Heatwaves and Household Credit Risk in Europe

Aoife Claire Fitzpatrick*

May 13, 2025

Abstract

This paper examines how heatwave exposure affects consumer loan outcomes using loan-level data from four major European economies: France, Germany, Italy, and Spain. Exploiting regional and temporal variation in extreme heat, I implement a difference-in-differences design to estimate causal impacts on loan pricing and performance. Loans originated after heatwaves carry modestly higher interest rates and significantly higher default rates in the following months. These effects are concentrated among lower-income borrowers, the self-employed, and urban areas. While lenders adjust pricing slightly, the increases in default are larger and not fully aligned with pricing changes. The results suggest that short-term climate shocks can impair borrower performance and are only partially reflected in loan contract terms.

Keywords:

JEL Classification:

*SAFE and Goethe University Frankfurt, fitzpatrick@safe-frankfurt.de.

1 Introduction

Extreme heat events are becoming more frequent, more intense, and more economically consequential across Europe. These shocks are now widely recognized as an emerging dimension of climate risk. According to the World Health Organization, heat stress is the leading cause of weather-related mortality and contributes to a range of adverse outcomes, including cardiovascular illness, reduced cognitive performance, and elevated accident risk. In Europe, heatwaves have been the deadliest climate-related hazard in recent decades, contributing to an estimated 55,000 to 72,000 deaths in each of the summers of 2003, 2010, and 2022. Between 2000 and 2020, heat-related mortality is estimated to have increased in 94% of monitored European regions[1]. Beyond their human toll, heatwaves generate diffuse but economically significant disruptions—spiking energy demand, straining public health systems, reducing agricultural yields, and impairing infrastructure, from warped railways to constrained river transport.

While the environmental and public health consequences of heatwaves are well-documented, their financial impact on households remains far less understood. A growing literature examines the macroeconomic effects of temperature increases—particularly in lower-income countries—but there is limited evidence on how acute, ambient climatic shocks affect household-level credit outcomes in advanced economies. This is particularly true in formal credit markets, where risks are often diffuse and difficult to price ex ante, but where even modest disruptions to income or liquidity can generate meaningful changes in borrower behavior.

Much of the existing work on climate shocks has focused on asset-damaging disasters such as floods, wildfires, and hurricanes, which have clear transmission channels to credit markets. In contrast, heatwaves exert more ambient and persistent pressure and may disrupt household finances through subtler channels. This is especially relevant in

[1]https://climate.copernicus.eu/esotc/2023/extreme-weather-and-human-health

Europe, where heatwaves are the most lethal weather-related phenomenon but remain understudied in the context of formal lending. A substantial literature shows that extreme heat reduces labor productivity, agricultural output, and GDP growth in developing countries (Dell et al. (2012); Burke et al. (2015)). However, the extent to which these effects translate to high-income settings—characterized by service-based economies, social insurance programs, and regulated financial systems—is an open empirical question. While rural areas may be protected by agricultural subsidies or crop insurance, urban centers may still be vulnerable to health shocks, labor disruptions, or volatility in discretionary income.

This paper examines the effects of summer heatwaves on household credit outcomes across four of Europe's largest economies: France, Germany, Italy, and Spain. Using a novel dataset of over seven million consumer loans issued between 2018 and 2022, I match detailed borrower- and loan-level information to high-frequency, geolocated temperature records. I focus on consumer loans—rather than mortgages or asset-specific credit like auto loans—because they tend to be shorter in maturity, more exposed to short-term liquidity constraints, and more directly reflect household consumption needs, discretionary borrowing behavior, and day-to-day financial stress. These characteristics make consumer credit a particularly informative margin through which to observe the effects of transient climate shocks such as heatwaves.

Germany, France, Italy, and Spain together represent the largest economies in the euro area and account for the majority of consumer lending activity across the continent. They also differ meaningfully in their exposure to climate risk: southern regions in Italy and Spain regularly experience extreme summer heat, while Germany and northern France have historically faced milder conditions. This geographic variation creates natural within-year, within-country contrasts in heatwave exposure. Moreover, these markets encompass a wide array of loan purposes—including auto financing, home improvement, electronics, medical expenses, and other forms of personal borrowing—allowing for rich heterogeneity analysis across borrower types and credit products. The breadth of institutional coverage and regional diversity enhances the external validity of the findings and provides insight into how climate shocks propagate through consumer credit markets across both Southern and Northern European economies.

The identification strategy exploits within-year variation in heatwave exposure across NUTS2 regions using a difference-in-differences framework. A loan is defined as treated if it originates in a region that experiences at least three heatwave days—based on national meteorological definitions—between May and August of that year. The empirical analysis examines two sets of outcomes: ex-ante contract terms (e.g. interest rates and maturities) and ex-post performance, measured by default within one year of origination. All specifications include granular borrower- and loan-level controls, as well as high-dimensional fixed effects at the regional and lender level.

I find that loans originated in heatwave-affected regions carry slightly higher interest rates—by approximately 22 basis points—but that this adjustment is insufficient to offset the increased credit risk. Default rates increase on average following heatwave exposure, representing a statistically and economically meaningful deterioration in borrower performance. These results hold after conditioning on income, employment type, loan characteristics, and precipitation. Importantly, maturities do not adjust, suggesting that pricing alone is the primary response—and that it is incomplete.

To test the timing and persistence of these effects, I implement a pre/post framework that compares loans originated in the months before (January–April) and after (September–December) the heatwave season. I find no differences in default between treated and control regions prior to heatwave exposure, supporting the parallel trends assumption. In contrast, loans originated after heatwaves in affected regions show significantly higher default rates, reinforcing the interpretation that heat stress impairs borrower liquidity or selection in a way that manifests after the initial shock. An event-study analysis further confirms that the divergence in default rates only emerges in the post-period.

Notably, the effects are concentrated in segments with limited financial buffers: low-income borrowers, those with informal or non-salaried employment, and loans without collateral. These are precisely the borrowers least equipped to absorb transitory income shocks or health-related expenses. In contrast, rural and agricultural areas—typically assumed to be vulnerable to temperature extremes—show no meaningful change in loan pricing or performance. This suggests that institutional protections (e.g. agricultural insurance) may buffer these sectors, while climate-induced financial fragility is more pronounced in urban, service-oriented labor markets.

Several mechanisms may explain the observed patterns. Extreme heat can reduce labor productivity and suppress earnings, particularly for self-employed or hourly workers. It can also raise out-of-pocket medical costs and increase the likelihood of behavioral misjudgment at the time of borrowing. Moreover, heatwaves have been associated with increases in crime and social instability, which may further stress household finances. That lenders appear to adjust interest rates only modestly suggests that these risks are not fully internalized at the time of origination, particularly for unsecured borrowers.

This paper contributes to three strands of literature. First, it expands research on climate risk and household finance by showing that even ambient weather shocks can affect borrower behavior in formal, regulated lending markets. Second, it adds to the understanding of credit fragility, highlighting climate as a latent risk factor for unsecured households. Third, it offers new evidence on how institutional and geographic characteristics mediate the impact of environmental stress, challenging conventional assumptions about where and how climate risk manifests.

The remainder of the paper proceeds as follows. Section 2 describes the data sources, institutional context, and construction of the climate exposure measures. Section 3 outlines the empirical strategy and identification assumptions. Section 4 presents the main results. Section 5 examines heterogeneity across borrower, loan, and regional characteristics. Section 6 concludes.

2 Related Literature

Heatwaves have increasingly been recognized as significant macroeconomic shocks with measurable impacts on aggregate output, labor supply, and sectoral productivity. Recent empirical work shows that extreme heat depresses economic activity by impairing labor performance, especially in heat-exposed sectors such as construction, manufacturing, and transport (Kahn et al. (2021)). For instance, Kjellstrom et al. (2016) estimate that in high-income countries, labor productivity losses due to heat stress could reach up to 0.3–0.5% of GDP annually by mid-century. At the macro level, cross-country panel data studies find that each additional day above a critical temperature threshold reduces annual GDP per capita, with more pronounced effects in service- and manufacturing-driven economies (Burke et al. (2015); Deryugina and Hsiang (2014)).

One major transmission channel for these macroeconomic effects is through energy markets. Heatwaves sharply increase electricity demand for cooling, often leading to price spikes and infrastructure strain. Xu et al. (2025) document how the 2022 Southern European heatwaves caused record-high power consumption and curtailed wind generation, exacerbating grid stress. Mosquera-López et al. (2024) show that extreme temperatures drive nonlinear increases in electricity prices across European markets, underscoring system vulnerability during heat events. These dynamics highlight how climate shocks can propagate through utility costs and energy price volatility, with potential feedback effects on both household welfare and macroeconomic stability.

At the microeconomic level, a growing body of research has identified several pathways through which extreme weather shocks—particularly high temperatures—affect household financial behavior. First, heat-induced reductions in labor productivity and earnings, especially among outdoor and informal workers, can tighten household budgets and elevate credit demand (Colmer (2021); Graff Zivin and Neidell (2014); Heal and Park (2016)). Second, extreme heat increases essential living costs through higher energy consumption for cooling and through health-related expenditures linked to heat stress and associated illnesses (Deschênes (2022); Graff Zivin and Shrader (2016); Park et al. (2021)). Together, these channels suggest that acute climate events may simultaneously raise short-term borrowing needs while undermining repayment capacity—especially for liquidity-constrained households.

At the broader level, this paper contributes to the growing literature on environmental shocks and household finance. Prior work has examined how natural disasters and climate transition risks affect household credit outcomes in traditional markets (Blonz and Troland (2023); Del Valle and Shore. (2022); Gallagher and Hartley (2017); Gallagher and Ricketts (2020); Beyene (2023)). Much of this research has focused on acute, asset-damaging events—such as floods, hurricanes, or wildfires—and their transmission through mortgage and credit card markets. In contrast, I examine the effects of ambient, non-destructive climatic stress—specifically heatwaves—on consumer credit outcomes using rich loan-level data from regulated lending markets.

Lastly, this paper is closely related to recent work by Xie et al. (2024), who show that extreme heat increases borrowing activity and default risk in the U.S. payday loan market, particularly when temperatures exceed 33°C. While their results highlight the vulnerability of low-income borrowers in high-cost credit markets, my analysis complements and extends this work in several key ways. I examine regulated consumer credit markets across four major European economies—France, Germany, Italy, and

Spain—where institutional safeguards, pricing rules, and borrower protections differ substantially from the U.S. payday sector. Using a difference-in-differences framework tied to exogenous heatwave shocks, I find that exposure to extreme temperatures at the time of origination increases subsequent default risk, with only limited adjustment in pricing. Notably, the deterioration in performance is not concentrated in agricultural or predominantly rural regions—where climate vulnerability is often assumed to be highest—but rather in urban and service-based economies, where income shocks are more likely to be uninsured and loans are often unsecured. The findings point to a latent form of financial fragility that is not well captured by geographic or occupational stereotypes and underscore the need for borrower-level credit risk assessments in the context of rising climate volatility.

3 Data

3.1 Loan Data

To investigate how extreme heat affects household credit conditions and loan performance, I use a comprehensive dataset of consumer loans originated across Europe, primarily composed of loans securitized by financial institutions, including both banks and non-bank lenders. The data are obtained from the European Data Warehouse (EDW), a centralized repository for loan-level information on securitized and private consumer credit portfolios across Europe. The EDW provides standardized, asset-class-specific data for Asset-Backed Securities (ABS) transactions, including detailed borrower characteristics, loan terms at origination, and ongoing performance updates over the life of the loan. The consumer loan category includes loans for education, living expenses, medical expenses, auto financing, debt consolidation, education, furniture, home improvement, travel, equipment, property and other unspecified purposes. I focus on consumer loans originated in Germany, France, Italy, and Spain between January 2018 and December 2022. These four countries represent the largest economies in the euro area and account for the majority of consumer lending volume across the continent. The sample includes 4,638 bank-county clusters, consisting of 11 banks that have each lent to at least 389 counties. The primary outcome variables used in the analysis are loan interest rates and the loan amount. Other variables from this dataset used in the empirical regression include loan term, loan purpose, borrower's primary income, and employment type. All financial variables are winsorized at the 1st and 99th percentiles to mitigate the influence of extreme outliers. This final dataset consists of 7,410,338 loans issued between January 2018 to December 2022.

3.2 Weather Data

To measure regional exposure to extreme heat, I use climatological heatwave data from the Copernicus Climate Change Service (C3S) (2024), aggregated at the NUTS2 level. The primary variable captures the number of heatwave days per month, defined according to the Climatological Heatwave Days Index. This index identifies a heatwave as a period of at least three consecutive days during which both the daily minimum and maximum surface air temperatures exceed the 99th percentile for that calendar day, based on the 1991–2020 reference period. This threshold is tailored to local climatic conditions and is particularly relevant for applications in public health, energy demand, agriculture, and infrastructure resilience. For the sample period between May and September, the average number of heatwave days per region-month is 0.37, with the most intense episode reaching 12.4 heatwave days in a single month. This definition allows for consistent identification of extreme heat events across diverse climatic regions and forms the basis for treatment assignment in the empirical analysis.

To control for broader environmental conditions that may influence household finances or credit market activity, I include a measure of local precipitation. Specifically, I use monthly total precipitation (in meters) from Copernicus Climate Change Service (C3S) (2021), aggregated at the NUTS2 level. The variable is measured as the natural logarithm of cumulative precipitation over the three months prior to loan origination. This control helps account for concurrent droughts or rainfall anomalies that may affect income—particularly in agriculture-adjacent regions—or alter household utility expenses, local economic activity, or general borrower liquidity. Including precipitation ensures that the estimated effects of extreme heat are not confounded by broader weather-related shocks that operate through complementary environmental channels.

4 Descriptive Statistics

Table 1 presents the distribution of loan purposes across the four countries in the sample: Germany, France, Italy, and Spain. The composition of loans varies substantially by country, though several consistent patterns emerge. In Germany, debt consolidation and vehicle financing represent a large share of loan volumes, with over 30,000 loans for debt consolidation and more than 33,000 loans for new or used cars. In France, home improvements and property-related loans dominate, with over 28,000 and 54,000 loans respectively. Italy displays a heavy concentration in appliance and vehicle financing, while Spain, the largest dataset in terms of observations, shows a remarkably high number of loans categorized as "Other" (over 2.5 million), alongside significant volumes for living expenses (586,517) and appliances/furniture (189,966). Notably, medical expenses appear in significant numbers only for Italy and Spain, suggesting country-specific lending patterns in response to health-related needs.

Table 2 reports the descriptive statistics for loan characteristics and borrower income by country. There is considerable heterogeneity across national credit markets. German loans are among the largest and longest: the average loan balance exceeds €16,000, and the average maturity is approximately 66 months. In contrast, Spain exhibits the shortest average loan terms (33 months) and the smallest average loan size, under €5,000, suggesting a prevalence of smaller-scale, short-term borrowing. Interest rates also vary widely: Italy records the highest average interest rate (6.7%), followed by Spain (5.4%), while France and Germany report significantly lower averages (3.8% and 5.0%, respectively). These differences likely reflect a combination of institutional factors, borrower risk profiles, and national lending standards.

Income distributions show marked variation. French and German borrowers report relatively moderate and tightly distributed incomes. In contrast, Spain exhibits an extremely high mean income (€144,576) paired with an unusually large standard deviation, indicating substantial outliers or a skewed distribution that may reflect data reporting artifacts.

4.1 Methodology

In this study, I investigate the causal effect of short-term extreme heat exposure on loan conditions and subsequent loan performance across NUTS2 regions in France, Germany, Spain, and Italy over the period 2018 to 2022. Specifically, I examine whether the occurrence of heatwaves in the immediate months preceding loan origination affects key loan characteristics, including the interest rate, loan amount, loan term, and the probability of default. To identify this relationship, I employ a Difference-in-Differences (DiD) framework that exploits regional and temporal variation in the occurrence of heatwaves, defined as periods with at least three heatwave days within a calendar month. For the purpose of this analysis, I restrict the sample to loans originated between the months of May and September, corresponding to the typical heatwave season in Europe.

The empirical specification is structured as follows:

$$\text{Outcome}_{irt} = \beta\,\text{Treated}_{rt} + X'_{irt}\theta + \gamma_r + \delta_t + \varepsilon_{irt} \tag{1}$$

In this equation, Outcome_{irt} denotes the loan outcome of interest for loan i in region r and month t, specifically the interest rate, loan amount, loan term, or an indicator for default. The treatment variable, Treated_{rt}, is a binary indicator equal to one if, in the month of loan origination or in the two preceding months, the borrower's NUTS2 region experienced at least three heatwave days; it is zero otherwise. The vector X_{irt} includes a set of borrower- and loan-level control variables such as logged borrower income, employment type, loan amount, loan term, and other relevant characteristics. I include γ_r, a full set ofBank fixed effects, NUTS2 region fixed effects, to control for time-invariant regional heterogeneity, as well as δ_t, a set of year-month fixed effects, to capture common macroeconomic shocks, seasonal patterns, and time trends.

The identification strategy exploits within-region, over-time variation in heatwave exposure, conditional on rich borrower, loan, regional, and time controls. The key identifying assumption is that, absent heatwave exposure, loan terms and default rates would have evolved similarly across regions. By limiting the sample to loans originated within the May–August period, I ensure that treatment and control observations are comparable in terms of seasonal borrowing patterns, thereby mitigating concerns related to endogenous loan demand fluctuations outside of the heatwave season.

Standard errors are clustered at the NUTS2-month-year level, corresponding to the level of treatment variation, to account for potential serial and spatial correlation in unobserved factors affecting loan conditions and borrower performance. For the analysis of default outcomes, which is a binary variable, I estimate both a linear probability model (LPM) and a probit model. In the probit specification, I report average marginal effects to facilitate economic interpretation. The use of high-dimensional fixed effects, combined with treatment assignment based on plausibly exogenous weather shocks, allows for a credible identification of the short-term impact of extreme heat exposure on credit market outcomes.

4.2 Main Results

This section presents the core findings on how short-term exposure to extreme heat influences loan contract terms at origination. Exploiting within-year, regional variation in heatwave exposure across four major euro area economies, I estimate the causal effect of experiencing three or more heatwave days in the two months prior to loan issuance on the pricing and structure of consumer credit. The empirical strategy employs a difference-in-differences design with high-dimensional fixed effects and detailed borrower-level controls to isolate the impact of heat stress at the point of contract formation.

Table 3 examines the effect of heatwave exposure on interest rates. Across specifications, I find that loans originated in heatwave-affected regions carry significantly higher interest rates—ranging from approximately 22 to 24 basis points above those in non-affected regions. These estimates are statistically significant at the 1% or 5% level and remain robust to the inclusion of controls for borrower income, employment type, loan size, loan purpose, amortization type, number of borrowers on the loan, origination channel, payment schedule and precipitation. While moderate in magnitude, this increase in rates suggests that lenders adjust pricing upward in response to recent climatic stress, potentially reflecting perceived increases in borrower risk or greater liquidity needs at the time of application.

Table 4 turns to other contractual dimensions of the loan. Columns (3) and (4) reveal that loans originated in treated regions are, on average, €225 to €235 larger in size than those in control regions, and these differences are statistically significant. This increase in principal suggests that borrowers exposed to recent heatwaves may demand or receive larger amounts of credit, possibly to buffer short-term costs or disruptions associated with extreme heat. By contrast, Columns (1) and (2) show no significant effect of heatwave exposure on loan maturity. The absence of change in loan duration—despite increases in both price and amount—implies that lenders do not extend repayment horizons to accommodate the larger loan sizes, leaving borrowers to absorb the added debt under unchanged amortization schedules.

Together, the results from Tables 3 and 4 indicate that lenders respond to recent extreme heat events primarily through price and volume adjustments, while maintaining term structures. This pattern suggests that climate stress affects the structure of credit supply, with interest rates and loan amounts both increasing in the wake of heatwave exposure. However, the rigidity in maturities may signal limited flexibility in underwriting standards or a lack of full adjustment to borrower liquidity constraints under climate-induced stress.

4.3 Effect of Heatwave Exposure on Loan Performance

In this section, I analyze the impact of heatwave exposure on borrower default rates. Table 2 presents the results from estimating the effect of heatwave exposure at the time of loan origination on the likelihood of default using a Probit model in columns (1) and (2) and a linear probability model in columns (3) and (4). The treatment variable indicates whether the borrower's NUTS2 region experienced at least three heatwave days in the month of loan origination or in the two months prior. As in the loan conditions analysis, the specification includes a comprehensive set of controls and fixed effects, including borrower income, employment type, loan amount, loan term, NUTS2 region, bank, and year-month fixed effects. Standard errors are clustered at the NUTS2-month-year level to account for spatial and temporal correlation in the residuals.

Table 5 presents strong evidence that heatwave exposure prior to loan origination is associated with elevated default risk, with results consistent across both binary and continuous model specifications. In the linear probability model, exposure increases the likelihood of default by approximately 0.21 percentage points, representing a 8.7% increase relative to the sample mean of 2.45%. The Probit model specifications seen in columns (1) and (2) yield qualitatively similar results, indicating that borrowers exposed to heat accumulate larger delinquent balances over the life of the loan. The estimated effects are stable across specifications that include rich sets of controls and fixed effects, including borrower income, precipitation, and geographic-by-time trends. These findings suggest that short-term climatic shocks such as heatwaves can impair borrower repayment capacity, potentially through transitory income disruptions, increased living expenses, or broader financial strain.

4.4 Pre and Post Periods

To further test the identifying assumptions underpinning the difference-in-differences design, I implement a pre/post framework to compare outcomes in the months immediately before and after the heatwave season, separately for treated and control regions. The objective is to assess whether any divergence in loan conditions is attributable to heatwave exposure, and not unrelated time dynamics or pre-existing regional differences.

I define treatment at the NUTS2 level, where a region is classified as treated if it experienced at least three heatwave days between May and August in a given year. The variable *Post* equals one for loans originated in the post-summer period (September–December), and zero for those originated in the pre-summer window (January–April). The identifying assumption is that in the absence of heatwave exposure, treated and control regions would have exhibited parallel outcome trends across these matched months.

The estimating equation is specified as follows:

$$Y_{irt} = \alpha + \beta_1 \text{Treated}_r + \beta_2 \text{Post}_t + \beta_3 (\text{Treated}_r \times \text{Post}_t) + X'_{irt}\theta + \gamma_{ry} + \delta_b + \varepsilon_{irt} \quad (2)$$

where Y_{irt} denotes the outcome for loan i in region r and time t, and X_{irt} includes borrower- and loan-level controls such as employment status, income, loan amount, loan term, loan purpose, and precipitation. Fixed effects γ_{ry} and δ_b capture NUTS1-year and bank-level unobserved heterogeneity, respectively. Standard errors are clustered at the NUTS2 $\times$ month-year level to account for within-region temporal correlation, which is the same level as the main regression.

Table 6 reports the results of this specification for both interest rates and default rates, across two levels of control saturation. In the interest rate regressions (Columns 1–2), the coefficient on the *Post* indicator is positive and significant in the baseline model, but turns negative and highly significant once additional controls are introduced—suggesting that seasonal patterns in loan pricing are sensitive to model saturation. Across all other specifications, *Post* effects are consistently negative and significant, reflecting broader seasonal declines in both pricing and default risk after summer. The *Treated* coefficient is not statistically significant, indicating that prior to the summer, there were no systematic differences in outcomes between treated and control regions, consistent with the parallel trends assumption.

The interaction term, *Treated* $\times$ *Post*, captures the differential post-period change in treated regions relative to control. In the interest rate regressions (Columns 1–2), the interaction is negative and significant in the baseline specification, suggesting that interest rates may have declined more sharply in treated regions following the heatwave season, although this effect becomes imprecisely estimated once additional controls are included. In contrast, the default rate regressions (Columns 4) show that borrowers in treated regions exhibit a statistically significant increase in default probability following heatwave exposure. The magnitude of the effect is small in absolute terms, but robust across specifications, reinforcing the interpretation that extreme heat acts as a short-run shock to borrower performance. These results suggest that while lenders do not consistently raise interest rates post-heatwave, borrower behavior deteriorates—pointing to a possible underpricing of climate risk.

To assess the validity of the identifying assumptions and explore the timing of the effects, I estimate an event-study specification where monthly indicators are interacted with heatwave exposure. Figures 1 and 2 present the resulting treatment effects, with April—defined as the final pre-treatment month—serving as the omitted category. Each coefficient reflects the difference between treated and control regions in a given month, relative to April of the same year.

Figure 1 shows the results for interest rates. The estimates for January through March are small and statistically insignificant, supporting the parallel trends assumption. Post-treatment, interest rates in treated regions decline modestly, with a marginally significant drop in December. This is consistent with earlier results showing limited evidence of systematic price adjustment following heatwave exposure, suggesting that lenders may not fully account for the increased credit risk in pricing.

Figure 2 displays the treatment effects on default probability. Unlike interest rates, default risk in treated regions increases after the summer heatwave period. The effects become statistically significant in November and December, while no differences are observed in the pre-treatment months. This pattern suggests that heatwave exposure contributes to a delayed but meaningful deterioration in borrower performance, consistent with short-term financial stress.

These results support the identification strategy and highlight that while loan pricing appears sticky, borrower risk increases meaningfully in the months following extreme heat events.

5 Borrower Heterogeneity

5.1 Employment Type

In this section, I investigate whether the effect of heatwave exposure on loan conditions and default risk varies across borrower employment types. Table 7 reports the results from regressions that include interaction terms between the heatwave treatment indicator and borrower employment categories, for both interest rate and default probability outcomes. Column (1) presents the interest rate regressions with interaction terms between the heatwave treatment indicator and employment categories. The base category is employed borrowers, so the main treatment coefficient reflects the interest rate premium for this group. The estimate indicates that employed borrowers experience a statistically significant increase in interest rates following heatwave exposure, consistent with the baseline results in Table 1. The interaction terms reveal that this pricing response is significantly lower for several other employment types. Specifically, self-employed borrowers receive interest rate increases that are 50 basis points lower than employed borrowers, while pensioners, students, and legal entities also face smaller pricing adjustments.

The attenuation in pricing for these groups may reflect lender screening behavior or differential assessment of borrower vulnerability under heat-related stress. For instance, pensioners and students may be perceived as having more stable or externally supported income flows, while legal entities and the self-employed may be evaluated under different risk frameworks—particularly if their loans are linked to business activity or collateral. Alternatively, lenders may view these groups as less exposed to immediate labor market or income disruptions during extreme heat, reducing the perceived need to adjust pricing upward in treated periods.

Column (2) examines heterogeneity in the effect of heatwave exposure on default probabilities. While the average treatment effect remains positive and significant, the interaction terms indicate substantial variation across borrower types. Self-employed borrowers exhibit the largest increase in default risk, with an effect 34 basis points higher than that of employed borrowers, significant at the 5% level.

Figure 3 presents the marginal effects of heatwave exposure on default probabilities across employment types. The estimates reveal that unemployed borrowers and civil servants experience statistically significant increases in default risk following heatwave exposure. By contrast, the marginal effects for students, pensioners, and legal entities are not significantly different from zero. Self-employed borrowers exhibit the largest increase in default probability overall, consistent with elevated income volatility and greater exposure to economic disruptions. These patterns suggest that borrowers with more precarious or cyclical income sources—particularly the self-employed and unemployed—are more susceptible to credit deterioration during periods of heat stress. The divergence in marginal effects across employment types underscores the role of labor market attachment in shaping vulnerability to climate shocks and highlights the importance of borrower characteristics in the transmission of environmental risk into credit outcomes.

5.2 Loan Type

Table 8 investigates heterogeneity in the effect of heatwave exposure on interest rates and default risk across loan purposes. Column (1) reports results for the interest rate specification, where the base category is tuition loans. The coefficient on the treatment indicator thus reflects the full effect of heatwave exposure on interest rates for tuition-related loans, while the interaction terms capture differential effects for other loan purposes relative to this baseline. The results indicate a substantial and statistically significant increase in interest rates for tuition loans following heatwave exposure, consistent with earlier findings. Importantly, loans used to finance living expenses and medical costs exhibit statistically indistinguishable treatment effects from tuition loans, suggesting that all three categories receive similarly elevated interest rate adjustments during heatwave periods. These results are consistent with lender risk-pricing behavior in which more forward-looking or necessity-based loans—those less easily collateralized or more reliant on borrower stability—are priced more conservatively in periods of heat stress.

In contrast, loans financing more discretionary expenditures or backed by tangible collateral receive markedly smaller price adjustments. Interest rate increases are 126 basis points lower for travel-related loans, 130 basis points lower for debt consolidation, and 141 basis points lower for loans used to finance other vehicles, with all differences significant at the 1% level. The attenuation in the pricing response for these categories suggests that lenders view them as less sensitive to borrower vulnerability during extreme heat, potentially due to clearer asset backing, or more selective borrower self-screening.

Column (2) examines heterogeneity in the effect of heatwave exposure on default. Across all loan purposes, there is no statistically significant difference in the treatment effect relative to tuition loans. While the point estimates vary, the null hypothesis of equal default effects across categories cannot be rejected. This divergence between pricing and realized performance reinforces the interpretation that lender responses reflect perceived ex ante risk differences across loan purposes, rather than systematic variation in ex post credit outcomes.

5.3 Urban–Rural Differences

Table 9 investigates heterogeneity in the effect of heatwave exposure on loan interest rates and default risk across regional settlement types, using the Eurostat urban–rural typology. This classification, applied at the NUTS3 level, categorizes regions based on population distribution across urban clusters and rural grid cells. Predominantly urban regions are defined as those where at least 80% of the population resides in urban clusters; intermediate regions have between 50% and 80% urban population; and predominantly rural regions are those where at least 50% of the population lives in rural grid cells (Eurostat, 2023). These typologies enable a granular investigation of spatial heterogeneity in credit responses to extreme heat events.

Column (1) reports the results for loan pricing. The main treatment effect, capturing the impact of heatwave exposure in predominantly rural areas (the base category), is not statistically significant. In contrast, the interaction term for predominantly urban regions is positive and statistically significant at the 5% level, indicating that loans originated in urban regions following a heatwave carry interest rates that are approximately 27 basis points higher than their rural counterparts. While the estimated effect for intermediate regions is also positive, it does not reach statistical significance. These findings imply that lenders impose a stronger risk premium in urban markets following extreme heat, suggesting that the economic consequences of heat wave shocks—at least in terms of credit pricing—are more pronounced in densely populated, urbanized settings.

Column (2) turns to loan performance. Here, the pattern broadly mirrors the pricing results. The treatment effect is again statistically insignificant in rural regions but becomes positive and significant for urban borrowers, with an increase in default probability of approximately 23 basis points relative to rural regions. As with pricing, the estimate for intermediate regions is similar in sign and magnitude but not precisely estimated. Notably, the absence of a significant treatment effect in rural regions runs counter to a common presumption that agricultural or less diversified rural economies would be more sensitive to temperature extremes. Instead, the results suggest that the short-run credit consequences of heat stress are concentrated in urban environments—possibly due to higher debt burdens, more volatile consumption needs, or greater exposure to heat-sensitive sectors such as services, logistics, and construction.

Together, these results challenge conventional expectations regarding climate vulnerability. While rural regions may indeed experience direct environmental impacts from heat, these do not appear to translate into observable credit market stress in the short term. In contrast, urban borrowers exhibit both tighter loan pricing and elevated default risk following heatwave exposure, underscoring the need to consider urban-specific channels of transmission when assessing the financial consequences of climate shocks. These may include labor market disruptions, heat-related productivity declines, or broader household budget pressures that are disproportionately borne by urban populations.

5.4 Income

Table 10 examines how the effect of heatwave exposure on loan pricing and borrower default varies across the income distribution. Borrowers are grouped into income terciles based on their position within the national income distribution: low-income borrowers fall below the 25th percentile, middle-income borrowers are between the 25th and 75th percentiles, and high-income borrowers are above the 75th percentile. This within-country classification accounts for cross-country variation in income levels and preserves meaningful relative comparisons.

Column (1) reports the treatment effects for loan interest rates. The base category is low-income borrowers, for whom the heatwave-related pricing effect is positive but not statistically significant. In contrast, the interaction term for middle-income borrowers is economically large and statistically significant, indicating that loans originated to borrowers in the middle of the income distribution following a heatwave carry interest rates that are approximately 32 basis points higher than those for low-income borrowers in treated periods. No such pricing differential is observed for high-income borrowers. These results suggest that lenders impose a heatwave-related premium most heavily on borrowers in the middle of the distribution—those with sufficient credit access to borrow but not the income insulation to avoid repricing under perceived risk.

Column (2) turns to loan performance. Here, the treatment effect for low-income borrowers is positive and statistically significant: loans originated to this group following a heatwave are associated with a 46 basis point increase in default probability. The interaction terms show that this effect is significantly attenuated for higher-income borrowers. Middle-income borrowers experience a 23 basis point smaller increase in default risk, while for high-income borrowers, the treatment effect is 32 basis points smaller. Importantly, these estimates reflect defaults on loans originated after a heatwave event, rather than defaults occurring during the heatwave itself. This timing distinction suggests that heatwave exposure at the time of origination acts as a stressor that subsequently materializes in repayment behavior—particularly for borrowers with limited financial slack.

Together, the results point to clear asymmetries in how climatic shocks at the time of loan origination translate into credit market outcomes. Lenders adjust pricing most sharply for middle-income borrowers, while the deterioration in loan performance is concentrated among those at the bottom of the income distribution. This wedge between pricing and realized risk highlights the limits of ex ante screening under environmental stress and underscores income as a central dimension of borrower vulnerability to climate-driven credit shocks.

6 Discussion

This paper provides new evidence on the role of acute heatwave shocks in shaping consumer credit markets. Using a large panel of loan-level data from four major European economies, I show that short-term heatwave exposure at or near the time of origination affects both the pricing and performance of retail credit. The identification strategy leverages plausibly exogenous variation in extreme temperature events across space and time, combined with high-dimensional fixed effects and granular borrower-level controls. The findings contribute to a growing literature on climate finance by documenting how even transient climatic shocks can have measurable impacts on loan terms and borrower outcomes.

The baseline estimates indicate that loans originated in the immediate aftermath of a heatwave carry higher interest rates and, on average, are slightly larger in size. These adjustments are consistent with lenders pricing in greater risk or responding to higher borrower demand during periods of heat stress. However, loan maturity does not appear to respond systematically to heat exposure, suggesting that credit durations are relatively inelastic to short-term weather shocks.

The analysis of borrower performance reveals that heatwave exposure increases the probability of default. This deterioration in repayment behavior is most pronounced in the months following a heatwave, reinforcing the interpretation that the shock operates through a lagged channel—either via reduced income stability, increased household expenses, or broader economic disruptions. The pre/post analysis supports the identification strategy, with no significant differences in default or pricing observed between treated and control regions in the months prior to heatwave exposure.

Heterogeneity analyses further reveal that the effects of heat exposure are not evenly distributed. Borrowers with more precarious employment arrangements—particularly the self-employed and unemployed—exhibit significantly higher default risk following heatwaves, while full-time and public sector employees are less affected. Similarly, loans used for tuition, living expenses, and medical costs show stronger pricing responses than those for collateralizable assets, consistent with lender perceptions of risk across loan purposes. The treatment effect is also concentrated in urban areas and among lower-income borrowers, suggesting that vulnerability to heatwave shocks is mediated by both geography and financial resilience.

Taken together, the results point to a potential misalignment between how lenders adjust pricing and where performance deteriorates most. While pricing adjustments are more common for mid-income borrowers, the highest increases in default occur among those with the least financial slack. This divergence underscores the challenge of pricing environmental risk in credit markets and highlights the need for a more systematic integration of climate risk into underwriting frameworks.

These findings have broader implications for consumer finance and risk management. As extreme weather events become more frequent, lenders and policymakers will need to account for climate-related credit risks that may not yet be fully internalized in current models. Failure to do so could result in mispriced risk, unexpected defaults, and growing inequality in credit access across demographic and geographic lines.

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7 Tables

Table 1: Distribution of Consumer Loan Purposes by Country

	Germany	France	Italy	Spain
Tuition Fees	853	3	5,118	5,247
Living Expenses	5,072	2,465	132,407	586,517
Medical Expenses	0	0	73,726	61,551
Home Improvements	6,094	28,645	89,634	185,027
Appliances/Furniture	2,252	214	401,465	189,966
Travel	2,166	266	1,061	2,910
Debt Consolidation	31,008	29,783	15,007	22,138
New Car	12,089	15,246	138,878	70,316
Used Car	21,025	12,615	208,267	29,110
Other Vehicle	73	672	77,204	94,908
Equipment	0	60,394	16,987	39,125
Property	0	54,153	2,973	27,004
Other	228,338	87,333	681,051	2,524,191

Note: This table reports the number of consumer loans by primary purpose category across four euro area countries: Germany, France, Italy, and Spain. Loan purposes are mutually exclusive and follow the original classification provided in the European DataWarehouse (EDW). The sample includes all consumer loans originated between 2018 and 2022 and reported by major banks and non-bank lenders.

Table 2: Summary Statistics of Loan Characteristics and Borrower Income by Country

	Mean	sd	p10	p25	p50	p75	p90	Count
Germany								
Interest Rate	4.997	3.496	0.04	2.896	4.956	6.993	8.79	613,294
Maturity (month)	65.71	25.37	25	48	72	84	97	613,294
Principal Balance	16,680	15,666	2,579	5,000	11,182	23,300	39,220	613,294
Income	33,797	13,260	17,928	25,000	39,000	39,000	45,000	598,092
France								
Interest Rate	3.8	1.9	1.9	2.7	3.5	4.8	5.8	291,789
Maturity (month)	58.59603	26.95316	24	38	60	72	96	291,789
Principal Balance	14469.89	11653.58	3500	6000	10550	20000	30000	291,789
Income	35467.31	24952.56	15600	20400	28000	42000	65000	291,789
Italy								
Interest Rate	6.7	3.4	0	5.4	7.0	8.95	10.1	2,045,039
Maturity (month)	63.6	33.8	20	36	60	84	120	2,037,220
Principal Balance	12660.22	10210.57	1540	4500	10566.69	17684.35	27590	2,045,039
Income	22292.42	11748.01	10980	15577	20148	26520	35808	2,038,862
Spain								
Interest Rate	5.409045	6.198272	0	0	4.2	9.45	16	4,395,116
Maturity (month)	33.38737	32.12742	1	6	20	60	96	4,395,117
Principal Balance	4933.195	7479.25	80.91	230.3	1062.94	6800	15150	4,395,117
Income	144576.6	563291.7	9000	12444.48	18000	31000	83000	4,395,111

Note: This table summarizes key loan characteristics and borrower income across countries in the sample. All monetary variables are denominated in euros and winsorized at the 1st and 99th percentiles. "Interest Rate" reflects the annual percentage rate at origination. "Maturity" is expressed in months. "Principal Balance" refers to the original loan amount disbursed. "Income" denotes self-reported gross annual income at origination.

Table 3: Impact of Heatwave Exposure on Interest Rates

	(1)	(2)	(3)
	Interest Rate	Interest Rate	Interest Rate
Treated	0.240***	0.221***	0.244**
	(0.0920)	(0.0834)	(0.104)
Log Precipitation	-0.0743	-0.0201	0.141**
	(0.101)	(0.0957)	(0.0690)
Log Income	-0.235***	-0.320***	-0.238***
	(0.0709)	(0.0704)	(0.0262)
Loan Term		0.0481***	0.0243***
		(0.00821)	(0.00128)
Log Loan Amount		0.572***	0.329***
		(0.0217)	(0.0762)
Constant	6.484***	2.229***	6.587***
	(0.955)	(0.827)	(0.748)
N	3833607	3829638	1114780
adj. R^2	0.227	0.271	0.358
Year-Month FE	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes
NUTS2 Region FE	Yes	Yes	Yes

Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: This table presents OLS regression results estimating the effect of regional heatwave exposure on loan interest rates at origination. The treatment variable equals one if a borrower's NUTS2 region experienced at least three heatwave days during the month of loan issuance or in the two prior months. All regressions include fixed effects for NUTS2 region, lender (bank), and year-month. Column (1) includes baseline controls. Column (2) adds borrower employment status and loan purpose. Column (3) includes additional controls for amortization type, number of borrowers, origination channel, and payment method. Standard errors are clustered at the NUTS2-Year-Month level.

Table 4: Impact of Heatwave Exposure on Loan Terms and Amounts

	(1)	(2)	(3)	(4)
	Loan Term	Loan Term	Loan Amount	Loan Amount
Treated	0.163	-0.104	233.5***	224.9***
	(0.354)	(0.239)	(89.34)	(48.69)
Log Income	0.268***	-0.597***	720.9***	643.0***
	(0.0838)	(0.0918)	(108.5)	(98.17)
Log Ave. Precip	-0.779**	-0.515**	-73.28	65.06*
	(0.324)	(0.235)	(69.00)	(34.35)
Interest Rate		0.428***		-99.66***
		(0.0145)		(11.70)
Log Loan Amount		7.686***		
		(1.064)		
Loan Term				189.2***
				(6.455)
Constant	23.29***	-21.50***	-2462.3**	-6211.2***
	(2.300)	(6.588)	(1180.5)	(1132.2)
Observations	3829639	3829638	3833608	3829638
adj. R^2	0.734	0.800	0.564	0.696
Year-Month FE	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes
NUTS2 Region FE	Yes	Yes	Yes	Yes

Standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: This table reports OLS estimates of the effect of heatwave exposure on loan maturity (in months) and principal balance (in euros) at origination. The treatment variable equals one if a borrower's NUTS2 region experienced at least three heatwave days in the month of origination or in the two prior months. All specifications include fixed effects for NUTS2 region, lender, and year-month. Columns (1)–(2) report results for loan term, while Columns (3)–(4) report results for loan amount. Column (2) and (4) include additional controls for amortization type, number of borrowers, origination channel, and payment method. Standard errors are clustered at the NUTS2-year-month level

Table 5: Impact of Heatwave Exposure on Default Rates (Marginal Effects)

	(1)	(2)	(3)	(4)
Treated	.0019746***	.0019309***	0.00213***	0.000369
	(.0004369)	(.0004205)	(0.000675)	(0.00101)
Average Preciptiation	-.0014372***	-.0013314***	0.000408	0.00134**
	(.0002982)	(0.0002894)	(0.000551)	(0.000652)
Log Income		-.0001553*	0.000427*	0.00108**
		(0.0000832)	(0.000220)	(0.000455)
Loan Term Length		.0000624***	0.0000771***	0.0000797***
		(5.78e-06)	(0.00000828)	(0.0000140)
Log Loan Amount		.0000794	0.0000198	0.000709*
		(.0001336)	(0.000112)	(0.000389)
Constant			0.0245***	0.0480***
			(0.00451)	(0.00635)
Observations	4,185,113	4,108,946	3829639	1114780
R^2	0.3520	0.3502	0.222	0.225
Year-Month FE	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes
NUTS2 Region FE	Yes	Yes	Yes	Yes

Standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: This table reports OLS estimates of the effect of heatwave exposure on loan maturity (in months) and principal balance (in euros) at origination. The treatment variable equals one if a borrower's NUTS2 region experienced at least three heatwave days in the month of origination or in the two prior months. All specifications include fixed effects for NUTS2 region, lender, and year-month. Columns (1)–(2) report results for loan term, while Columns (3)–(4) report results for loan amount. Column (2) and (4) include additional controls for amortization type, number of borrowers, origination channel, and payment method. Standard errors are clustered at the NUTS2-year-month level

Table 6: Pre/Post Heatwave Effects on Interest and Default Rates

	(1)	(2)	(3)	(4)
	Interest Rate	Interest Rate	Default Rate	Default Rate
Treated	0.157	-0.0573	-0.000933	-0.000770
	(0.131)	(0.111)	(0.00130)	(0.00121)
Post	0.120**	-0.306***	-0.00603***	-0.00577***
	(0.0498)	(0.0504)	(0.00129)	(0.000636)
Treated × Post	-0.204**	0.0520	0.00252	0.00304***
	(0.0880)	(0.126)	(0.00184)	(0.00114)
Log Average Precipitation	-0.0992***	-0.326***	-0.000566*	-0.000685
	(0.0184)	(0.0192)	(0.000311)	(0.000422)
_cons	3.678***	5.705***	0.0464***	0.0645***
	(0.610)	(0.593)	(0.00544)	(0.00603)
N	2753731	1718983	2753732	1718983
adj. R^2	0.311	0.344	0.211	0.216
NUTS1-Year FE	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes

Standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: This table reports OLS estimates of the effect of heatwave exposure on loan maturity (in months) and principal balance (in euros) at origination. The treatment variable equals one if a borrower's NUTS2 region experienced at least three heatwave days in the month of origination or in the two prior months. All specifications include fixed effects for NUTS2 region, lender, and year-month. Columns (1)–(2) report results for loan term, while Columns (3)–(4) report results for loan amount. Column (2) and (4) include additional controls for amortization type, number of borrowers, origination channel, and payment method. Standard errors are clustered at the NUTS2-year-month level.

Table 7: Heterogeneity in Heatwave Effects by Employment Type

	Interest Rate	Default Rate
Treated	0.312***	0.00163**
	(0.0878)	(0.000670)
Treated × Employed	0	0
	(.)	(.)
Treated × Civil Servant	-0.00331	0.00243
	(0.0781)	(0.00188)
Treated × Unemployed	-0.418**	0.00216
	(0.204)	(0.00138)
Treated × Self-Employed	-0.501***	0.00340**
	(0.114)	(0.00171)
Treated × Legal Entity	-0.781***	-0.00148
	(0.282)	(0.0191)
Treated × Student	-0.238	-0.00265
	(0.209)	(0.00307)
Treated × Pensioner	-0.211	0.000267
	(0.148)	(0.00115)
Treated × Other	-0.332***	0.0000253
	(0.118)	(0.00220)
Constant	2.275***	0.0247***
	(0.825)	(0.00450)
Observations	3829638	3829639
R^2	0.271	0.2219
Year-Month FE	Yes	Yes
Bank FE	Yes	Yes
NUTS2 Region FE	Yes	Yes

Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: This table estimates differential effects of heatwave exposure on interest rates and default probabilities by borrower employment type. The base category is "Employed." All models include fixed effects for lender, year-month, and NUTS2 region, and control for loan purpose, income, loan amount, term, and precipitation. Standard errors clustered at the NUTS2-year-month level.

Table 8: Heterogeneity in Heatwave Effects by Loan Purpose

	(1) Interest Rate	(2) Default Rate
Treated	1.072***	0.00311
	(0.355)	(0.0102)
Treated × Tuition Fees	0	0
	(.)	(.)
Treated × Living Expenses	-0.379	-0.00137
	(0.423)	(0.0103)
Treated × Medical Expenses	-0.335	0.00761
	(0.398)	(0.0115)
Treated × Home Improvements	-0.896**	-0.000822
	(0.356)	(0.0104)
Treated × Appliance/Furniture	-1.140**	0.00115
	(0.494)	(0.0102)
Treated × Travel	-1.259***	-0.00556
	(0.334)	(0.0123)
Treated × Debt Consolidation	-1.302***	0.00191
	(0.326)	(0.0108)
Treated × New Car	-0.660**	-0.00192
	(0.299)	(0.0105)
Treated × Used Car	-0.879***	0.000302
	(0.290)	(0.0109)
Treated × Other Vehicle	-1.411***	0.000305
	(0.422)	(0.0107)
Treated × Equipment	0.0328	-0.00343
	(0.748)	(0.0109)
Treated × Property	-0.695*	-0.000493
	(0.386)	(0.0104)
Treated × Other	-1.108***	-0.00260
	(0.397)	(0.0103)
Constant	4.130***	0.0250***
	(0.914)	(0.00639)
Observations	3829638	3829639
Adjusted R^2	0.271	0.2220
Year-Month FE	Yes	Yes
Bank FE	Yes	Yes
NUTS2 Region FE	Yes	Yes

Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: This table shows how the impact of heatwave exposure varies by loan purpose. The reference group is tuition loans. All regressions control for borrower employment status, income, loan amount, term, and precipitation, with fixed effects for lender, year-month, and NUTS2 region. Standard errors clustered at the NUTS2-year-month level.

Table 9: Urban–Rural Differences in Heatwave Effects

	(1) Interest Rate	(2) Default Rate
Treated	0.0274	-0.000375
	(0.0939)	(0.00130)
Predominately Rural	0	0
	(.)	(.)
Intermediate Region	-0.0594	0.000131
	(0.111)	(0.000618)
Predominately Urban	0.0241	0.000837
	(0.0931)	(0.000622)
Treated × Predominately Rural	0	0
	(.)	(.)
Treated × Intermediate Region	0.158	0.00226
	(0.114)	(0.00151)
Treated × Predominately Urban	0.265**	0.00231*
	(0.109)	(0.00137)
Constant	2.241***	0.0243***
	(0.840)	(0.00447)
Observations	3736268	3736269
Adjusted R^2	0.2684	0.2167
Year-Month FE	Yes	Yes
Bank FE	Yes	Yes
NUTS2 Region FE	Yes	Yes

Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: This table estimates treatment effects by regional settlement type using Eurostat's urban–rural classification. The base category is "Predominantly Rural." Interaction terms show differential impacts in intermediate and urban regions. All models control for employment status, income, loan amount, term, precipitation, and loan type, with fixed effects for lender, year-month, and NUTS2 region. Standard errors clustered at the NUTS2-year-month level.

Table 10: Heterogeneity in Heatwave Effects by Income Level

	Interest Rate	Default Rate
Treated	0.0556	0.00461***
	(0.107)	(0.00133)
Low Income	0	0
	(.)	(.)
Middle Income	-0.585***	-0.000296
	(0.0566)	(0.000279)
High Income	-1.036***	-0.000317
	(0.0782)	(0.000367)
Treated × Low Income	0	0
	(.)	(.)
Treated × Middle Income	0.303***	-0.00217*
	(0.0978)	(0.00130)
Treated × High Income	0.128	-0.00326**
	(0.116)	(0.00150)
Constant	-0.636	0.0303***
	(0.582)	(0.00299)
Observations	3849500	3849501
Adjusted R^2	0.270	0.226
Year-Month FE	Yes	Yes
Bank FE	Yes	Yes
NUTS2 Region FE	Yes	Yes

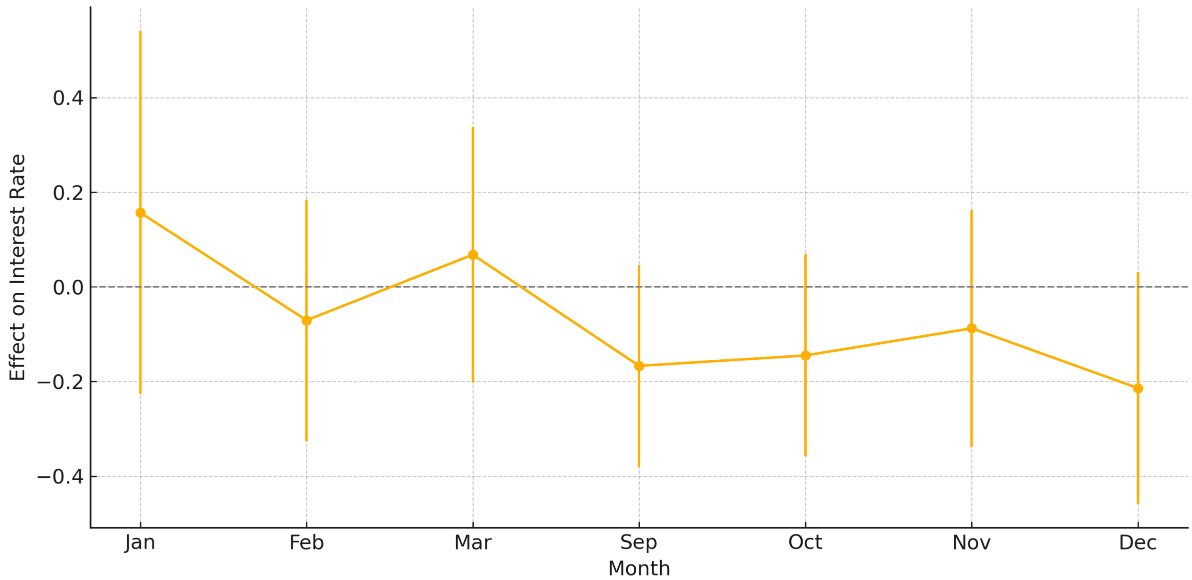
Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: This table presents treatment effects by income group, using national income terciles. The reference group is low-income borrowers. Interaction terms identify differential effects for middle- and high-income groups. All regressions include borrower and loan controls, precipitation, and fixed effects for region, lender, and year-month. Standard errors clustered at the NUTS2-year-month level.

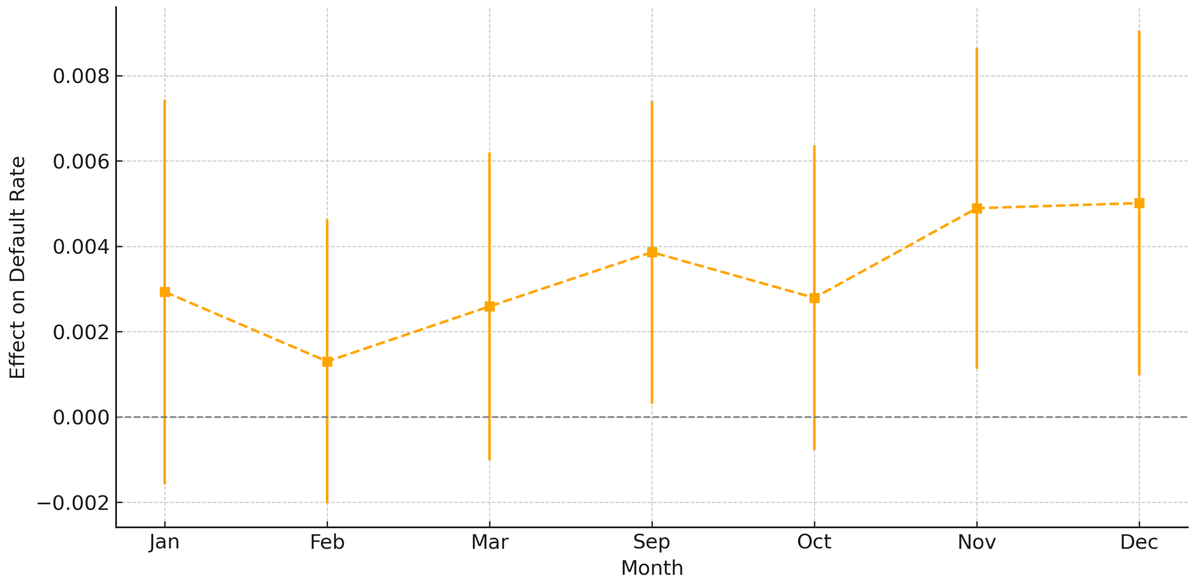
8 Figures

Figure 1: Event-Study Estimates of Heatwave Exposure on Interest Rates



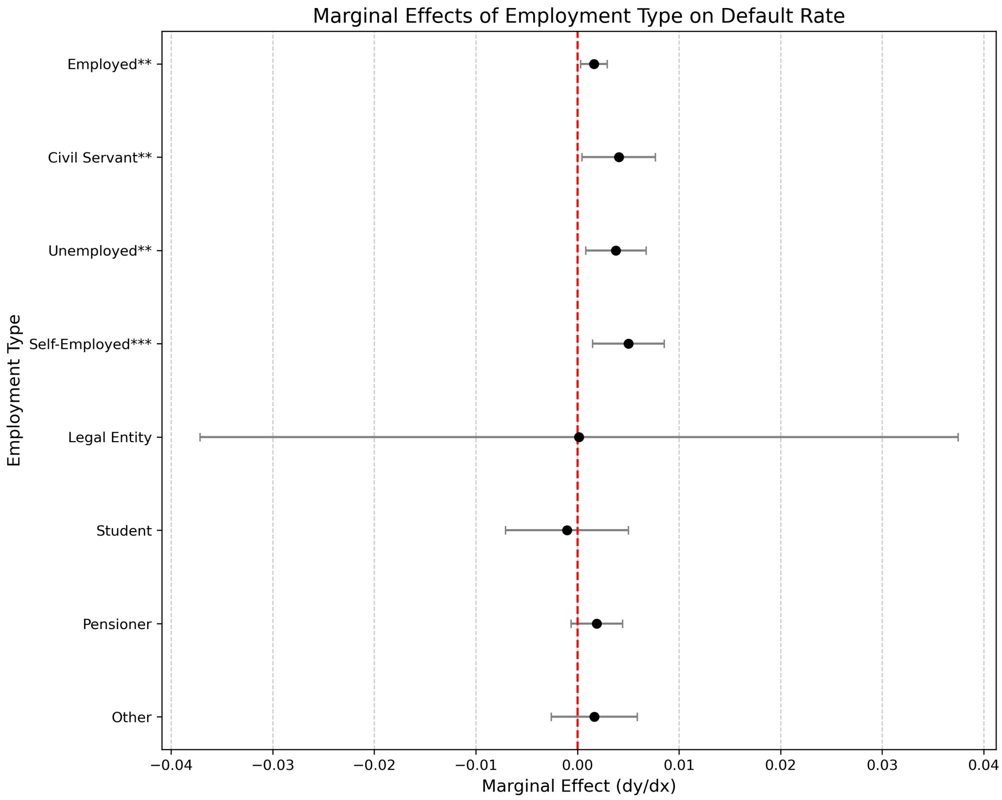
Note: This figure plots monthly event-study coefficients for the effect of heatwave exposure on loan interest rates, with April as the omitted (reference) month. Coefficients reflect the difference in interest rates between treated and control regions for each month, relative to April of the same year. Pre-treatment estimates (January–March) are close to zero and not statistically significant, supporting the parallel trends assumption. Post-treatment months show small and imprecise declines in interest rates, indicating limited lender response to increased borrower risk. All models include fixed effects for bank and NUTS1-year, and control for borrower and loan characteristics. Confidence intervals are shown at the 95% level.

Figure 2: Event-Study Estimates of Heatwave Exposure on Default Probability



Note: This figure plots monthly event-study coefficients for the effect of heatwave exposure on borrower default rates, with April as the omitted reference month. Estimates compare treated and control regions relative to April of the same year. No significant differences are observed in the pre-treatment period (January–March), supporting the parallel trends assumption. After the heatwave season, default rates in treated regions rise significantly, with effects emerging in November and December. The models include fixed effects for bank and NUTS1-year, and control for borrower and loan characteristics. Shaded areas represent 95% confidence intervals.

Figure 3: Marginal Effects of Heatwave Exposure on Default by Employment Type



Note: This figure displays the estimated marginal effects of heatwave exposure on default probability across borrower employment categories. Estimates are derived from interaction terms in the default regression model, with "Employed" as the reference group. Self-employed, unemployed, and civil servant borrowers exhibit significantly higher default probabilities following heatwave exposure, while effects for pensioners, students, and legal entities are not statistically significant. Results highlight differential vulnerability to climate stress based on labor market attachment. Confidence intervals are shown at the 95% level.

9 Appendix

Table 11: Event Study of Monthly Treatment Effects Pre/Post Heatwave

	(1)	(2)
	Interest Rate	Default Rate
Treatment	0.107	-0.00251
	(0.111)	(0.00191)
January × Treatment	0.157	0.00293
	(0.196)	(0.00230)
February × Treatment	-0.0706	0.00130
	(0.130)	(0.00170)
March × Treatment	0.0681	0.00259
	(0.138)	(0.00184)
April (Base) × Treatment	0	0
	(.)	(.)
September × Treatment	-0.167	0.00386**
	(0.109)	(0.00181)
October × Treatment	-0.145	0.00279
	(0.109)	(0.00182)
November × Treatment	-0.0876	0.00489**
	(0.128)	(0.00192)
December × Treatment	-0.214*	0.00501**
	(0.125)	(0.00206)
Log Average Precip	0.0338	-0.000246
	(0.0525)	(0.000655)
Constant	3.567***	0.0475***
	(0.611)	(0.00562)
N	2753731	2753732
adj. R^2	0.312	0.211
NUTS1-Year FE	Yes	Yes
Bank FE	Yes	Yes

Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Controls for all columns - Employment status, Log Loan Amount, Loan term, Log income, log average & percipitation, Loan type. Standard errors clustered by NUTS2- Month-Year.