Thermal stress and financial distress: Extreme temperatures and firms' loan defaults in Mexico*

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Abstract

The frequency and intensity of extreme temperature events are likely to increase with climate change. Using a detailed dataset containing information on the universe of loans extended by commercial banks to private firms in Mexico, we examine the relationship between extreme temperatures and credit performance. We find that unusually hot days increase delinquency rates, primarily affecting the agricultural sector, but also non-agricultural industries that rely heavily on local demand. Our results are consistent with general equilibrium effects originated in agriculture that expand to other sectors in agricultural regions. Additionally, following a temperature shock, affected firms face increased challenges in accessing credit, pay higher interest rates, and provide more collateral, indicating a tightening of credit during financial distress.

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Introduction

Global temperatures have reached their highest levels in the past decade since the 1850s, and the frequency and intensity of extreme temperatures are expected to rise due to climate change (IPCC, 2021). This outlook has heightened concerns about the potential consequences of extreme weather, particularly in low- and middle-income economies (LMIEs), where the resources to cope with environmental challenges are scarce. In the economic arena, recent studies find that extreme weather events increase firms' costs and reduce local demand. There is evidence that these events diminish agricultural yields, reduce labor productivity, increase absenteeism, diminish local spending, and, when they induce adaptation, raise operational costs (Graff Zivin and Neidell, 2014; Blanc and Schlenker, 2017; Jessoe *et al.*, 2018; Zhang *et al.*, 2018; Colmer, 2021; Somanathan *et al.*, 2021; Addoum *et al.*, 2023).[1]

The impact of weather on costs and demand may create liquidity shortages for firms that may become solvency problems. Firms that do not obtain the financing they need to cope with the harmful effects of extreme weather may default on their loans. This increase in default could not only reflect immediate financial distress but it might also deteriorate credit scores, worsening longer-term outcomes such as access to future credit and growth prospects. This is particularly concerning since credit availability is an important determinant of employment creation (Chodorow-Reich, 2013; Greenstone *et al.*, 2020; Gutierrez *et al.*, 2023) and higher investment and exports (Amiti and Weinstein, 2018; Berton *et al.*, 2018; Fraisse *et al.*, 2020; Chodorow-Reich and Falato, 2022). However, despite the prevalence of research analyzing the effects of extreme temperatures on variables that determine firms' profitability, there is a lack of empirical work that credibly examines how they affect credit delinquency and credit use, particularly in the context of LMIEs.

The extent of these economic effects, the challenges in obtaining the necessary credit, and the consequences of delinquency for future access to credit could differ between developed nations and LMIEs. LMIEs often lack the necessary equipment

[1] See Dell *et al.* (2014) for an earlier review of this literature.

to mitigate environmental challenges effectively, and their resources for investing in adaptive technologies are limited, increasing firms´ vulnerability to weather shocks (Dell *et al.*, 2012; IPCC, 2014; Burke *et al.*, 2015; Carleton and Hsiang, 2016; Hsiang *et al.*, 2019). In addition, in LMIEs certain markets often function in relative isolation from the global economy. In such instances, a reduction in production caused by extreme weather conditions might be counterbalanced by a local price surge. This could be particularly important for the agricultural sector, which might face a more inelastic demand in isolated markets. Consequently, the profitability of agricultural firms in isolated markets may exhibit less fluctuation compared to those in integrated markets, potentially mitigating the likelihood of default.[2] Moreover, agricultural firms employ a large share of workers in LMIEs. In these contexts, a negative shock to profits in the agricultural sector could more easily trigger spillover effects to other sectors of the economy.

Although the effect of weather shocks on firms' profitability may or may not be larger in LMIEs, the challenges in obtaining the necessary credit and the consequences of credit delinquency could be more severe. Because of the idiosyncratic characteristics of their financial systems, access to credit is constrained due to shallower credit markets, and this constraint is more challenging for small and medium-sized firms (SMEs) (Beck *et al.*, 2004; Djankov *et al.*, 2007; Calomiris *et al.*, 2017; Gutierrez *et al.*, 2023).[3] Hence, when confronted with extreme weather with similar economic effects, SMEs in LMIEs could find it particularly difficult to obtain necessary credit, potentially leading to credit delinquency. The consequences could also be more severe in LMIEs because heightened information asymmetry concerns make credit history critical in addressing them in these countries. Understanding whether this is the case is crucial because of the importance of credit access for SMEs growth in LMIEs, where these enterprises are the primary source of employment and job creation (Ayyagari *et al.*, 2012; Beck *et al.*, 2004).

[2] Research in other settings has shown this type of adjustment for shocks driven by aid (Cunha *et al.*, 2018) or by rainfall (Jayachandran, 2006).

[3] SMEs in LMIEs face higher interest rates and larger credit constraints. In Mexico, where we focus our study, 36.8 percent of SMEs needed external financing in 2018 but did not use banking credit because their applications were rejected or because the offered interest rate was too high, compared to only 3 percent of large firms (Instituto Nacional de Estadística y Geografía, 2019).

In this paper, we investigate the effects of extreme weather events on credit use and credit delinquency for SMEs in a middle-income economy, Mexico. We also investigate whether credit delinquency caused by extreme weather events has a persistent effect on firms' access to credit on favorable terms. To the best of our knowledge, this is the first paper to study the effects of extreme temperatures on credit use, credit delinquency, and its persistent effect on firms of any size. Therefore, it is also the first to address these questions for SMEs in a middle-income economy.

In order to analyze these effects, we exploit an extraordinarily detailed administrative data set containing loan-level information on the universe of loans extended by commercial banks to private firms in Mexico between 2010 and 2019. This data set allows us to identify loans for which the borrower was not able to meet the loan's obligations (i.e., non-performing loans), to distinguish between large firms and SMEs, to know the industry of the borrowing firm and to identify the municipality where each loan is used.[4] The data also contains information on a broad set of credit characteristics, such as interest rate, loan maturity, whether the loan is secured with collateral and if it corresponds to a new credit line.

To measure exposure to extreme temperatures, in our empirical analysis we follow Addoum *et al.* (2020) and Somanathan *et al.* (2021) and define absolute thresholds. Specifically, we define our measure of exposure as the number of days in a quarter that minimum and maximum temperatures are below 3°C and above 35°C, respectively, corresponding to the bottom 5 percent and top 5 percent of the daily minimum and maximum temperature distribution in the country. The use of absolute thresholds enables us to capture extremes that may be masked using average measures. In the robustness section, we also test the sensitivity of our results to the definition of alternative absolute thresholds as well as relative thresholds that depend on municipality-specific daily minimum and maximum temperature distribution.

We build delinquency rates as the ratio of non-performing loans to total outstanding credit. We then construct monthly delinquency rates at the municipality

[4]Municipalities are the second-level administrative units (after states) in Mexico.

level and relate them to the number of anomalous days of extreme temperature in a given municipality during the last three months. The identification strategy relies on the assumption that these extreme temperature shocks (i.e., the number of anomalous days of extreme temperature) are exogenous after controlling for seasonality and time trends specific to each municipality, as well as for national-level changes in credit delinquency rates over time.

Our analysis begins by evaluating the impact of both extreme heat and cold on credit delinquency rates, differentiating between small and large firms. We find that an increase in the number of anomalous days of extreme heat in a given municipality raises its credit delinquency rate. In particular, the immediate and lagged exposure to extreme heat increases credit delinquency rates for SMEs, a result that is not evident for large firms. In terms of magnitudes, ten unusual days of extreme heat during the previous three months increase the delinquency rate of SMEs by 0.17 percentage points, equivalent to 4.4% of the observed sample mean (3.9%). This finding is consistent with the notion that SMEs in LMIEs are less equipped to cope with extreme temperatures, and they find it more difficult to access further credit in times of financial stress. We find no adverse effect from extreme cold for either business size category.

We also explore the potential heterogeneous impacts of extreme temperatures across industries and regions, which manifest through various channels, with severity and implications varying based on the industry and the nature of the temperature extreme. The critical role of weather as a crucial input in agriculture implies that extreme heat has stronger negative impacts in this sector. For instance, high temperatures can affect plant growth drastically, leading to considerable disruptions in agricultural productivity (Mendelsohn *et al.*, 1994; Blanc and Schlenker, 2017). Moreover, extreme heat reduces task efficiency and hours worked by inducing fatigue and cognitive impairment, particularly in exposed sectors like agriculture and manufacturing (Zhang *et al.*, 2018; De Lima *et al.*, 2021). Finally, thermal stress creates discomfort and diminishes consumer demand, particularly affecting sectors like leisure, retail, and outdoor services (Addoum *et al.*, 2023; Chan and Wichman, 2022). These sectors, reliant on discretionary consumer spending and outdoor activities, are especially vulnerable to declines in demand during periods of extreme temperatures.[5]

Consistent with these mechanisms, we find that the negative effect of extreme heat is stronger in agriculture. Interestingly, however, extreme heat also has sizable effects on non-agricultural industries in regions with a sufficiently large proportion of agricultural workers. In the case of agriculture, the results imply an increase in delinquency rates of 0.29 percentage points for every ten days of exposure to extreme heat (6.9% of the sample mean) compared to 0.11 in non-agriculture (2.8% of the sample mean). The effects in the non-agricultural sector are concentrated in services and retail, that is, non-tradable sectors that rely heavily on local demand. The results are suggestive of spillover effects originating in agriculture that expand to non-agricultural industries through reduced local spending. For extreme cold, there is no evidence of adverse effects on credit delinquency for any region or sector.[6]

In addition, employing diverse measures of market integration in agriculture production, we find that weather shocks have a stronger effect on credit default among agricultural firms in more integrated markets. This result is consistent with the notion that a price surge partially offsets a decrease in local production caused by extreme weather in more isolated markets. This evidence indicates that financial institutions may be less vulnerable to temperature shocks in relatively isolated markets, as it allows firm profits to remain relatively stable amidst quantity changes due to weather shocks.

Finally, we study the persistent effects on credit access and credit conditions in the agriculture sector following a temperature shock. The fact that credit markets are underdeveloped and asymmetric information concerns are more significant in LMIEs may imply that weather shocks have persistent effects on access to credit on favorable terms, especially if such shocks increase lenders' uncertainty

[5]Overall, the evidence is less conclusive for extreme cold (Colmer, 2021; Graff Zivin and Neidell, 2014; Hsiang, 2010; Somanathan *et al.*, 2021).

[6]There is only a handful of papers that show strong effects for extreme cold, when focusing on some outdoor leisure activities(Graff Zivin and Neidell, 2014; Chan and Wichman, 2022). In Mexico, cold extremes, defined as temperatures below the 5^{th} percentile of the minimum daily temperature distribution or 3°C, are generally not severe enough to disrupt economic activity, as they usually occur in the early morning hours.

about borrowers' future repayment ability.[7] Consistent with this hypothesis, we find that temperature shocks reduce the number of firms with access to credit in the affected municipality for some time. Credit composition also changes after the weather shock: we find a decrease in credit for investments and new firms, and a rise in interest rates for new loans. These results align with the notion that post-shock, banks may curtail lending to borrowers and specific loan categories characterized by heightened information asymmetries. Other credit aspects, like maturity and loan amounts, remain mostly unchanged, except for more new loans requiring collateral.

To ensure that these market-level findings are not skewed by riskier firms disproportionately entering or surviving, we conduct firm-level analyses. The results at the firm level confirm that composition effects do not drive the observed changes. Specifically, exposure to extreme heat translates into increased interest rates for new loans within the same firm, heightened collateral requirements, and declined credit access. Taken together, the results at the firm and market level show that in response to shocks, banks tighten credit for two to three quarters, a critical resource at a time when firms most need financial flexibility. These findings contrast with those found in advanced economies, particularly the US, where the evidence suggests that firms use credit lines to manage liquidity during extreme weather (Brown *et al.*, 2021; Collier *et al.*, 2020). Mexican SMEs seem unable to use new loans similarly.

Our results are robust to a battery of different characterizations of the treatment variable. We conduct an extensive analysis employing different absolute and relative thresholds, exploring nonlinearities, and varying temperature bins. We show that only temperatures that surpass theoretically relevant constraints for

[7] In Mexico, any default is part of the firm's credit history, and its record is kept in the credit bureau for up to six years. All commercial banks can access the same information independently of the institution that granted the defaulted loan. In our sample, only around 10% of SMEs that default on a loan regain access to new credit in the following 12 months, as opposed to 70% of SMEs that do not default. For other countries, Bonfim *et al.* (2012) show that after a default episode in Portugal, it is particularly difficult to regain access to credit for small firms who borrow from only one bank. Likewise, de Roux (2021) finds that coffee farmers in Colombia who incur default due to extreme precipitation are more often denied loan applications in the future, even when they have recovered their ability to repay.

agricultural productivity impact delinquency rates. This suggests that a reduction in agricultural yields is the primary mechanism driving our results. Our findings are also robust to specifications that include time-fixed effects interacted with key municipality-level variables, indicating that they are not driven by unobserved differences in regional trends related to firm self-selection biases.

This paper contributes to a growing literature studying the impact of weather shocks on economic outcomes. Closely linked to our study, Addoum *et al.* (2020) analyze the detrimental effect of extreme temperatures on firms' sales, Graff Zivin and Neidell (2014) and Colmer (2021) study labor allocation responses, Somanathan *et al.* (2021) analyzed the effect on labor productivity and Blanc and Schlenker (2017) discuss the literature analyzing impacts on agricultural yields. We show that the economic effects found in this literature affect firms' ability to meet their loan obligations. An additional contribution of this paper is that we exploit differences not only across regions but also across economic sectors. We believe that this additional dimension of analysis is relevant to inform about the heterogeneity of the effects and the corresponding design of climate adaptation policies in LMIEs (Davlasheridze and Geylani, 2017; Kousky, 2014).[8]

In addition, the present paper contributes to the emerging literature on the effects of extreme weather events on financial outcomes. Following the increased interest of policy-makers (Bolton *et al.*, 2020; Semenenko and Yoo, 2019; Furukawa *et al.*, 2020; International Monetary Fund, 2019a), a number of studies have emphasized this effect. Brown *et al.* (2021) find that the loans obtained by small solvent firms in the aftermath of abnormal snow in the US had shorter maturities and higher interest rates. Collier *et al.* (2020) show that the loan applications of firms that were negatively affected by a hurricane were more likely to be denied or be granted at a higher cost. Gallagher and Hartley (2017) show that homeowners in the most flooded areas of New Orleans used insurance payouts to pay off mortgages after hurricane Katrina. Inundated residents ten years after this hurricane had higher insolvency rates and lower home-ownership than their

[8]To the extent that there exists a potential for long-run adaptation that can mitigate adverse effects from extreme temperature, our estimates would overstate the impact of future climate change. Hence, the results from our current empirical setting are best interpreted in the context of the near-future occurrence of unexpected extreme events.

non-flooded neighbors (Bleemer and van der Klaauw, 2019). In the context of an LMIE, de Roux (2021) finds that the probability of defaulting loans among Colombian coffee farmers increases upon exposure to extreme precipitation. Another set of papers also analyzes the impact of extreme climate events on financial intermediaries' portfolios composition and performance (Brei *et al.*, 2019; Cortés and Strahan, 2017; Koetter *et al.*, 2020; Bayangos *et al.*, 2021; Klomp, 2014). While previous research has significantly advanced our understanding of climate-induced financial risks, our study is pioneering in its analysis of the direct effects of extreme temperatures on loan defaults and credit use within an LMIE, shedding light on a critical aspect of climate economics that has previously been overlooked.

1 Background and theoretical predictions

1.1 The Mexican context

Mexico's climate is highly diverse due to its sizeable territorial extension, seven mountain ranges, and 9,330-kilometer coastline. The Tropic of Cancer effectively divides the country into temperate and tropical zones. Land north of the twenty-fourth parallel experiences relatively large reductions in temperatures during the winter months. South of the twenty-fourth parallel, temperatures are relatively consistent all year round and vary mainly as a function of elevation. Notably, due to its location in the Tropic of Cancer, the variety of climatic conditions still ranges within what would be considered warm temperatures. During the analyzed period, more than 95% of daily minimum temperatures are higher than 3°C, while virtually all the maximum temperatures reached in the period 2010-2019 were registered above 10°C.

Mexico is a desirable setting to study the effects of extreme temperatures on credit default and credit use. Among the 15 largest countries globally regarding territorial extension, Mexico encompasses different regions with diverging degrees of economic development and industrial composition. During 2013-2017, the contribution of industries highly sensitive to weather, such as agriculture, fishing, and agribusiness, to the national GDP was 7.6 percent (SAGARPA, 2018). While this figure may not seem particularly large, the municipality-level median share of employment in the agricultural sector is about a third of the total employment, which may ease the propagation of adverse effects into other industries.

LMIEs have lower saving rates than rich countries, and their institutions are less prepared to deal with informational asymmetries. Thus, SMEs face worse loan terms and greater credit constraints than large firms in their own countries and other SMEs in rich nations (Gutierrez *et al.*, 2023). Lack of credit access and inadequate credit conditions are important obstacles to SME growth in LMIEs (Ayyagari *et al.*, 2012). According to a recent survey, 36.8 percent of Mexican SMEs needed external financing in 2018 but did not use banking credit because their applications were rejected or the offered interest rate was too high, compared to only 3 percent of large firms (Instituto Nacional de Estadística y Geografía, 2019). In other Latin American countries, Eastern Europe, and Central Asia, SMEs also report being credit-constrained (Kuntchev *et al.*, 2013).

The 2018 Economic Census (Instituto Nacional de Estadística y Geografía, 2019) reveals that only 12.4% of firms make use of credit for their business operations. Access to finance disproportionately favors larger enterprises: only 11.6% of firms with fewer than 10 employees have credit access, compared to 26% for those with 10 to 50 employees and 38% for firms with over 50 employees. Most of this credit comes from banks (46%), other financial institutions that are not in our data called Cajas de Ahorro Popular (19.86%), family and friends (16%), trade credit provided by suppliers (10.2%), and other sources including private lenders (7.5%).[9] In terms of the use of credit (more than one option available), firms in Mexico declare to use it to purchase inputs (50%), to buy equipment or to increase their operations (30%), to start a new business (20%), and to pay off existing debt (11%). Firms with over 5 employees tend to rely much more on bank credit (80%). Because larger firms have more access to credit from commercial banks, the administrative data used in this paper have a smaller share of firms with less than 10 employees (75.2%) compared to the universe of all small firms in Mexico (94.0%). These numbers reflect the lack of credit access and inadequate

[9]Cajas de Ahorro Popular are cooperatives whose objective is to carry out savings and loan operations with their members.

credit conditions that face SMEs in LMIEs, which are important obstacles to firm growth in these contexts (Ayyagari *et al.*, 2012).

The relevance of focusing on SMEs in LMIEs cannot be stressed enough. In Mexico, SMEs represent 99.8 percent of all firms and employ more than two-thirds of the labor force. It is noteworthy that loan defaults can affect future access to credit for SMEs (Bonfim *et al.*, 2012; de Roux, 2021). In Mexico, any default is part of a firm's credit history, and its record is kept in the credit bureau for up to six years. All commercial banks can access the same information independently of the institution that granted the defaulted loan. In our sample, only around 10% of SMEs that default on a loan regain access to new credit in the following 12 months, as opposed to 70% of SMEs that do not default.

1.2 Theoretical predictions

There is ample evidence that extreme temperatures can adversely affect economic outcomes by increasing firms' costs and reducing demand (Dell *et al.*, 2014). The extent of these adverse effects may vary based on factors such as firms' size, industry, and the characteristics of the local market in which they operate. In this section, we summarize relevant findings from the literature to motivate the potential channels through which extreme temperatures can adversely impact the financial performance of firms. We use these findings, specifically the differential effects that extreme weather may have in distinct environments, to inform our empirical analysis and guide the interpretation of our results.

Labor productivity. We begin by discussing a labor productivity channel common to all industries. Research indicates that thermal stress may induce discomfort, fatigue, and cognitive impairment, thereby potentially resulting in a decrease in hours worked and task efficiency (Colmer, 2021; Graff Zivin and Neidell, 2014; Hsiang, 2010; Somanathan *et al.*, 2021). These symptoms also translate into lower labor productivity and increased absenteeism (Graff Zivin and Neidell, 2014). The labor productivity effect is expected to be more pronounced for workers employed in industries with high exposure to ambient temperatures, such as agriculture, mining, construction, and transportation.

For some industries, adopting costly climate control technologies may alleviate the impact. For instance, Somanathan *et al.* (2021) find that a higher number of days of extreme heat diminishes productivity and raises absenteeism in Indian manufacturing. They also find that climate control mitigates the negative effect on productivity but it does not alleviate the adverse impact on absenteeism. They interpret these results as evidence that extreme heat induces discomfort and leads to negative health effects that extend beyond the workplace. In contrast, there is less consensus regarding the effects of extreme cold.[10] Consistent with these findings, the labor productivity channel may be more likely to emerge in our data for extreme heat than for extreme cold.

Agricultural yields. In agriculture, extreme temperatures affect labor productivity, much like in other sectors where work is directly influenced by ambient temperatures. Additionally, weather extremes directly impair plant growth, a key factor in agricultural yields. This dual impact makes the agricultural sector particularly sensitive to temperature fluctuations, a focus of extensive research (Mendelsohn *et al.*, 1994; Blanc and Schlenker, 2017). For instance, Schlenker and Roberts (2009) find harmful effects on crop yields in the US, and Cui (2020) find impacts on crop abandonment (areas not harvested). Importantly, these studies do not find evidence of detrimental effects of cold temperatures during the US growing season, spanning from spring through fall.[11] Hence, we hypothesize that, in our data, the agricultural yield channel may materialize more clearly upon exposure to extreme heat than extreme cold. However, a decline in agricultural production due to extreme weather could be compensated by an increase in local prices, especially in markets that tend to operate in isolation. Thus, we also hypothesize that firms might be less vulnerable to temperature shocks in isolated markets, as it allows firm profits to not vary as dramatically amidst quantity changes due to weather shocks.

[10] Zhang *et al.* (2018) find that the output of Chinese manufacturing firms responds negatively to cold temperatures, but only at extremely low levels that are not typically observed in the Mexican territory.

[11] Because the number of days with low temperatures is not negligible in the relatively warmer season on which these studies concentrate, the lack of effects is unlikely to be driven by a loss of precision due to low level of exposure to cold days that could increase standard errors.

Operating and adaptive costs. Across various sectors, extreme temperatures —particularly heat— can escalate operational expenses. While the detrimental effects of these extremes can be mitigated to some extent through protective measures like air conditioning, such adaptation may require substantial investments and result in a significant increase in costs. Indirect evidence from the US supports this notion, showing that sales from the energy sector increase during extreme weather seasons (Addoum *et al.*, 2023; Auffhammer *et al.*, 2017). In the agricultural sector, protective measures such as irrigation and crop substitution may mitigate the negative effects of extreme heat, as found by Cui (2020). However, these adaptation strategies also entail substantial costs in both implementation and operation. In credit-constrained contexts, firms may choose to deviate resources from loan repayment into addressing immediate cash needs to mitigate the impact of high temperatures. We propose that this increase in operational costs due to weather extremes could negatively affect firms across all industries.

Consumer demand. Extreme temperatures can also induce consumer discomfort, diminishing the appeal of outdoor leisure activities and subsequently reducing their demand. In contrast to the labor and land productivity channels, recent evidence suggests that discretionary consumer demand also responds to low temperatures. For example, a study examining earnings from 60 industries by Addoum *et al.* (2023) finds that cold seasons reduce firms' earnings in the leisure and travel industries. This result is in line with the findings of Graff Zivin and Neidell (2014) and Chan and Wichman (2022) who find that time allocated to outdoor leisure tends to decrease with low temperatures.[12] Based on this evidence, we hypothesize that the consumer discomfort channel may emerge in our data for extreme cold days.

Spillover effects. Beyond the immediate impacts, extreme temperatures can also trigger spillover effects that extend through the economy. These indirect repercussions may be more important in regions where the most sensitive activities are predominant, such as regions highly dependent on agricultural output.

[12] Chan and Wichman (2022) finds that time allocated to boating, fishing, and hiking falls with higher temperatures. In another study for cities in Canada, the US, and Mexico, they find that cold temperatures reduce cycling time, while bikers respond to days with heat extremes by modifying their intra-day scheduling of cycling towards cooler times (Chan and Wichman, 2020).

For example, extreme temperatures may lead to reduced wages and employment in agriculture, and these reductions may diminish local spending in other industries (Jessoe *et al.*, 2018). Arguably, spillover effects are expected to be more pronounced for non-tradable activities that heavily rely on local spending and income, such as retail, services, and construction, for which we expect the spillover channel to emerge more clearly in our data. In contrast, non-agricultural tradable industries, mainly manufacturing, may exhibit greater resilience.[13]

Firm size and credit access. SMEs often lack risk management systems (Asgary *et al.*, 2020), internal resources (Eggers, 2020) and are typically more credit-constrained, particularly in countries with shallow credit markets (Kalemli-Ozcan *et al.*, 2020; Chodorow-Reich *et al.*, 2022). Hence, SMEs are less likely to be equipped to implement costly protective measures that can mitigate the negative impacts of extreme temperatures outlined above, such as irrigation and indoor climate control. As mentioned earlier, days with extreme heat have a smaller negative effect on the productivity of industries that use air conditioning more intensively compared to industries in which climate control equipment is uncommon (Somanathan *et al.*, 2021). Moreover, SMEs tend to concentrate their sales in fewer sectors and regions than large companies, which makes them more vulnerable to adverse local climatic conditions or other sector-specific shocks. Hence, we hypothesize that SMEs may be more adversely affected by extreme temperature shocks than large firms.

2 Data and descriptive statistics

We utilize a proprietary data set provided by the central bank (Banco de México, Banxico) that encompasses comprehensive information on the universe of credit lines issued by private banks to firms within the country from January 2010 to December 2019. Commercial banks must submit monthly reports to the regulator, the National Banking and Values Commission (Comisión Nacional Bancaria y de Valores, CNBV). These reports include detailed records of all new and existing

[13]The tradable sector might even benefit slightly from a decline in agricultural employment. (Colmer, 2021) finds that manufacturing benefited by absorbing excess labor in the agricultural sector in India after a temperature shock, but only in regions with more flexible labor markets.

loans provided to firms.

For each loan, an extensive array of attributes is recorded. For the objectives of this analysis, we have access to the following data for each loan: the municipality where the firm is located, the economic sector of the firm, the loan amount, and whether the loan is non-performing or not. A loan is deemed non-performing when the borrower fails to meet payment obligations within a specified time frame. Banks self-report the status of a loan as non-performing.[14] Additionally, the data also contains information on a broad set of credit characteristics, such as interest rate, credit maturity, whether the loan is secured with collateral and if it corresponds to a new credit line. It also allows us to classify firms as new (less than 5 years old) or old. We analyze the importance of these additional characteristics in Section 5.2.

In our main specifications, we normalize non-performing loans by the total amount of outstanding credit, which includes both performing and non-performing loans. This normalization yields a ratio corresponding to the delinquency rate, a metric commonly used to assess the health of financial systems worldwide—also referred to as the default rate or the ratio of non-performing loans to total gross loans.[15]

We categorize firms by size according to their credit history. Specifically, a firm is classified as an SME if it has not secured a loan exceeding 100 million pesos, adjusted for 2018 constant prices (roughly equivalent to 5 million USD in 2018). This SME delineation is consistent with the criteria commonly employed by the

[14]Regulatory guidelines stipulate that a loan must be classified as non-performing if it has not been paid before a pre-specified deadline that varies from 1 to 90 days and is determined by the specific terms of the loan, such as the amount and the stipulated repayment period.

[15]The non-performing loans to total gross loans ratio is part of the International Monetary Fund Financial soundness indicators. It is computed by dividing the amount of non-performing loans (NPLs) by the total loan portfolio value (comprising both NPLs and performing loans before any specific loan-loss provision deductions). Our definition of NPLs aligns with the guidelines provided by International Monetary Fund (2019b), which delineate NPLs as loans where (1) payments of interest or principal are overdue by 90 days or more; (2) interest payments have been capitalized, refinanced, or rolled over equivalent to 90 days or more; or (3) there is substantive evidence to consider them non-performing despite not being 90 days. Per these guidelines, the recorded amount for non-performing loans should reflect the gross value on the balance sheet, not merely the overdue sum.

central bank in its principal reports. Given that the municipality represents the most detailed geographic unit identifiable within the loan database, we aggregate the data at this level and at a monthly frequency.

We process weather estimates from NASA's Oak Ridge National Laboratory (ORNL) Daymet dataset to quantify local exposure to extreme temperatures. Specifically, we employ the most recent release, Version 4 (V4), published in 2021 (Thornton *et al.*, 2021). The Daymet data product is derived from algorithms that interpolate and extrapolate daily meteorological observations to produce gridded estimates of daily weather patterns. Daymet data includes minimum and maximum temperature measures on a 1km x 1km gridded surface. We process this information and construct municipality-level variables by obtaining the municipality surface's daily average maximum and minimum temperature. Additionally, daily data on precipitation is obtained from the ERA5 dataset, a data product from the European Centre for Medium-Range Weather Forecasts (Hersbach *et al.*, 2020). The data covers the surface of interest on a 30km grid. Monthly total rainfall at the municipality level was calculated by overlaying the municipality polygons to the gridded data.

Figure 1 illustrates the distribution of daily maximum and minimum temperatures at the municipality level across Mexico, revealing key characteristics of the country's temperature extremes during our period of analysis. Firstly, minimum temperatures tend to be moderate, averaging around 12°C. Cold extremes, defined as temperatures below the 5^{th} percentile of the minimum daily temperature distribution or 3°C, are generally not severe enough to disrupt economic activity, as they usually occur in the early morning hours.[16] Secondly, extreme heat events, characterized as temperatures exceeding the 95^{th} percentile of the maximum daily temperature distribution or 35°C, have been shown to adversely affect health, labor, and land productivity. Overall, the data suggest that Mex-

[16]Evidence suggests that outdoor leisure activities (Chan and Wichman, 2022; Graff Zivin and Neidell, 2014) and electricity consumption (Auffhammer *et al.*, 2017), with respective thresholds at 10°C and 4°C, are sensitive to cold extremes. However, there is no consistent evidence linking cold extremes to impacts on agricultural yields (Schlenker and Roberts, 2009), labor productivity (Somanathan *et al.*, 2021), or labor supply (Graff Zivin and Neidell, 2014)—factors that would be expected to have more first-order effects on firms' financial health.

ico is more susceptible to the detrimental impacts of excessive heat than extreme cold.[17]

To categorize municipalities into agricultural and non-agricultural, we use occupation data from the 2010 Mexican Census conducted by the Instituto Nacional de Estadística, Geografía e Informática (INEGI), which aligns with the initial year of our credit data at the local level. Agricultural municipalities are defined as those with employment in agriculture exceeding 28 percent, which is the closest absolute value to the median of the sample.

2.1 Descriptive statistics

Table 1 presents the means and standard deviations for the main variables considered in our study for all municipalities in our sample and for two sub-samples partitioned by the percentage of agricultural employment in the municipality. Consistent with the temperature trends illustrated in Figure 1, the municipalities exhibit generally mild climate conditions on average. The number of days with extreme temperatures is highly variable in both sub-samples. Notably, municipalities with a higher proportion of agricultural employment experience marginally warmer mean temperatures and fewer days of extreme temperatures, suggesting that these areas may offer a more favorable climate for agriculture. The data also reveal an overall delinquency rate of 3.9%, with similar rates observed in municipalities with high (3.84%) and low (3.9%) agricultural intensity. Agricultural firms exhibit a delinquency rate of 4.2%, and they hold an economically relevant share of total credit (15%). As expected, the percentage of credit in agricultural sectors is higher in municipalities with more agricultural employment.

[17] Heat extremes in various regions surpass thresholds associated with negative impacts on economic parameters as noted in the literature. Specifically, agricultural yields are affected above 34°C (Schlenker and Roberts, 2009), labor productivity beyond 33°C (Somanathan *et al.*, 2021), labor supply past 37°C (Graff Zivin and Neidell, 2014; Somanathan *et al.*, 2021), and electricity consumption above 27°C (Auffhammer *et al.*, 2017).

3 Empirical Framework

Our empirical strategy aims to quantify the impact of days of extreme temperature on credit delinquency. To define extreme temperature days, we first obtain the daily distribution of minimum and maximum temperatures of all municipalities in Mexico during 2010-2019. Then, following Addoum *et al.* (2020) and Somanathan *et al.* (2021), we use absolute thresholds for daily minimum and maximum temperatures, that is, thresholds that are common to all municipalities. In particular, we consider that a municipality was exposed to extreme cold if the minimum temperature during the day dropped below the fifth percentile of the minimum temperature distribution, equal to 3°C. Similarly, a municipality was exposed to extreme heat if the maximum temperature rose above the 95^{th} percentile of the maximum temperature distribution, equal to 35°C. Using absolute thresholds facilitates comparability to other research considering different periods and regions of analysis. Section 6 shows that our results are robust to defining different absolute thresholds (e.g., 2.5 -97.5^{th} percentiles and 1-99^{th} percentiles of the minimum-maximum daily temperature distribution) and we discuss the results when defining municipality-specific thresholds based on the distribution of daily temperature within municipalities, known as relative temperature shocks.

We start with a flexible monthly specification (m) capturing contemporary and lagged monthly exposure to days of extreme heat and days of extreme cold, as described below:

$$\begin{aligned} \text{Delinquency}_{cst} = & \sum_{k=0}^{3} \beta^{m}_{1(t-k)} \text{DaysExtremeHeat}_{c(t-k)} \\ & + \sum_{k=0}^{3} \beta^{m}_{2(t-k)} \text{DaysExtremeCold}_{c(t-k)} \\ & + \Psi^{m}_{cst} + \varepsilon^{m}_{cst}, \end{aligned} \tag{1}$$

where $Delinquency_{cst}$ represents the delinquency rate of firms in municipality (or county) c, sector s (either agriculture or non-agriculture), at time t (defined as calendar month-year). $DaysExtremeHeat_{c(t-k)}$is the number of days of extreme heat of municipality c during time $(t-k)$; $DaysExtremeCold_{c(t-k)}$ indicates the number of days with extreme cold in municipality c during the same period $(t-k)$. Ψ^m_{cst} is a vector of controls that includes municipality-year-sector, municipality-month-sector, and time fixed effects. In all the regressions presented in the paper, Ψ^m_{cst} also includes the average municipality-level precipitation, using the same lag structure as the extreme temperature measures. The superscript m indicates that the coefficients pertain to the monthly level measure of exposure.

The municipality-year-sector fixed effects are included to flexibly control for trends at the municipality level that might vary between sectors. These fixed effects capture time-varying variables such as migration, technological changes, and public safety at the municipality level. In addition, the municipality-month-sector fixed effects flexibly adjust for local seasonality in social and economic determinants of firms' performance. This becomes particularly pertinent for municipalities with a substantial share of firms in highly seasonal sectors, such as tourism or agriculture. Lastly, time-fixed effects control for overarching national-level shifts or common shocks experienced across municipalities.

The coefficients of interest are $\beta^m_{1(t-k)}$ and $\beta^m_{2(t-k)}$, which measure the percentage point change in delinquency rates for each day of anomalous extreme temperature during the contemporaneous month and each of the next three lags. Note that the variation exploited is the difference in the number of days with extreme temperature with respect to the municipality-monthly-specific historical averages, after controlling for nonlinear trends specific to each municipality.

As we show in Section 4, we only find that the contemporaneous temperature and its first two lags have a statistically significant effect on delinquency rates. Thus, to ease exposition, in our main analyses we aggregate temperature shocks at the quarterly level (q) and examine the effects of days of extreme temperature during the last three months on our variables of interest. Specifically, in each month we sum the extreme temperature days of the contemporaneous month and the two previous months to construct our treatment variable, and refer to this as our quarterly exposure. Consequently, our main specification is defined as follows:

$$
\begin{aligned}
Delinquency_{cst} = &\beta_1^q DaysExtremeHeat_{cq} + \beta_2^q DaysExtremeCold_{cq} \\
&+ \Psi_{cst}^q + \varepsilon_{cst}^q,
\end{aligned} \tag{2}
$$

where $DaysExtremeHeat_{cq}$ and $DaysExtremeCold_{cq}$ are the number of days of extreme heat and cold, respectively, of municipality c during the quarter q (sum of days of extreme temperature in months t, $t-1$ and $t-2$). All the other variables are defined as in Equation 1, except for rain that is defined as the average precipitation in the last three months. Our coefficients of interest, β_1^q and β_2^q, measure the effect of each additional anomalous day of extreme heat and cold during the last quarter on firms' delinquency rate, respectively. The superscript q indicates that the coefficients now pertain to the quarterly level measure of exposure. Note that the only difference with respect to the previous equation is that the treatment is now defined at a quarterly level.

The identifying assumption in this empirical framework is that the temperature shocks in a region are not associated with unobserved factors that could potentially affect firms' delinquency rate in the same region. More specifically, causal identification relies on the assumption that, once we control for regions' baseline climate conditions in each season (through municipality-month fixed effects), for region-specific nonlinear trends (through municipality-year fixed effects), and for common shocks to all municipalities (through time fixed effects), any residual difference in days of extreme temperature can be considered unexpected and, consequently, exogenous to other time-varying factors that could affect credit delinquency. A possible threat to our identification has to be a systematic short-term shock taking place in some municipalities that are also undergoing a temperature shock, generating a spurious correlation between delinquency rates and exposure to extreme temperatures. If this were the case, these shocks are likely to occur in municipalities with specific characteristics, such as the level of development, the importance of agriculture, or the population size of the municipality. In the robustness section, we show that our results are robust to controlling for several municipality characteristics interacted with time-fixed effects.

It is worth noting that a subset of the literature uses a flexible function of temperature bins to characterize the impacts of weather on relevant economic outcomes (Deryugina and Hsiang, 2014; Schlenker and Roberts, 2009). The goal of our paper is qualitatively different from that line of work. While such studies seek to characterize the temperature-outcome relationship, we strive to estimate how firms deal with the cumulative impact of extreme temperatures. Hence, in our preferred specification, we count the days per quarter in which they are exposed to extreme heat and cold. However, in Section 6, we show results using temperature bins as well.

4 Main Results

We start by presenting the results of the main specification for small and large firms separately. Table 2 details the impact of extreme temperature—both heat and cold—spanning the current month and the preceding three months. The table shows statistically significant harmful effects of days of extreme heat only for SMEs, with no robust evidence to indicate a corresponding adverse effect from extreme cold for either business size category. This trend aligns with the broader spectrum of heat-specific consequences anticipated within the climatic parameters of Mexico, as discussed in Section 2.

In particular, we find that contemporaneous exposure to extreme heat, as well as lagged effects of exposure during the previous two months, increase delinquency rates of small firms. In terms of magnitudes, one unusual day of extreme heat during the quarter increases the delinquency rate of SMEs by 0.012 and 0.023 percentage points, depending on the timing of the shock. To put this into perspective, ten such days within a quarter would translate to a 0.12 to 0.23 percentage point rise in delinquency rates, equivalent to 3.1-5.9% of the observed sample mean of 3.9%.[18] This suggests that SMEs' vulnerability to transient shocks is pronounced, likely due to their limited internal resources and constrained credit access. Under these conditions, liquidity shortages may easily become solvency problems, jeopar-

[18]Robustness checks for spatial correlation in the residuals were conducted following Conley (1999) methodology, with varying reference distances, detailed in Appendix Table A1.

dizing their operations or debt repayment capabilities (Kalemli-Ozcan *et al.*, 2020; Eggers, 2020). Moreover, small firms are less likely to be diversified across space and sectors than large firms, making them more vulnerable to adverse local climatic conditions or shocks that affect a particular sector. However, comparisons between the impact on large firms and SMEs should be approached with caution due to the considerably smaller observation size for large firms, which are less prevalent across municipalities.[19]

Building on insights from Table 2, the discussion hereafter focuses on the influence of extreme heat on the delinquency rates of SMEs in the preceding quarter. As indicated in the initial column of Table 3, we observe that the quarterly days of extreme heat carry over their effects into the monthly delinquency rates for all SMEs firms; this mirrors the monthly effects observed from time t to t-2 in Table 2. Additionally, Table 3 shows the results separating delinquency rates in each municipality among firms in the agriculture sector and the non-agriculture sector. We find effects in both sectors, although the point estimate for extreme heat is almost three times as large in agriculture compared to non-agriculture. In the case of agriculture, the results imply an increase in delinquency rates of 0.29 percentage points for every ten days of exposure to extreme heat compared to 0.11 in non-agriculture, equivalent to 6.9% and 2.8%, respectively, of the observed sample mean in each sector. This pattern is consistent with extreme temperature directly affecting crop yields, as a large body of literature has documented (as reviewed in Blanc and Schlenker (2017) and Ortiz-Bobea (2021)).[20] It is also consistent with

[19]When 1,000 regression estimations are conducted for SMEs, using random subsamples sized to match the large firm dataset, the findings do not reach statistical significance.

[20]Similar to our results for all firms, additional regressions for agriculture that incorporate lags of the temperature shock show that the adverse effect is statistically significant only for the contemporaneous quarter. This is somehow surprising because adverse meteorological conditions in a quarter might affect crop yields for more than one quarter. However, this result is consistent with farmers anticipating the future effect on sales and failing to repay their loans right after they observe the shock. The result is also consistent with farmers having to incur unanticipated costs that reduce their ability to duly repay current loans, especially in the absence of immediate credit access. Unfortunately, the limitations of detailed data on crop yields and input use prevent us from disentangling the relative importance of these mechanisms. In Section 5, we study the effect on access to credit and other credit characteristics in agriculture, and we find that the adverse effects last for two or three quarters after the shock, suggesting that the decline in profits might be longer-lived.

extreme temperatures directly affecting non-agricultural firms through labor productivity, operating costs, and consumer discomfort channels, as well as indirectly affecting these firms through general equilibrium effects from a reduction in local aggregate demand.

Table 4 presents the outcomes of our primary analysis, further stratifying the sample based on whether municipalities have an agricultural worker population above or below the median. Although the influence of extreme heat on delinquency rates for agricultural firms remains consistent across both regional types, its impact on non-agricultural firms is predominantly observed in municipalities with a higher proportion of agricultural workers. This trend implies that non-agricultural entities might experience the repercussions of extreme heat through general equilibrium effects.[21]

Local general equilibrium effects exerted by extreme weather conditions could be more pronounced in sectors heavily reliant on local consumption, such as retail and services. To explore this, Table 5 divides the non-agriculture sectors into tradables (manufacturing) and non-tradables (encompassing construction, retail, and services). The impacts of extreme heat are concentrated in the non-tradable sector in high agricultural regions. These findings are consistent with climatic shocks having a direct negative impact on agriculture that spills over into the broader regional economy, corroborating previous research that has identified adverse effects of extreme heat on local rural employment in Mexico (Jessoe *et al.*, 2018). In contrast, recent literature for developed countries finds a null effect of extreme heat on sales and earnings of large US retail and services firms (Addoum *et al.*, 2020, 2023). Our results highlight the diverging impacts of extreme heat on firms depending on their size and socioeconomic context.

We do not find evidence that the potential adverse effects of heat on the tradable sector translate into higher delinquency rates in the Mexican case. This contrasts with findings from other developing countries, where heat has been shown to adversely impact manufacturing labor productivity (Somanathan *et al.*, 2021),

[21] Municipalities with a greater concentration of agricultural labor often have lower income levels and are less developed, potentially rendering them more vulnerable to the adverse consequences of extreme temperature fluctuations.

which could lead to higher delinquency rates. Conversely, other recent papers have found that firms in the tradable sector might actually benefit from local agricultural downturns by leveraging decreased demand for agricultural labor and the resulting downward pressure on wages across sectors (Colmer, 2021). Such a dynamic could lower labor costs in manufacturing, offsetting the negative productivity impacts of heat on delinquency rates. The lack of effects observed on the tradable sector in Column 2 of Table 5 aligns with this hypothesis, indicating that its exposure to these divergent forces may neutralize the overall effect on delinquency. As before, we find no effect of days of extreme cold across all columns.[22]

5 Extensions relevant to LMIEs

The core findings of our study confirm expected patterns: agricultural firms are more susceptible to default following unanticipated negative temperature shocks, and such shocks can ripple through the economy via general equilibrium effects. Having established this relationship, the unique aspects of our study's context enable us to delve into how these impacts vary across diverse dimensions that are more salient in developing economies, and whether they transcend immediate effects. Exploring whether there are differential impacts for local markets with different characteristics is crucial for understanding the distribution of the burden of climate change across the globe.

The impact of weather shocks in developing economies may differ from those in other settings for at least two reasons: first, some markets in developing countries tend to operate in isolation from the rest of the world, and second, the relative lack of depth of financial markets in these countries may imply different

[22] The effect of extreme cold has been closely associated with the consumer discomfort channel, which reduces demand for leisure activities during cold days. For instance, Graff Zivin and Neidell (2014) and Chan and Wichman (2022) find that people spend less time outdoors on colder days, and Addoum *et al.* (2023) finds that colder springs reduce earnings of consumer discretionary industries such as those related to travel, shopping, and dining. The lack of effect, even for the non-tradable industries, is consistent with Mexico being a country with relatively warm temperatures, such that extreme cold days might not be sufficiently harmful to its effects to be detected in delinquency rates.

long-term impacts on the availability of credit for local firms. In this section, we explore the role of these characteristics in exacerbating or mitigating the financial consequences of environmental extremes.

5.1 Market integration

Isolated markets may experience very different consequences from weather shocks. As it has been documented in other contexts (Cunha *et al.*, 2018; Jayachandran, 2006), supply shifts in local production due to weather shocks can impact local prices.[23] For instance, if a decrease in supply is accompanied by an increase in local agricultural prices in less integrated areas, agricultural firms' profits may not vary as much as in integrated markets, and their probability of default may not increase. However, the price increase may also imply differential general equilibrium effects towards indirectly affected firms in the non-agriculture sector. This could be the case if increases in food prices imply higher household expenditures on these commodities and lower expenditures on the rest of the goods, generating a leftward shift in local demand in other sectors of the economy. Consequently, price changes due to weather shocks can mitigate or exacerbate the financial impacts on firms across different sectors.

We perform two different analyses to explore if weather shocks have differential impacts on default by the degree to which local markets are integrated into the global (or national) economy. To do so, we calculate two different indexes of market integration and use them to classify municipalities as less and more integrated. Firstly, we assess the correlation between municipal and national-level agricultural prices, thereby classifying municipalities into "isolated markets" with low correlation and "integrated markets" with high correlation. Secondly, we categorize municipalities based on the nature of the correlation between local quantities and prices—specifically, whether this correlation is negative (indicative of local price sensitivity to local quantity changes) or otherwise.

To construct these measures, we use the yearly dataset of agricultural production and prices from Servicio de Información Agroalimentaria y Pesquera (Cierre

[23] Crop choices may also vary with the degree of market integration (Allen and Atkin, 2022).

de Producción Agrícola). This dataset contains local prices and local volumes at the municipality level of all agricultural products from 2003 to 2020. For our first measure of market integration, we separately estimate the correlation between the logarithm of local prices and the logarithm of national prices for each of the 23,089 municipality-product combinations observed for at least 10 years. To ensure accuracy and avoid spurious correlations, we compute national prices as the ratio of total national revenue to total volume, deliberately excluding the prices from the municipality under study. Then, we calculate a weighted average of these coefficients at the municipality-year level, using the share of revenue of each agricultural product in that municipality-year cell as weights. Finally, we compute the average across years to have a unique measure at the municipality level of the correlation between local and national prices. In our regression sample, the mean of this index is 0.76 and the standard deviation is 0.18.

For our second measure of market integration, we estimate a linear regression of local prices on local volume, controlling for the logarithm of the national prices, where our estimate of interest is the coefficient associated with local volume. This specification aims to isolate the relationship between local prices and local volumes, independent of the influence exerted by national prices. To aggregate this data to the municipality level, we follow the same approach as previously described. We sum the coefficients relevant to each municipality-agricultural product combination, using the revenue share of each product in the municipality-year as weights. This results in a municipality-specific measure that captures the degree of market integration based on the unique relationship between local price and volume, distinct from the impact of national price trends.

These two measures of market integration are used to split the sample of municipalities, and we estimate our baseline model in Equation 2 separately for each subsample. Results for the impacts of the weather shocks on agricultural firms are presented in Table 6. Panel A uses delinquency rates for agricultural firms as outcomes, while panel B restricts attention to non-agricultural firms. Informed by the results in the previous section, we restrict our attention to high-temperature shocks in agricultural regions for non-agricultural firms.

Columns 1 and 3 present results for relatively isolated markets, categorized based on the correlation between local and national prices and between local prices and quantities, respectively. Conversely, Columns 2 and 4 present findings for the more integrated markets. The results suggest that extreme temperature shocks have a larger impact on agricultural firms' default in integrated markets, regardless of the criterion used for categorizing municipalities. Similarly, the indirect shock to non-agricultural firms is also somewhat larger in these contexts, inconsistent with non-agricultural firms experiencing a decline in local demand in isolated municipalities. Consequently, isolation might reduce vulnerability for financial institutions, as it appears to buffer firm profits from dramatic fluctuations in response to weather-induced quantity changes.

5.2 Persistent effects on credit characteristics

In well-functioning credit markets, the impact of weather shocks like the ones studied in this paper should be short-lived as long as they are internalized as exogenous and independent of future shocks. In imperfect credit markets, however, their impact can be longer-lived. For instance, if the defaults generated by the shock increase lenders' uncertainty as to borrowers' ability to repay their loans in the future, they might charge higher interest rates for new loans and reduce credit availability, increasing firms' credit constraints. This is especially relevant for credit types for which the ability to repay is more uncertain, such as new SMEs with scarce credit history, or for firms needing investment loans, which have longer maturity and higher uncertainty about future profits that the investment would generate.

Overall, the impact of i.i.d. shocks could be longer-lived when hitting credit markets that deal less efficiently with informational asymmetries such as the ones in LMIEs.[24] For instance, lenders in these countries find it harder to force repayment or seize collateral due to weaker legal protection for investors. Additionally, acquiring information about borrowers can be challenging due to underdeveloped credit registries (La Porta *et al.*, 1997; Djankov *et al.*, 2007; Calomiris *et al.*, 2017). This partly explains why the private credit to GDP ratio is generally lower in

[24] While these informational asymmetries are common to all countries, in LMIEs the institutional frameworks are less prepared to deal with these asymmetries (Gutierrez *et al.*, 2023).

LMIEs (Djankov *et al.*, 2007).[25] Under such a scenario, exogenous and transitory shocks can affect credit scores and, thus, exclude producers from credit markets, even when they can repay the loan.

However, the lack of competition and contract enforceability that characterizes developing countries' credit markets is fertile ground for relationship lending. Facing few options, firms typically interact with one or very few financial institutions. While this may allow lenders to restrict credit more effectively, it may also foster longer-term relationships that could solve information asymmetries, allowing banks to better identify the forces behind their creditors' delinquency. Thus, if banks can correctly identify idiosyncratic shocks in these countries, a temporary increase in credit delinquency might not generate long-run effects on credit access and loan terms (Bolton *et al.*, 2016). Thus, exploring empirically whether temperature shocks have longer than immediate impacts on credit is an empirical question, crucial for correctly assessing the potential consequences of these shocks.

In this section, we focus on agricultural firms, for which the effect on delinquency rates was significantly larger, and explore the impact of contemporaneous and lagged high-temperature shocks on several credit outcomes. To do so, we run our main specification described in Equation 2 for different outcome variables, including two additional lags to examine longer-lived impacts on credit characteristics at the extensive and intensive margins. Appendix Table A2 shows the descriptive characteristics of the variables used in this section.[26]

We start by exploring in Table 7 the impact of temperature shocks on credit characteristics at the extensive margin using several outcome variables: a binary indicator of credit availability in a municipality (Column 1), a hyperbolic sine transformation of the number of credit lines to include zero values (Column 2), the total number of firms receiving credit (Column 3), and the count of new loans (Column 4). Following a quarter with a temperature shock, there is a notable

[25]Consistent with this, de Roux (2021) finds that rainfall shocks to coffee farmers in Colombia have long-term impacts on their credit histories and credit scores, leading to a persistent lack of access to future loans, even after farmers' profits have recovered.

[26]Similar to the previous section, we focus on days of extreme heat, and we no longer include days of extreme cold to ease exposition. However, results are robust to controlling for both types of extreme temperatures.

reduction in the presence of credit, the number of credit lines, and the count of firms receiving credit. Interestingly, two quarters post-shock, there appears to be an increase in the issuance of new credit lines to local firms (Column 4), potentially restoring the total volume of loans to its pre-shock level. This pattern suggests that the temperature shock had a more persistent effect on credit access when compared to the contemporaneous effect on default, but the effect does not endure over the long term at the municipality level.

We next examine changes in the characteristics of credit stocks and those of new credit (Table 8). We find evidence that temperature shocks diminish the share of credit in investment and to new firms (Columns 1 and 2, respectively). This pattern is consistent with the idea that after a shock, banks might cut lending to borrowers and loan types for which information asymmetries are more pronounced. However, the effects are once again either contemporaneous or short-lived.

When we study the effects on interest rates (Column 3), we observe a delayed increase, suggesting that banks adjust their lending rates upward in the quarter following a surge in defaults. This hypothesis is corroborated by the data on new credit lines, which indicate that loans issued in the subsequent quarter post-shock carry higher interest rates on average (Column 4). Despite this increase in interest rates, we find little change in other credit characteristics, such as maturity, collateral, and average amount, except for a contemporaneous rise in the share of new loans with collateral. Overall, these results show that temperature shocks have persistent effects by exacerbating financial burdens for borrowers for at least two quarters.

Given that the analyses above are conducted at the market level, the uncovered surge in interest rates could be driven by changes in the composition of the credit portfolio. For example, if riskier firms remain active while less risky ones exit the market, this could elevate the average interest rate within a municipality, coinciding with the reduction in new firm participation described in our extensive margin analysis. Although this is unlikely because of the decline in the share of new firms, which tend to be riskier, we run firm-level regressions to rule out this explanation empirically. Specifically, we now compare the interest rate charged to a firm exposed to a temperature shock with the interest rate charged to the same firm without the shock. In other words, the firm-level data allow us to control for time-invariant characteristics of the firm by incorporating firm-level fixed effects. In particular, we run the following specification:

$$\mathrm{y}_{icst} = \sum_{k=0}^{2} \beta^{f}_{1(q-k)} \mathrm{DaysExtremeHeat}_{c(q-k)} + \omega_i + \Psi^{f}_{cst} + \varepsilon^{f}_{cst}, \tag{3}$$

where y_{icyt} is the outcome of interest for firm i in municipality c, sector s month t, ω_i are firm-level fixed effects. All other parameters are defined as in Equation 2, with the superscript f indicating that coefficients pertain to the firm level regression.

Firm-level results reinforce our earlier findings and show that they are not driven by composition effects (Table 9). First, there is a long-lasting effect on credit access at the extensive and intensive margins (Columns 1 and 2). Secondly, there is a notable increase in interest rates; firms exposed to extreme heat face higher rates for new loans in the subsequent quarter compared to periods without such exposure (Columns 3 and 4). We also find a contemporaneous increase in maturity and collateral for new credit (Columns 6 and 7), but again there is no effect on the average loan amount (Column 5). These results indicate that after a temperature shock, firms are less likely to access credit, and those who access it tend to have less outstanding credit, and pay a higher interest rate for their new loans even after providing more collateral.

Taken together, these findings indicate that exposure to unusual extreme heat worsens loan terms and lowers total credit amounts at the firm and market levels. They are consistent with banks reacting to shocks by temporarily limiting their credit supply. Critically, the adverse effects we find in this section on credit amount and credit characteristics are more persistent than the effect of default but somewhat short-lived. However, they occur precisely when firms undergo financial distress and might be in need of access to credit to cope with the temporary shock effectively. Unlike in the US, where firms use credit lines to manage liquidity during extreme weather (Brown *et al.*, 2021; Collier *et al.*, 2020), Mexican SMEs seem unable to use new loans similarly.

6 Robustness Checks

6.1 Varying definitions of extreme temperature

6.1.1 Considering different absolute thresholds

Our primary definition of extreme temperature is based on a predefined threshold, which may be considered somewhat arbitrary. Table 10 displays the sensitivity of our main result for SMEs to varied definitions of extreme temperature based on the temperature distribution. Notably, estimates are robust to various alternative definitions of extreme cold and heat: 10-90, 7-93, 5-95, 2-98, and 1-99 percentiles of the daily minimum-maximum temperature range, respectively. Similar to our preferred estimates, the effect is concentrated on extreme heat, varies between 0.1 and 0.18 percentage points for every ten days of extreme weather conditions, and maintains statistical significance. The point estimate becomes larger as we move to higher thresholds for extreme heat, but tends to flatten out after the 95th percentile ($35°C$).[27] The results tend to be slightly noisier (higher standard deviation) as we consider more extreme percentiles. The decline in precision is expected, given that a smaller portion of the sample is treated and some affected observations become part of the control group.

6.1.2 Considering relative thresholds

Our main specification includes municipality-by-month fixed effects to control for seasonality specific to each municipality. Thus, the identification is based on the effect of an unexpected additional day above $35°C$ in a particular month in a particular municipality. However, some work in the literature uses region-specific thresholds to define extreme temperatures. Both definitions have compelling arguments to support them. The concept of absolute thresholds assumes that firm productivity is subject to specific, unchanging limits. In contrast, relative thresholds rely more on the assumption that adaptation to varying baseline climates can mitigate the influence of temperature extremes.

[27] This is consistent with the results in Figure 2 presented below, which shows that only when temperatures rise to the range of $\geq 35°C$, the average delinquency rate correspondingly elevates.

To study the sensitivity of our results to using relative thresholds, Appendix Table A3 employs municipality-specific thresholds (based also on percentiles) to categorize extreme temperature days. No discernible effects arise using this specification. It is worth noting that, despite its location in the Tropic of Cancer, a significant share of the municipalities in Mexico have relatively mild local temperature extremes. Appendix Figure A1 illustrates the municipality-specific 95^{th} percentile temperature threshold distribution. A dashed line indicates the median of this distribution, revealing that half of these thresholds (red dashed line) fall below the $32.6°C$ mark.

We hypothesize that if there are inherent physiological and/or technological limits to the functioning of local economies, then relative thresholds might mask these effects by assigning treated status to days that do not have economically significant impacts. Given that the core of our results comes from the agricultural sector, we propose a hybrid version between absolute and relative thresholds that incorporates the considerations discussed above. Appendix Table A4 synthesizes findings from biological studies regarding the productivity thresholds for Mexico's primary seasonal crops. Crop growth and survival begin to be compromised when temperatures exceed these thresholds, which vary depending on the crop but generally range in the low thirties.

Considering the well-defined biological limits presented in Table A4, beyond which significant and immediate costs are anticipated for the agricultural sector, we refine our analysis using relative thresholds in Table 11. Here, we conduct two exercises: first, we interact the treatment with a dummy indicating whether the municipality is relatively warm, and second, whether its 95^{th} percentile threshold is high enough to harm the municipality's main crops. Specifically, in the first test, the days of extreme heat in the quarter $Days_{heat}$ interact with a variable indicating whether the municipality's c median temperature t^c_{p50} is within the top half of the national distribution $[t^c_{p50} \geq t^{MX}_{p50}]$. For the second test, we interact the days of extreme heat and cold with a variable indicating whether the 95^{th} percentile threshold t^c_{p95} is larger than the weighted average of the thresholds of the main crops $\hat{t}_w \simeq 34°C$. Here, the weights are defined using the share of each crop amongst the top six seasonal crops. Notably, this weighted average is consistent with thresholds found in other studies of climate impacts on agricultural yields (e.g. Schlenker and Roberts, 2009).

The outcomes in Table 11 indicate that the impact of extreme heat on default rates spans from a 0.10 to 0.16 percentage point rise for every ten days of such conditions, but only if the municipality's temperature is sufficiently high or its 95^{th} threshold surpasses a science-based critical mark. These findings bridge our absolute and relative results, emphasizing that while locally defined extremes matter, they do so within theoretically relevant constraints for crop growth. These results suggest that one of the main mechanisms affecting agricultural firms is the decline in crop yield.

6.2 Potential nonlinearities of weather impacts

Some works in the literature employ temperature bins to obtain flexible specifications of the impacts of temperature extremes that account for potential nonlinearities (as reviewed in Deschenes, 2014; Dell *et al.*, 2014). In this section, we use a binned specification to examine whether there are nonlinearities in a) the impact of days within each temperature bin or b) the number of days above a critical threshold.

In our first robustness test of the functional form of the temperature-delinquency link, we allow for nonlinearities in the maximum temperature reached while preserving the assumption that days within a single temperature bin have linear impacts. We estimate Equation 4, where the first and last bins correspond to the 5^{th} and 95^{th} percentile of maximum daily temperature, and the rest of the bins are equally spaced, spanning three $^{\circ}C$ each. We estimate the following specification:

$$Delinquency_{cst} = \sum_{b=1}^{7} \Omega_b \mathbb{1}\left\{t_{\max_{ct}} \in (\underline{t}_b, \bar{t}_b]\right\} + \Psi^r_{cst} + \varepsilon^r_{cst}, \tag{4}$$

where $\underline{t}_b$ and $\bar{t}_b$ are the lower and upper bounds for each temperature bin $b = 1, \ldots, 7$, as displayed in Figure 2. We employ the same set of fixed effects and controls as in Equation 1, captured in the parameter Ψ^r_{cst}. The point estimates Ω_b measure the effect of exposure to a temperature bin b with respect to the omitted bin [$23°C$-$26°C$). We consider two different specifications: The contemporaneous month and the previous quarter. For the contemporaneous month, each bin is constructed considering the average of the daily maximum temperature during that month. Similarly, for the previous quarter, each bin is constructed as the average of the bins of the contemporaneous month and the two previous months. In the last specification, each bin can take the value of 0, 1/3, 2/3, or 1, according to the share of months in a bin during the quarter.

Figure 2a illustrates the impact of *contemporaneous month* temperatures on the end-of-the-month delinquency rate, as defined in our baseline model (Equation 1). We observe a notable increase in delinquency rates occurring only when temperatures reach or exceed $35°C$. Similarly, Figure 2b, which examines the impacts during the *Previous Quarter* as per our preferred model of extreme temperature exposure (Equation 2), demonstrates that temperatures above $35°C$ significantly influence credit delinquency. These findings align with the earlier discussion on relative thresholds and various definitions of absolute thresholds, underscoring that only temperatures surpassing certain theoretically relevant limits for agricultural and labor productivity lead to increased delinquency rates.

As a complementary approach, we address nonlinearities in the number of days above our threshold. Although extreme heat days above $35°C$ might affect productivity, the exposure to only a few days in a quarter might not be enough to increase delinquency rates. To study if this is the case, we adapt our preferred model (as per Equation 2) to a more flexible format that accounts for varying levels of exposure. This is achieved by categorizing observations into distinct treatment bins based on the intensity of heat exposure.

Our reference group consists of instances with no extreme heat days (0 days), serving as our baseline. The remaining sample, representing positive heat exposure, is divided into quartiles to ensure an equal distribution of observations across each bin. The categorization is as follows: the first quartile encompasses days with extreme heat ranging from 1 to 3 days ($DaysExtreme \leq Q1$), the second quartile includes 4 to 10 days ($Q1 < DaysExtreme \leq Q2$), the third quartile covers 11 to 31 days ($Q2 < DaysExtreme \leq Q3$), and the fourth quartile comprises more than 31 days ($DaysExtreme > Q3$). Given these definitions, we modify our main specification as follows:

$$
\begin{aligned}
Delinquency_{cst} = & \phi_1 \mathbb{1}\left\{DaysExtremeHeat_{cq} \leq Q_1\right\} \\
& + \sum_{i=2}^{3} \phi_j \mathbb{1}\left\{DaysExtremeHeat_{cq} \in (Q_{i-1}, Q_i]\right\} \\
& + \phi_4 \mathbb{1}\left\{DaysExtremeHeat_{cq} > Q_3\right\} \\
& + \Psi^R_{cst} + \varepsilon^R_{cst}
\end{aligned}
\tag{5}
$$

The coefficients ϕ_1, ϕ_2, ϕ_3, and ϕ_4 denote the effects of days of exposure within the respective quartiles. Ψ^R_{cst} is the matrix of fixed effects and controls defined in Equation 1 (the superscript r indicates that these coefficients pertain to a different regression). Lastly, the ε^R_{cst} term is the residual. Each point estimate is interpreted in relation to the omitted category, that is 0 days of extreme temperature.

Figure 3 shows statistically significant effects only for the two highest quartiles. The results from this exercise align with the premise that very short-lived episodes of extreme heat do not impact credit delinquency in an economically meaningful way. The results also show that the effects are not exclusively driven by municipalities in the right tail of the distribution of extreme temperature days. On the contrary, we find effects for treatments of more than 11 days of exposure to extreme heat (third quartile). To facilitate interpretation and increase the precision of our estimates, we focus on average effects throughout the paper.

6.3 Other robustness tests

The identifying assumption in this empirical framework is that the temperature shocks in a region are not associated with unobserved factors that could potentially affect firms' delinquency rate in the same region. A possible threat to our identification could be a systematic short-term shock taking place in some municipalities that are also undergoing a temperature shock, generating a spurious correlation between delinquency rates and exposure to extreme temperatures. This is more likely to happen if similar firms self-select into particular areas based on characteristics correlated with resilience to weather shocks — due to those areas offering, for instance, better infrastructure, more qualified human capital, or economic specialization in specific sectors. If this were the case, these systematic short-term shocks are likely to be shared across municipalities with similar characteristics related to the level of infrastructure or economic development, the education of its population, the degree of specialization in agriculture, or the population size of the municipality.

To mitigate this potential source of bias, we include heterogeneous trends based on baseline municipality characteristics. This approach considers that certain municipalities may be undergoing an economic shock due to inherent features unrelated to our weather shocks of interest. By allowing for these differential effects, we control for the possibility that any observed effects capture underlying differences in firms' growth or resilience based on their location choices. In Table 12, we include specifications with time fixed effects interacted with key municipality-level variables, progressively including indicators of infrastructure quality (percentage of households with electricity and sewerage and bank branches per capita), economic development (average income, poverty rates, social security as a proxy for workers employed in the formal sector, population), human capital (average years of education), and the degree of specialization in agriculture (share of workers in agriculture).[28] Our main results are robust to accounting for these differential effects. The point estimate barely changes across columns as we include additional controls. This robustness lends further credence that our main specification allows us to capture the impact of extreme temperature shocks on financial outcomes rather than being driven by unobserved differences in regional trends related to firm self-selection biases.

7 Discussion

This study delves into the effects of extreme weather events on credit use and credit delinquency of SMEs in Mexico. Understanding these effects is vital in

[28]Except for Bank Branches, all variables are constructed using the 2010 Mexican Census. Data from Bank Branches comes from public data of the Comisión Nacional Bancaria y de Valores for 2015.

a country where SMEs play a crucial role in employment and job creation. Our study's setting in Mexico provides a unique perspective, given the country's diverse economic landscape and the critical role of SMEs. The findings from Mexico offer insights potentially applicable to other LMIEs, contributing to the broader discourse on the economic implications of climate change.

Firstly, we show that extreme heat increases the delinquency rates of SMEs. In particular, one day of extreme temperature per quarter in a given municipality increases its credit delinquency rate by 0.17 percentage points. These findings highlight the acute vulnerability of SMEs to such environmental shocks, primarily due to the limited resources they have to invest in adaptive and mitigating technologies and the challenges in obtaining necessary credit during periods of financial stress. Our research further uncovers the varying impacts of temperature shocks across industries and regions. In agriculture, extreme heat has a pronounced negative effect. Moreover, there are broader economic repercussions beyond the directly affected sectors. In areas with a substantial agricultural workforce, this impact spills over into non-agricultural sectors, particularly those dependent on local demand like services and retail. We also find that the impacts are more pronounced in relatively more integrated markets, where local agricultural prices respond less to changes in local production. Thus, isolation appears to buffer firm profits from dramatic fluctuations in response to weather-induced quantity changes.

In examining the credit market dynamics, we find that extreme weather events lead to a contraction in credit take-up that persists for some time. Furthermore, there is a reduction in credit allocated to investments and new firms, higher interest rates for new loans, and increased collateral requirements, indicating a tightening of credit during periods of weather-related financial distress.

The findings in this paper provide empirical support to concerns regarding the potential effects of extreme weather on the financial system (Bolton *et al.*, 2020). Regulatory authorities and central banks worldwide are considering including climate risks in the design of policies that can contribute to reducing banks' exposures to those risks (Litterman *et al.*, 2020; Prudential Regulation Authority, 2021). These policies may effectively reduce the direct exposure of banks' balance sheets to these risks. Still, they can also generate unintended consequences by further restricting SMEs' financial access upon the realization of weather shocks. These firms may not access financing precisely when they most need it as an extreme weather event hits or in the future when they have already recovered their solvency after a default episode. Thus, our results suggest that policies seeking to reduce direct exposure to climate shocks in banks' balance sheets would ideally be implemented along with other complementary policies. Such policies could compensate for unintended consequences by deepening SMEs' access to credit, especially when firms are coping with the impact of weather shocks.

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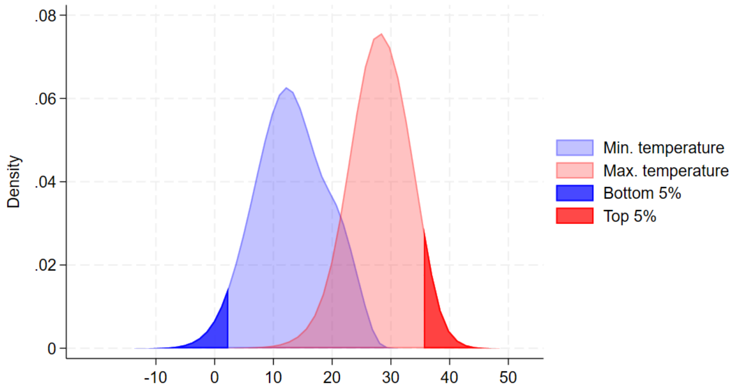
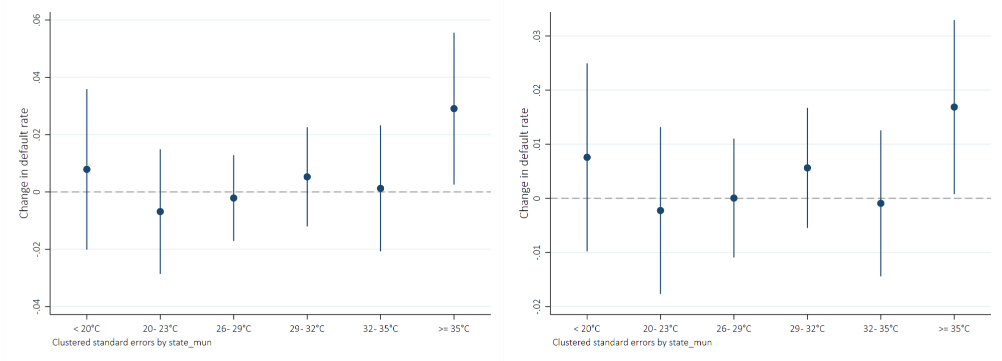
Figure 1: Distribution of maximum and minimum daily temperature in Mexico 2010-2019



Notes: The figure shows the distribution of minimum (blue) and maximum (red) daily temperature for Mexican municipalities. The bottom 5% of minimum temperature (less than 3°C) and top 5% of maximum temperature(more than 35°C) are highlighted.

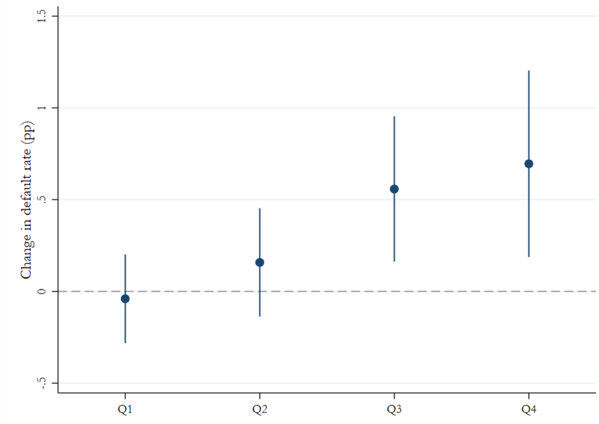
Figure 2: Nonlinear effects of extreme temperatures on delinquency rates: temperature bins

(a) Contemporaneous month (b) Previous quarter



Notes: The figure shows the results of equation 4 for the *contemporaneous month* (Panel A) and the *contemporaneous quarter* as defined in our baseline models by Equation 1 and 2, respectively. The point estimates measure the effect of exposure to a temperature bin with respect to the omitted bin ($23°C$-$26°C$). For the contemporaneous month, each bin is constructed considering the average of the daily maximum temperature during that month. The previous quarter is constructed as the average of the bins of the contemporaneous month and the two previous months. The 95 percent confidence intervals are presented. Standard errors are clustered at the municipality level.

Figure 3: Nonlinear effects of extreme temperatures on delinquency rates: quartiles of days



Notes: The figure shows the results of equation 5 separating the quarterly days of exposure to extreme heat into four quartiles. The categorization is as follows: the first quartile encompasses days with extreme heat ranging from 1 to 3 days ($DaysExtreme \leq Q1$), the second quartile includes 4 to 10 days ($Q1 < DaysExtreme \leq Q2$), the third quartile covers 11 to 31 days ($Q2 < DaysExtreme \leq Q3$), and the fourth quartile comprises more than 31 days ($DaysExtreme > Q3$). The point estimates measure the effect of exposure to certain number days of extreme heat with respect to the base category (0). The 95 percent confidence intervals are presented. Standard errors are clustered at the municipality level.

Table 1: Descriptive statistics

	Full sample	By agricultural intensity	
		High	Low
Panel A: Temperature			
Monthly average maximum temperature	28.25	28.66	27.66
	(4.51)	(4.35)	(4.67)
Quarterly days of extreme heat[a]	5.68	5.54	5.89
	(14.37)	(13.84)	(15.09)
Quarterly days of extreme cold[b]	4.49	3.86	5.38
	(12.39)	(11.95)	(12.94)
Panel B: Credit			
Delinquency rate - all sectors[c]	3.90	3.84	3.90
	(4.53)	(10.96)	(3.97)
Delinquency rate - agricultural	4.20	4.00	4.25
	(9.74)	(13.05)	(8.80)
Delinquency rate-non agricultural	3.87	3.77	3.87
	(3.81)	(9.89)	(3.41)
Fraction of credit in agriculture	0.15	0.18	0.10
	(0.27)	(0.31)	(0.20)
Log outstanding credit	15.57	14.62	16.66
	(2.79)	(2.33)	(2.86)
Interest rate	13.99	14.74	13.14
	(5.20)	(5.45)	(4.77)
Panel C: Agricultural intensity			
Fraction of employment in agriculture	0.35	0.50	0.13
	(0.22)	(0.15)	(0.09)
Municipalities	2,037	1,237	800
Observations	303,087	161,253	141,834

Notes: Authors' calculation using monthly credit data on small firms (2010-2019), temperature data (2010-2019), and census data for employment in agriculture (2010). The table shows sample averages with standard deviations in parenthesis. High agricultural regions are municipalities with employment in agriculture above the closest absolute value to the median of the sample (28 percent). [a] Measured as days reaching a maximum temperature above the 95^{th} percentile of the national distribution: $35°C$. [b] Measured as days reaching a minimum temperature below the 5^{th} percentile of the national distribution: $3°C$. [c] Percentage of loan amount that is non-performing.

Table 2: Effect of extreme temperature on delinquency rates by firm's size

	Small		Large	
	(1)	(2)	(3)	(4)
Days of extreme heat in t	0.023***	0.024***	0.008	0.009
	(0.008)	(0.008)	(0.011)	(0.011)
Days of extreme heat in t-1	0.012*	0.012*	-0.000	-0.000
	(0.006)	(0.006)	(0.010)	(0.011)
Days of extreme heat in t-2	0.018**	0.018***	-0.003	-0.003
	(0.009)	(0.007)	(0.012)	(0.009)
Days of extreme heat in t-3		0.005		0.003
		(0.010)		(0.014)
Days of extreme cold in t	-0.011	-0.010	0.010	0.012
	(0.011)	(0.011)	(0.016)	(0.016)
Days of extreme cold in t-1	0.011	0.011	0.017	0.019
	(0.008)	(0.008)	(0.013)	(0.014)
Days of extreme cold in t-2	0.002	-0.000	0.030*	0.023
	(0.009)	(0.008)	(0.017)	(0.014)
Days of extreme cold in t-3		0.002		0.020
		(0.009)		(0.014)
Observations	300,862	300,862	31,249	31,249
R-squared	0.849	0.849	0.802	0.802

Notes: Authors' estimation using 2010-2019 credit data on small and large firms. The point estimate measures the effect of one day of unusual exposure to extreme temperatures on firm credit delinquency rates following Equation 1. All regressions include municipality-by-month-by-sector fixed effects, municipality-by-year-by-sector fixed effects, time fixed effect, and average quarterly precipitation at the municipality level. Standard errors are clustered at the municipality level. *** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

Table 3: Effect of extreme temperature on delinquency rates by firm's sector

	All (1)	Agriculture (2)	Non-Agriculture (3)
Days of extreme heat in q (last quarter)	0.017***	0.029**	0.011*
	(0.005)	(0.011)	(0.006)
Days of extreme cold in q (last quarter)	0.001	-0.008	0.008
	(0.007)	(0.016)	(0.006)
Observations	300,862	101,413	199,449
R-squared	0.849	0.875	0.797

Notes: Authors' estimation using 2010-2019 credit data on small firms. The point estimate measures the effect of one day of unusual exposure in the previous quarter to extreme temperatures on firm credit delinquency rates following Equation 2. Credit to firms in non-agriculture includes commerce, construction, industrial, transportation, and services. All regressions include municipality-by-month fixed effects, municipality-by-year fixed effects, time fixed effect, and average quarterly precipitation at the municipality level. Standard errors are clustered at the municipality level. *** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

Table 4: Effect of extreme temperature on delinquency rates by firm's sector and region

	High agriculture regions (1)	Low agriculture regions (2)
Panel A: All Sectors		
Days of extreme heat in q	0.022***	0.011
	(0.008)	(0.007)
Days of extreme cold in q	-0.008	0.012
	(0.010)	(0.009)
Observations	159,544	141,318
R-squared	0.859	0.825
Panel B: Credit to firms in agriculture		
Days of extreme heat in q	0.031*	0.027*
	(0.017)	(0.014)
Days of extreme cold in q	-0.039	0.027
	(0.027)	(0.019)
Observations	50,792	50,621
R-squared	0.885	0.846
Panel C: Credit to firms in non-agriculture		
Days of extreme heat in q	0.017**	0.003
	(0.008)	(0.009)
Days of extreme cold in q	0.007	0.005
	(0.009)	(0.009)
Observations	108,752	90,697
R-squared	0.801	0.789

Notes: Authors' estimation using 2010-2019 credit data on small firms. The point estimate measures the effect of one day of unusual exposure in the previous quarter to extreme temperatures on firm credit delinquency rates following Equation 2. Credit to firms in non-agriculture includes commerce, construction, industrial, transportation, and services. High agricultural regions are municipalities with employment in agriculture above the median of the sample (28 percent). All regressions include municipality-by-month-by-sector fixed effect, municipality-by-year-by-sector fixed effect, time fixed effect, and average quarterly precipitation at the municipality level. Standard errors are clustered at the municipality level. *** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

Table 5: Effect of extreme temperature on delinquency rates for non-agriculture firs, by tradability of firm's production and region

	Non-tradeable (1)	Tradeable (2)
Panel A: All Municipalities		
Days of extreme heat in q	0.012**	0.009
	(0.006)	(0.011)
Days of extreme cold in q	0.008	0.011
	(0.006)	(0.010)
Observations	196,021	110,141
R-squared	0.785	0.817
Panel B: High Agricultural Regions		
Days of extreme heat in q	0.015*	0.020
	(0.008)	(0.019)
Days of extreme cold in q	0.010	0.004
	(0.009)	(0.020)
Observations	106,422	40,081
R-squared	0.796	0.825
Panel C: Low Agricultural Regions		
Days of extreme heat in q	0.009	0.001
	(0.009)	(0.013)
Days of extreme cold in q	0.004	0.011
	(0.009)	(0.012)
Observations	89,599	70,060
R-squared	0.761	0.810

Notes: Authors' estimation using 2010-2019 credit data on small firms. The point estimate measures the effect of one day of unusual exposure in the previous quarter to extreme temperatures on firm credit delinquency rates following Equation 2. Credit to firms in non-agriculture includes commerce, construction, industrial, transportation, and services. High agricultural regions are municipalities with employment in agriculture above the median of the sample (28 percent). Non-tradable sectors include commerce, construction, and services. The tradable sector refers to manufacturing. All regressions include municipality-by-month fixed effect, municipality-by-year fixed effect, time fixed effect, and average quarterly precipitation at the municipality level. Standard errors are clustered at the municipality level. *** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

Table 6: Effect of extreme temperature on delinquency rates by level of market integration

	By association between local and national price		By association between local price and local volume	
	Low (< 0.76)	High (> 0.76)	Negative (< 0)	Non-negative (≥ 0)
	(1)	(2)	(3)	(4)
Panel A: Agriculture sector				
Days of extreme heat in q	0.020*	0.034**	0.024	0.035**
	(0.021)	(0.013)	(0.017)	(0.015)
Observations	37383	64030	50389	51024
R-squared	0.874	0.876	0.869	0.882
Panel B: Non-Agriculture sector				
Days of extreme heat in q	0.011	0.012	0.005	0.018**
	(0.010)	(0.007)	(0.008)	(0.009)
Observations	83505	115944	100921	98528
R-squared	0.800	0.795	0.791	0.803

Notes: Authors' estimation using 2010-2019 credit data on small firms. The point estimate measures the effect of one day of unusual exposure in the previous quarter to extreme temperatures on firm credit delinquency rates following Equation 2. Credit to firms in non-agriculture includes commerce, construction, industrial, transportation, and services. All regressions include municipality-by-month, municipality-by-year, time fixed effect, and average quarterly precipitation at the municipality level. Standard errors are clustered at the municipality level. *** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

Table 7: Effects on credit characteristics: extensive margin

	Positive credit amount (1)	Credit lines (2)	Number of firms (3)	Total loans (4)	Number of New loans (5)
10 Days of extreme heat in q	-0.003***	-0.006**	-0.004**	-0.038**	0.001
	(0.001)	(0.002)	(0.002)	(0.017)	(0.021)
10 Days of extreme heat in $q-1$	-0.002*	-0.005**	-0.004**	-0.025	0.011
	(0.001)	(0.002)	(0.002)	(0.016)	(0.020)
10 Days of extreme heat in $q-2$	-0.000	-0.002	0.000	0.003	0.047**
	(0.001)	(0.002)	(0.002)	(0.018)	(0.021)
Observations	167640	167640	167640	167640	167640
R-squared	0.912	0.977	0.977	0.937	0.676

Notes: Authors' estimation using 2010-2019 credit data on small agricultural firms. The point estimate measures the effect of one day of unusual exposure in the previous quarter to extreme temperatures on different outcome variables following Equation 2. All regressions include municipality-by-month fixed effect, municipality-by-year fixed effect, time fixed effect, and average quarterly precipitation at the municipality level. Outcome variables are defined as follows. Positive credit amount refers to a binary indicator of credit availability in a municipality; Credit lines is the number of credit lines in a municipality (hyperbolic sine transformation to include zero values); Number of firms refers to the total number of firms receiving credit (hyperbolic sine transformation); Total credit refers to the total credit volume (hyperbolic sine transformation); and New loans refers to the number of new loans granted in a municipality (hyperbolic sine transformation). Descriptive statistics of these variables can be found in Appendix Table A2. Standard errors are clustered at the municipality level. *** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

Table 8: Effects on credit characteristics: stock and new credit

	Credit stock			New credit			
	Share investment	Share new firms	Interest rate	Interest rate	Average amount	Maturity	Share collateral
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
10 Days of extreme heat in q	-0.159*	-0.213*	-0.012	-0.039	-0.001	0.300	0.891*
	(0.081)	(0.111)	(0.009)	(0.026)	(0.018)	(0.228)	(0.482)
10 Days of extreme heat in $q-1$	0.056	-0.221*	0.015**	0.065**	0.016	-0.301	0.357
	(0.086)	(0.118)	(0.006)	(0.025)	(0.013)	(0.241)	(0.433)
10 Days of extreme heat in $q-2$	0.024	-0.143	0.013*	0.003	0.002	0.070	-0.671
	(0.082)	(0.097)	(0.007)	(0.025)	(0.014)	(0.201)	(0.434)
Observations	101,413	101,413	101,413	25,941	25,941	25,941	25,941
R-squared	0.926	0.872	0.976	0.806	0.657	0.528	0.634

Notes: Authors' estimation using 2010-2019 credit data on small agricultural firms. The point estimate measures the effect of one day of unusual exposure in the previous quarter to extreme temperatures on different outcome variables following Equation 2. All regressions include municipality-by-month fixed effect, municipality-by-year fixed effect, time fixed effect, and average quarterly precipitation at the municipality level. Outcome variables are defined as follows. Share of investment refers to the share of total outstanding credit for investment purposes; Share new firms refers to the share of total outstanding credit granted to firms less than 5 years old; Interest rate is the weighted average of all loans in a municipality (for total outstanding loans and new credit lines); Average amount is the log of the average credit amount for new credit; Maturity refers to the weighted average of the maturity of new loans in a municipality; Collateral share is the share of new credit that provides collateral.Descriptive statistics of these variables can be found in Appendix Table A2. Standard errors are clustered at the municipality level. *** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

Table 9: Effects on credit characteristics: firm-level regressions

	Characteristics of credit stock			Characteristics of new credit			
	Extensive margin (1)	Intensive margin (2)	Interest rate (3)	Interest stock (4)	Average amount (5)	Maturity new (6)	Collateral share (7)
10 Days of extreme heat in q	-0.0031***	-0.008***	-0.004	-0.022	0.008	0.289*	0.549*
	(0.0010)	(0.003)	(0.006)	(0.026)	(0.010)	(0.150)	(0.310)
10 Days of extreme heat in $q-1$	-0.0024**	-0.007**	0.012**	0.050***	-0.001	-0.020	-0.014
	(0.0009)	(0.003)	(0.005)	(0.019)	(0.009)	(0.136)	(0.287)
10 Days of extreme heat in $q-2$	0.0001	-0.008**	0.005	-0.015	0.005	-0.021	-0.655**
	(0.0007)	(0.003)	(0.005)	(0.022)	(0.011)	(0.130)	(0.276)
Observations	3,226,200	860,762	860,762	73,102	73,102	73,102	73,102
R-squared	0.368	0.862	0.907	0.846	0.721	0.622	0.650

Notes: Authors' estimation using 2010-2019 credit firm-level data on small agricultural firms. The point estimate measures the effect of one day of unusual exposure in the previous quarter to extreme temperatures on firm credit delinquency rates following Equation 3. All regressions include municipality-by-month fixed effect, municipality-by-year fixed effect, firm fixed effects, time fixed effect, and average quarterly precipitation at the municipality level. Outcome variables are defined as follows. Extensive margin refers to a dummy variable equal to 1 if the firm has positive credit amount and 0 otherwise. Intensive margin is the log total outstanding credit of each firm. Interest rate is the weighted average of all loans of the firm (for total outstanding loans and new credit lines); Average amount is the log of the average credit amount for new credit for each firm; Maturity refers to the weighted average of the maturity of new loans of the firm; Collateral share is the share of the volume of new credit that provides collateral.Descriptive statistics of these variables can be found in Appendix Table A2. Standard errors are clustered at the municipality level. *** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

Table 10: Robustness to using different percentiles to define extreme temperature days

Percentiles	10-90 Min 5°, Max 34° (1)	8-92 Min 4°, Max 34.5° (2)	5-95 Min 3°, Max 35° (3)	3-97 Min 2°, Max 36° (4)	1-99 Min 0°, Max 38° (5)
Days of extreme heat in q	0.010***	0.013***	0.017***	0.017***	0.018***
	(0.003)	(0.003)	(0.004)	(0.004)	(0.006)
Days of extreme cold in q	-0.001	0.001	0.001	0.002	-0.000
	(0.003)	(0.004)	(0.004)	(0.005)	(0.009)
Observations	300,862	300,862	300,862	300,862	300,862
R-squared	0.849	0.849	0.849	0.849	0.849

Notes: Authors' estimation using 2010-2019 credit data on small firms. The point estimate measures the effect of one day of unusual exposure to extreme temperature in a quarter on firm credit delinquency rates following Equation 2. Each column represents alternative definitions of extreme temperatures based on different percentiles of the minimum and maximum daily temperature distribution displayed in Figure 1. All regressions include municipality-by-quarter-by-sector fixed effects, municipality-by-year-by-sector fixed effects, time fixed effects, and average precipitation at the municipality level in each quarter. Column (3) contains the main results from column (1) in Table 3. Standard errors are clustered at the municipality level. *** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

Table 11: Robustness to using different relative percentiles to define extreme temperature days

Percentiles	10-90	8-92	5-95	3-97	1-99
	(1)	(2)	(3)	(4)	(5)
Panel A: Interaction with baseline climate t^i_{p50} above the national median t^{MX}_{p50}					
$Days_{heat}$	-0.005	-0.004	-0.002	-0.002	0.008
	(0.003)	(0.004)	(0.004)	(0.004)	(0.011)
$Days_{heat} \times \mathbb{1}[t^c_{p50} \geq t^{MX}_{p50}]$	0.016***	0.014***	0.010*	0.010*	-0.006
	(0.005)	(0.005)	(0.006)	(0.006)	(0.015)
$Days_{cold}$	0.000	-0.001	0.002	-0.002	-0.001
	(0.004)	(0.005)	(0.006)	(0.008)	(0.016)
$Days_{cold} \times \mathbb{1}[t^c_{p50} \geq t^{MX}_{p50}]$	-0.000	0.000	-0.003	-0.001	0.006
	(0.005)	(0.006)	(0.008)	(0.010)	(0.020)
Observations	300,862	300,862	300,862	300,862	300,862
R-squared	0.849	0.849	0.849	0.849	0.849
Panel B: Interaction with t^c_{p95} above the weighted average of main crops' thresholds $\hat{t}_w$					
$Days_{heat}$	-0.005	-0.004	-0.004	-0.004	-0.005
	(0.003)	(0.003)	(0.004)	(0.004)	(0.010)
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$Days_{heat} \times \mathbb{1}[t^c_{p95} \geq \hat{t}_w]$	0.016***	0.015***	0.014**	0.014**	0.021
	(0.005)	(0.005)	(0.006)	(0.006)	(0.015)
$Days_{cold}$	-0.003	-0.003	0.000	-0.002	-0.003
	(0.004)	(0.005)	(0.006)	(0.008)	(0.015)
$Days_{cold} \times \mathbb{1}[t^c_{p95} \geq \hat{t}_w]$	0.007	0.006	-0.000	-0.001	0.012
	(0.006)	(0.006)	(0.008)	(0.010)	(0.021)
Observations	300,862	300,862	300,862	300,862	300,862
R-squared	0.849	0.849	0.849	0.849	0.849

Notes: Authors' estimation using 2010-2019 credit data on small firms. The point estimate measures the effect of one day of unusual exposure to extreme temperature in a quarter on firm credit delinquency rates for alternative definitions of extreme temperatures based on county-specific temperature thresholds. All regressions include municipality-by-month-by-sector, municipality-by-year-by-sector, time fixed effect, and average quarterly precipitation at the municipality level. Panel A interact the treatment with dummy variable indicating whether the municipality's (c) median temperature t^c_{p50} is within the top half of the national distribution $[t^c_{p50} \geq t^{MX}_{p50}]$. Panel B interact the treatment with a dummy variable indicating whether the 95^{th} percentile threshold t^c_{p95} is larger than the weighted average of the thresholds of the main crops $t\hat{t}_w \simeq 34°C$. Standard errors are clustered at the municipality level. *** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

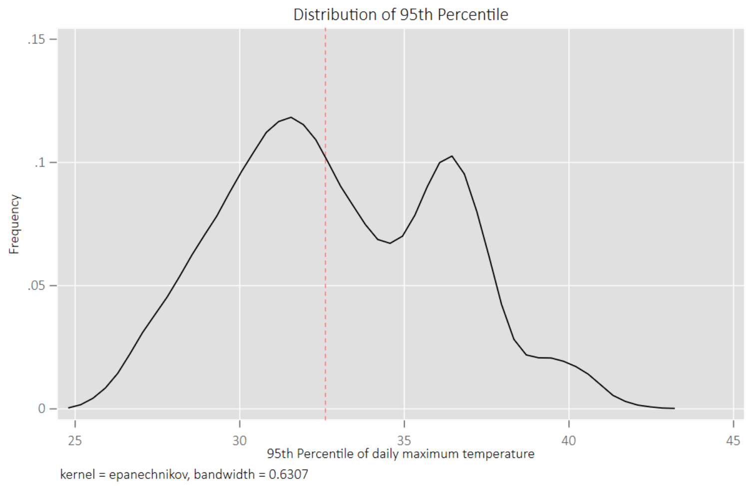
Table 12: Robustness to including heterogeneous trends

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Days of extreme heat in q	0.017***	0.019***	0.019***	0.019***	0.019***	0.018***	0.018***	0.018***	0.018***
	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.005)	(0.005)	(0.006)	(0.006)
Days of extreme cold in q	0.001	0.001	0.000	0.000	-0.000	-0.001	0.000	0.000	0.000
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Fixed effects:									
Sector-Municipality-Quarter	x	x	x	x	x	x	x	x	x
Sector-Municipality-Year	x	x	x	x	x	x	x	x	x
Time (Quarter by Year)	x	x	x	x	x	x	x	x	x
Time - HH Income (mean)		x	x	x	x	x	x	x	x
Time - HH w electricity (%)			x	x	x	x	x	x	x
Time - Adult education (mean)				x	x	x	x	x	x
Time - Population					x	x	x	x	x
Time - Social security (%)						x	x	x	x
Time - Employment in agri. (%)							x	x	x
Time - HH w sewage (%)								x	x
Time - Bank branches (per capita)									x
Observations	300,862	300,862	300,862	300,862	300,862	300,862	300,862	300,862	300,862
R-squared	0.849	0.849	0.849	0.849	0.849	0.849	0.849	0.849	0.849

Notes: Authors' estimation using 2010-2019 credit data on small firms. The point estimate measures the effect of one day of unusual exposure to extreme temperature in a quarter on firm credit delinquency rates following Equation 2. All regressions include municipality-by-month-by-sector fixed effects,municipality-by-year-by-sector fixed effects, time fixed effects, and average precipitation at the municipality level in each quarter. Additionally, each column progressively incorporates a time fixed effects interacted with each control. Data on the controls is public and comes from the Population Census of 2010 and the Comision Nacional Bancaria y de Valores. *** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

Online Appendix
Thermal stress and financial distress: Extreme temperatures and firms' loan defaults in Mexico

Figure A1: Distribution of the 95 percentile threshold in Mexico 2010-2019



Notes: The figure shows the county-level distribution of the 95 percentile of the daily maximum temperature for Mexican municipalities.

Table A1: Robustness allowing spatially-correlated standard errors

	(1)	(2)	(3)
Days of extreme heat in q	0.017***	0.017***	0.017***
	(0.0033)	(0.0032)	(0.0031)
Days of extreme cold in q	0.001	0.001	0.001
	(0.0040)	(0.0040)	(0.0038)
Observations	300,862	300,862	300,862
Distance cut-off	25km	50km	100km

Notes: Authors' estimation using 2010-2019 credit data on small firms. The point estimate measures the effect of one day of unusual exposure in the previous quarter to extreme temperatures on firm credit delinquency rates. All regressions include municipality-by-month-by-sector fixed effects, municipality-by-year-by-sector fixed effects, time fixed effect, and average quarterly precipitation at the municipality level. Standard errors are estimated allowing for spatial correlation in error terms applying Conley (1999) approach and using different values of the reference distance. Columns (1) to (3) are comparable to column (1) from Table 3. *** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

Table A2: Credit characteristics, descriptive statistics

	Mean	Median	Sd	Observations
Panel A: Municipality level				
Extensive margin				
Positive credit amount	0.6	1.0	0.5	167,640
Credit lines	1.5	0.9	1.6	167,640
Number firms	1.2	0.9	1.3	167,640
Total loans	9.7	13.5	7.9	167,640
New loans	2.8	0.0	6.1	167,640
Intensive margin (stocks)				
Share investment	13.0	0.0	25.7	101,413
Share new moral	7.9	0.0	22.0	101,413
Interest rate	12.9	12.3	4.6	101,413
Intensive margin (new credit)				
Interest rate	11.2	10.3	4.9	25,941
Average amount (log)	14.5	14.7	1.7	25,941
Maturity	19.3	10.4	20.3	25,941
Share collateral	42.6	26.2	43.9	25,941
Panel B: Firm level				
Extensive margin				
Positive credit amount	0.3	0.0	0.4	3,226,200
Intensive margin (stocks)				
Log credit	13.4	13.5	2.3	860,762
Interest rate	13.8	12.9	6.1	860,762
Intensive margin (new credit)				
Interest rate	11.6	10.6	5.2	73,102
Average amount (log)	14.1	14.4	2.0	73,102
Maturity	18.8	8.0	22.3	73,102
Share collateral	39.9	0.0	48.3	73,102

Notes: Authors' calculation using monthly credit data on small firms (2010-2019). The table shows sample average, the median, the standard deviation and the number of observations. Panel A presents the descriptive statistics of outcomes variables in Table 7 and Table 8. Panel C shows the descriptive characteristics of the firm-level outcomes in Table 9. All variables referring to credit amount are in logarithm, and are expressed in real Mexican pesos as of December 2018 using Mexican price index.

Table A3: Robustness to different definitions of extreme Temperature using relative measures

Percentiles	10-90	8-92	5-95	3-97	1-99
	(1)	(2)	(3)	(4)	(5)
Days of extreme heat	0.003	0.003	0.003	0.003	0.005
	(0.002)	(0.003)	(0.003)	(0.003)	(0.008)
Days of extreme cold	0.000	-0.001	-0.000	-0.002	0.001
	(0.004)	(0.004)	(0.005)	(0.006)	(0.012)
Observations	300,862	300,862	300,862	300,862	300,862
R-squared	0.849	0.849	0.849	0.849	0.849

Notes: Authors' estimation using 2010-2019 credit data on small firms. The point estimate measures the effect of one day of unusual exposure to extreme temperature in a quarter on firm credit delinquency rates for alternative definitions of extreme temperatures based on county-specific temperature thresholds. All regressions include municipality-by-month-by-sector fixed effects, municipality-by-year-by-sector fixed effects, time fixed effects, and average precipitation at the municipality level in each quarter. Standard errors are clustered at the municipality level. *** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

Table A4: Thresholds for top 5 seasonal crops in Mexico

Rank	**Crop**	**Revenue** [1]	**Threshold**	**Reference**
1	Maize	36.2 %	35°C	(Luo, 2011)
2	Tomato	6.6 %	26 °C	(Alsamir *et al.*, 2021)
3	Wheat	6.17 %	37.4 $°C$	(Porter and Gawith, 1999)
4	Sorghum	6.16 %	40/30$°C$ [a]	(Prasad *et al.*, 2006)
5	Green Chili	5.54 %	33 $°C$	(Rosmaina and Zulfahmi, 2022)
6	Bean	3.57 %	32$°C$	(Prasad *et al.*, 2002)

[1] As a share of Mexico seasonal crops
[b] day/night temperatures