Boiling Banks - How Heat Harms Bank Performance *

Steffen Vollmar
University of Münster †

Fabian Wening
University of Münster ‡

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In the face of rising temperatures and increasingly extreme weather events, we examine how local heat waves affect bank performance. We exploit an institutional setting in Germany, which limits the operations of small and medium sized banks geographically, to identify the regional effect of high temperatures. Our results are based on daily and hourly weather station observations and show that heat reduces the performance of regional banks significantly. Further analyses taking the composition of the local economy into account suggest that reduced productivity of bank clients causes the decline in performance. The results suggest that physical climate risks threaten the business model of local banks, endangering financial stability at large.

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†. Corresponding author: Steffen Vollmar, University of Münster, Universitätsstraße 14-16, 48143 Münster, Germany, Email: steffen.vollmar@wiwi.uni-muenster.de.

‡. Fabian Wening, University of Münster, Universitätsstraße 14-16, 48143 Münster, Germany, Email: fabian.wening@wiwi.uni-muenster.de.

1 Introduction

Global mean temperatures have risen in recent decades, and climate scientists predict a further significant increase with difficult-to-predict swings (NASA, 2023). The Intergovernmental Panel on Climate Change predicts with increasing certainty that the intensity and frequency of climate-related events, such as heat waves, will continue to increase throughout the 21st century (IPCC, 2019). Despite being less salient than other physical climate risk realizations like hurricanes and rising sea levels, heat waves are hazardous for humans and are estimated to become the most costly for developed economies (Hsiang et al., 2017; Acharya et al., 2022). Economists have identified negative financial consequences from high temperatures for companies worldwide (Pankratz et al., 2023), and there is a growing consensus among global and national financial authorities that climate change-related financial losses pose a major threat to financial stability (Baudino and Svoronos, 2021). In Diamond's (1984) model of modern banking theory, it is optimal for financial intermediaries to eradicate all hedge able risks, but traditional commercial banks are forced to take on geographical climate risks in full as they cannot evade regionally limited operations without losing locally gained information advantages.

Accordingly, this paper analyzes the effect of heat stress on banks that are regionally restricted by law in their core business of traditional borrowing and lending activities. We use balance sheet information from non-listed, local banks and empirically analyze the effect of hot temperature extremes on bank profitability. Our empirical results based on daily and hourly temperature data from national weather stations show that heat significantly reduces regional banks' performance. Further analyses take into account the share of the local domestic product, the numbers of employed people, and the different vulnerability to high temperatures across industries and reveal that the reduced productivity of bank clients can explain the reduction in bank performance. To the best of our knowledge, this is the first paper to focus on heat stress's impact on bank profitability, particularly this banking group, which is essential for financing private households and small and medium enterprises (DeYoung et al., 2004; Hasan et al., 2017). Local and regional banks play a crucial role in the European banking system. But also, the US and

UK, with a stronger focus on access to financial markets than on intermediaries, have created financial institutions for community development (Allen and Gale, 1995; Hakenes et al., 2015). An individual analysis is essential, as past studies reveal the tremendous threat of natural disasters on (local) banks (Klomp, 2014; Wang, 2023).

The ten warmest years since records began have all occurred after 2010. This is just a preview of what is to come with the predicted increasing frequency of temperature extremes. (National Centers for Environmental Information, 2023). Among physical climate risks, heat stress already contributes most to economic losses in the United States (Acharya et al., 2022). Furthermore, Hsiang et al. (2017) estimate that towards the year 2100, direct damage caused from heat in form of rising energy expenses, excess mortality, and dropping labor productivity will account for several percentage points of GDP. Accordingly, a growing economic literature strand investigates potential adverse effects of high extreme temperatures.

The economic research on climate change has revealed a globally negative relationship between high temperatures and aggregate economic output, particularly in developing countries (Dell et al., 2012; Burke et al., 2015). One economic explanation is that extreme temperatures are linked to lower crop gains in agriculture and industrial output in further sectors (Auffhammer et al., 2006; Jones and Olken, 2010). Another explanation might be the negative impact on labor productivity (Hsiang, 2010). When heat is generated inside the human body by physical activity, it must be dissipated to maintain the core temperature. If this becomes infeasible in the work environment, it is necessary to limit the workload (International Organization for Standardization, 1989). Adverse effects are not limited to physical activities; e.g., early field experiments by Mackworth (1946) show that hearing and recording accuracy are seriously affected inside hot rooms. Physiological and epidemiological studies confirm negative consequences from heat on workers' health and physical as well as cognitive productivity (for meta-reviews see: Pilcher et al., 2002; Acharya et al., 2018). Accelerated by climate change, extreme temperatures affect the marginal productivity of labor in heat-exposed sectors such as construction, agriculture, and manufacturing (Graff-Zivin and Neidell, 2014). Research on how heat stress affects performance at the company-level initially targeted small, unlisted companies in developing nations (Pankratz et al., 2023). For example, Somanathan et al. (2021) provide evidence that productivity losses of Indian firms due to workers' increased absenteeism on hotter days result in negative annual plant capacity of about two percent per degree Celsius. Zhang et al. (2018) show further adverse effects of high temperatures on productivity using data from half a million Chinese manufacturing plants. Addoum et al. (2020) were the first to study how exposure to abnormal temperatures impact corporate performance in the United States. They find no evidence that high (or low) extreme temperatures impact establishment sales or production, even for industries classified as "heat exposed". These findings may indicate greater resilience to weather extremes by companies in the industrialized world. However, Pankratz et al. (2023) demonstrate a significant negative effect of expanded exposure to extreme heat on firms' revenues and operating income across an extensive sample of developed countries. In addition to the economic channels of increased labor input, the results also point to rising costs of goods sold and general, selling, and administrative expenditures that rising energy costs for cooling could cause. More recently, Addoum et al. (2023) show the bi-directional effects of extreme temperatures on earnings in various United States' industrial sectors during the four seasons. Inter alia, their results indicate that hot summers reduce firms' earnings in several industries and provide further evidence for heat-induced labor losses.

Evaluating financial risks for assets and business models induced by climate changes requires deep knowledge of technically demanding climate change models and scenario simulations (Fiedler et al., 2021). Although data on temperature is publicly available, investors' assessment of the primary financial loss channel of climate change may be delayed or incomplete. A concurrent study by Acharya et al. (2022) indicates that S&P 500 stocks reflect pricing of higher heat stress exposure only since 2013. Addoum et al. (2023) show investors' and analysts' delayed reactions to observable extreme temperature shocks in the United States. Pankratz et al. (2023) document that capital market participants do not fully anticipate the financial threat of heat on firm performance across countries. Growing concerns about the markets' revaluation of assets stowed on bank balance sheets have prompted regulators and central banks to investigate whether climate change risk threatens financial stability. Acharya et al. (2023) state that in addition to adverse shifts in banks' asset portfolios (market risks), physical climate risks might affect banks' loan portfolios (credit risk). They argue that losses due to climate risk realizations typically materialize over a medium-long time horizon, which exceeds the average maturity of bank loans and, therefore, are unlikely to lead to a borrowers' default. Nevertheless, climate change is shaping bank lending. De Marco and Limodio (2023) show that high temperature fluctuations reduce mortgage lending through the deterioration of house prices in affected areas. Meisenzahl's (2023) supervisory data analysis demonstrates that large banks significantly reduce lending to borrowers in regions more exposed to physical climate risk. Acharya et al. (2023) assume that even if single loan repayments are not jeopardized, banks' profitability and franchise value could fall due to reduced borrowers' cash flows in the near future. To minimize their physical climate risk exposure, (large) banks could diversify their customer portfolio geographically. By contrast, small local and regional banks generally depend on the informational advantage they have gained in regional borrowing and lending activities in their localized business areas (Hakenes et al., 2015). These non-listed banks are essential for financing small and medium-sized enterprises and ensuring regional economic growth and stability, especially during crisis times (Berger and Udell, 1995; Alessandrini et al., 2010; Puri et al., 2011). As recent studies have shown, heat waves might negatively affect borrowers' collateral, such as land or equipment (Islam and Singh, 2022), and raise energy expenditures and labor input (Acharya et al., 2022; Acharya et al., 2023), which thus might threaten the financial health of the local financial institutions' customer base. However, research on the climate vulnerability of non-listed banks is scarce, hampered by the general hurdle that established market-based approaches cannot be applied (see Engle et al., 2023).

Our paper contributes to the new climate finance literature strand on heat exposure and firm performance outcomes by focusing on financial institutions' profitability. Exploiting a unique institutional setting and bank-specific exposures to local industry compositions, we are able to analyze the impact of varying high temperatures on banks' actual profits. Our study connects climate science with policy implications by pointing out disadvantages for regions. Our results suggest that physical climate risk endangers the business model of all companies geographically bounded to heat-affected regions. We also contribute to the literature strand of regional banks emphasizing the critical role of those banks for economic growth and the threat physical climate risk pose to the financial stability as it threatened local banks' business model.

The structure of the paper is as follows. In Section 2, we present our data set and define key variables. Section 3 provides the results of the main analyses while Section 4 continues with further robustness checks. Section 5 concludes.

2 Research Design and Methodology

2.1 Data Sources and Sample Selection

As previously outlined, we focus on the impact of hot temperatures through their effects on the local economy on regionally restricted banks. To this end, we collect data from various data sources, including information on banks, weather and climate, and regional as well as national economic conditions. This section describes our data sources and explains the variable selection.

We derive balance sheet and income statement data from the database *Fitch Connect* for German banks with (legally) limited business areas. Our sample comprises a comprehensive data set of 1,900 savings and cooperative banks from 2001–2021. Together, these (typically) small and unlisted financial institutions hold 45% of all national retail deposits and are responsible for granting almost half of the German banking sectors' total loans to households and firms (Deutsche Bundesbank, 2021). Both banking groups have a similar business profile and are limited by law or statute in their business region to the immediate vicinity of their headquarters (for a detailed explanation, see Hakenes et al., 2015). Therefore, it is unfeasible for individual banks to diversify geographically. Moreover, a subsample of 533 cooperative banks (so called "Raiffeisen Banken") were founded primarily for agricultural businesses in the early 19th century and still maintain a strong customer relationship with these companies today. The regional customer deposit business is essential for both banking groups (Fecht et al., 2019) because the reliably low remuneration of current deposits accounts for a significant portion of the net interest income of these banks and compensates for the payment and liquidity services provided to retail customers (Busch and Memmel, 2021).

We adjust the sample for institutions that differ from their peers in terms of business model[1] and the final sample comprises 533 savings and 1,338 cooperative banks. Because both banking groups are geographically restricted, those banks' business area is generally limited to one or two German counties[2]. We assigned the primary business county to the bank based on the address of the headquarter. Figure 1 plots the location of the headquarters of all banks in our final data set.

Figure 1 about here.

Banks included in the data set represent, on average, 98.88% of the savings and 85.26% of the cooperative banking sector in Germany spread across the entire country[3], with the federal states of the former German Democratic Republic having fewer institutions compared to states in West Germany (see Table A1 for a more detailed breakdown).

To measure banks' exposure to heat, we use temperature data from the German Weather Service (DWD)[4]. We collect daily temperature data from German weather stations from 1981 onward, as well as hourly temperature data from 2006 onward. We remove stations in inaccessible regions, such as at sea or on mountains, as well as data from weather stations with less than 350 observation days per year. We end up with daily maximum temperature data from 693 stations, with an average of 462 active stations per year, and hourly temperature data from 544 stations, with an average of 497 reporting stations per year[5]. Figure 2 plots the location of all weather stations that reported the maximum temperature at some time within our observation period from 2001 to 2021.

Figure 2 about here.

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1. This includes umbrella organizations and cooperative banks with a limited focus on certain professional groups or social projects.

2. In this paper, we work with data at the level of German counties, divided according to the NUTS-3 classification. The NUTS-3 code is a geographic code unique to each German county. In Germany, the first digit of the code indicates the federal state (NUTS-1), the second digit the administrative region (NUTS-2), and the third digit the independent cities and counties (NUTS-3) (Statistisches Bundesamt, 2023).

3. Due to numerous mergers, the number of single institutions steadily decreases towards the end of the period under review.

4. The DWD is the German government weather service with about 500 weather stations evenly distributed over Germany.

5. See Table A2 for a detailed list of the number of reporting stations in each year

To match data from weather stations and banks, we search the addresses of given longitudes and latitudes of the weather stations and assign them to the corresponding county (again based on the NUTS-3 classification). For counties with multiple active weather stations in a year, we average the data, and for counties without a single reporting weather station, we assign them the average value of the adjacent counties. Figure 3 shows the number of days above 30°C in 2017 and 2018. The figure visualizes the rough temperature pattern for Germany with higher temperatures and, therefore, more heat days, stretching from the southwest to the northeast counties, while regions near the coast rarely observe days above 30°C. Figure B2 shows the days above 30°C for all years between 2001 and 2021. This cross-year overview illustrates the first consequences of climate change, with heat waves varying over the years and expanding in different regions.

Figure 3 about here.

Heat does not affect all industries equally; physical work is significantly more affected by heat than non-physical work, whether outdoors, as in agriculture or construction, or indoors, as in manufacturing (Addoum et al., 2023; Xia et al., 2018; Szewczyk et al., 2021; Takakura et al., 2018). The same applies to particularly negatively affected yields in the agricultural and forestry sectors (Trenczek et al., 2022) and potential additional energy costs in other sectors (Acharya et al., 2022). We argue that the negative impact of heat on the local economy and individual industries has a knock-on effect on regional banks, as they have people and businesses from the region as customers and generate revenue from them. Due to these differences in exposure to heat, it is essential in our analysis to control for the local industry distribution, as banks in regions with a high proportion of heat-sensitive businesses might bear a higher risk. Therefore, we collect data on the share of nominal GDP in each sector as well as the number of deployed people in these sectors to measure the exposure the local industry distribution represents for the banks.

We also use established bank-specific control variables in our analysis to distinguish the effects of heat from other effects. To this end, we collect data for inflation and the interest rate environment for our observation period from 2001 to 2021. German savings banks and cooperative banks merged during the observation period. To separate the balance sheet changes attributable to these mergers from other effects, we create a dummy variable that is one if the bank merged in the corresponding year and zero otherwise. The absorbed institutes remain in the data set as long as they are active on the market.

2.2 Heat Measures and Metrics for Heat Exposure

To examine the relationship between extreme heat temperatures and the performance of regional banks, we are using different heat measures (HM). Each measure is collected for each county c in Germany and each year t between 2001 and 2021.

$$\mathrm{HM}_{c,t} := \text{Heat Measure}_{c,t}$$

Studies worldwide show that working productivity decreases starting at temperatures above 25°C and with increasing rates at temperatures above 30°C (Seppänen et al., 2003; Kjellstrom et al., 2009). Further Schlenker and Roberts (2006; 2009) indicated temperatures above 30°C also harm agriculture and cause harvest losses. Therefore, we use 30°C as the threshold to distinguish between “normal” temperatures and “heat”. As concrete heat measures for a county, we are using the number of days per year with a reported maximum temperature above 30°C, and from 2006 onward also the number of hours above 30°C per year.

Some workers and companies might partially adapt to repetitive hot temperatures by shifting work times. Therefore, in addition to the absolute temperature, the decisive factor might be whether this temperature was to be expected for the time of year at a particular location. We classify days with temperatures above 30°C as extreme if the maximum temperature is unusual for the county and time of year. To assess whether the observed temperature on the day is extreme, we follow the approach of Perkins and Alexander (2013) and Pankratz et al. (2023) and build a historical temperature distribution of the maximum temperatures for each county. To construct this temperature distribution for a specific date, we collect data on the maximum temperature on the date, as well as the previous and subsequent five days of the 20 years prior to our observation period (i.e., from 1981 to 2000). We calculate the 90 percent quantile of this temperature distribution and classify a day as extreme if the maximum temperature of a given day exceeds this thresholds.

To control for the knock-on effect of the structure of the local economy, we construct a measure for the heat exposure (HE) in county c and year t by multiplying the heat measure with a measure of the vulnerability of the county's economy to heat.

$$\mathrm{HE}_{c,t} = \text{Heat Measure}_{c,t} \cdot \text{Affected Local Industry}_{c,t}$$

We construct the affected local industry index $I_{c,t}$ in county c and year t according to the formula:

$$I_{c,t} := \sum_{i=1}^{n} \left(w_i \cdot \frac{\mathrm{GDP}_{i,c,t}}{2 \cdot \sum_{i=1}^{n} \mathrm{GDP}_{i,c,t}} + w_i \cdot \frac{\#\mathrm{Worker}_{i,c,t}}{2 \cdot \sum_{i=1}^{n} \#\mathrm{Worker}_{i,c,t}} \right) \tag{2.1}$$

where $\mathrm{GDP}_{i,c,t}$ is the nominal GDP that the county c generates in the year t in industry sector i and $\#\mathrm{Worker}_{i,c,t}$ is the number of workers that work in sector i of the county. $w_i \in [0, 1]$ are non-adjustment factors of industry sector i measuring the inability of the sector to adapt to rising temperatures (see Table 1).

Table 1 about here.

These non-adjustment factors can be interpreted as follows: A number close to zero indicates that the effects of heat can be partially compensated by the sector, for example, with cooling systems[6] or heat prevention measures in office buildings. A one, on the other side, means that the effects of heat cannot be compensated at all, for example, in agriculture. These non-adjustment factors are derived especially for Germany by Trenczek et al. (2022) on behalf of the government as a result of the hottest years at that time, 2018 and 2019. Figure 4 shows the calculated exposures of equation 2.1 for the GDP and number of workers for each German county. It is particularly noticeable from workers' exposure that cities and urban regions are significantly less susceptible to heat than rural

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[6] Electricity prices for industrial consumers in Germany mostly exceeded the OECD average within our observation period (Sachverständigenrat, 2023). Although implementing air conditioning systems boosts working productivity, it is only possible at increased costs with unclear overall efficiency (Trenczek et al., 2022).

regions. This observation was to be expected given the greater importance of the service sector with its lower non-adaptation factors in these regions (compare Table 1).

Figure 4 about here.

Table 2 reports descriptive values of bank and macroeconomic variables and temperature measures over the observation period from 2001 to 2021. The first part shows the mean, standard deviation, median, first and third quartiles, and the one and ninety-ninth quantile for key bank variables. The second part presents the same characteristics for key macroeconomic variables, and the third part shows the characteristics of the observed temperatures and calculated heat exposure indices.

Table 2 about here.

On average, we observe 9.5 days and 40 hours with a temperature above 30°C, which results in an exposure to heat of 5.38 and 23.04, respectively. In the case of the heat measures, the large standard deviation should be noted, with the 99th percentile being about four times bigger than the median. As already suspected from graph 3, there are significant geographical differences in addition to temperature variations over the years. For example, regions in the southwest and east of Germany have, on average, about three more heat days than the rest of Germany[7]. As the extreme days measure the unexpected heat days in a year, we have on average 8 “unexpected” heat days for the 90th percentile and 6.7 in the case of the 95th percentile.

2.3 Methodology

We perform three steps to identify the effects of heat on regional banks. In a first step, we are examining whether heat generally affects banks’ profitability. This impact can stem from physical factors as well as knock-on effects from the local economy. In the next step, we investigate the possible transmission effect in more detail by controlling for the composition of the local economy via our heat exposures in addition to hot temperature

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[7] The mean heat days for the states of Baden-Württemberg, Rhineland-Palatinate, Saarland, Saxony, Brandenburg, and Berlin is 11.47 while the other states have an average of 8.57 heat days.

extremes. Finally, we test how different levels of exposure to extreme temperatures interact with the heat vulnerability of the local industry in a bank's business area.

In the first step, we estimate the coefficients of the following formula with a panel OLS regression

$$\text{Bank Profitability}_{b,c,t} = \alpha_b + \beta_{\text{heat}}\,\text{HM}_{c,t} + \beta_{\text{control}}\,X_{b,c,t} + \varepsilon_{b,t}, \tag{2.2}$$

with $HM_{c,t}$ as the corresponding heat measure for the business area of the bank in year t. In the second step, we exchange the heat measure with the calculated heat exposure index for the business area of the bank:

$$\text{Bank Profitability}_{b,c,t} = \alpha_b + \beta_{\text{heat}}\,\text{HE}_{c,t} + \beta_{\text{control}}\,X_{b,c,t} + \varepsilon_{b,t}. \tag{2.3}$$

We measure the profitability of a bank by using the standard variables return on assets (ROA) (García-Herrero et al., 2009; Heggestad, 1977; Bourke, 1989) In both regression models (2.2; 2.3), we control for several covariates. For the size of the bank, we include the logarithm of total assets, for the capital and liquidity structure we use the share of equity and liquidity of total assets; and for the bank's efficiency the cost-to-income ratio. Further, we consider the bank's risk by including the losses from non-performing loans and the loan growth in our regressions. We also include a dummy variable, which is one if the bank has merged in a given year and zero otherwise. The literature identifies these variables to drive bank performance (Iannotta et al., 2007; Heidinger and Gatzert, 2018; Berger and Bouwman, 2013). Like Dietrich and Wanzenried (2011) and Borio et al. (2017) we also control for macroeconomic variables like the nominal GDP growth, the inflation rate, the interest rate environment, and the years of the global financial crisis.

A unique feature of savings and cooperative banks is that their business area is predetermined and limited due to their historical and institutional origins. Building on this condition, we examine how the vulnerability of the local industry (according to Equation 2.1) interacts with the number of heat days. We estimate an OLS regression that interacts the number of classified heat days in a bank's business area with the vulnerability of the local industry that makes a bank more or less prone to heat stress:

$$\begin{aligned}\text{Bank Profitability}_{b,c,t} = \alpha + \beta_{\text{Ind}}\, I_{c,t} + \beta_{\text{Terc}}\, \text{HeatDayTercile}_b \\ + \beta_{\text{Ind}\times\text{Terc}}\, I_{c,t} \times \text{HeatDayTercile}_b + \varepsilon_{b,t},\end{aligned} \tag{2.4}$$

where the profitability of a bank b in county c at year t is as defined as above. We divide banks into heat percentiles based on the observed classified hot days in their business area. We include tercile indicators in our regression for banks in the second tercile, which correspond with a medium heat risk, and for banks with a high heat risk in the third tercile. We are especially interested in the tercile indicators' interaction with the business area's predetermined heat vulnerability $I_{c,t}$. The close comparison of these terms to one another speaks to how critical hot temperatures are versus how vulnerable bank customers and their businesses are towards heat stress.

3 Results

3.1 Heat Impact on Bank Performance

We start by examining the general impact of heat on banks' profitability. Table 3 reports our results for the banks' profitability measured by the return on assets (ROA) for equation 2.2. As described in Section 2.2 we are using the number of days with a maximum temperature above 30°C (heat days), the number of hours above this threshold (heat hours), and the number of days with temperatures above the 90th quantile of the historic temperature distribution for that day (deviation days), as explanatory variables. We also include the in Section 2.1 introduced control variables to account for the influences of other known factors on the ROA.

Table 3 about here.

The results show a significant negative relationship between heat and regional bank profitability independent of the used measurement. For example, a bank's ROA is reduced by 0.0011 percentage points for each day in a year with a maximum temperature above 30°C. Taking into account the average ROA of 0.24 percent over the observation period; this reduction means that a bank observing ten heat days has a ROA that is about 4.5% lower than a bank observing no heat days. With climate forecasts like IPCC (2019) predicting an increase in heat days in the future, this difference between banks can threaten the competitiveness and existence of regional banks. The coefficient for deviation days is smaller as not all heat days are also deviation days. Because, on average, each heat day has 4.3 hours above 30°C we observe a smaller impact on the ROA per heat hour, but the result is in line with the one for the number of heat days.

The results for the bank-specific and macroeconomic control variables are consistent with expectations from the literature and economic theory. However, the liquidity share of banks does not significantly affect the ROA. This fact may be explained by the relative homogeneity of our data set, as all banks have the same business model. Because of the different observation periods (2006–2021 for heat hours and 2001–2022 for heat days and deviation days), we find different results between the measures for some variables. For example, the loan growth variable is insignificant if we use the number of hours above 30°C to measure heat, while the merger variable is significant at the 1% level.

Overall, our results for equation 2.2 in Table 4 indicate that banks operating at a regional level are indeed negatively affected by high temperatures and banks in warmer regions are less profitable compared to banks in colder regions.

3.2 Enhancing Effects of the Local Economy

Our results so far reveal that heat significantly reduces the performance of local banks, as banks more exposed to heat are less profitable compared to less exposed banks. There are various reasons for the negative impact of hot temperatures on bank performance. First, banks are affected by the direct negative effects of heat shown in Addoum et al. (2023) and Pankratz et al. (2023) in the form of higher energy costs for cooling and lower productivity of employees. However, as a traditional service provider, these effects should affect banks to a much lesser extent. Therefore, we argue that the shown negative impact of heat on banks' profitability is indirectly through their customers because local banks work with the people and businesses in their business area. If these are less profitable due to heat, this lower profitability is transferred to the bank and, therefore, banks in hotter regions report lower profits than comparable banks in areas less affected by heat. This transmission takes place in various ways. For one, there is a clear correlation between the number of heat-related deaths (see Figure B1) and the number of heat days (see Figure B2) observed in a year (for example, the years with the most heat days 2003, 2018, and 2019 also have the most heat-related deaths). Therefore, the strong variation in heat between years and geographic regions affects individual banks to varying degrees as customer deaths generally reduce bank profits.

Another reason is the strong correlation between heat and crop yields. As Schlenker and Roberts (2009) showed, temperatures above 30°C are harmful to plant growth. Our correlation studies for the most important crops grown in Germany prove this (see Table A3). For example, the yield per hectare of potatoes and forage maize is strongly negatively correlated with the number of heat days in a year, at -0.7 and -0.87, respectively. The yield per hectare of summer wheat is also lower in years with many heat days (see Figure B3). Conversely, winter wheat is less susceptible to heat waves due to a more extended cultivation period in colder months. In addition to the general detrimental effect of hot temperatures on crop yields, we again find clear geographical differences. For example, the northern federal states bordering the coasts have fewer hot days than the other federal states and, therefore, lower harvest effects. Agricultural companies are typical customers of local banks, and as written in Chapter 2, around 25% of the banks in our data set were primarily founded by and for farmers ("Raiffeisen banks"). Therefore, the geographical differences in agribusinesses' profitability can be transferred to their banks.

As a subsequent analysis, we take a closer look at the transmission channel of the negative impact of heat on firms to banks, as a consequence of which the bank has less profitable customers. We investigate this by including heat exposure indices calculated as described in Section 2.2. A heat exposure index is an interaction term of a heat measures and an index for the vulnerability of the economy in the region to heat. The analysis results are reported in Table 4.

Table 4 about here.

We find comparable results for the heat exposure indices to the heat measures and also for the control variable coefficients (see Table 3). Thus, the coefficients for the heat exposure indices have a significant negative impact on bank performance. Again, the exception is that the indices calculated based on the extreme heat days are insignificant for the return on equity. In all regressions, the magnitude of the coefficients of the heat exposure indices is larger than the impact of the corresponding heat measures alone. We conclude that a local economy with a high heat vulnerability amplifies heat's impact on bank performance. In contrast, a low heat vulnerability reduces the impact of hot temperatures on banks' profitability. These results are consistent with previous economic research revealing a negative relationship between hot temperatures and economic output, especially in heat-exposed industry sectors.

Next, we want to test how the—from a savings or cooperatives bank's perspective—predetermined heat vulnerability of the aggregated local economy interacts with different levels of heat days. Table 5 reports the results estimating from equation 2.4.

Table 5 about here.

The direct effect of potential heat vulnerability of the local industry in columns (1) to (3) has a positive impact on banks' ROA. The second column shows the regression results when we add dummy variables for differentiating between banks experiencing medium and high intensities of heat days. Being in the second heat day tercile (T2) has no statistically significant effect on banking performance. Still, being an institute with, on average, the highest number of heat days in our observation period (T3) reduces the average ROA by 0.0185 percentage points. This reinforces the impression that only exaggerated heat is reflected in banks' balance sheets. However, statistical significance vanishes if we control for bank and macro-specific characteristics (see Table A4). Of greater importance is the investigation of the interaction effects in column three. We see that it has no statistical significant impact if a bank is in the second or third heat day tercile anymore, but the interaction with the heat vulnerability of its local business area matters. The interaction effect is negative in both cases. This supports the view that economic damage caused by heat is amplified through the structure of the local economy. Overall, these results shows the importance of the geographic region in which a bank conducts its business.

4 Robustness Checks

In this chapter, we perform robustness checks to further validate our findings in Section 3.

Although our data set consists of predominantly homogeneous banks that operate the same business model, there are some outliers in terms of their size approximated by balance sheet volume, for example, the Hamburger Savings Bank (*Haspa*) or the Berliner Cooperative Bank (*Berliner Volksbank*). The former is designated a "Significant Institution" and is directly supervised by the European Central Bank (European Central Bank, 2018). Its total assets exceed EUR 50 bn, and the bank employs more than 4,000 people. As Berger and Udell (1998) and Mkhaiber and Werner (2021) show, larger banks typically have larger companies as customers, which in turn are less affected by temperatures in one region. In contrast, small companies rely on funding from small banks. As a result, larger banks may be less vulnerable to heat, while small banks are particularly affected. To examine how heat affects banks of different sizes, we split our data set and examine the largest (and smallest) 10% of banks by total assets. To check to what extent the larger banks in our sample influence our previous results, we exclude the largest 10% in a further subsample. The results of the analyses for these subsamples can be found in Table 6. In each analysis, we investigate the impact on the ROA and include the number of heat days and the heat exposure index based on the number of heat days as dependent variables.

Table 6 about here.

We find for the large bank subsample, the heat variable is still negative but not significant. This suggests that these banks, with their larger business area and lower importance of regional banking for revenue, are less susceptible to heat. The smaller coefficients for our analysis of the smallest banks compared to Table 3 and Table 4 further underline the assumption that smaller banks are particularly affected due to their reliance regional active companies.

The results excluding the largest banks are also consistent with previous observations. The magnitude of the coefficients aligns between the results for the full sample and the results for the smallest banks. We conclude that larger banks in the sample are less affected by heat and do not drive our main results. In fact, the effect of heat on large banks partly dilutes our main results.

Next, we check whether other variables drive the results for the heat measures and exposure indices. To do this, we exclude different groups of control variables and report the results in Table 7.

Table 7 about here.

Column 1 shows the results for the dependent variable ROA if we only include the heat measure or the heat exposure index in the regression. In this case, the return on assets shrinks by 0.001 percentage points for heat measure and by 0.002 percentage points for the heat exposure index for for every heat day. In Column 2, we only include bank variables, and in Column 3, we repeat the regression with macroeconomic variables only. Including bank variables reduces the negative effect of heat while including macroeconomic variables increases heat's impact on the return on assets. In both regressions, both the heat measure and heat exposure index remain significant. In the last column of Table 7, we exclude the GDP change in addition to all bank variables. With doing so, we remove all variables that might be correlated with the return on assets. We still find a significant negative impact for both heat variables. The significant impact of both heat variables across all regression combinations on the return on assets suggests that variable correlations or interdependencies do not drive the negative impact of heat on bank profitability.

We also repeat the regressions for equation 2.2, excluding weather observations during our observation period made on Sundays or public holidays. In Germany, people are not allowed to work on these days, or only to a limited extent, which means that heat on these days might only have a minor impact on the locale economy and thus on bank performance.

Table 8 about here.

However, the results in Table 8 are consistent with those in Table 4 and the negative correlation between heat and bank performance, measured in the return on assets remain significant. Possible explanations for this finding are that specific sectors are exempt from the general prohibition on working on Sundays and public holidays, as well as that physical damage caused by heat, for example, in agriculture, still occurs on these days.

5 Conclusion

Small, locally operating banks remain fundamental to economic development and financial stability in advanced financial markets. In this paper, we examine how heatwaves affect their profitability. By focusing on banks that are limited from expanding geographically, we are able to demonstrate the negative impact of these increasingly occurring extreme heat temperatures. We collect daily and hourly weather data as well as bank balance sheet information and regional macroeconomic conditions for nearly 2000 banks over a period of 20 years and show that the composition of the local economy and its vulnerability to heat is crucial for the transmission of the negative effects of high temperatures from the local economy to the banks.

Affected banks have a lower return on assets than comparable banks in less heat-affected regions. This exogenous disadvantage should be taken into account by central banks and policymakers in their decisions. Further, our results reveal that smaller banks with stronger regional ties and a greater importance of traditional banking services are more affected than larger banks.

Our results show a significant negative impact of heat on bank performance, but the magnitude of the coefficients is currently too small to have been business-threatening over the last two decades. However, this could change rapidly in the context of accelerating global warming and regular new temperature records.

Our analyses show a negative impact of warm temperatures on banks' profitability. However, as Addoum et al. (2023) show in their comprehensive study, hot temperatures can also benefit certain business industries. Our work, therefore, states that for the regional banks we examined, the negative effects on business industries such as agriculture or construction predominate. A branch structure with fixed operating costs is essential for commercial banks and protects them against interest rates risks (Drechsler et al., 2021). The threat of the probably most expensive physical climate risk will become increasingly difficult to manage for banks and their clients if temperatures continue to rise and energy prices do not return to the level before the Russia-Ukraine war.

References

Acharya, Payel, Bethany Boggess, and Kai Zhang. 2018. "Assessing heat stress and health among construction workers in a changing climate: a review." *International Journal of Environmental Research and Public Health* 15 (2): 247.

Acharya, Viral V, Richard Berner, Robert Engle, Hyeyoon Jung, Johannes Stroebel, Xuran Zeng, and Yihao Zhao. 2023. "Climate stress testing." *Annual Review of Financial Economics* 15.

Acharya, Viral V, Timothy Johnson, Suresh Sundaresan, and Tuomas Tomunen. 2022. *Is physical climate risk priced? Evidence from regional variation in exposure to heat stress.* National Bureau of Economic Research.

Addoum, Jawad M, David T Ng, and Ariel Ortiz-Bobea. 2020. "Temperature shocks and establishment sales." *The Review of Financial Studies* 33 (3): 1331–1366.

Addoum, Jawad M, David T Ng, and Ariel Ortiz-Bobea. 2023. "Temperature shocks and industry earnings news." *Journal of Financial Economics* 150 (1): 1–45.

Alessandrini, Pietro, Andrea F Presbitero, and Alberto Zazzaro. 2010. "Bank size or distance: what hampers innovation adoption by SMEs?" *Journal of Economic Geography* 10 (6): 845–881.

Allen, Franklin, and Douglas Gale. 1995. "A welfare comparison of intermediaries and financial markets in Germany and the US." *european economic review* 39 (2): 179–209.

Auffhammer, Maximilian, V Ramanathan, and Jeffrey R Vincent. 2006. "Integrated model shows that atmospheric brown clouds and greenhouse gases have reduced rice harvests in India." *Proceedings of the National Academy of Sciences* 103 (52): 19668–19672.

Baudino, Patrizia, and Jean-Philippe Svoronos. 2021. "FSI Insights on policy implementation." *Financial Stability Institute,* no. 34.

Berger, Allen N, and Christa HS Bouwman. 2013. "How does capital affect bank performance during financial crises?" *Journal of Financial Economics* 109 (1): 146–176.

Berger, Allen N, and Gregory F Udell. 1995. *Universal banking and the future of small business lending,* NYU Working Paper No. FIN-95-009.

Berger, Allen N, and Gregory F Udell. 1998. "The economics of small business finance: The roles of private equity and debt markets in the financial growth cycle." *Journal of Banking & Finance* 22 (6-8): 613–673.

Borio, Claudio, Leonardo Gambacorta, and Boris Hofmann. 2017. “The influence of monetary policy on bank profitability.” *International Finance* 20 (1): 48–63.

Bourke, Philip. 1989. “Concentration and other determinants of bank profitability in Europe, North America and Australia.” *Journal of Banking & Finance* 13 (1): 65–79.

Burke, Marshall, Solomon M Hsiang, and Edward Miguel. 2015. “Global non-linear effect of temperature on economic production.” *Nature* 527 (7577): 235–239.

Busch, Ramona, and Christoph Memmel. 2021. *Why are interest rates on bank deposits so low?,* Deutsche Bundesbank Discussion Paper 46/2021.

De Marco, Filippo, and Nicola Limodio. 2023. *Climate, amenities and banking: El Nino in the US,* Discussion Paper DP17909. Centre for Economic Policy Research.

Dell, Melissa, Benjamin F Jones, and Benjamin A Olken. 2012. “Temperature shocks and economic growth: Evidence from the last half century.” *American Economic Journal: Macroeconomics* 4 (3): 66–95.

Deutsche Bundesbank. 2021. Banking statistics, Tables of the Statistical Series. October 2021. https://www.bundesbank.de/en/statistics/banks-and-other-financial-corporations/banks/banking-statistics-816050.

Deutsche Bundesbank. 2023. Reports concerning bank offices and Statistics of bank offices. https://www.bundesbank.de/en/tasks/banking-supervision/documentation/bank-offices-623034.

DeYoung, Robert, William C Hunter, and Gregory F Udell. 2004. “The past, present, and probable future for community banks.” *Journal of Financial Services Research* 25: 85–133.

Diamond, Douglas W. 1984. “Financial intermediation and delegated monitoring.” *The Review of Economic Studies* 51 (3): 393–414.

Dietrich, Andreas, and Gabrielle Wanzenried. 2011. “Determinants of bank profitability before and during the crisis: Evidence from Switzerland.” *Journal of International Financial Markets, Institutions and Money* 21 (3): 307–327.

Drechsler, Itamar, Alexi Savov, and Philipp Schnabl. 2021. “Banking on Deposits: Maturity Transformation Without Interest Rate Risk.” 76 (3): 1091–1143.

Engle, Robert F, Tina Emambakhsh, Simone Manganelli, Laura Parisi, and Riccardo Pizzeghello. 2023. *Estimating systemic risk for non-listed euro-area banks,* ECB Working Paper.

European Central Bank. 2018. List of supervised entities. https://www.bankingsupervision.europa.eu/ecb/pub/pdf/ssm.list_of_supervised_entities_201812.en.pdf.

Fecht, Falko, Stefan Thum, and Patrick Weber. 2019. "Fear, deposit insurance schemes, and deposit reallocation in the German banking system." *Journal of Banking & Finance* 105: 151–165.

Fiedler, Tanya, Andy J Pitman, Kate Mackenzie, Nick Wood, Christian Jakob, and Sarah E Perkins-Kirkpatrick. 2021. "Business risk and the emergence of climate analytics." *Nature Climate Change* 11 (2): 87–94.

García-Herrero, Alicia, Sergio Gavilá, and Daniel Santabárbara. 2009. "What explains the low profitability of Chinese banks?" *Journal of Banking & Finance* 33 (11): 2080–2092.

Graff-Zivin, Joshua, and Matthew Neidell. 2014. "Temperature and the Allocation of Time: Implications for Climate Change." *Journal of Labor Economics* 32 (1): 1–26.

Hakenes, Hendrik, Iftekhar Hasan, Philip Molyneux, and Ru Xie. 2015. "Small banks and local economic development." *Review of Finance* 19 (2): 653–683.

Hasan, Iftekhar, Krzysztof Jackowicz, Oskar Kowalewski, and Łukasz Kozłowski. 2017. "Do local banking market structures matter for SME financing and performance? New evidence from an emerging economy." *Journal of Banking & Finance* 79:142–158.

Heggestad, Arnold A. 1977. "Market structure, risk and profitability in commercial banking." *The Journal of Finance* 32 (4): 1207–1216.

Heidinger, Dinah, and Nadine Gatzert. 2018. "Awareness, determinants and value of reputation risk management: Empirical evidence from the banking and insurance industry." *Journal of Banking & Finance* 91: 106–118.

Hsiang, Solomon, Robert Kopp, Amir Jina, James Rising, Michael Delgado, Shashank Mohan, DJ Rasmussen, Robert Muir-Wood, Paul Wilson, Michael Oppenheimer, et al. 2017. "Estimating economic damage from climate change in the United States." *Science* 356 (6345): 1362–1369.

Hsiang, Solomon M. 2010. "Temperatures and cyclones strongly associated with economic production in the Caribbean and Central America." *Proceedings of the National Academy of sciences* 107 (35): 15367–15372.

Iannotta, Giuliano, Giacomo Nocera, and Andrea Sironi. 2007. "Ownership structure, risk and performance in the European banking industry." *Journal of Banking & Finance* 31 (7): 2127–2149.

International Organization for Standardization. 1989. *Hot Environments: Estimation of the Heat Stress on Working Man, Based on the WBGT Index (Wet Bulb Globe Temperature).*

IPCC. 2019. "Summary for Policymakers." In *Climate Change and Land: IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems.* Cambridge University Press.

Islam, Emdad, and Mandeep Singh. 2022. *Information on Hot Stuff: Do Lenders Pay Attention To Climate Risk?,* Working Paper.

Jones, Benjamin F., and Benjamin A. Olken. 2010. "Climate Shocks and Exports." *The American Economic Review* 100 (2): 454–459.

Kjellstrom, Tord, Ingvar Holmer, and Bruno Lemke. 2009. "Workplace heat stress, health and productivity–an increasing challenge for low and middle-income countries during climate change." *Global Health Action* 2 (1): 2047.

Klomp, Jeroen. 2014. "Financial fragility and natural disasters: An empirical analysis." *Journal of Financial Stability* 13: 180–192.

Mackworth, N. H. 1946. "Effects of heat on wireless telegraphy operators hearing and recording Morse messages." *British Journal of Industrial Medicine* 3: 143–158.

Meisenzahl, Ralf. 2023. *How climate change shapes bank lending: Evidence from portfolio reallocation,* FRB of Chicago Working Paper 2023-12.

Mkhaiber, Achraf, and Richard A. Werner. 2021. "The relationship between bank size and the propensity to lend to small firms: New empirical evidence from a large sample." *Journal of International Money and Finance* 110.

NASA. 2023. *Global temperature.* Accessed October 26, 2023. https://climate.nasa.gov/vital-signs/global-temperature/.

National Association of German Cooperative Banks (BVR). 2022. Entwicklung der Genossenschaftsbanken ab 1970. Accessed November 14, 2023. https://www.bvr.de/p.nsf/0/F0F8A6D1636D3A1CC1257D0A00540564/$file/Entwicklung%20der%20Banken%20seit%201970_SB.pdf.

National Centers for Environmental Information. 2023. *Monthly global climate report for annual 2022.* Accessed November 10, 2023. https://www.ncei.noaa.gov/access/monitoring/monthly-report/global/202213/supplemental/page-1.

Pankratz, Nora, Rob Bauer, and Jeroen Derwall. 2023. "Climate change, firm performance, and investor surprises." *Management Science.*

Perkins, Sarah E, and Lisa V Alexander. 2013. "On the measurement of heat waves." *Journal of Climate* 26 (13): 4500–4517.

Pilcher, June J, Eric Nadler, and Caroline Busch. 2002. "Effects of hot and cold temperature exposure on performance: a meta-analytic review." *Ergonomics* 45 (10): 682–698.

Puri, Manju, Jörg Rocholl, and Sascha Steffen. 2011. "Global retail lending in the aftermath of the US financial crisis: Distinguishing between supply and demand effects." *Journal of Financial Economics* 100 (3): 556–578.

Sachverständigenrat. 2023. *Energy Crisis and structural change: Prospects for German industry.* Accessed November 16, 2023. https://www.sachverstaendigenrat-wirtschaft.de/fileadmin/dateiablage/gutachten/jg202223/JG202223_Chapter_5.pdf.

Schlenker, Wolfram, and Michael Roberts. 2006. "Nonlinear effects of weather on crop yields: implications for climate change." *Review of Agricultural Economics* 28.

Schlenker, Wolfram, and Michael J Roberts. 2009. "Nonlinear temperature effects indicate severe damages to US crop yields under climate change." *Proceedings of the National Academy of Sciences* 106 (37): 15594–15598.

Seppänen, Olli, William J Fisk, and David Faulkner. 2003. *Cost benefit analysis of the night-time ventilative cooling in office building,* Working Paper.

Somanathan, Eswaran, Rohini Somanathan, Anant Sudarshan, and Meenu Tewari. 2021. "The impact of temperature on productivity and labor supply: Evidence from Indian manufacturing." *Journal of Political Economy* 129 (6): 1797–1827.

Statistisches Bundesamt. 2023. *NUTS classification.* Accessed November 8, 2023. https://www.destatis.de/Europa/EN/Methods/Classifications/OverviewClassification_NUTS.html.

Szewczyk, Wojciech, Ignazio Mongelli, and Juan-Carlos Ciscar. 2021. "Heat stress, labour productivity and adaptation in Europe—a regional and occupational analysis." *Environmental Research Letters* 16 (10): 105002.

Takakura, Jun'ya, Shinichiro Fujimori, Kiyoshi Takahashi, Tomoko Hasegawa, Yasushi Honda, Naota Hanasaki, Yasuaki Hijioka, and Toshihiko Masui. 2018. "Limited role of working time shift in offsetting the increasing occupational-health cost of heat exposure." *Earth's Future* 6 (11): 1588–1602.

Trenczek, J, O Lühr, L Eiserbeck, M Sandhövel, and D Ibens. 2022. "Schäden der Dürre- und Hitzeextreme 2018 und 2019-eine ex-post-Analyse." *Prognos AG, Berlin, Studie im Auftrag des Bundesministeriums für Wirtschaft und Klimaschutz.*

Wang, Jiaxuan. 2023. “Three Essays in Banking: Usury Law, Climate Risk and Bank Equity Capital.” PhD diss., University of Bristol.

Winklmayr, Claudia; Muthers, Stefan; Niemann, Hildegard; Mücke, Hans-Guido; an der Heiden, Matthias. 2022. “Heat-Related Mortality in Germany From 1992 to 2021.” *Deutsches Ärzteblatt International* 119 (26): 451–457.

Xia, Yang, Yuan Li, Dabo Guan, David Mendoza Tinoco, Jiangjiang Xia, Zhongwei Yan, Jun Yang, Qiyong Liu, and Hong Huo. 2018. “Assessment of the economic impacts of heat waves: a case study of Nanjing, China.” *Journal of Cleaner Production* 171: 811–819.

Zhang, Peng, Olivier Deschenes, Kyle Meng, and Junjie Zhang. 2018. “Temperature effects on productivity and factor reallocation: Evidence from a half million Chinese manufacturing plants.” *Journal of Environmental Economics and Management* 88: 1–17.

6 Tables and Figures

6.1 Tables

Table 1: Non-adjustment factors

Sector	Non-adjustment factor
Agriculture	1.00
Production without construction	0.61
Construction	1.00
Trade, transport and storage, hospitality, information and communication	0.48
Financial, insurance and business activities, real estate and housing activities	0.40
Public and other service providers, education and health, private households with domestic staff	0.61

This table reports the non-adjustment factors for Germany by Trenczek et al. (2022) on behalf of the Federal Ministry for Economic Affairs and Climate Action for the different industry sectors used in the analysis.

Table 2: Descriptive Statistics for Bank and Macroeconomic Variables and Heat Measures

Variable	Observations	Mean	Sd	p1	p25	p50	p75	p99
Bank Characteristics								
Total Assets (log.)	28,558	20.12	1.30	17.30	19.24	20.11	21.05	23.07
Equity Share (%)	28,558	7.64	2.47	3.45	5.64	7.40	9.30	14.41
Liquidity Share (%)	28,558	12.59	7.51	2.24	7.28	10.95	16.10	37.83
Cost-Income Ratio (%)	28,533	70.35	9.12	48.46	64.84	70.07	75.57	94.14
Loan Losses (%)	27,844	0.40	0.95	-2.93	0.00	0.37	0.85	2.76
Loan Growth (%)	27,930	4.73	12.77	-8.99	0.24	3.07	6.30	61.66
ROA (%)	28,534	0.24	0.22	0.00	0.13	0.21	0.31	0.93
Macroeconomic Variables								
GDP Change (nominal, %)	28,558	2.72	3.97	-8.28	0.78	2.94	4.85	12.09
Inflation Change (%)	28,558	1.49	0.71	0.30	1.00	1.50	1.90	3.10
3-Month Interest Rate (%)	28,558	1.35	1.69	-0.55	-0.26	0.81	2.33	4.63
Heat Measures and Exposures								
Heat Days	28,558	9.54	7.26	0.00	4.00	8.00	13.00	33.00
Heat Hours	21,635	40.85	36.15	0.00	14.00	29.00	59.00	166.00
Deviation Days	28,558	8.01	7.01	0.00	3.00	6.33	11.67	31.00
Heat Index Days	28,558	5.38	4.09	0.00	2.29	4.53	7.42	18.57
Heat Index Hours	21,635	23.04	20.32	0.00	7.99	16.48	33.22	92.88
Heat Index Deviation Days	28,558	4.52	3.96	0.00	1.67	3.58	6.48	17.36

This table reports summary statistics for all balance sheet and macroeconomic variables used in our analysis, as well as the heat measures and heat exposure indices. Statistics are calculated based on the values for the period 2001–2021. Sd refers to standard deviation, and p1, p25, p50, p75, and p99 refer to the first, twenty-fifth, fiftieth, seventy-fifth, and ninety-ninth quantiles.

Table 3: Heat and Bank Performance

	ROA		
	Heat Days	Heat Hours	Deviation Days
Heat Measure	-0.0011*** (0.0002)	-0.0002*** (0.0000)	-0.0007*** (0.0001)
Log Total Assets	-0.1321*** (0.0080)	-0.1618*** (0.0090)	-0.1330*** (0.0080)
Equity Share	0.0029** (0.0012)	-0.0011 (0.0012)	0.0026** (0.0012)
Liquidity Share	0.0001 (0.0003)	0.0001 (0.0003)	0.0001 (0.0003)
Cost-Income Ratio	-0.0066*** (0.0003)	-0.0054*** (0.0003)	-0.0066*** (0.0003)
Loan Losses	-0.0356*** (0.0037)	-0.0229*** (0.0032)	-0.0359*** (0.0037)
Loan Growth	0.0003*** (0.0001)	0.0001 (0.0001)	0.0003*** (0.0001)
Financial Crisis	-0.0308*** (0.0039)	-0.0571*** (0.0042)	-0.0281*** (0.0039)
Local GDP Change	0.0010*** (0.0003)	0.0003 (0.0002)	0.0010*** (0.0003)
Inflation Change	-0.0167*** (0.0015)	-0.0145*** (0.0014)	-0.0155*** (0.0015)
3-Month Interest Rate	0.0122*** (0.0019)	0.0100*** (0.0018)	0.0117*** (0.0019)
Merger Dummy	0.0031 (0.0073)	0.0305*** (0.0065)	0.0032 (0.0073)
Const	3.3771*** (0.1624)	3.9270*** (0.1821)	3.3922*** (0.1626)
R squared	0.1215	0.1620	0.1208
Observations	27,840	21,635	27,840
Bank Fixed Effects	✓	✓	✓

This table reports the estimations results of equation 2.2 for the three different heat measures: Heat Days is the number of days in a year with a reported maximum temperature above 30°C, Heat Hours is the number of hours in a year above 30°C, Deviation Days is the number of extreme days above the 90th percentile of the historic temperature distribution. The dependent variable in all three specifications is the ROA. Robust standard errors are clustered at the entity level and reported in parentheses. Statistical significance is denoted with *, **, and *** at 10%, 5%, and 1% level, respectively.

Table 4: Heat Exposure and Bank Performance

	ROA		
	Exposure Days	Exposure Hours	Exposure Dev. Days
Heat Exposure	-0.0019*** (0.0003)	-0.0003*** (0.0001)	-0.0013*** (0.0003)
Log Total Assets	-0.1320*** (0.0080)	-0.1618*** (0.0090)	-0.1329*** (0.0080)
Equity Share	0.0030** (0.0012)	-0.0011 (0.0013)	0.0026** (0.0012)
Liquidity Share	0.0001 (0.0003)	0.0001 (0.0003)	0.0001 (0.0003)
Cost-Income Ratio	-0.0066*** (0.0003)	-0.0054*** (0.0003)	-0.0066*** (0.0003)
Loan Losses	-0.0356*** (0.0037)	-0.0229*** (0.0032)	-0.0358*** (0.0037)
Loan Growth	0.0003*** (0.0001)	0.0001 (0.0001)	0.0003*** (0.0001)
Financial Crisis	-0.0310*** (0.0039)	-0.0572*** (0.0042)	-0.0282*** (0.0039)
Local GDP Change	0.0010*** (0.0003)	0.0003 (0.0002)	0.0010*** (0.0003)
Inflation Change	-0.0167*** (0.0015)	-0.0145*** (0.0014)	-0.0155*** (0.0015)
3-Month Interest Rate	0.0123*** (0.0019)	0.0101*** (0.0018)	0.0118*** (0.0019)
Merger Dummy	0.0031 (0.0073)	0.0304*** (0.0065)	0.0032 (0.0073)
Const	3.3756*** (0.1624)	3.9254*** (0.1821)	3.3910*** (0.1625)
R squared	0.1215	0.1621	0.1208
Observations	27,840	21,635	27,840
Bank Fixed Effects	✓	✓	✓

This table reports the estimations results of equation 2.3 for the three different heat exposure based on our heat measurements and the affected local industry index. Heat Days is the index based on the number of days in a year with a reported maximum temperature above 30°C, Heat Hours is based on the number of hours in a year above 30°C, Deviation Days is the number of extreme days above the 90th percentile of the historic temperature distribution. The dependent variable in all three specifications is the ROA and bank fixed effects are included. Robust standard errors are clustered at the entity level and reported in parentheses. Statistical significance is denoted with *, **, and *** at 10%, 5%, and 1% level, respectively.

Table 5: Heat Day Terciles and Affected Local Industry

	ROA		
	(1)	(2)	(3)
Affected Local Industry Index	0.5462*** (0.1858)	0.4864*** (0.1875)	0.4929*** (0.1873)
$\mathbb{1}\{\text{Heat Day Tercile} = 2\}$ (T2)		-0.0093 (0.0078)	0.0044 (0.0086)
T2 × Affected Local Industry Index			-0.0027*** (0.0005)
$\mathbb{1}\{\text{Heat Day Tercile} = 3\}$ (T3)		-0.0185** (0.0075)	-0.0050 (0.0086)
T3 × Affected Local Industry Index			-0.0017*** (0.0004)
Constant	-0.0642 (0.1049)	-0.0213 (0.1062)	-0.0250 (0.1061)
R squared	0.0017	0.0028	0.0037
Observations	28,534	28,534	28,534

This table reports OLS estimation results of Equation 2.4 for the affected local industry index $I_{c,t}$ (see Equation 2.1), the differences in the number of hot days, and the interaction of both. We divide banks into heat percentiles based on the observed average days with a maximum temperature above 30 degrees. The characteristic function T2 is equal to one for banks in the second tercile, and the function T3 is equal to one for banks in the third tercile, i.e. for banks with on average the most number of heat days in our observation period. The dependent variable in all three specifications is the ROA. Robust standard errors are clustered at the entity level and reported in parentheses. Statistical significance is denoted with *, **, and *** at 10%, 5%, and 1% level, respectively.

Table 6: Estimation Results for Different Bank Sizes

	> 90% Quantile		< 10% Quantile		< 90% Quantile	
	Heat Days	Exposure Days	Heat Days	Exposure Days	Heat Days	Exposure Days
Heat Measure/ Heat Exposure Index	-0.0004	-0.0007	-0.0017**	-0.0030**	-0.0012***	-0.0022***
	(0.0002)	(0.0004)	(0.0007)	(0.0012)	(0.0002)	(0.0003)
Log Total Assets	-0.0723***	-0.0723***	-0.1545**	-0.1544**	-0.1406***	-0.1405***
	(0.0155)	(0.0155)	(0.0628)	(0.0628)	(0.0088)	(0.0088)
Equity Share	-0.0018	-0.0018	0.0082	0.0082	0.0035**	0.0035**
	(0.0021)	(0.0021)	(0.0053)	(0.0053)	(0.0014)	(0.0014)
Liquidity Share	-0.0004	-0.0004	-0.0007	-0.0007	0.0001	0.0001
	(0.0005)	(0.0005)	(0.0008)	(0.0008)	(0.0003)	(0.0003)
Cost-Income Ratio	-0.0035***	-0.0035***	-0.0065***	-0.0065***	-0.0071***	-0.0071***
	(0.0005)	(0.0005)	(0.0009)	(0.0009)	(0.0003)	(0.0003)
Loan Losses	-0.0272***	-0.0272***	-0.0257*	-0.0257*	-0.0372***	-0.0372***
	(0.0075)	(0.0075)	(0.0145)	(0.0145)	(0.0041)	(0.0041)
Loan Growth	-0.0000	-0.0000	-0.0006	-0.0006	0.0004***	0.0004***
	(0.0002)	(0.0002)	(0.0007)	(0.0007)	(0.0001)	(0.0001)
Financial Crisis	-0.0281***	-0.0282***	-0.0603***	-0.0603***	-0.0317***	-0.0318***
	(0.0080)	(0.0080)	(0.0183)	(0.0183)	(0.0044)	(0.0044)
Local GDP Change	0.0007	0.0007	-0.0003	-0.0003	0.0011***	0.0011***
	(0.0005)	(0.0005)	(0.0011)	(0.0011)	(0.0003)	(0.0003)
Inflation Change	-0.0114***	-0.0115***	-0.0133	-0.0133	-0.0177***	-0.0178***
	(0.0025)	(0.0025)	(0.0092)	(0.0092)	(0.0017)	(0.0017)
3-Month Interest Rate	0.0065**	0.0065**	0.0271***	0.0271***	0.0133***	0.0133***
	(0.0031)	(0.0031)	(0.0098)	(0.0098)	(0.0021)	(0.0021)
Merger Dummy	0.0014	0.0014	0.1131	0.1131	0.0017	0.0017
	(0.0109)	(0.0109)	(0.0726)	(0.0726)	(0.0091)	(0.0091)
Const	2.0636***	2.0633***	3.4931***	3.4923***	3.5447***	3.5433***
	(0.3402)	(0.3402)	(1.0804)	(1.0802)	(0.1763)	(0.1763)
R squared	0.1134	0.1135	0.1774	0.1774	0.1255	0.1256
Observations	3,705	3,705	1,839	1,839	24,135	24,135
Number Entities	187	187	187	187	1,684	1,684
Bank Fixed Effects	✓	✓	✓	✓	✓	✓

This table shows the results of the analyses of the effects of heat on bank performance for banks of different sizes. The performance measure is the ROA, and we use the number of days above 30°C as heat measure and heat exposure index. The first two columns show the results for banks whose total assets belong to the 90 percentile of all banks. Columns 3 and 4 contain the results for the smallest banks whose total assets are smaller than the 10% quantile. The largest banks were excluded from the regressions in columns 5 and 6. Bank fixed effects are included in all regressions and robust standard errors are clustered at the entity level and reported in parentheses. Significance levels are denoted with *, **, and *** at 10%, 5%, and 1% levels.

Table 7: Estimation Results for Partial Models

	(1) ROA - Heat only		(2) ROA - Bank Variables		(3) ROA - Macro Variables		(4) ROA - No GDP	
	Heat Days	Exposure Days	Heat Days	Exposure Days	Heat Days	Exposure Days	Heat Days	Exposure Days
Heat Measure/ Heat Exposure Index	-0.0011***	-0.0020***	-0.0004***	-0.0008***	-0.0020***	-0.0036***	-0.0020***	-0.0036***
	(0.0001)	(0.0003)	(0.0001)	(0.0002)	(0.0002)	(0.0003)	(0.0002)	(0.0003)
Log Total Assets			-0.1568***	-0.1568***				
			(0.0074)	(0.0074)				
Equity Share			-0.0004	-0.0004				
			(0.0011)	(0.0011)				
Liquidity Share			-0.0002	-0.0002				
			(0.0003)	(0.0003)				
Cost-Income Ratio			-0.0067***	-0.0067***				
			(0.0003)	(0.0003)				
Loan Losses			-0.0347***	-0.0347***				
			(0.0036)	(0.0036)				
Loan Growth			0.0003**	0.0003**				
			(0.0001)	(0.0001)				
Financial Crisis					-0.0636***	-0.0638***	-0.0674***	-0.0676***
					(0.0041)	(0.0041)	(0.0039)	(0.0039)
Local GDP Change					0.0015***	0.0015***		
					(0.0003)	(0.0003)		
Inflation Change					-0.0248***	-0.0249***	-0.0221***	-0.0221***
					(0.0012)	(0.0012)	(0.0011)	(0.0011)
3-Month Interest Rate					0.0177***	0.0177***	0.0176***	0.0176***
					(0.0012)	(0.0012)	(0.0012)	(0.0012)
Merger Dummy			0.0111	0.0112				
			(0.0074)	(0.0074)				
Const	0.2549***	0.2551***	3.8948***	3.8947***	0.2809***	0.2812***	0.2815***	0.2819***
	(0.0014)	(0.0013)	(0.1507)	(0.1507)	(0.0025)	(0.0025)	(0.0025)	(0.0025)
R squared	0.0013	0.0014	0.1166	0.1166	0.0225	0.0227	0.0217	0.0218
Observations	28,534	28,534	27,840	27,840	28,534	28,534	28,534	28,534
Bank Fixed Effects	✓	✓	✓	✓	✓	✓	✓	✓

This table shows the results for the effects of heat exposure on the ROA for the number of days and the number of hours above 30°C. The columns show the results for different combinations of included control variables. Significance levels are denoted with *, **, and *** at 10%, 5%, and 1% levels.

Table 8: Estimation Results with excluded non-Weekdays

	ROA		
	Exposure Days	Exposure Hours	Exposure Dev. Days
Heat Exposure	-0.0019*** (0.0003)	-0.0003*** (0.0001)	-0.0012*** (0.0003)
Log Total Assets	-0.1323*** (0.0080)	-0.1619*** (0.0090)	-0.1331*** (0.0080)
Equity Share	0.0029** (0.0012)	-0.0012 (0.0012)	0.0025** (0.0012)
Liquidity Share	0.0001 (0.0003)	0.0001 (0.0003)	0.0001 (0.0003)
Cost-Income Ratio	-0.0066*** (0.0003)	-0.0055*** (0.0003)	-0.0066*** (0.0003)
Loan Losses	-0.0356*** (0.0037)	-0.0229*** (0.0032)	-0.0358*** (0.0037)
Loan Growth	0.0003*** (0.0001)	0.0001 (0.0001)	0.0003*** (0.0001)
Financial Crisis	-0.0303*** (0.0039)	-0.0571*** (0.0041)	-0.0278*** (0.0039)
Local GDP Change	0.0010*** (0.0003)	0.0003 (0.0002)	0.0010*** (0.0003)
Inflation Change	-0.0161*** (0.0015)	-0.0142*** (0.0014)	-0.0151*** (0.0015)
3-Month Interest Rate	0.0120*** (0.0019)	0.0099*** (0.0018)	0.0116*** (0.0019)
Merger Dummy	0.0032 (0.0073)	0.0305*** (0.0065)	0.0033 (0.0073)
Const	3.3810*** (0.1625)	3.9294*** (0.1819)	3.3953*** (0.1627)
R squared	0.1213	0.1620	0.1207
Observations	27,840	21,635	27,840
Bank Fixed Effects	✓	✓	✓

This table reports the estimations results of equation 2.3 for the three different heat exposure based on our heat measurements and the affected local industry index. Heat Days is the index based on the number of days in a year with a reported maximum temperature above 30°C, Heat Hours is based on the number of hours in a year above 30°C, Deviation Days is the number of extreme days above the 90th percentile of the historic temperature distribution. All heat exposures were calculated under the exclusion of Sundays and public holidays. The dependent variable in all three specifications is the ROA and bank fixed effects are included. Robust standard errors are clustered at the entity level and reported in parentheses. Statistical significance is denoted with *, **, and *** at 10%, 5%, and 1% level, respectively.

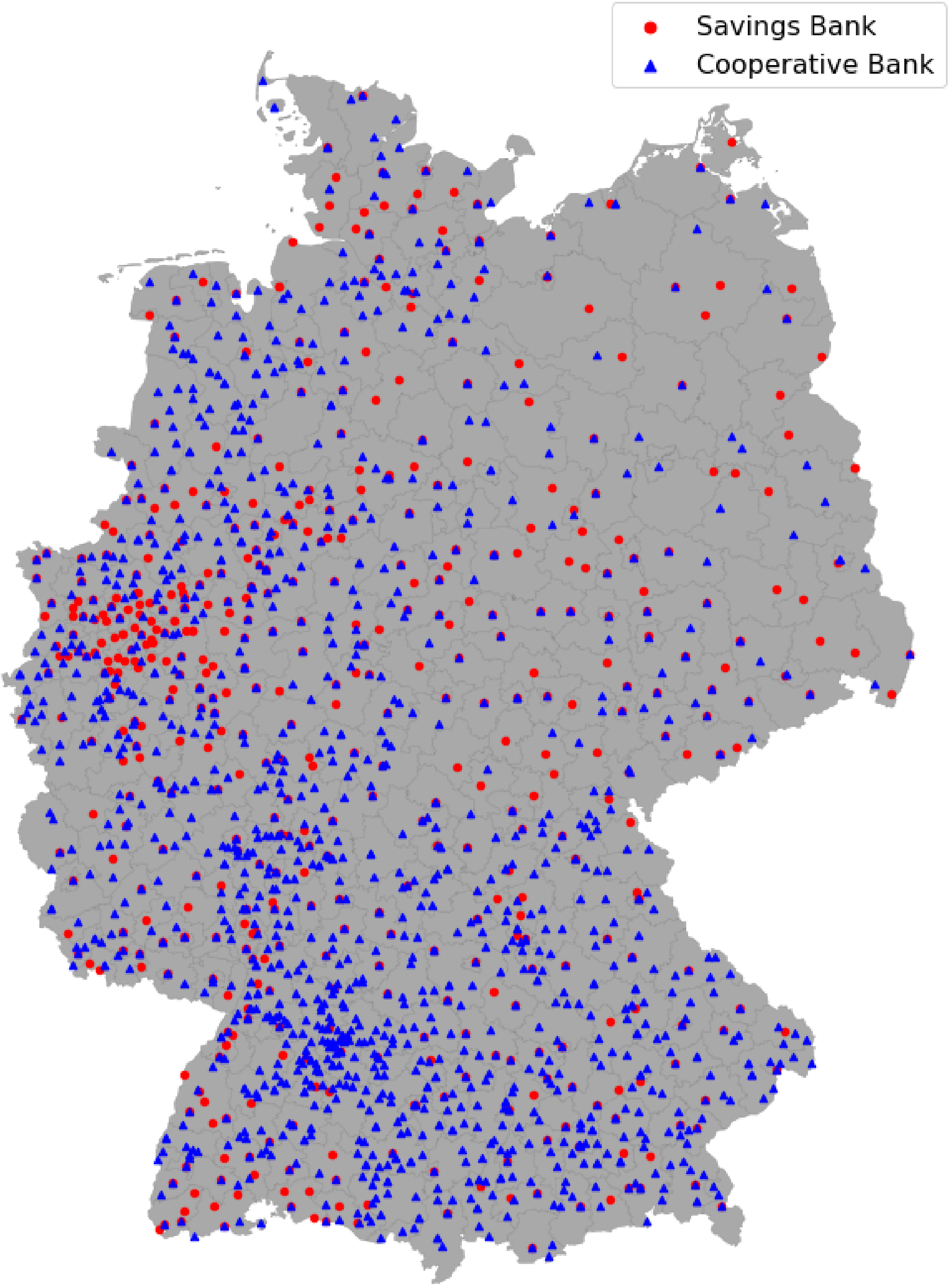


Figure 1: Headquarter Locations of German Savings- and Cooperative Banks
This chart plots the location of the headquarters of 533 savings banks as red circles and the headquarters of 1,338 cooperative banks as blue triangles in our data set in the sample period between 2001 and 2021.

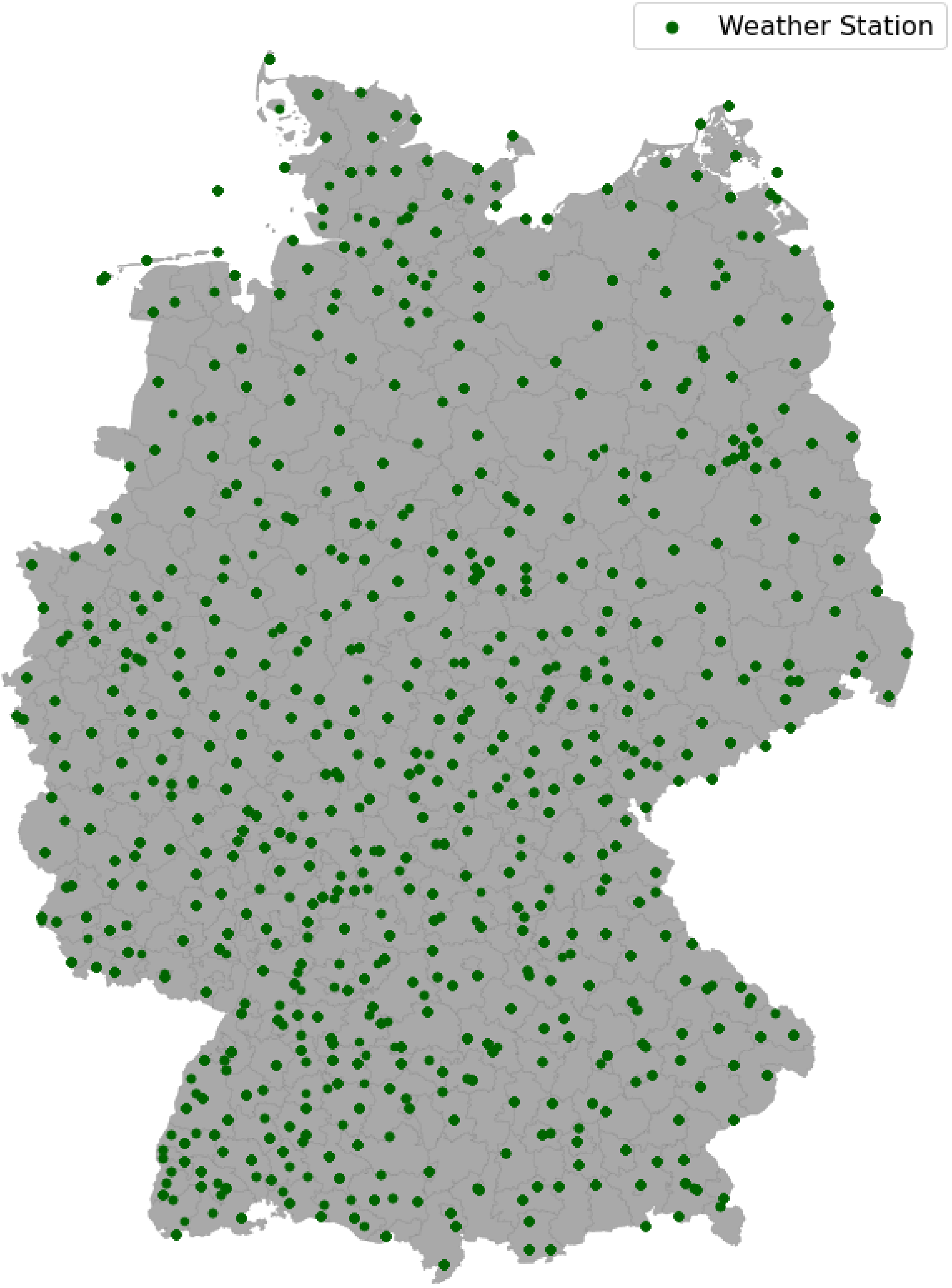
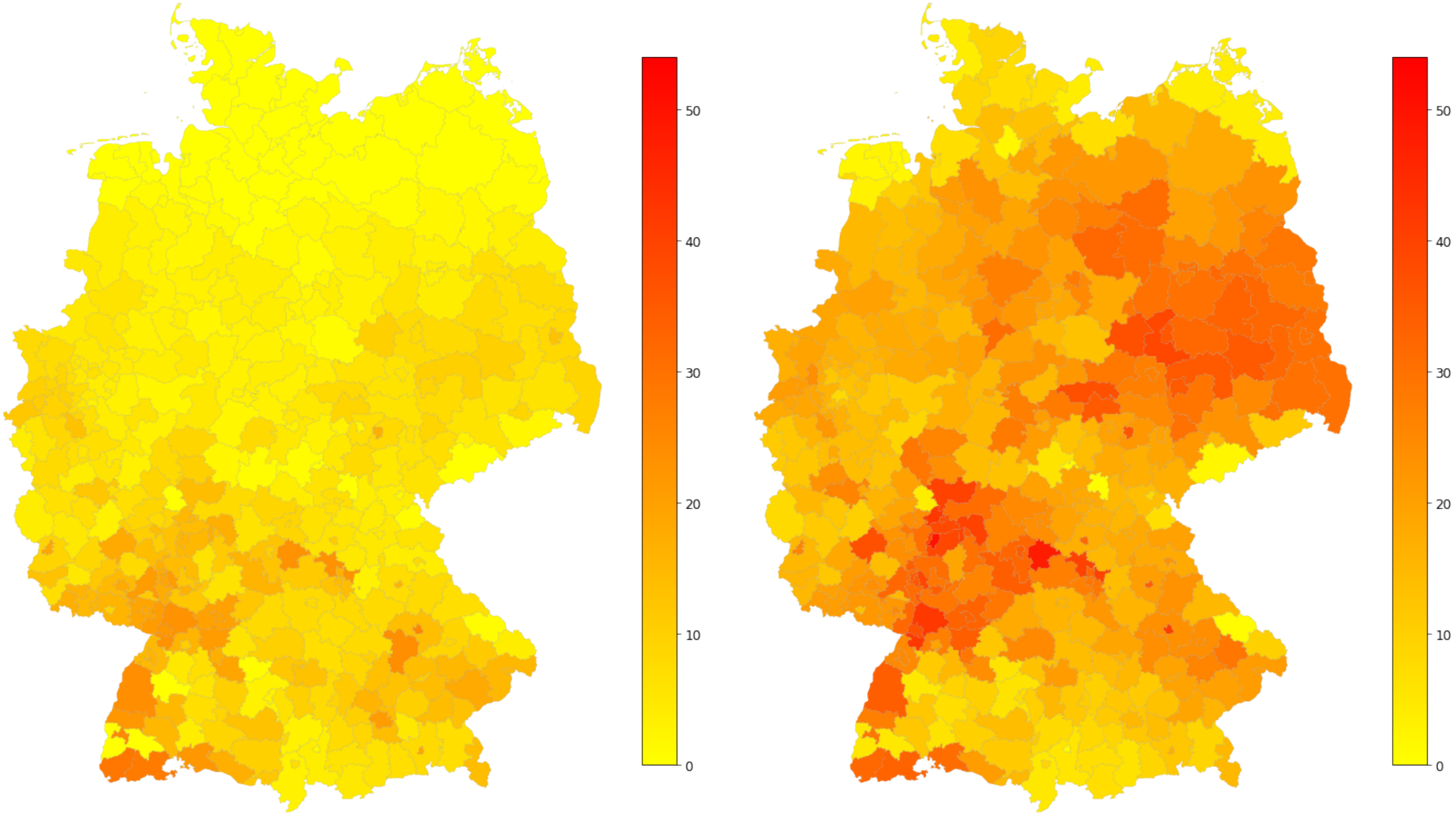


Figure 2: Weather Station Locations

This chart plots the location of all 670 weather stations of the German Weather Service (DWD) as green circles, that reported daily maximum temperature at some point between 2001 and 2021.

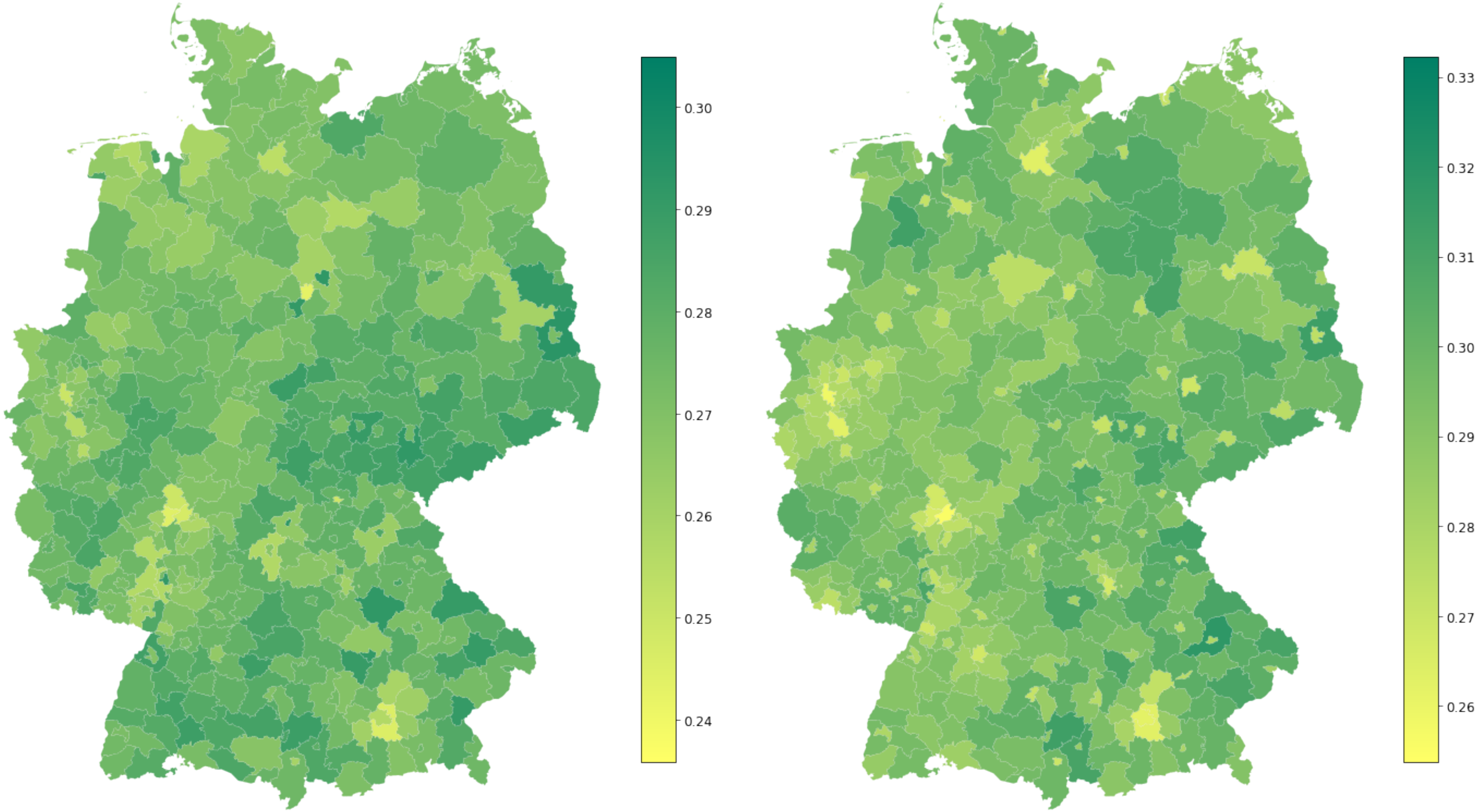


Heat Days 2017

Heat Days 2018

Figure 3: Number of Heat Days in 2017 and 2018

This figure plots the observed number of heat days for each German county in 2017 (left) and 2018 (right). We classify a day as a heat day if the reported maximum temperature is above 30°C. The number of days scales between 0 (light yellow) and 55 (bright red)



GDP Exposure 2017

Worker Exposure 2017

Figure 4: Affected Local Industry Indices 2017

This figure plots the calculated affected local industry indices as parts of Equation 2.1 for the GDP (left) and number of deployed people (right) in each German county for the year 2017. Both exposures can take on values between 0 (no exposure to heat) and 0.5 (maximum exposure to heat).

A Additional Tables

Table A1: Sample coverage of German savings and cooperative banks

Year	# Savings banks in Germany	Sample	Coverage	# Cooperative banks in Germany	Sample	Coverage
2001	534	516	96.63%	1,621	935	57.68%
2002	519	494	95.18%	1,489	839	56.35%
2003	489	468	95.71%	1,392	760	54.60%
2004	477	462	96.86%	1,335	750	56.18%
2005	463	456	98.49%	1,290	1,036	80.31%
2006	457	450	98.47%	1,255	1,047	83.42%
2007	446	443	99.32%	1,232	1,039	84.33%
2008	438	432	98.63%	1,197	1,011	84.46%
2009	431	427	99.07%	1,156	1,028	88.93%
2010	429	426	99.30%	1,138	1,051	92.36%
2011	426	422	99.06%	1,121	1,079	96.25%
2012	423	421	99.53%	1,101	1,060	96.28%
2013	417	416	99.76%	1,078	1,039	96.38%
2014	416	415	99.76%	1,047	1,008	96.28%
2015	413	409	99.03%	1,021	981	96.08%
2016	403	402	99.75%	972	931	95.78%
2017	390	389	99.74%	915	873	95.41%
2018	386	385	99.74%	875	832	95.09%
2019	380	379	99.74%	841	796	94.65%
2020	377	376	99.73%	814	775	95.21%
2021	370	370	100.00%	772	730	94.56%

The second and fifth columns report the official number of savings banks and cooperative banks in Germany in the period 2001–2021 (National Association of German Cooperative Banks (BVR), 2022; Deutsche Bundesbank, 2023). The third and sixth columns show the related number of banks in our data set. The average coverage within our sample is 98.88% and 85.26% respectively. Because of numerous mergers within both banking groups, the number of single institutions steadily decreases towards the end of the period under review.

Table A2: Number of reporting weather stations in each year

Year	Daily Reporting Stations	Hourly Reporting Stations
2001	484	166
2002	471	231
2003	468	234
2004	419	361
2005	444	427
2006	464	458
2007	458	491
2008	462	506
2009	472	505
2010	474	507
2011	469	509
2012	466	505
2013	463	500
2014	469	496
2015	465	496
2016	465	497
2017	465	500
2018	457	499
2019	453	493
2020	456	494
2021	462	493

This table shows the number of active Deutscher Wetterdienst (DWD) weather stations for each year of the observation period. The second column presents the number of daily reporting stations, and the third column the number of hourly reporting stations. In the case of hourly reporting stations, we have to omit the years before 2006 in our analyses because there were too few reporting stations to cover the majority of German counties.

Table A3: Correlation between Number of Heat Days and Harvest Volumes

	Potatos	Forage Maize	Summer Wheat	Winter Wheat
Germany	-0.7009	-0.8786	-0.4400	-0.2766
Baden-Württemberg	-0.3428	-0.7308	-0.2587	-0.0496
Bavaria	-0.6625	-0.8032	-0.4263	-0.1730
Brandenburg	-0.5819	-0.8621	-0.5419	-0.3758
Hesse	-0.6837	-0.7803	-0.1491	-0.1049
Lower Saxony	-0.7558	-0.8309	-0.1218	-0.2514
Mecklenburg Western Pomerania	-0.8772	-0.7378	-0.4902	-0.1921
Northrhine-Westphalia	-0.5660	-0.8596	-0.2487	-0.1441
Rhineland Palatinate	-0.5672	-0.7759	0.0952	0.0721
Saarland	-0.7258	-0.8244	-0.4622	-0.1732
Saxony	-0.5575	-0.7898	-0.4763	-0.2829
Saxony-Anhalt	-0.7554	-0.8310	-0.5070	-0.5152
Schleswig-Holstein	-0.2962	-0.2303	-0.4526	-0.3019
Thuringia	-0.6664	-0.7586	-0.6112	-0.3043

This table shows the correlation between the number of days with a maximum temperature above 30°C and harvest volumes for four of the most important crops in Germany. Each column shows the correlation for Germany as a whole and the individual federal states, excluding the city-states of Berlin, Hamburg, and Bremen. The correlation is calculated based on the average crop harvest per hectare and number of heat days in Germany and each state, respectively.

Table A4: Heat Day Terciles and Affected Local Industry

	ROA		
	(1)	(2)	(3)
Affected Local Industry Index	-0.5982*** (0.1602)	-0.6130*** (0.1617)	-0.6041*** (0.1615)
$\mathbb{1}\{\text{Heat Day Tercile} = 2\}$ (T2)		-0.0093 (0.0060)	0.0095 (0.0068)
T2 × Affected Local Industry Index			-0.0037*** (0.0005)
$\mathbb{1}\{\text{Heat Day Tercile} = 3\}$ (T3)		-0.0074 (0.0059)	0.0082 (0.0069)
T2 × Affected Local Industry Index			-0.0020*** (0.0004)
Log Total Assets	-0.0389*** (0.0020)	-0.0387*** (0.0020)	-0.0385*** (0.0020)
Equity Share	0.0156*** (0.0015)	0.0155*** (0.0015)	0.0159*** (0.0015)
Liquidity Share	-0.0007** (0.0003)	-0.0007** (0.0003)	-0.0007** (0.0003)
Cost-Income Ratio	-0.0068*** (0.0003)	-0.0068*** (0.0003)	-0.0067*** (0.0003)
Loan Losses	-0.0390*** (0.0038)	-0.0390*** (0.0038)	-0.0386*** (0.0038)
Loan Growth	0.0002* (0.0001)	0.0002* (0.0001)	0.0002** (0.0001)
Financial Crisis	-0.0420*** (0.0040)	-0.0422*** (0.0040)	-0.0480*** (0.0042)
Local GDP Change	0.0012*** (0.0003)	0.0012*** (0.0003)	0.0012*** (0.0003)
Inflation Change	-0.0304*** (0.0015)	-0.0304*** (0.0015)	-0.0331*** (0.0016)
3-Month Interest Rate	0.0385*** (0.0021)	0.0386*** (0.0020)	0.0389*** (0.0021)
Merger Dummy	0.0241*** (0.0081)	0.0243*** (0.0081)	0.0239*** (0.0081)
Constant	1.7342*** (0.1184)	1.7459*** (0.1192)	1.7355*** (0.1191)
R squared	0.1923	0.1939	0.1941
Observations	27,840	27,840	27,840

This table reports OLS estimation results of Equation 2.4 for the affected local industry index $I_{c,t}$ (see Equation 2.1), the different heat exposures, and the interaction of both and a variety of typical bank control variables. We divide banks into heat percentiles based on the observed average days with a maximum temperature above 30 degrees. The characteristic function T2 is equal to one for banks in the second tercile, and the function T3 is equal to one for banks in the third tercile, i.e. for banks with on average the most number of heat days in our observation period. The dependent variable in all three specifications is the ROA. Robust standard errors are clustered at the entity level and reported in parentheses. Statistical significance is denoted with *, **, and *** at 10%, 5%, and 1% level, respectively.

B Additional Figures

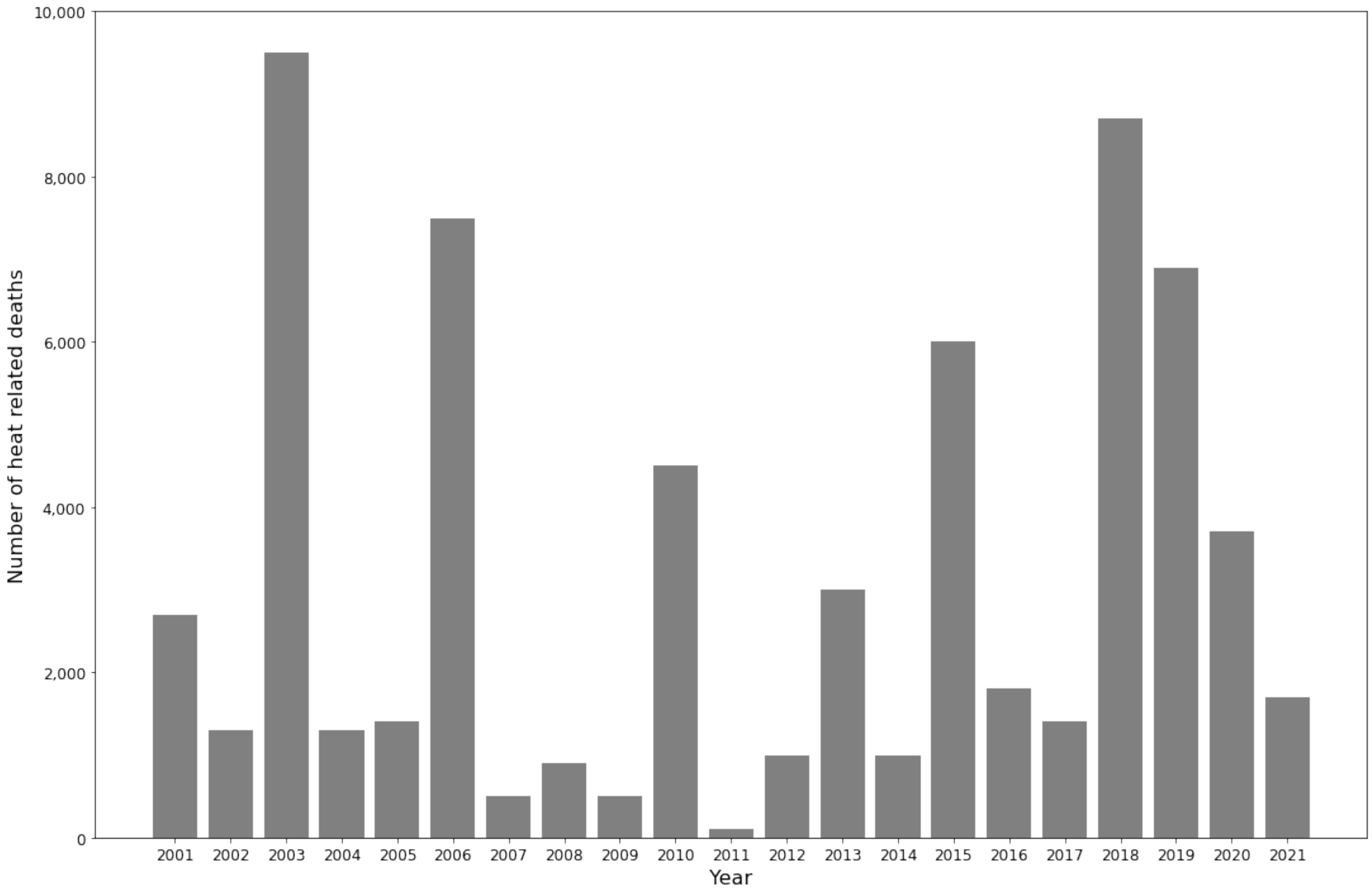
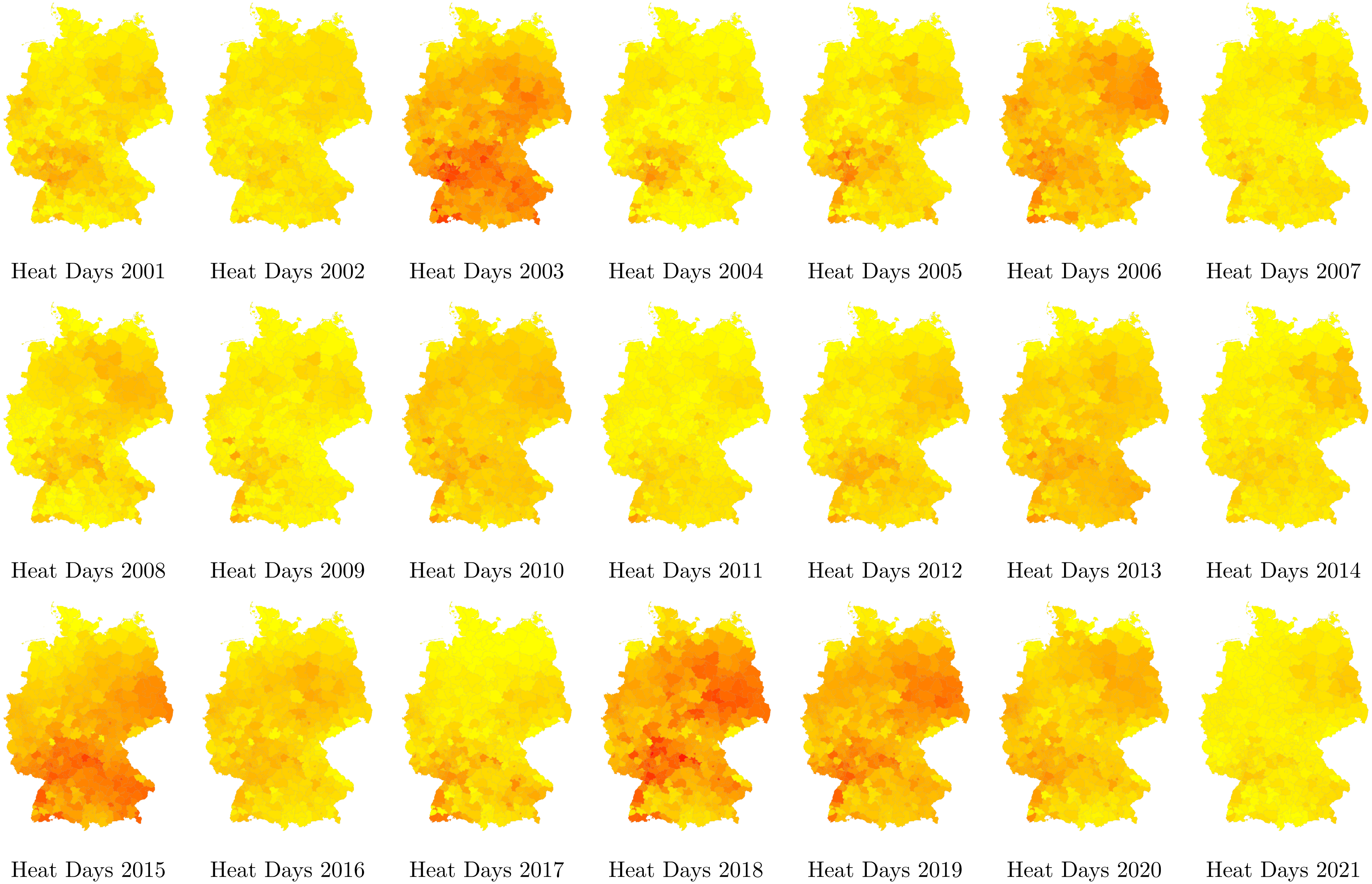


Figure B1: Number of Heat Related Deaths

This chart plots the number of heat-related deaths in Germany between 2001 and 2021 (Winklmayr, Claudia; Muthers, Stefan; Niemann, Hildegard; Mücke, Hans-Guido; an der Heiden, Matthias, 2022). The particularly hot years of 2003, 2006, 2015, 2018, and 2019 clearly stand out.



Heat Days 2001 Heat Days 2002 Heat Days 2003 Heat Days 2004 Heat Days 2005 Heat Days 2006 Heat Days 2007

Heat Days 2008 Heat Days 2009 Heat Days 2010 Heat Days 2011 Heat Days 2012 Heat Days 2013 Heat Days 2014

Heat Days 2015 Heat Days 2016 Heat Days 2017 Heat Days 2018 Heat Days 2019 Heat Days 2020 Heat Days 2021

Figure B2: Number of Heat Days between 2001 and 2021

This figure plots the observed number of heat days for each German county between 2001 and 2021. We classify a day as a heat day if the maximum temperature is above 30°C. You can clearly see the variation in the number of hot days within Germany in one year, but also the differences between individual years, with particularly extreme years such as 2003, 2006, 2015, 2018 and 2019 clearly standing out. The number of days scales between 0 (light yellow) and 55 (bright red).

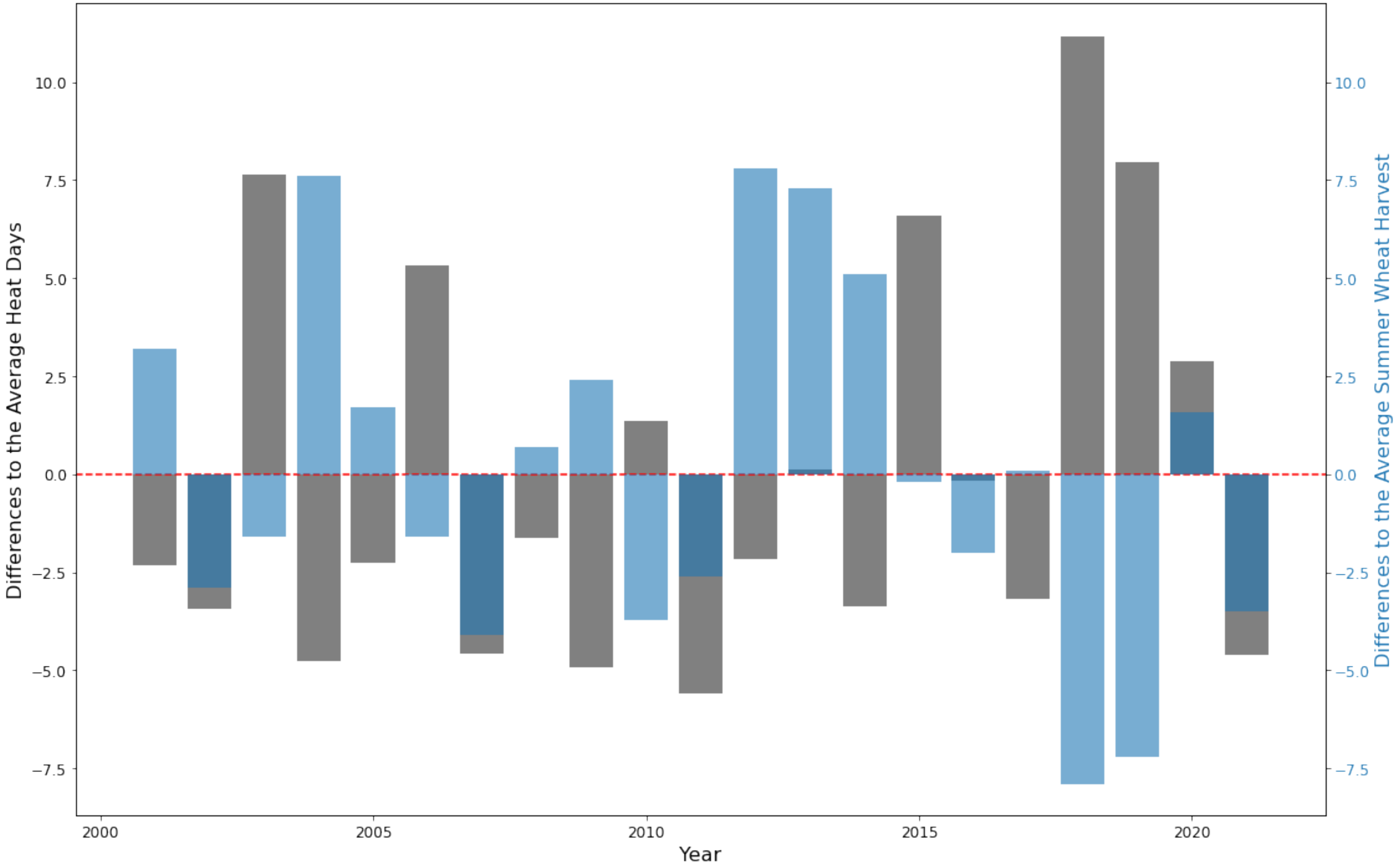


Figure B3: Time Series of Summer Wheat Harvest and Number of Heat Days

This chart plots the average harvest volume per hectare of summer wheat in deciton per year in Germany as blue line against the average number of days with a maximum temperature above 30°C in Germany. There is a noticeable drop in harvest volume in years with an above average number of heat days.