average speed of adjustment of the data, and Λ is the vector of coefficients to be estimated. The marginal effects of $RegGap_{ij,t-1}$for different values of Z_{jt-1} offer estimates of the different values of the speed of adjustment within the sample.

To explore which factors are related to the observed cross-country differences in the adjustment speeds, we follow Öztekin and Flannery (2012), De Jonghe and Öztekin (2015) and Gilani et al. (2021), and estimate Eq. (9) in two steps. In the first step, we estimate Eq. (5) country-by-country using system GMM and obtain a heterogenous estimate of target capital ratio across countries, $\widehat{\mathrm{CAR}}^{*}_{\mathrm{ij,t}}$, which we use to compute each bank's deviation from its (estimated) target capital adequacy labeled $RegGap_{ij,t-1}$. The second step involves the estimation of Eq. (9) using a pooled ordinary least square (OLS). We regress the change in a capital adequacy ratio ($\Delta CAR_{\mathrm{ij,t}}$) on a set of variables defined as the product of $RegGap_{ij,t-1}$ and the country-specific covariates (proxies for climate risk) affecting the adjustment speed. With vector of estimated coefficients in hand, we can test more accurately the determinants and the presence of a flexible adjustment speed. To ease economic interpretation, we standardize the independent variables, Z_{jt-1}, before interacting them with $RegGap_{ij,t-1}$. We cluster the standard errors at the country-year level, allowing the residuals to be correlated among the same banks in a given country in a given year.[15]

Table 7 shows the results for Eq. (9), where we allow for heterogeneity in the adjustment speed towards the optimal capital structure. We analyse the effect of climate risk on the speed of adjustment in two different ways. First, we include a measure of abnormal hot temperature and carbon emission intensity. Subsequently, we use the climate risk-index which allocates bank-year observations in quintiles according to these two climate risk aspects. The composite climate risk index (referred to as the '*CR-index*') provides a summary statistic of the environmental challenges as it covers in a meaningful way two equally-weighted dimensions of climate risk. The index ranges from two to ten, with the highest value indicating the highest level of climate risk an individual bank can be exposed to, i.e., a value of ten mean that the bank is highly exposed to both abnormal hot temperature and carbon emission intensity. For a precise construction of the CR-index, see Section 2.2.
In column 1, we report the homogenous speed of adjustment. In line with previous results (at across countries and pooled full sample), average capital adequacy speed is 0.41. Thus, on average, banks close 41.68% of the regulatory gap between actual and target capital adequacy ratio per year. In the next three columns, we introduce separately (columns 2–3) and jointly (column 4) the effects of abnormal hot temperature (AbTemp) and carbon emission intensity (CEI) on capital speed of adjustment. We find a positive and statistically significant relationship between AbTemp and the speed of adjustment, indicating that banks highly exposed to abnormal temperature adjust faster upward/downward toward their internal capital target over time. Similarly, we find that CEI carries a positive and statistically significant effect, suggesting that banks highly exposed to carbon pollution adjust quickly to their target. These findings are also in line with the additional estimation reported in columns 5, where we utilize the CR–index. The results strongly suggest that banks highly exposed to both dimensions of climate risk, i.e., abnormal temperature and carbon pollution, adjust significantly faster towards their desired targets.

Economically, based on the results on column 2 (3), a one standard deviation increases in AbTemp (CEI) increases the average speed of adjustment by around 0.04 (0.02) (compared to a baseline adjustment speed of 0.42 (0.41)) and explains 20% (10%) of the observed cross-country standard deviation in the speed of adjustment, 0.22, leading to a significantly higher half-life. This is also replicated in column 5, where we use the climate-risk–index. We find that banks highly exposed to both climate risk measures adjust 19% faster towards their desired target ratio, indicating once more that for capital adjustments, both abnormal temperature and carbon emission play a positive role.

[Insert Table 7 about here]

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[15] In the interest of brevity, more insight about the procedure, see Öztekin and Flannery (2012), De Jonghe and Öztekin (2015), Bakkar et al. (2019) and Gilani et al. (2021).

On the whole, banks adjust to their capital adequacy ratio target differently depending on their climate risk exposure. Our findings highlight the importance of "bridging" climate risk to the capital adjustment decisions of banks and provide strong evidence that climate risk is directly associated with the dynamics of bank capital. Such findings also suggest that banks are more sensitive to adjusting their capital adequacy ratio faster when they are highly exposed to climate-related hazards. Taken together, these results are consistent with the view that banks with the rising awareness about climate concerns are more likely to take proactive actions, for example, implementing appropriate risk management tools, to hedge their climate risks, thereby making it relatively less difficult and costlier for them to converge to their target. Our results are also consistent with Nguyen and Phan (2020), Javadi and Masum (2021) and Reghezza et al. (2021), who argue that climate risks increasingly interact with the organizational decisions and policies of banks, notably capital decisions.

4.1.2. Validity and sensitivity analyses

We perform a myriad of sensitivity analyses to check for the validity of our findings. The regression results are provided in Panels A and B of Table 8. Panel A (columns 1a–7a) documents our finding by jointly assessing the effects of AbTemp and CEI on speed of adjustment, while the evidence in Panel B (columns 1b–7b) displays the results using the CR-index.

In columns 1a and 1b, we rerun our estimation utilizing only the publicly listed banks. The results mimic the baseline results, suggesting that our findings (reported in Table 7) are not driven by whether banks are traded or not. In columns 2a and 2b, we follow De Jonghe and Öztekin (2015) and drop bank observations with substantial changes in the growth of total assets to exclude M&As and divestitures. We define a substantial change in total assets as an annual growth less than −10% or greater than 15% (though alternative growth cutoffs lead to similar results). Our baseline results continue to hold except for the CEI which now becomes insignificant at the conventional significance levels. Overall, our conclusions remain, by and large, the same indicating that our results are not driven by M&As or divestitures. In columns 3a and 3b, we analyze the subsample of commercial and savings banks, which constitute 80% of the entire sample. Eliminating cooperative banks, investments banks and mortgage banks does not affect the results. In columns 4a and 4b, we replicate the analysis with a subsample of only commercial banks that constitute about 47% of our sample. Our results with commercial banks mimic the results reported in columns 3a and 3b, suggesting that our main findings as reported in Table 7 are not driven by the sample splits or reduction in sample size. In columns 5a and 5b, we verify that the results are robust to the exclusion of the systemic banking crisis episode, defined as the 2008–2010 global financial crisis. Systemic banking crisis encompasses roughly 15% of the bank-year observations in the sample. Excluding bank-year observations over the 2008–2010 period, our baseline results remain unchanged. In columns 6a and 6b, we test the impact of the dominance of Germain, Italian and other large countries in our sample. We rerun our estimation utilizing WLS in which weights for each bank are proportional to the inverse number of country observations. Our findings are largely similar in comparison to the setup without sample weights. One notable difference is that the effect of CEI enters insignificant (in Panel A). In columns 7a and 7b, we consider an alternative measure of regulatory capital ratio: Tier 1 capital divided by risk-weighted assets. We verify that our results remain similar for alternative capital measure, indicating that no differences are due to the definition of the capital ratio.

[Insert Table 8 about here]

4.2. How does regulatory pressure influence our results?

In this subsection, we examine whether these differences are caused by climate regulation (COP21) and capital regulation (regulatory pressure). On the one hand, we conjecture that the Paris Agreement, as the world's first comprehensive climate agreement, raised public awareness of climate-related risk and increased the soft commitment of policymakers to a stricter enforcement of climate policy. We expect that this will shift the perception of climate risk by banks, therefore will materially change the effect of exposure to climate risk on their speed of adjustment. On the other hands, banks might have less leeway to freely adjust their capital adequacy ratio when their regulatory capital buffer is small or when they are below the minimum requirements.

First, to capture the effect of the climate regulatory risk that resulted from the subsequent period of the Paris Agreement, we define the dummy variable '*PostCOP21*' in our model which takes a value of one if the observation is from 2015 to 2021 and zero otherwise. Second, we classify banks into two categories: well capitalized banks and banks under regulatory pressure. The category distinction is based on whether or not banks have both regulatory capital ratios, the risk-weighted Tier1 ratio and the capital adequacy ratio, above the FDICs 'Well Capitalized' levels, 8% and 10%, respectively. If they do not meet both thresholds, we classify them as potentially being under regulatory pressure (referred to '*RegPressure*'). We then construct the dummy variable 'RegPressure' in our model to distinguish these two categories.[16] Results are presented in Panel A of Table 9. The leftmost blocks of columns (columns 1–3 of Table 9) report results of the interactions with the PostCOP21, whereas the effect of regulatory pressure is presented in the rightmost panel (columns 4–6 of Table 9). In columns 1 and 4, we examine whether banks over the post-COP21 period and under regulatory pressure, respectively, have a different adjustment speed. The COP21 is considered to be a shock that increases bank awareness about climate risk. In columns 2 and 5, we interact exposures to abnormal hot temperature (AbTem) and carbon emission intensity (CEI) with PostCOP21 and RegPressure, respectively, to investigate their joint impacts on adjustment speeds. In columns 3 and 6, we report results using the CR-index interaction with PostCOP21 and RegPressure, respectively. As highlighted above, the CR-

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[16] We follow Bakkar et al. (2019) and define 'Regulatory Pressure' dummy. This variable takes the value of one if a bank's Tier1 RWA capital ratio falls below 8% and/or its Total RWA capital ratio falls below 12%. These thresholds coincide with the levels used by the BCBS/FDIC to determine whether US banks are well-capitalized or not. Under regulatory pressure banks, various Prompt Corrective Actions may come into play putting regulatory pressure on adjustment (mechanisms) of bank characteristics. We use the FDIC thresholds for European banks in the sample in the absence of such information for non-US banks. It is important to note, from Tables 2 and 4, that most banks hold regulatory capital ratios well above the minimum requirements. We are thus mostly differentiating banks that are well above both regulatory requirements versus banks with small, but positive buffers.

index apprehends the aggregate climate risk index constructed based on the quintiles of AbTemp and CEI.

First of all, we find that banks adjust faster to the desired capital target during the post-COP21 period *vis-à-vis* the period prior to the Paris Agreement (column 1). The difference is economically important. Accordingly, because of tighter supervisory scrutiny, market discipline and climate change awareness during the post-COP21 period, banks are more sensitive to adjust their capital adequacy ratio faster. In the next column, introducing joint effects of exposures to AbTem and CEI on adjustment speed, we find a positive and statistically significant relationship between CEI and the speed of adjustment during the post-COP21 period. This indicates that banks highly exposed to carbon pollution adjust faster over the post Paris Agreement period. Subsequently, in columns 3, results show that banks highly exposed to both climate risks (higher CR-index) adjust more quickly during the post-COP21 period. In column 4, using RegPressure, we find that banks that are the lowest capitalization group (i.e., under regulatory pressure) adjust slower to the capital adequacy compared to those who are not. The difference is economically important, indicating that banks that are not in the most comfortable zone with respect to capital adequacy threshold may indeed not have discretion in their channels of adjustment, which could slow down the adjustment speed on the capital adequacy ratio. Subsequently, in columns 5 and 6, we do not find that the interactions between AbTemp and CR-index with RegPressure, respectively, are significant. Contrary, banks under regulatory pressure highly exposed to carbon pollution adjust more quickly to their optimal capital structure. Yet, the results documented in column 4 and in Table 7 pertain.

On the whole, our findings indicate that banks adjust their regulatory capital ratio faster during the post- *vis-à-vis* the pre-COP21 period, especially if they are highly exposed to climate risk, potentially with the rising awareness about the climate-related hazards. This observation indicates that such banks have become more concerned about the environmental threats since the Paris Agreement and the call for more standardized measures and disclosures of climate risks. In addition, banks slow down adjustment speed when they hold small regulatory capital buffers, possibly because of additional scrutiny and pressure from regulators. These banks, however, boost their adjustment specifically when they are exposed to carbon pollution.

In the lower Panel B of Table 9 we present the adjustment speeds implied by the estimated coefficients for the pre- *vis-à-vis* the post-COP21 period and for the group of well capitalized banks *vis-à-vis* the group of under regulatory pressure banks, for less, average and highly exposed banks to climate risk (with respect to CR-index). These analyses are constructed based on the coefficients in the columns (3) and (6) of Panel A. Less (highly) exposed banks are defined as those for which the normalized CR-index is –1 (+1), i.e., one standard deviation below (above) the mean.

[Insert Table 9 about here]

4.3. Climate risk effects on adjustments toward target adequacy capital ratio

In this section, we gauge the importance of the climate risk for capital management and the main funding strategies that banks use to adjust their capital adequacy ratio in respond to a capital shock. Specifically, we examine funding strategies based on capital adjustments and funding strategies based on asset adjustments by evaluating various subcomponents of balance sheet. The *capital adjustment* channel includes the annual change in the level of Tier 1 regulatory capital minus the amount of retained earnings (denoted hereafter as Δ*Tier 1*). The *asset adjustment* channels consist of (i) the annual change in total assets (Δ*Assets*), (ii) the annual change in net loans, excluding interbank loans, (*ΔLoans*), and (iii) the annual change in risk-weighted assets (Δ*RWA)*. We scale all changes by average bank assets (from time *t* to time *t–1*). We allow for asymmetric adjustments depending on the sign of the regulatory gap and on exposure to climate risk (CR-index). To test whether banks choose a specific adjustment mechanism in response to a regulatory shortfall or surplus *vis-à-vis* their exposure to climate challenges, we estimate the following set of straightforward threshold regressions:

$$\begin{aligned}(10)\qquad \Delta Mechanism_{ij.t} &= \lambda_0 + \beta_0 \text{CR–index}_{ij,t-1} + (\lambda_1 + \beta_1 \text{CR–index}_{ij,t-1}) RegGap^{+}_{ij,t-1} \\ &+ (\lambda_2 + \beta_2 \text{CR–index}_{ij,t-1}) RegGap^{-}_{ij,t-1} + \delta V_{\mathrm{ij,t-1}} + \mathrm{u_i} + \mathrm{v_t} + \varepsilon_{i,t}.\end{aligned}$$

More specifically, the dependent variable $\Delta Mechanism_{ij.t}$ is defined five different funding channels strategies based on equity and asset adjustments. It accounts either for capital adjustment (ΔTier1), or assets adjustment (ΔAssets, ΔLoans and ΔRWA). These growth rates are specified to be the key balance sheet components through which banks would respond to the capital shock and alter the adequacy capital ratio. They are regressed on deviation from target regulatory capital. The test variables are $RegGap^{+}_{ij,t-1}$ (undercapitalized) and $RegGap^{-}_{ij,t-1}$ (overcapitalized) referring to the values of the regulatory gap between the estimated target and the lagged actual capital adequacy ratio when the bank is below or above the desired target, respectively. This approach is similar to the one adopted by previous works to examine strategies adjustment strategies (e.g., Lepetit et al., 2015; Bakkar et al., 2019; Gilani et al., 2021), but it represents a contribution to the literature as it allows us to examine two potential sources of non-linearities in the speed of adjustment, and thus the mechanisms of adjustment, the sign of the regulatory gap on the one hand and the exposure to environmental threats on the other hand. $V_{\mathrm{ij,t-1}}$ is a vector of bank- and country-level controls.

In Table 10, we present our estimates of the model in Eq. (10). We allow for asymmetric adjustments depending on the sign of the regulatory gap and also allow this asymmetric adjustment to depend on banks' exposure to climate risk as measured by the CR-index. Specifically, we jointly consider the regulatory gaps ($RegGap^{+}_{ij,t-1}$ and $RegGap^{-}_{ij,t-1}$) and their interactions with the CR-index. The columns correspond with the growth rates in key balance sheet items. Columns (1–4) describes the parsimonious specification, whilst columns (5–8) add control variables. The results show that the coefficients associated with the CR-index are in general significant and negative, indicating that banks highly exposed to climate risk, in comparison to banks less exposed to climate risk, have ceteris paribus a lower growth rate in the two components of the adequacy capital ratio (ΔTier1 and ΔRWA) as well as the two other balance sheet components (ΔLoans and ΔAssets). In addition, we find that the interaction with the CR-index is more often significant when banks experience a negative regulatory gap (hence overcapitalization). The responsiveness of Tier 1 capital and risk-weighted assets are larger, for a given magnitude of the capital surplus for banks highly (*vs*. less) exposed to climate risk. Put differently, for decreasingly negative gap, banks highly exposed to climate hazards resort mainly to expanding risk-weighted assets (substituting safer assets for risker ones), but not their assets and lending, while they are not found to be reluctant to issue more Tier 1 capital. However, the presence of a capital shock (undercapitalized), banks highly (*vs*. less) exposed to climate risk exhibit a lower responsiveness in adjustment mechanisms and favor the implementation of adjustments via a strong decrease of the risk-weighted assets (swapping risker assets for safer ones) to boost their capital adequacy ratio. This strategy appears to facilitate a faster adjustment when banks are below the desired target. As a consequence, for both sets of results, external recapitalization is limited, and banks exposed to climate concerns rely on reshuffling their risk-weighted assets and reallocating them to reach the desired capital level.

[Insert Table 10 about here]

Furthermore, to capture the impact of the Paris Agreement (COP21) on the above banks' adjustment mechanisms, we split the sample period into two halves, the pre and the post Paris Agreement subperiods, and rerun the Eq.(10). The results are reported in Table 11. Prior to the Paris Agreement (PreCOP21, in the leftmost panel), undercapitalized banks highly exposed to climate risk rely on Tier 1 capital issuance and reducing lending, to a lower extent, to increase their capital adequacy ratio. Whereas overcapitalized banks highly exposed to climate risk rely on Tier 1 equity repurchases and expanding assets but without significantly increasing lending. During the post Paris Agreement (PostCOP21, in the rightmost panel), the results ascertain findings for banks highly exposed to climate risk presented in Table 10. Hence, such banks experiencing a capital shortfall boost their capital adequacy ratios via a strong decrease of the risk-weighted assets without cutting lending; whereas banks experiencing a capital surplus rely on substituting safer assets for risker ones, while they do not issue new equity, to adjust the capital adequacy ratio downward. In terms of economic magnitude, the responsiveness and the relative magnitudes of the estimated coefficients for ΔTier1 and ΔRWA are slightly stronger, with comparison to the results reported in Table 10. In all instances, these both sets of findings are also consistent with the results in Table 7, where we found a faster adjustment speed for banks exposed to climate risk compared to the other peers.

These specifications also highlight the key difference in terms of adjustment process between banks with different exposure to climate risk, before and after the Paris agreement. Our results generally support the conjecture that banks exposed to climate risk have more capacity to reshuffle their assets and adjust faster downward and upward during the post Paris Agreement period. Such banks are not found to be reluctant to issue new equity when they adjust downward.

[Insert Table 11 about here]

4.4. Robustness tests and further issues

In this section, we conduct additional robustness checks. First, we examine the main source of non-linearity in the speed of adjustment, and test whether climate risk impact the speed of adjustment depending on the sign of the regulatory gap. For this purpose, we follow Bakkar et al. (2019), who show the existence of asymmetry in capital behavior for systemic banks and allow for asymmetric adjustment speeds for over– and undercapitalized banks depending on the stance (sign) of the regulatory gap. We look at the impact on the speed of adjustment, which summarizes the underlying adjustment mechanism. The asymmetries result in the speed of adjustment are reported in Table 12. In summary, we show in column 1 that the speed of adjustment is significantly higher when banks are undercapitalized than when they are overcapitalized. In column 2, the interaction coefficients with the abnormal hot temperature and carbon emission intensity are positive and significant. Results show that the asymmetry in adjustment speed is more exacerbated if banks are exposed to abnormal hot temperature compared to those exposed to carbon pollution. Whereas such asymmetry in adjustment speed when banks are overcapitalized is more pronounced if they are more exposed to carbon pollution. In column 3, we find that the asymmetry in adjustment speed for over– and undercapitalized banks is equally exacerbated when banks are exposed to climate risk, i.e. to the equally-weighted dimensions of climate threats: abnormal hot temperature and carbon emission intensity. Second, we further conduct a battery of robustness tests of the non-linearities of the speed of adjustment using different sample selection criteria, namely, small banks, large banks, listed banks, banks extremely under- and overcapitalized, bank-year observations prior and posterior to the Paris Agreement, excluding the Covid-19 crisis period and excluding the top five carbon-based economies. We document these findings in Table 13. Our results are robust to these alternative sample selection criteria.[17]

5. Conclusion

Central banks (notably the European Central Bank) have started to design scenarios for climate stress tests and examining climate risk buffer requirements and climate risk weight policies in response to unaddressed systemic climate risk to the banking industry. This paper contributes to these recent debates and examines how climate risk influence bank capital decisions to reach their optimal capital structure.

Employing a large sample of European banks across 39 economies from 2006 to 2021, we investigate the impact of different measures of climate risk, namely abnormal hot temperature and caron emission intensity, on the speed of adjustment, and explore the possible adjustment channels adopted by banks highly exposed to climate risk. Our findings indicate that banks highly exposed to climate risk significantly increase the speed of adjustment, in particular, during the post Paris Agreement on the climate change (COP21). Subsequently, such banks adjust their regulatory capital ratio downward by expanding more risk-weighted assets; however, to adjust upward, they rely more on shrinking their expansion (downsizing) and reshuffling risky assets, particularly cutting lending, than issuing new equity.

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[17] In unreported tests, we conduct additional analyses using a variety of alternative target estimation techniques to ensure that our model specification does not drive the results. Our main conclusions largely hold regardless of how we specify the target estimation model.

This study makes an original contribution to the literature on bank capital and climate risk and to the recent studies on how environmental-based threats affect bank capital decisions. Our findings demonstrate that banks with rising awareness on climate change-related concerns are more likely to take proactive actions to reach their target and to achieve a capital management more aligned to the climate uncertainty and the regulatory objective of enhancing stability. These findings also demonstrate that climate risk interacts with the organizational decisions and policies of banks, notably capital decisions, and highlight the importance of "bridging" climate risk to bank capital adjustments. A final note of caution in interpreting our findings is warranted. Our results only cover the main two types of climate change risks that global financial sector is facing, according to NGFS (2020), and thereby do not have to be seen as that the other typologies of climate change risks are useless in banking.

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Figure 1. Evolution of bank capital and climate risks over time: 2006–2021

This figure shows the evolution of bank capital adequacy ratio and the abnormally hot temperature (*physical risk*, left panel) and natural logarithm of total carbon emission (*transition risk*, right panel) over the sample period. Capital adequacy ratio (CAR) is initially calculated at the bank-year level, whereas both climate risk measures (AbTemp and CEI) are calculated at the country-year level. All measures are then averaged by country on a yearly basis between 2006 and 2021. The plotted lines correspond with the yearly averages of these cross-country averages.

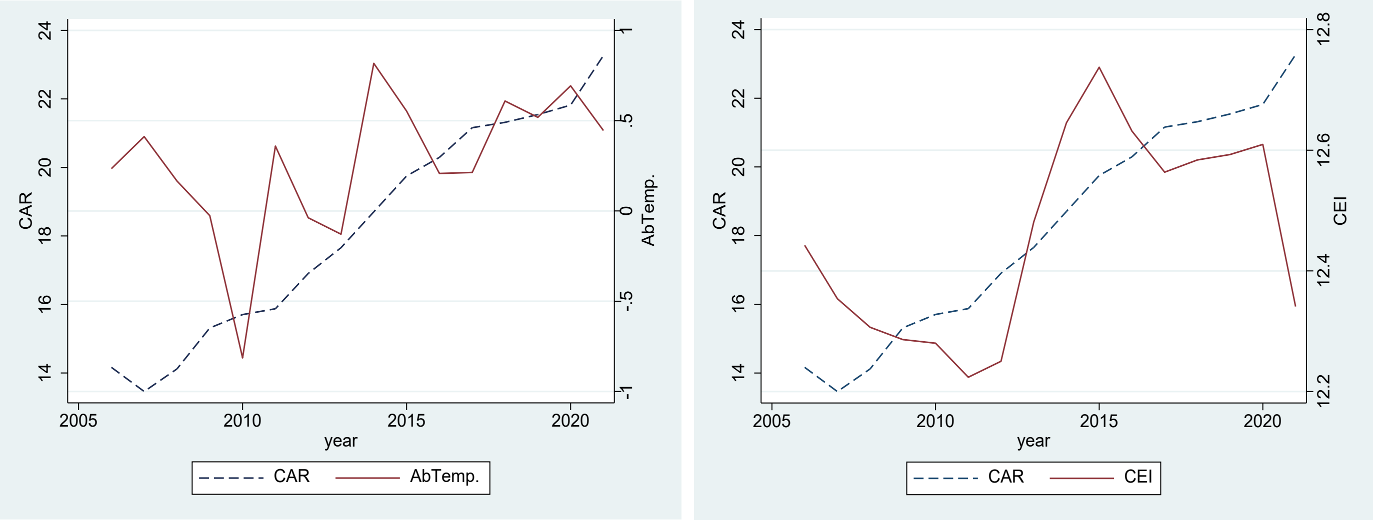
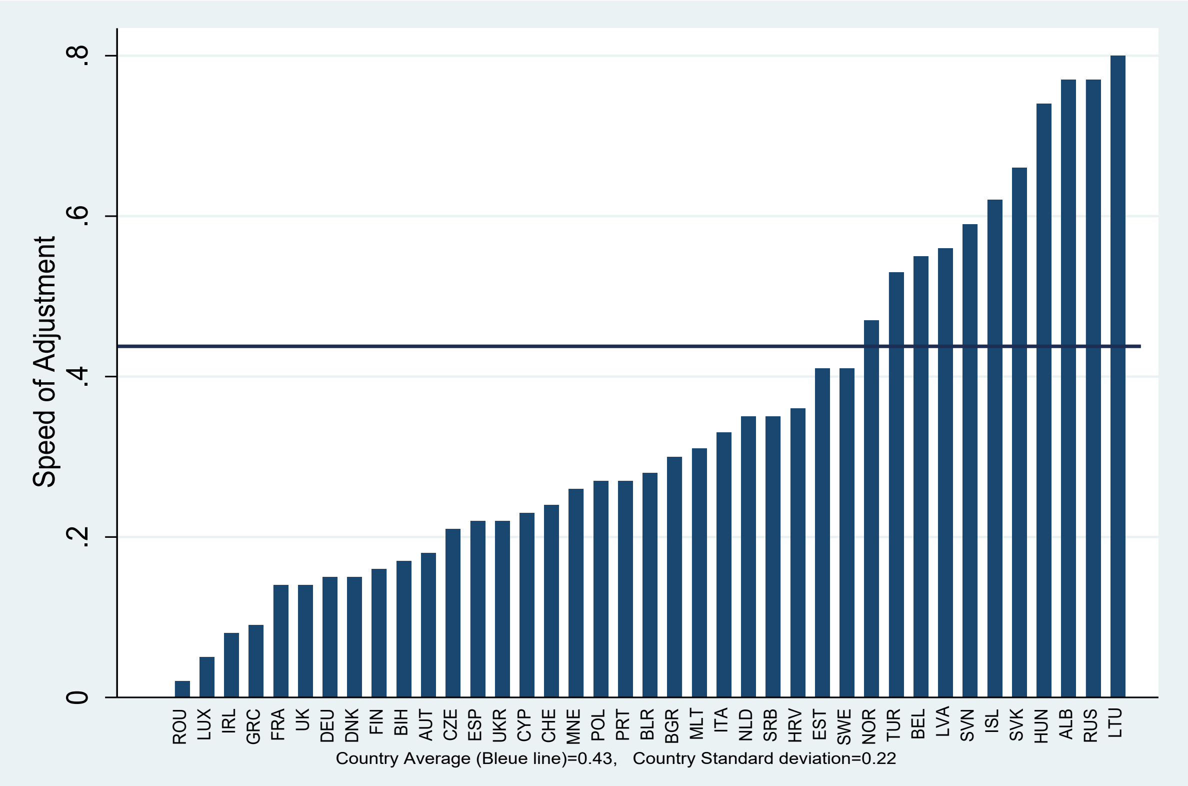


Figure 2. Country-specific adjustment speeds

The figure contains information on the adjustment speed estimates for the 39 countries in our sample and are obtained from the estimation of the partial adjustment model of bank capital: $CAR_{ij,t} = (1-\lambda)CAR_{ij,t-1} + \lambda(\beta X_{ij,t-1} + c_j + v_t + u_i) + \eta_{ij,t}$ separately for each country using the Blundell and Bond (1998) GMM estimator. CAR is the capital adequacy ratio, λ is the adjustment parameter; X is a set of bank-level and macroeconomic characteristics; and ε is a random-error term. The definitions and the sources of the variables are provided in Table 1.



Country Average (Bleue line)=0.43, Country Standard deviation=0.22

Code	Country	SOA	Code	Country	SOA
ROU	Romania	0.02	BGR	Bulgaria	0.30
LUX	Luxembourg	0.05	MLT	Malta	0.31
IRL	Ireland	0.08	ITA	Italy	0.33
GRC	Greece	0.09	NLD	Netherlands	0.35
UK	UK	0.14	SRB	Serbia	0.35
FRA	France	0.14	HRV	Croatia	0.36
DNK	Denmark	0.15	SWE	Sweden	0.41
DEU	Germany	0.15	EST	Estonia	0.41
FIN	Finland	0.16	NOR	Norway	0.47
BIH	BiH	0.17	TUR	Turkey	0.53
AUT	Austria	0.18	BEL	Belgium	0.55
CZE	Czech	0.21	LVA	Latvia	0.56
ESP	Spain	0.22	SVN	Slovenia	0.59
UKR	Ukraine	0.22	ISL	Iceland	0.62
CYP	Cyprus	0.23	SVK	Slovakia	0.66
CHE	Switzerland	0.24	HUN	Hungary	0.74
MNE	Montenegro	0.26	ALB	Albania	0.77
PRT	Portugal	0.27	RUS	Russia	0.77
POL	Poland	0.27	LTU	Lithuania	0.80
BLR	Belarus	0.28	–	–	–

Table 1. Distributions of European banks and representativeness of the final sample

This table shows the breakdown of the 4,606 European banks by country and their specialization during the 2006–2021 period. It presents the representativeness of the final sample and provides number of banks and observation per country in the final sample of European banks. Our final sample consists of 2,158 Commercial Banks, 723 Saving Banks, 1,479 Cooperative Banks, 115 Investment Banks, and 131 other banks. Among all banks, 553 are publicly listed.

Country	Banks	Observations	Specialization					Listed	non-listed
			Commercial bank	Savings bank	Cooperative bank	Investment bank	Others		
Albania	14	86	11	2	0	1	0	0	14
Austria	166	1132	53	30	64	3	16	14	152
Belarus	36	239	33	3	0	0	0	6	30
Belgium	31	268	23	6	2	0	0	0	31
BiH	26	178	24		1	1		17	9
Bulgaria	30	220	28	2	0	0	0	8	22
Croatia	28	223	26	1	1	0	0	8	20
Cyprus	37	241	35	0	1	1	0	4	33
Czech	28	282	23	0	4	1	0	3	25
Denmark	86	779	44	31	6	0	5	35	51
Estonia	12	101	10	0	0	2	0	0	12
Finland	155	788	29	9	114	1	2	9	146
France	135	1102	41	11	75	3	5	20	115
Germany	1319	10030	67	375	823	24	30	14	1305
Greece	17	175	13	0	2	2		11	6
Hungary	33	215	28	0	0	0	5	8	25
Iceland	8	58	3	4	0	1	0	3	5
Ireland	25	200	18	0	0	6	1	5	20
Italy	400	3023	100	15	265	18	2	48	352
Latvia	23	157	23	0	0	0	0	0	23
Liechtenstein	1	7	1	0	0	0	0	0	1
Lithuania	9	92	8	1	0	0	0	3	6
Luxembourg	42	308	36	3	2	1	0	0	42
Malta	15	85	11	1	1	2	0	5	10
Monaco	0	0	0	0	0	0	0	0	0
Montenegro	10	62	10	0	0	0	0	7	3
Netherlands	31	309	25	0	2	3	1	3	28
Norway	160	1245	31	123	0	2	4	61	99
Poland	163	1034	90	3	66	0	4	30	133
Portugal	40	326	24	5	5	6	0	0	40
Romania	32	215	27	4	1	0	0	7	25
Russia	782	4494	759	4	2	17	2	93	689
Serbia	27	199	24	1	0	0	0	3	24
Slovakia	14	123	9	3	0	0	2	4	10
Slovenia	21	207	18	2	1	0	0	3	18
Spain	90	653	41	12	35	2	0	13	77
Sweden	106	652	45	52	0	3	6	11	95
Switzerland	117	585	96	14	4	2	1	9	108
Turkey	98	896	97	0	1	0	0	47	51
UK	156	1086	96	1	0	13	45	7	149
Ukraine	83	431	78	5	1	0	0	34	49
Total	4,606	32,506	2,158	723	1,479	115	131	553	4,053

Table 2. Summary statistics

This table provides summary statistics, description, and source of the main different variables used in our empirical analyses. The main dataset is constructed based on a cross-section of 4,606 banks headquartered in 39 European countries during the years 2006 to 2021. The full sample contains 32,506 observations. The table consists of four panels. For all explanatory and control variables (in Panels A, B, C, D), this table reports number of observations, means, standard deviations, as well as some percentiles (p25, median and p75) for all variables, across all banks and countries, used throughout the paper. Climate risk data is collected from the Climate Change Knowledge Portal (CCKP). Bank specific data is retrieved from the Thomsen Reuters Eikon and Bloomberg, while country specific data is retrieved from World Development Indicators (WDI) and World Economic Outlook (WEO). All variables, except dummy variables, are winsorized at the 1st and 99th percentiles of the sample distributions.

Variable	Observations	Mean	Standard deviation	p25	p50	p75	Definition	Source
Panel A. Climate risk indicators								
AbTemp	32,506	0.379	0.462	0.138	0.386	0.681	Abnormal hot temperature measure is a proxy for physical risk, see Eq. (1).	World Bank, Climate Change Knowledge Portal (CCKP).
CEI	32,506	12.53	1.468	11.09	12.84	13.52	Carbon emission intensity, proxy for transition risk, defined by the ratio of total carbon emission to total output in percentage, see Eq. (2).	Climate Watch Data and Asset 4.
CR-index	32,506	6.130	2.140	5	6	8	Aggregated climate risk index.	Climate Watch Data and CCKP.
Panel B. Determinants of the capital adequacy								
CAR	32,506	19.92	8.268	14.80	17.60	21.73	Capital adequacy ratio, total capital tier1 over to total risk weighted assets, (percentage).	Thomsen Reuters Eikon and Bloomberg
ΔCAR	32,506	0.283	3.073	-0.700	0.110	1.230	Change in capital adequacy ratio, (percentage).	
Size	32,506	14.35	2.366	12.69	14.22	15.85	Natural logarithm of bank total assets in billions of US dollars.	Thomsen Reuters Eikon
Funding	32,506	81.98	0.199	75.98	87.49	9608	Retail funding, total customer deposit divided by total funding (short-term borrow + total customer deposits), (percentage).	Thomsen Reuters Eikon
Credit Risk	32,506	9.23	0.206	0.25	5.54	14.37	Ratio of loan loss provisions to interest income, (percentage).	
Liquidity	32,506	59.24	18.46	48.98	61.96	72.55	Net loans over total deposit, (percentage).	Thomsen Reuters Eikon
Tangibility	32,506	1.48	0.022	0.43	0.86	1.58	The ratio between fixed to total assets, (percentage).	Thomsen Reuters Eikon
Efficiency	32,506	68.87	22.46	56.29	67.56	78.24	Cost income ratio, non-interest expense over total income, (percentage).	Thomsen Reuters Eikon
RoA	32,506	2.39	0.019	1.36	1.85	2.62	Profitability, return on assets, ratio of net income to total assets, (percentage).	Thomsen Reuters Eikon
Revenue Mix	32,506	82.51	1.427	19.50	42.64	94.06	Share of non-interest income in total income, (percentage).	Thomsen Reuters Eikon
Regulatory pressure	32,506	0.035	0.183	0.01	0.26	0.93	Dummy takes one if a bank's Tier1 capital ratio falls below 8% and/or its total capital ratio falls below 12%.	Thomsen Reuters Eikon and Bloomberg

LLProvisions	32,491	0.88	0.026	0	0.003	0.009	Ratio of loan loss provisions to net loans, (percentage).	Thomsen Reuters Eikon
Deposit	32,506	64.70	0.202	55.65	70.54	79.01	Ratio of customer deposits to total assets, (percentage).	Thomsen Reuters Eikon
Listed	32,506	0.153	0.360	0	0	0	Dummy equal to one if the bank is listed and zero otherwise.	Bloomberg
Panel C. Growth in adjustment mechanisms								
ΔTier1	28,942	0.057	0.133	0	0.051	0.109	Annual change in Tier 1 capital minus current retained earnings divided by average total equity, defined as (total equity at time t+total equity at time t−1)/2.	Thomsen Reuters Eikon and Bloomberg
ΔLoans	32,493	0.053	0.158	-0.012	0.041	0.099	Annual change in net loans (excluding interbank loans) divided by average total assets, defined as (total assets at time t+total assets at time t−1)/2.	Thomsen Reuters Eikon and Bloomberg
ΔAssets	32,506	0.050	0.127	-0.006	0.042	0.095	Annual change in total assets divided by average total assets, defined as (total assets at time t+total assets at time t−1)/2.	Thomsen Reuters Eikon and Bloomberg
ΔRWA	30,142	0.045	0.220	-0.038	0.028	0.091	Annual change in risk-weighted assets divided by average total assets (percent).	Thomsen Reuters Eikon and Bloomberg
Panel D: Country-specific characteristics								
Credit-to-GDP	31,842	84.763	34.14	56.408	79.308	94.06	Domestic credit to the private sector divided by a country's GDP. This ratio represents the financial resources, such as loans from financial institutions to the private sector.	World Development Indicators (WDI) and World Economic Outlook (WEO)
ΔGDP	32,499	1.069	3.046	0.5	1.619	2.623	The annual growth rate of a country's GDP.	WDI and WEO
InteTrade	32,499	84.161	39.282	58.604	84.439	88.434	The sum of a country's exports and imports of goods and services, divided by GDP.	WDI and WEO
OilRents	32,499	1.369	2.909	0.011	0.028	0.316	Oil rents as a percentage of a country's GDP.	WDI
PostCOP21	32,506	0.412	0.448	0	1	1	Dummy equal to one if the observation is from 2015 to 2021, i.e., during the post Paris Agreement period, and zero otherwise.	Bloomberg
d(Crisis)	32,506	0.135	0.342	0	0	0	Dummy equal to one if the observation is from 2008 or 2009 and zero otherwise.	Bloomberg

Panel 3. Pearson correlation matrix for the variables used in our analysis

This table provides information on the Pearson correlation coefficients for the key variables of our analyses for the period from 2006 to 2021. Definitions and sources for all the variables are in Panel A of Table 2. In parentheses below the correlation coefficients are their corresponding *p*-values. ***, **, and * represent the statistical significance levels of 1%, 5% and 10%, respectively.

	CAR	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1) AbTemp	0.043	1												
	(0.000)													
(2) CEI	0.016	0.213	1											
	(0.003)	(0.00)												
(3) CR-index	–0.019	0.728	0.712	1										
	(0.000)	(0.000)	(0.000)											
(4) Size	0.351	–0.224	–0.209	–0.296	1									
	(0.000)	(0.000)	(0.000)	(0.000)										
(5) Funding	–0.098	0.12	–0.002	0.079	–0.311	1								
	(0.000)	(0.000)	(0.696)	(0.000)	(0.000)	(0.000)								
(6) Credit Risk	–0.083	–0.05	–0.073	–0.084	0.072	–0.077	1							
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)								
(7) Liquidity	0.190	–0.02	–0.042	–0.057	0.018	0.066	–0.010	1						
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.086)							
(8) Tangibility	0.121	0.104	0.199	0.215	–0.336	0.166	0.021	–0.089	1					
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)						
(9) Efficiency	0.059	0.08	0.125	0.132	–0.199	0.092	–0.136	–0.127	0.197	1				
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)					
(10) ROA	–0.169	–0.083	0.231	0.238	–0.371	0.21	0.124	0.091	0.327	0.109	1			
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)				
(11) Revenue Mix	0.111	0.105	–0.012	–0.050	0.267	–0.318	0.008	–0.104	–0.038	0.001	–0.156	1		
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.164)	(0.000)	(0.000)	(0.810)	(0.00)			
(12) PostCOP21	0.231	0.173	0.039	0.108	–0.241	0.214	–0.059	0.013	0.07	0.086	0.042	–0.259	1	
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.021)	(0.000)	(0.000)	(0.000)	(0.000)		
(13) Log(Surface)	0.158	0.154	0.729	0.541	–0.293	0.085	0.001	0.005	0.314	0.000	0.492	0.031	0.128	1
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.824)	(0.335)	(0.00)	(0.953)	(0.000)	(0.000)	(0.000)	
(14) GDP Growth	–0.036	–0.17	–0.128	–0.142	0.055	0.041	–0.155	–0.001	–0.057	–0.057	0.035	0.004	-0.023	–0.084
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.833)	(0.000)	(0.000)	(0.000)	(0.509)	(0.00)	(0.00)

Table 4. Bank characteristics and climate risk

This table compares the financial characteristics of banks with high and low exposure to the different climate risk measure over the 2006–2021 period. Using the median values as a control threshold, we classify banks with a high exposure to abnormal the temperatures (carbon emissions intensity) for the sample of banks with above the median value of abnormal temperatures measure (carbon emission intensity measure), each group counts 16,258 (16,341) observations. Similarly, we classify banks with low exposure to abnormal temperatures (carbon emissions intensity) for the sample of banks with below the median value of abnormal temperatures measure (carbon emission intensity measure), counting 16,258 (16,165) observations. Abnormal temperatures measure is a proxy for physical risk, whereas carbon emissions intensity measure is a proxy for transition risk. All the variables are expressed in percentages except banks' size (natural logarithm of total asset in millions of USD). For each variable, we report the average value and report tests for equality of means (*t-statistics*). Table 3 displays descriptive statistics and definitions for all the bank financial characteristics. **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively, for a bilateral test.

	Abnormal hot temperature: *AbTemp*			Carbon emission intensity: *CEI*		
Variable	Low exposure: *below median*	High exposure: *above median*	Test for equality of means (*t-statistics*)	Low exposure: *below median*	High exposure: *above median*	Test for equality of means (*t-statistics*)
Capital Adequacy Ratio	19.69	20.16	–5.12***	19.76	20.09	–3.64***
Tier 1 RWA	17.51	17.77	–2.67**	16.72	18.56	–20.11***
Size	14.71	14.00	27.55***	14.94	13.76	46.11***
Funding	80.49	83.46	–13.49***	80.28	83.70	–15.57***
Deposit	62.64	66.76	–18.47***	61.10	68.33	–32.78***
Liquidity	59.65	58.83	4.02***	59.90	58.58	6.46***
RoA	2.35	2.44	–4.05***	2.07	2.72	–30.85***
Credit Risk	10.27	8.20	9.07***	13.05	5.39	34.11***
Provisions	0.92	0.84	2.67**	0.94	0.82	4.32***

Table 5. Climate risk and the Target Capital Adequacy Ratio.

Table presents the parameters for the partial adjustment model, estimated for an unbalanced panel of 32,506 bank-year observations for European between 2006 and 2021. Panel A of this table estimates Eq. (5) and presents results for two-step System Generalized Method of Moments (GMM) estimation of a partial adjustment model of bank capital adequacy using dynamic generalized method of moments techniques (Blundell and Bond 1998). All right-hand side variables are lagged one year. Column (1) reports the estimated coefficients from Eq. (5), while column (2) shows the coefficients for the target capital adequacy equation that we have obtained by dividing the coefficients in column (1) by the speed of adjustment (equal to 1 minus the estimated coefficient of $CAR_{i,t-1}$). To check the validity of the estimators, we conduct two tests, over-identifying test and test for autocorrelation. Hansen test is a test of exogeneity of all instruments as a group. Arellano-Bond test is a test of the absence of second order residual autocorrelation. p-values based on robust standard errors are shown in parentheses. ***, ** and * indicate statistical significance at the 1, 5 and 10 percent levels, respectively. Panel B of this table reports summary statistics (mean, standard deviation, p5, p25, p50, p75 and p95) for the estimated targeted capital adequacy ratio and the deviations from the targeted capital (namely, the difference between the target capital adequacy ratio and the actual capital adequacy ratio). The average target ratio is 20%, while the average deviation from the target is 7.75%.

Panel A. Partial Adjustment Model of Bank Capital Adequacy Ratio.

Dependent	Coefficients for the observed capital adequacy ratio (1)	Coefficients for the target ratio (2)
CAR$_{t-1}$	**0.517***** **(0.0266)**	**λ=0.483**
Size$_{t-1}$	-0.557*** (0.0443)	-1.153***
Funding $_{t-1}$	-0.757** (0.324)	-1.567**
Credit_Risk$_{t-1}$	0.133* (0.023)	0.275*
Liquidity$_{t-1}$	-0.033*** (0.004)	-0.068***
Tangibility$_{t-1}$	-0.337 (3.286)	-0.698
Efficiency$_{t-1}$	-0.004* (0.002)	-0.008*
RoA$_{t-1}$	-2.136 (5.159)	-4.422
Diversification$_{t-1}$	-0.019* (0.065)	-0.040*
Listed$_{t-1}$	-0.189* (0.146)	-0.391*
AbTemp$_{t-1}$	0.215** (0.024)	0.445**
CEI$_{t-1}$	1.319*** (0.483)	2.730***
PostCOP215$_{t-1}$	0.033** (0.029)	0.068**
Log(surface)$_{t-1}$	3.867*** (0.536)	8.006***

ΔGDP_{t-1}	-0.019*	0.039*
	(0.007)	
Constant	18.670***	
	(1.272)	
Observations	32,506	
Bank Fixed Effects	Yes	
Year Fixed Effects	Yes	
Number of Banks	4,606	
Number of Countries	39	
Hansen test (p-value)	0.201	
AR2 test (p-value)	0.378	

Panel B. Deriving Target Capital and Deviations

Variable	N	Mean	SD	p5	p25	p50	p75	p95
Target capital adequacy ratio								
Target CAR (%)	32506	20.23	7.745	12.420	15.540	18.080	21.930	39.360
Deviation from the target								
Capital Gap: *RegGap* (%)	32506	0.590	4.359	-5.200	-0.824	0.595	2.037	6.209
Below Target CAR (%)	20146	2.579	3.361	0.159	0.766	1.620	3.043	8.158
Above Target CAR (%)	12345	-2.654	3.824	-9.545	-3.824	-1.392	-0.570	-0.022

Table 6. Balance sheet dynamics: climate risk and adjustment strategies

This table compares the balance sheet dynamics of group banks with high and low exposure to the different climate risk measure over the 2006–2021 period. Using the median values as a control threshold, we classify banks with a high (*vs* low) exposure to abnormal the temperatures (Panel A) or carbon emissions intensity (Panel B). Panel C shows the balance sheet adjustment mechanisms for banks before and after the Paris agreement. For each group, we provide evidence of whether the average annual growth rates of the main banks' adjustment mechanisms vary in various quintiles of the capital ratio deviation (RegGap). Quintile 1 (Q1) corresponds with the most overcapitalized banks (underleveraged banks, i.e. largest negative gap), Quintile 3 (Q3) banks are closest to their capital ratio target, whereas banks in quintile 5 (Q5) are the most undercapitalized (overleveraged banks, i.e. largest positive gap). Thus, we compare the change rates of the capital adequacy ratio (ΔCAR) and the scaled annual growth rates of the financial characteristics: regulatory Tier 1 capital (Tier 1), net loans (Loans), total assets (Assets), and risk-weighted-assets (RWA). For each variable, we report the average growth rate, the number of observations per group (below the mean value) and the results of pairwise t-tests of equality of means of the extreme quintiles compared with the middle quintile, respectively. We report the p-values of these equality of means tests. Differences in the observations are due to differences in data availability. All variables are expressed in percentages. For more details, Table 3 displays descriptive statistics and definitions for all the bank financial characteristics. **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively, for a bilateral test.

	Block 1. High exposure					Block 2. Low exposure					$Q1_{High}=Q1_{Low}$ P-Value/ Significance	$Q5_{High}=Q5_{Low}$ P-Value/ Significance
	Q1	Q3	Q5	Q1 vs Q3	Q3 vs Q5	Q1	Q3	Q5	Q1 vs Q3	Q3 vs Q5		
	Mean/ (Observations)			P-Value/ Significance		Mean/ (Observations)			P-Value/Significance			
Panel A. AbTemp												
ΔCAR	-2.13	0.21	2.7	0	0	-1.7	0.31	2.15	0	0	0	0
	(3382)	(3554)	(3290)	***	***	(3116)	(2956)	(3195)	***	***	***	***
Tier 1	2.79	5.78	7.13	0	0	1.25	4.38	7.47	0	0	0	0.55
	(3028)	(3208)	2975)	***	***	(2762)	(2605)	2739)	***	***	***	
Loans	6.87	3.95	1.11	0	0	6.37	3.93	1.06	0	0	0.45	0.93
	(3381)	(3552)	(3285)	***	***	(3115)	(2954)	3194)	***	***		
Assets	6.34	4.9	2.36	0	0	5.69	3.87	0.76	0	0	0.18	0.18
	(3382)	(3554)	(3290	***	***	(3116)	(2956)	(3195)	***	***		
RWA	10.94	3.35	-5.76	0	0	8.31	2.14	-4.02	0	0	0	0
	(3182)	(3326)	(3068)	***	***	(2913)	(2726)	2870)	***	***	***	***

Panel B. LogCo2

ΔCAR	-1.96	0.18	2.91	0	0	-1.88	0.34	2.12	0	0	0.38	0
	(3430)	(3593)	(2528)	***	***	(3068)	(2917)	(3957)	***	***		***
Tier 1	2.77	5.4	3.35	0	0	1.29	4.84	9.73	0	0	0	0
	(2997)	(3217)	(2183)	***	***	(2793)	(2596)	(3531)	***	***	***	***
Loans	4.92	3.31	-1.81	0	0	8.54	4.72	2.93	0	0	0	0
	(3429)	(3590)	(2523)	***	***	(3067)	(2916)	(3956)	***	***	***	***
Assets	4.92	3.77	-0.63	0	0	7.27	5.25	2.98	0	0	0	0
	(3430)	(3593)	(2528)	***	***	(3068)	(2917)	(3957)	***	***	***	***
RWA	10.51	2.85	-9.28	0	0	8.77	2.74	-2.2	0	0	0	0
	(3186)	(3398)	(2282)	***	***	(2909)	(2654)	(3656)	***	***	***	***

Panel C. Adjustment mechanisms in response to the Paris agreement

	Block 1. Pre COP21					Block 2. Post COP21					$Q1_{Pre}=Q1_{Post}$ P-Value/ Significance	$Q5_{Pre}=Q5_{Post}$ P-Value/ Significance
	Q1	Q3	Q5	Q1 vs Q3	Q3 vs Q5	Q1	Q3	Q5	Q1 vs Q3	Q3 vs Q5		
	Mean/ (Observations)			P-Value/ Significance		Mean/ (Observations)			P-Value/Significance			
ΔCAR	-1.55	0.39	1.86	0	0	-2.11	0.22	2.75	0	0	0	0
	(2074)	(1404)	(2334)	***	***	(4448)	(5118)	(4187)	***	***	***	***
Tier 1	4.26	7.41	9.27	0	0	2.795	5.31	7.02	0	0	0	0
	(1681)	(1093)	(1956)	***	***	(4147)	(4738)	(3810)	***	***	***	***
Loans	7.42	4.53	3.57	0	0.06	8.29	4.88	3.39	0	0	0.09	0.70
	(2073)	(1403)	(2334)	***	***	(4448)	(5115)	(4183)	***	***	*	
Assets	6.56	4.26	3.30	0	0.03	6.92	5.16	3.37	0	0	0.38	0.84
	(2074)	(1404)	(2334)	***	***	(4448)	(5118)	(4187)	***	***		
RWA	10.77	3.79	-1.39	0	0	14.57	3.89	-2.51	0	0	0	0.90
	(1832)	(1214)	(2065)	***	***	(4286)	(4850)	(3908)	***	***	***	***

Table 7. Speed of adjustment to target regulatory capital structure: effects of climate risk

This table reports coefficient estimates for a heterogeneous partial adjustment model for the capital adequacy ratio when we interact climate risk measures with RegGap: $\Delta CAR_{\mathrm{ij,t}} = \left(\lambda_0 + \Lambda Z_{jt-1}\right) RegGap_{ij,t-1} + \eta_{\mathrm{ij,t}}$. Based on a sample of listed European banks over the 2006–2021 period. The dependent variable is the change in the capital adequacy ratio, which is regressed on the RegGap (deviation between the estimated target and the lagged value of the capital adequacy ratio) and interactions of the gap with other variables captured by ΛZ_{jt-1}. In columns 1, report the homogenous speed of adjustment. In columns 2 and 3, we include interactions of RegGap with abnormally temperature (AbTemp) and carbon emission intensity (CEI), respectively, whereas in column 4, both interactions with AbTemp and CEI are included. In column 5, we use a composite indicator of these two climate risk dimensions, climate-risk-index, labelled CR-index. Climate risk measures are standardized before being interacted with the regulatory deviation to facilitate the economic magnitude interpretation. p-values based on robust standard errors are shown in parentheses. Coefficients significantly different from zero at the 1% level are marked with $***$.

	(1) ΔCAR	(2) ΔCAR	(3) ΔCAR	(4) ΔCAR	(5) ΔCAR
RegGap$_{ij,t-1}$	0.413***	0.415***	0.409***	0.411***	0.408***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
RegGap$_{ij,t-1}$#**AbTemp**$_{t-1}$		**0.042*****		**0.040*****	
		(0.007)		(0.007)	
RegGap$_{ij,t-1}$#**CEI**$_{t-1}$			**0.020*****	**0.018*****	
			(0.006)	(0.006)	
RegGap$_{ij,t-1}$#**CR-index**$_{t-1}$					**0.038*****
					(0.006)
Observations	32,506	32,506	32,506	32,506	32,506
Number of Banks	4,606	4,606	4,606	4,606	4,606
Adjusted R-squared	0.346	0.348	0.347	0.349	0.349

Table 8. Effects of Climate Risk on speed of adjustment: *additional results*

This table reports coefficient estimates for a heterogeneous partial adjustment model for the capital adequacy ratio when we interact climate risk measures with RegGap: $\Delta CAR_{\mathrm{ij,t}} = (\lambda_0 + \Lambda Z_{jt-1}) RegGap_{ij,t-1} + \eta_{\mathrm{ij,t}}$, by considering seven alternative specifications. In Column (1), we consider only banks. In column 2, we drop bank observations with substantial changes in the total assets as an annual growth less than −10% or greater than 15%. In column 3, we use a subsample of commercial and savings banks. In column 4, we consider a subsample of commercial banks only. In column 5, we exclude bank-year observations related the systemic banking crisis episode, defined as the 2008–2010 global financial crisis. In column 6, we use a weighted least squares (WLS) estimation to control for country representation in the sample's total observations. In column 7, we consider an alternative measure of regulatory capital ratio: the Tier 1 capital divided by risk-weighted assets. Panel A results interactions of RegGap with both AbTemp and CEI, while Panel B results interactions of RegGap with the climate risk-index (CR-index). p-values based on robust standard errors are shown in parentheses. Coefficients significantly different from zero at the 1% level are marked with ∗∗∗.

	Listed banks	Normal growth: 0.10<Gr(TA)<0.15	Commercial & Saving banks	Commercial banks only	No crisis	WLS	Alternative capital ratio: Tier 1RWA
	ΔCAR	ΔCAR	ΔCAR	ΔCAR	ΔCAR	ΔCAR	
Panel A: Abnormally hot temperature and CO2							
	(1a)	(2a)	(3a)	(4a)	(5a)	(6a)	(7a)
RegGap$_{ij,t-1}$	0.428***	0.397***	0.419***	0.425***	0.411***	0.392***	0.435***
	(0.011)	(0.009)	(0.007)	(0.008)	(0.007)	(0.018)	(0.007)
RegGap$_{ij,t-1}$#**AbTemp**$_{t-1}$	0.028***	0.046***	0.052***	0.049***	0.041***	0.040***	0.030***
	(0.011)	(0.008)	(0.008)	(0.010)	(0.007)	(0.013)	(0.008)
RegGap$_{ij,t-1}$#**CEI**$_{t-1}$	0.024**	0.009	0.020***	0.022***	0.019***	-0.012	0.027***
	(0.009)	(0.008)	(0.006)	(0.006)	(0.006)	(0.018)	(0.006)
Observations	5,016	24,622	25,010	14,887	31,175	32,506	30,140
Number of Banks	553	4,397	3,637	2,158	3,410	4,606	4,606
Adjusted R-squared	0.349	0.329	0.355	0.369	0.349	0.330	0.362
Panel B: Aggregated climate risk-index							
	(1b)	(2b)	(3b)	(4b)	(5b)	(6b)	(7b)
RegGap$_{ij,t-1}$	0.425***	0.394***	0.414***	0.419***	0.408***	0.428***	0.433***
	(0.011)	(0.008)	(0.007)	(0.008)	(0.007)	(0.014)	(0.007)
RegGap$_{ij,t-1}$#**CR-index**$_{t-1}$	0.032***	0.033***	0.044***	0.046***	0.038***	0.038***	0.039***
	(0.011)	(0.008)	(0.007)	(0.008)	(0.006)	(0.013)	(0.007)
Observations	5,016	24,622	25,010	14,887	31,175	32,506	30,140
Number of Banks	553	4,387	3,637	2,158	3,410	4,606	4,606
Adjusted R-squared	0.349	0.328	0.354	0.369	0.349	0.329	0.362

Table 9. The effects of COP21 and regulatory pressures on the speed of adjustment and climate risk
This table reports coefficient estimates for a heterogeneous partial adjustment model for the capital adequacy ratio when we interact climate risk measures with RegGap: $\Delta CAR_{\text{ij,t}} = (\lambda_0 + \Lambda Z_{jt-1}) RegGap_{ij,t-1} + \eta_{\text{ij,t}}$. Based on a sample of listed European banks over the 2006–2021 period. The dependent variable is the change in the capital adequacy ratio, which is regressed on the RegGap (deviation between the estimated target and the lagged value of the capital adequacy ratio) and interactions of the gap with other variables captured by ΛZ_{jt-1}. In column 1, we include an interaction of RegGap with with an indicator that is one if the observation is during the post Paris Agreement period (PostCOP21), whereas in columns 2 and 3, we add interactions with abnormally temperature (AbTemp) and carbon emission intensity (CEI), and with the aggregated climate risk-index, respectively. In Column 4, we add an interaction of RegGap with an indicator that is one if either the Tier 1 RWA is below 8% or the Total Capital Ratio is below 12% (not Well-Capitalized), whereas in columns 5 and 6 we add interactions with AbTemp and CEI, and with the composite climate risk-index. All continuous variables are standardized before being interacted with the All climate risk variables are standardized before being interacted with the capital deviation to facilitate the economic magnitude interpretation. In Panel A, we report the obtained regression coefficients. In Panel B, we report the implied adjustment speeds in the pre and post the Paris Agreement on climate change periods for banks highly vis-à-vis average and less exposed to climate risk, corresponding respectively with cases where the standardized CR-index takes on the value of 1, 0 and –1. *p*-values based on robust standard errors are shown in parentheses. Coefficients significantly different from zero at the 1%, 5% and 10% level are marked with ∗∗∗/ ∗∗/ ∗.

Panel 9A: Underlying results

	Paris Agreement (COP21)			Regulatory pressures		
	(1) ΔCAR	(2) ΔCAR	(3) ΔCAR	(4) ΔCAR	(5) ΔCAR	(6) ΔCAR
RegGap$_{ij,t-1}$	0.343***	0.355***	0.341***	0.423***	0.422***	0.418***
	(0.010)	(0.013)	(0.012)	(0.007)	(0.007)	(0.007)
RegGap$_{ij,t-1}$#**PostCOP21**$_{t-1}$	**0.100*** **	**0.078*** **	**0.089*** **			
	(0.012)	(0.014)	(0.013)			
RegGap$_{ij,t-1}$#AbTemp$_{t-1}$		0.023**			0.041***	
		(0.011)			(0.007)	
RegGap$_{ij,t-1}$#CEI$_{t-1}$		-0.010			0.020***	
		(0.011)			(0.006)	
RegGap$_{ij,t-1}$#CR-index$_{t-1}$			-0.003			0.042***
			(0.012)			(0.006)
RegGap$_{ij,t-1}$#AbTemp$_{t-1}$#**PostCOP21**$_{t-1}$		**-0.004**				
		(0.016)				
RegGap$_{ij,t-1}$#CEI$_{t-1}$#**PostCOP21**$_{t-1}$		**0.031*** **				
		(0.012)				
RegGap$_{ij,t-1}$#CR-index$_{t-1}$#**PostCOP21**$_{t-1}$			**0.033** **			
			(0.014)			
RegGap$_{ij,t-1}$#**RegPressure**$_{t-1}$				**-0.222*** **	**-0.264*** **	**-0.239*** **
				(0.035)	(0.033)	(0.031)
RegGap$_{ij,t-1}$#AbTemp$_{t-1}$#**RegPressure**$_{t-1}$					**-0.056**	
					(0.058)	
RegGap$_{ij,t-1}$#CEI$_{t-1}$#**RegPressure**$_{t-1}$					**0.050** **	
					(0.024)	
RegGap$_{ij,t-1}$#CR-index$_{t-1}$# **RegPressure**$_{t-1}$						**0.005**
						(0.041)

Observations	32,506	32,506	32,506	32,506	32,506	32,506
Number of Banks	4,606	4,606	4,606	4,606	4,606	4,606
Adjusted R-squared	0.350	0.351	0.351	0.350	0.354	0.354

Table 9B: Implied adjustment speeds according to the different scenarios

	CR-index= –1	**CR-index= 0**	**CR-index= 1**
Pre COP21	0.344	0.341	0.338
Post COP21	0.400	0.430	0.460
WellCapitalized	0.439	0.481	0.523
RegPressure	0.195	0.242	0.289

Table 10. Climate risk and capital adequacy ratio adjustment

This table reports the coefficient estimates for the following model: $\Delta Mechanism_{ij.t} = \lambda_0 + \beta_0 \text{CR–index}_{ij,t-1} + (\lambda_1 + \beta_1 \text{CR–index}_{ij,t-1}) RegGap^{+}_{ij,t-1} + (\lambda_2 + \beta_2 \text{CR–index}_{ij,t-1}) RegGap^{-}_{ij,t-1} + \delta X_{\text{ij},\text{t}-1} + \text{c}_\text{i} + \text{v}_\text{t} + \varepsilon_{i,t}$. $RegGap^{+}_{ij,t-1}$ (undercapitalized) denotes the value of the regulatory gap between the target and the lagged capital adequacy ratio when the bank is below its target and zero otherwise. $RegGap^{-}_{ij,t-1}$ (overcapitalized) refers to the value of the regulatory gap between the estimated target and the lagged capital adequacy ratio when the bank is above the desired target and zero otherwise. Δ*Tier 1* is the annual change in Tier 1 capital less current retained earnings divided by average assets. Δ*Loans*, Δ*Assets* and Δ*RWA* are, respectively, the annual changes in net loans (excluding interbank loans), total assets, and risk-weighted assets divided by average assets. We define average assets as (total assets at time *t*+total assets at time *t*−1)/2. Table 3 displays descriptive statistics and definitions for all the control variables. P-values based on robust standard errors are shown in parentheses. $*$, $**$, and $***$ indicate statistical significance at the 10%, 5%, and 1% level, respectively.

	(1) ΔTier1	(2) ΔLoans	(3) ΔAssets	(4) ΔRWA	(5) ΔTier1	(6) ΔLoans	(7) ΔAssets	(8) ΔRWA
$RegGap^{+}_{ij,t-1}$	0.875***	0.235	-0.278**	-0.307*	0.600***	0.337*	-0.160**	-0.423*
	(0.220)	(0.295)	(0.211)	(0.303)	(0.227)	(0.301)	(0.215)	(0.299)
$RegGap^{-}_{ij,t-1}$	0.676***	-0.830***	-0.426**	-0.105*	0.887***	-0.628**	-0.291**	0.098*
	(0.209)	(0.272)	(0.206)	(0.240)	(0.209)	(0.272)	(0.206)	(0.243)
$RegGap^{+}_{ij,t-1}$#**CR-index$_{t-1}$**	-0.050	-0.047	-0.002	-0.166***	-0.013	-0.042	-0.006	-0.140***
	(0.032)	(0.045)	(0.033)	(0.046)	(0.032)	(0.046)	(0.033)	(0.045)
$RegGap^{-}_{ij,t-1}$#**CR-index$_{t-1}$**	-0.073**	0.031	0.011	-0.267***	-0.093***	0.004	-0.011	-0.302***
	(0.032)	(0.044)	(0.031)	(0.039)	(0.032)	(0.044)	(0.031)	(0.039)
CR-index$_{t-1}$	-0.140**	-0.044*	0.176**	-0.060**	-1.132***	-1.077***	-1.074***	-1.411***
	(0.076)	(0.092)	(0.079)	(0.093)	(0.118)	(0.144)	(0.110)	(0.134)
LLProvisions$_{t-1}$					-11.051	-19.182	-16.307**	-4.217
					(8.349)	(12.575)	(8.103)	(9.698)
Deposit$_{t-1}$					15.653***	7.256**	9.201***	18.637***
					(2.382)	(3.191)	(2.726)	(2.975)
ΔGDP$_{t-1}$					-0.268***	-0.003	-0.386***	-0.326***
					(0.093)	(0.109)	(0.083)	(0.101)
Credit-to-GDP$_{t-1}$					0.011	-0.106***	-0.079***	-0.027
					(0.014)	(0.018)	(0.013)	(0.017)
InterTrade$_{t-1}$					0.217***	0.173***	0.222***	0.147***
					(0.028)	(0.039)	(0.029)	(0.037)
OilRent$_{t-1}$					-2.512***	-1.948***	-1.863***	-0.891***
					(0.149)	(0.230)	(0.163)	(0.200)
Constant	5.126***	3.675***	3.210***	3.205***	-15.541***	4.791	-2.345	-9.376**
	(0.499)	(0.594)	(0.439)	(0.587)	(3.283)	(4.238)	(3.372)	(4.418)
Observations	28,881	32,489	32,506	30,142	28,252	31,819	31,823	29,511
Number of Banks	4,365	4,603	4,606	4,432	4,274	4,512	4,512	4,341
Bank FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R-squared	0.090	0.056	0.087	0.112	0.192	0.161	0.175	0.171

Table 11. Climate risk and capital adequacy ratio adjustment: effect of the COP21

This table shows the estimation results of the following model: $\Delta Mechanism_{ij.t} = \lambda_0 + \beta_0\text{CR–index}_{ij,t-1} + (\lambda_1 + \beta_1\text{CR–index}_{ij,t-1})RegGap^{+}_{ij,t-1} + (\lambda_2 + \beta_2\text{CR–index}_{ij,t-1})RegGap^{-}_{ij,t-1} + \delta X_{\text{ij,t}-1} + \text{c}_\text{i} + \text{v}_\text{t} + \varepsilon_{i,t}$ on the effect of the COP21. $RegGap^{+}_{ij,t-1}$ (undercapitalized) denotes the value of the regulatory gap between the target and the lagged capital adequacy ratio when the bank is below its target and zero otherwise. $RegGap^{-}_{ij,t-1}$ (overcapitalized) refers to the value of the regulatory gap between the estimated target and the lagged capital adequacy ratio when the bank is above the desired target and zero otherwise. Δ*Tier 1* is the annual change in Tier 1 capital less current retained earnings divided by average assets. Δ*Loans*, Δ*Assets* and Δ*RWA* are, respectively, the annual changes in net loans (excluding interbank loans), total assets, and risk-weighted assets divided by average assets. We define average assets as (total assets at time *t*+total assets at time *t*−1)/2. This table compares the capital dynamics of banks over the pre-COP21 (pre- Paris Agreement) and the post-COP21 (post Paris Agreement) periods. The post-COP21 corresponds to the subperiod (2015–2021) when European countries' governments ratified the Paris Agreement and committed to take part in the legally binding international accords on climate change. Table 3 displays descriptive statistics and definitions for all the control variables. P-values based on robust standard errors are shown in parentheses. $*$, $**$, and $***$ indicate statistical significance at the 10%, 5%, and 1% level, respectively.

	Pre COP21				Post COP21			
	(1) ΔTier1	(2) ΔLoans	(3) ΔAssets	(4) ΔRWA	(1) ΔTier1	(2) ΔLoans	(3) ΔAssets	(4) ΔRWA
$RegGap^{+}_{ij,t-1}$	2.883***	1.088*	0.239	-0.489	0.388	0.111	-0.679**	-0.631
	(0.461)	(0.643)	(0.361)	(0.707)	(0.359)	(0.440)	(0.304)	(0.434)
$RegGap^{-}_{ij,t-1}$	-0.765	-0.279	0.232	-1.084**	1.411***	-0.983**	-0.347	0.100
	(0.495)	(0.485)	(0.397)	(0.470)	(0.284)	(0.384)	(0.279)	(0.317)
$RegGap^{+}_{ij,t-1}$#**CR-index$_{t-1}$**	**-0.237*** **	**-0.182* **	-0.088	-0.173	0.019	0.000	0.070	**-0.184* **
	(0.088)	(0.111)	(0.066)	(0.118)	(0.048)	(0.064)	(0.044)	(0.062)
$RegGap^{-}_{ij,t-1}$#**CR-index$_{t-1}$**	**0.325*** **	-0.068	**-0.145* **	-0.124	**-0.164*** **	0.050	-0.003	**-0.340*** **
	(0.111)	(0.091)	(0.078)	(0.082)	(0.040)	(0.056)	(0.039)	(0.046)
CR-index$_{t-1}$	-1.431***	-1.682***	-1.452***	-1.475***	-0.617***	-0.847***	-1.094***	-1.461***
	(0.330)	(0.316)	(0.225)	(0.324)	(0.131)	(0.179)	(0.129)	(0.159)
LLProvisions$_{t-1}$	-9.825	-59.461**	-37.678**	-38.889	-10.761	-8.708	-8.028	-0.096
	(32.329)	(24.856)	(19.008)	(28.011)	(8.699)	(13.890)	(8.367)	(10.894)
Deposit$_{t-1}$	0.752	10.275	20.664***	8.904	16.595***	-2.587	2.351	18.621***
	(6.069)	(7.090)	(4.971)	(6.220)	(3.153)	(4.964)	(4.129)	(4.129)
ΔGDP$_{t-1}$	0.763***	0.874***	0.554***	0.608***	-0.443***	-0.497***	-0.665***	-0.650***
	(0.196)	(0.175)	(0.112)	(0.157)	(0.133)	(0.156)	(0.125)	(0.152)
Credit-to-GDP$_{t-1}$	0.097**	-0.127***	-0.026	-0.041	0.098***	-0.056**	-0.053**	0.018
	(0.039)	(0.027)	(0.020)	(0.033)	(0.020)	(0.025)	(0.021)	(0.022)
InterTrade$_{t-1}$	0.421***	0.377***	0.256***	0.194***	0.293***	0.260***	0.314***	0.293***
	(0.071)	(0.070)	(0.045)	(0.063)	(0.044)	(0.062)	(0.043)	(0.050)
OilRent$_{t-1}$	-1.257*	-1.617**	-0.357	-1.308**	-2.090***	-1.890***	-1.969***	-0.702***
	(0.677)	(0.718)	(0.579)	(0.600)	(0.163)	(0.276)	(0.186)	(0.234)
Constant	-39.026***	-19.442**	-24.680***	-10.719	-33.916***	-2.312	-6.806	-25.080***
	(8.420)	(8.030)	(5.327)	(7.597)	(4.817)	(6.713)	(5.020)	(5.949)
Observations	7,022	8,791	8,792	7,642	21,230	23,028	23,031	21,869
Number of Banks	4,274	4,512	4,512	4,341	4,274	4,512	4,512	4,341
Bank FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R-squared	0.118	0.124	0.124	0.163	0.098	0.050	0.065	0.191

Table 12. Non-linearities in the speed of adjustment: asymmetric response to climate risk

The table provides evidence of whether the climate risk factors of heterogeneity in the speed of adjustment vary with the magnitude and the sign of the RegGap (i.e., is asymmetric). To that end, we estimate the following equation: $\Delta CAR_{ij,t} = (\lambda_1 + \beta_1 Z_{jt-1}) RegGap^{+}_{ij,t-1} + (\lambda_2 + \beta_2 Z_{jt-1}) RegGap^{-}_{ij,t-1} + \eta_{ij,t}$. The dependent variable is the change in the capital adequacy ratio, which is regressed on the regulatory gap (deviation between the estimated target and the lagged value of the capital adequacy ratio) and interactions of the regulatory gap with other climate risk measure captured by Z_{jt-1}. $RegGap^{+}_{ij,t-1}$ corresponds to the situation when bank has regulatory capital shortfall, it takes value of one if the bank's actual capital adequacy ratio is below the target capital ratio, and zero otherwise. $RegGap^{-}_{ij,t-1}$ corresponds to the situation when bank has regulatory capital surplus, is take one if the bank's actual capital adequacy ratio is above the target capital ratio, and zero otherwise. P-values based on robust standard errors. Coefficients significantly different from zero at the 1%, 5% and 10% level are marked with ***, **, *.

In column 1, we estimate a constrained version of the above equation. We show results for a sample of listed European banks over the 2006–2021 period. In column (2), we include as interaction variables: the abnormal hot temperature (AbTemp) and the carbon emission intensity (CEI). In column 3, we use a composite indicator of these two dimensions of climate risk.

	(1) ΔCAR	(2) ΔCAR	(3) ΔCAR
$RegGap^{+}_{ij,t-1}$	0.414***	0.252***	0.299***
	(0.008)	(0.051)	(0.024)
$RegGap^{-}_{ij,t-1}$	0.411***	0.209***	0.300***
	(0.009)	(0.064)	(0.023)
$RegGap^{+}_{ij,t-1}$#**AbTemp**$_{t-1}$		**0.095*****	
		(0.019)	
$RegGap^{-}_{ij,t-1}$#**AbTemp**$_{t-1}$		**0.074*****	
		(0.024)	
$RegGap^{+}_{ij,t-1}$#**CEI**$_{t-1}$		**0.010****	
		(0.004)	
$RegGap^{-}_{ij,t-1}$#**CEI**$_{t-1}$		**0.014*****	
		(0.005)	
$RegGap^{+}_{ij,t-1}$#**CR-index**$_{t-1}$			**0.018*****
			(0.004)
$RegGap^{-}_{ij,t-1}$#**CR-index**$_{t-1}$			**0.018*****
			(0.004)
Observations	32,506	32,506	32,506
Adjusted R-squared	0.331	0.334	0.334

Table 13. Non-linearities in the speed of adjustment: additional evidence

The table reports the results of the estimation of the following equation: $\Delta CAR_{\text{ij,t}} = (\lambda_1 + \beta_1 \text{CR-index}_{jt-1}) RegGap^{+}_{ij,t-1} + (\lambda_2 + \beta_2 \text{CR-index}_{jt-1}) RegGap^{-}_{ij,t-1} + \eta_{\text{ij,t}}$, using alternative sample selection criteria. Model in column (1) uses small European banks with total assets lower then \$10millions. Model in column (2) includes large European banks with total banks higher than \$10millions banks. Model in column (3) considers listed European banks. Model in column (4) includes the most undercapitalised (i.e. largest positive RegGap) and the most overcapitalised (i.e. largest negative RegGap) European banks. Model in column (5) consider the pre-COP21 subperiod, model in column (6) uses the pre-COP21 subperiod and model (7) excludes the Covid-19 crisis that covers the 2020-2021 period. In model (8), we exclude the top 5 countries responsible for climate change and largest countries based on the cumulative CO2 emissions from fossil fuels, land use and forestry, according to carbonbrief.org. Namely: Russia, Germany, UK, Ukraine and France. Robust standard errors are reported in parentheses below their coefficient estimates and adjusted for both heteroskedasticity and within correlation. ***, **, and * indicate significance of the p-value respectively at the 1%, 5%, and 10% levels.

	Small banks: Assets<\$10millions	Large banks: Assets≥\$10millions	Listed banks	The most under- and overcapitalised banks	Pre COP21	Post COP1	Covid-19 crisis excluded	Excluding top 5 carbon-based economies
	(1) ΔCAR	(2) ΔCAR	(3) ΔCAR	(4) ΔCAR	(5) ΔCAR	(6) ΔCAR	(7) ΔCAR	(8) ΔCAR
$RegGap^{+}_{ij,t-1}$	0.423***	0.353***	0.487***	0.405***	0.313***	0.449***	0.411***	0.417***
	(0.009)	(0.016)	(0.017)	(0.008)	(0.016)	(0.010)	(0.008)	(0.013)
$RegGap^{-}_{ij,t-1}$	0.415***	0.324***	0.458***	0.408***	0.379***	0.412***	0.414***	0.393***
	(0.009)	(0.034)	(0.025)	(0.009)	(0.017)	(0.010)	(0.009)	(0.020)
$RegGap^{+}_{ij,t-1}$**#CR-index$_{t-1}$**	**0.030*****	**0.036****	**0.085*****	**0.042*****	**-0.015**	**0.017**	**0.043*****	**0.029****
	(0.010)	(0.017)	(0.017)	(0.009)	(0.015)	(0.012)	(0.009)	(0.013)
$RegGap^{-}_{ij,t-1}$**#CR-index$_{t-1}$**	**0.041*****	**-0.033**	**0.047***	**0.038*****	**0.008**	**0.041*****	**0.039*****	**0.002***
	(0.009)	(0.027)	(0.024)	(0.008)	(0.021)	(0.009)	(0.009)	(0.010)
Observations	25,220	7,284	5,016	12,983	19,167	13,339	30,125	15,643
Adjusted R-squared	0.352	0.243	0.375	0.413	0.297	0.349	0.289	0.298