WIDER Working Paper 2024/71

Climate shocks and economic resilience

Evidence from Zambia's formal sector

Kwabena Adu-Ababio,[1] Evaristo Mwale,[2] and Rodrigo Oliveira[1]

December 2024

United Nations University World Institute for Development Economics Research

wider.unu.edu

Abstract: Low-income countries face the combined challenges of climate shocks and limited domestic revenue mobilization, yet these issues are rarely studied together. This paper provides new evidence on the impact of climate shocks on firm performance and tax revenue in a low-income country context, using firm-level data from Zambia. We find that extreme weather events, such as excessive rainfall and high temperatures, significantly reduce firms' sales, input purchases, and tax collection, particularly in sectors such as manufacturing, retail, accommodation, and construction. Firms respond by reducing employment and wages, reflecting a decline in productivity. Our findings highlight the need to consider the combined effects of climate shocks on both formal sector productivity and government revenue in developing countries, where taxation on services and goods (e.g. VAT) represents a larger share of government budgets.

Key words: value-added tax (VAT), climate shocks, Zambia, domestic revenue mobilization, firms

JEL classification: H32, Q54, Q56

Acknowledgements: We thank Edson Severnini, Julien Wolfersberger, Jukka Pirttilä, Kunal Sen, Anna Zasova, Gabriel Monteiro, Kelvin Mpembamoto, and Sebastian Castillo for feedback and suggestions. The usual disclaimer applies.

[1] UNU-WIDER, Helsinki, Finland; [2] Zambia Revenue Authority (ZRA), Lusaka, Zambia; corresponding authors: oliveira@wider.unu.edu, adu-ababio@wider.unu.edu

This study has been prepared within the UNU-WIDER project Tax research for development (phase 3), which is part of the research area Creating the fiscal space for development. The project is part of the Domestic Revenue Mobilization programme, which is financed through specific contributions by the Norwegian Agency for Development Cooperation (Norad).

Information and requests: publications@wider.unu.edu

ISSN 1798-7237 ISBN 978-92-9267-534-9

https://doi.org/10.35188/UNU-WIDER/2024/534-9

Typescript prepared by Gary Smith.

United Nations University World Institute for Development Economics Research provides economic analysis and policy advice with the aim of promoting sustainable and equitable development. The Institute began operations in 1985 in Helsinki, Finland, as the first research and training centre of the United Nations University. Today it is a unique blend of think tank, research institute, and UN agency—providing a range of services from policy advice to governments as well as freely available original research.

The Institute is funded through income from an endowment fund with additional contributions to its work programme from Finland and Sweden, as well as earmarked contributions for specific projects from a variety of donors.

Katajanokanlaituri 6 B, 00160 Helsinki, Finland

1 Introduction

Low-income countries are grappling with two monumental challenges: combating climate change and increasing domestic revenue mobilization. While most academic literature and policy discussions treat these issues separately, they are closely interrelated because climate shocks directly impact economic productivity and tax revenue, particularly in low-income countries reliant on agriculture. Studies relying on macro-level data have shown that high temperatures are negatively correlated with the national output (Dell et al. 2012; Tol 2018), and rainfall is a significant determinant of poor economic growth for African countries (Barrios et al. 2010). Fuje et al. (2023) calculate that droughts and storms in developing countries may reduce economic growth by 1.4 and 1.8 percentage points, respectively. They also measured the absolute revenue decline due to droughts at about 4.5 percentage points. The impacts are more pronounced in low-income countries with a higher dependence on the agricultural sector (Acevedo et al. 2020).

Despite the extensive literature on the impacts of climate change on mortality rates (Carleton et al. 2022; Deschênes and Greenstone 2011), food security (Reed et al. 2022), and education and health (Maccini and Yang 2009), there is limited understanding of its effects on non-farm businesses and state revenues in developing countries, particularly in low-income countries (Grover and Kahn 2024; Kala et al. 2023).[1] Notably, most of the existing evidence does not use firm-level administrative records. Measuring the impacts of climate shocks on firms' performance is even more relevant in low-income countries, where the contribution of income tax to government budgets is much lower. Taxes on goods and services account for 51.9% of the revenue in African countries, while the OECD average is 31.9% (OECD 2024). In Zambia these taxes represent 22.8% of total revenues in the country.

This paper provides the first nationwide causal evidence of the impacts of climate shocks on firms' performance and revenue collection in a low-income country. We combine firm-level administrative records of monthly sales, purchases, taxable sales, and value-added tax (VAT) from the Zambia Revenue Authority (ZRA) between 2014 and 2020 and granular rainfall and temperature data between 1980 and 2020. Our empirical strategy leverages differences in temperature and rainfall by month and district to identify extreme rainfall episodes (a proxy for storms or floods) and extreme temperatures (a proxy for droughts), controlling for a wide range of firms, time, and districts' fixed effects. The final sample accounts for about 12,000 formal firms from 21 economic sectors in all Zambian provinces.

The main results suggest that extremely high temperatures and rainfall cause a reduction in firm value production, input purchases, and revenue collection. In our preferred econometric specification, a month with rainfall more than one standard deviation above the historical average reduces firms' sales by 4.2%, firms' purchases by 5.6%, and tax on sales collection by 4.4%. Rainfall in the previous two months also negatively impacts the outcomes, suggesting a persistent impact over time. Extreme high temperatures reduce sales by 3.1% and tax on sales collection by 2.7%. The heterogeneity analysis shows that the effects are driven by four economic sectors: manufacturing, wholesale and retail trade, accommodation, and construction. We show rainfall shocks affect all firm sizes, with a higher impact on smaller firms, while temperature shocks affect only medium and large firms.[2]

For a sub-sample of months between January 2019 and December 2020, we were able to disentangle the climate shock impacts on tax on sales, tax on purchases (known as VAT refunds), and VAT. The

[1] For instance, Grover and Kahn (2024) conducted a recent literature review and identified only two papers about Ugandan and Tanzanian firms' responses to climate shocks. Even in middle-income countries, the literature is not large, with some papers about Brazil, China, India, Mexico, Pakistan, and Sri Lanka.

[2] Note that ZRA has its own definition of firm size. Small firms are those with annual turnover below ZMW800,000, while medium firms have annual turnover between ZMW800,000 and ZMW50,000,000.

results suggest a strong negative impact of climate shocks on VAT driven mostly by the increase in the tax refunds, which may be driven by increases in the prices of inputs. Additionally, we show some important firms' margins of adjustments. Firms reduce their number of employees and their total payroll costs to cope with climate shocks. This happens because of a drop in a firm's productivity level. We do not observe any impacts on firms relocating to other areas less prone to climate shocks. Unfortunately, the ZRA tax data does not allow us to explore potential mechanisms of firms' adaptation and changes in the value chains by diversifying firms' customers and input providers. It is also not possible to observe whether a firm closed.[3]

This paper has three major contributions to the literature. First, it is the first paper to estimate the causal effects of climate shocks on formal sectors in a low-income country using tax records. The existing evidence concentrates on high-income countries, and the little evidence for developing countries is from Indonesia (Xie 2024), Pakistan (Balboni et al. 2023), and India (Castro-Vincenzi et al. 2024). Other research has focused not on measuring the causal impacts of climate on firms but on mitigation and adaptation measures in Kenya and Senegal (Crick et al. 2018) and Tanzania (Rentschler et al. 2021). There is also some evidence about the impacts of climate change on labour and productivity, with a concentration of studies on India (Colmer 2021; Somanathan et al. 2021).

The second main contribution adds to the insufficient but growing literature on the effects of climate shocks on firms' outcomes in developing countries. Particularly, we provide evidence of climate shocks' effects on the non-agricultural sector in low-income countries. We show that not only small businesses are affected by climate shocks, and that there is large sectoral variation in the impacts of extreme weather events. We also contribute to understanding how firms in a low-income country with strong credit constraints may adapt to climate change. For instance, Adhvaryu et al. (2020) showed that adopting LED lights improves worker productivity in India, Davis and Gertler (2015) found that air conditioning is an important strategy for Mexican firms, and De Mel et al. (2012) show that access to capital facilitates recovery and growth for firms exposed to natural disasters.

Third, we also contribute to the literature on government revenue collection, which surprisingly has neglected the pervasive impacts of climate change. The existing literature focuses on macroeconomic studies (Acevedo et al. 2020; Dell et al. 2012; Fuje et al. 2023). The only exception is Balboni et al. (2023), who similarly estimate the negative impacts of climate shocks on VAT in Pakistan.

2 Data and preliminary evidence

2.1 Zambia's vulnerability to climate shocks

Studying the impacts of climate shocks in Zambia is crucial due to the country's heightened vulnerability to natural hazards such as droughts, floods, and extreme temperatures, which have intensified in severity and frequency in recent decades. Historically, Zambia, as a land-locked country, has been regularly affected by seasonal floods, flash floods, and prolonged droughts, which significantly disrupt the livelihoods of its predominantly rural and impoverished population. The most recent household survey (ZAMSTATS 2024) suggests that about 60% of the population is below the poverty line and that a large portion of Zambia's infrastructure is inadequate. These climate shocks pose a serious threat to economic stability and growth, food security, and overall public health.

[3] The reason is that only firms with annual turnover tax above ZMW800,000 should register for VAT. Therefore, a firm not being observed in the data does not mean it is closed. It suggests that the firm is small, or it can be interpreted as evidence of non-compliance.

Zambia's reliance on agriculture, a sector which employs about 70% of the population and is mainly rain-fed, makes the economy highly susceptible to climate variability. The frequent droughts, including the ongoing drought since January 2024, have led to substantial crop failures, reduced livestock productivity, and subsequent economic losses. The ongoing drought, one of the worst in recent history, underscores the urgent need to address climate resilience in Zambia. It has further strained water resources, increased electricity load-shedding, exacerbated food insecurity, and pushed many households into deeper poverty, highlighting the vulnerability of the agricultural sector to prolonged dry spells.

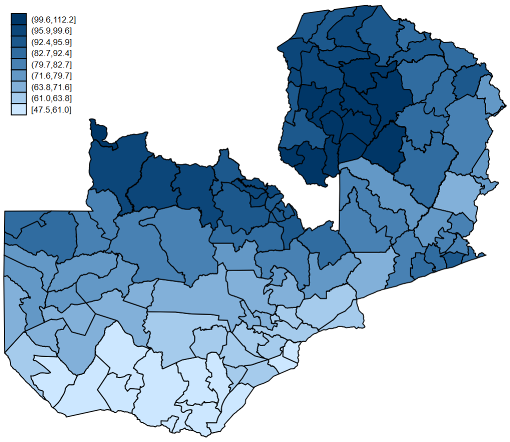
Moreover, Zambia's vulnerability is compounded by the spatial distribution of natural hazards, which often overlap with areas of high poverty and limited development (Oliveira et al. forthcoming). Evaluating the impacts of these hazards is essential for identifying the most exposed regions and implementing targeted interventions. For instance, flood-prone regions frequently suffer from damaged infrastructure, disrupted transport routes, and compromised water and sanitation systems, which hinder economic activity.

The study utilizes historical data on average temperature (in Celsius) and monthly cumulative precipitation (in millimetres) from 1980 to 2022. The temperature data was sourced from the Modern-Era Retrospective analysis for Research and Applications (MERRA-2) provided by NASA, which offers daily mean air temperatures measured at a height of 2 metres. This data was represented on a grid with a spatial resolution of 0.5×0.625 degrees. Precipitation data was obtained from the Global Precipitation Climatology Centre (GPCC) of NOAA, featuring monthly cumulative precipitation based on global station data, organized on a grid with a 1×1 degree resolution. Both datasets were aggregated at the district level to facilitate analysis.

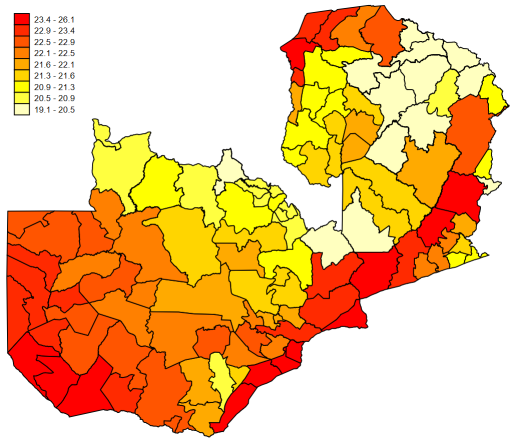
Two important characteristics of Zambia's climate stand out. Appendix Figure A1 shows that both temperature and rainfall in Zambia are extremely seasonal, with the rainy and hotter periods concentrated between November and February. While temperature variation is not very large, this is not the case for rainfall, and Zambia is expected to suffer more from extreme rainfall than extreme temperature episodes.

Panels (a) and (b) of Figure 1 show the average rainfall and temperature by district in Zambia. This figure suggests warmer districts are concentrated in the southern and south-western provinces, and the rainy districts are concentrated in the northern and north-western provinces. Panels (c) and (d) of Figure 1 show the corresponding figures for districts with ZRA tax offices. The white-marked districts have a limited presence of formal firms, and ZRA operations are minimal due to the lack of local offices. Firms in these areas either use e-services or visit nearby ZRA offices to comply with tax requirements. Notably, for tax purposes, each firm is registered in only one district, although it may conduct business across multiple districts. This creates an incentive for firms to register in larger districts with stronger ZRA operational capacity. However, current data does not enable us to pinpoint all the districts where these firms are active

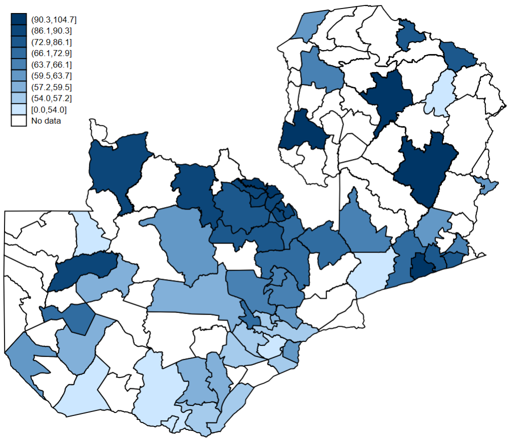
Figure 1: Rainfall and temperature in Zambia by district



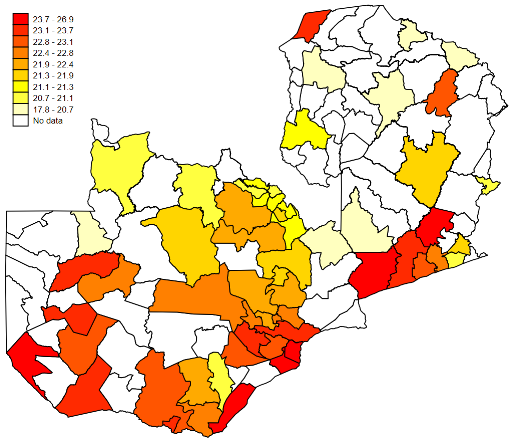
(a) Rainfall (all districts)



(b) Temperature (all districts)



(c) Rainfall (districts with ZRA office)



(d) Temperature (districts with ZRA office)

Note: The figure displays the average rainfall (mm) and temperature (Celsius) in Zambia between 2014 and 2020 by district. Panels (c) and (d) show only the districts with ZRA offices.

Source: authors' compilation.

2.2 VAT data

Our main tax administrative dataset is the VAT returns provided by the ZRA. Even though informality in Zambia is widespread, VAT still accounts for 23% of all revenue collection in Zambia, which is similar to the VAT share of total revenues in other developing countries (Brockmeyer et al. 2024). It is interesting to note that in this era of technological advancement, where most revenue authorities have introduced fiscal devices to record firm-to-firm transactions to widen the tax net, Zambia as of 2024 has not introduced such electronic devices to aid revenue collection due to their tracked receipting mechanism.

VAT in Zambia works in a similar fashion to in other developing countries. All firms with a monthly turnover tax above ZMW66,667 (US$2,513.49) must self-report to the ZRA at monthly intervals. Even though the ZRA used to conduct some audits sporadically, no auditing systems prior to 2020 were implemented, and there was a lack of proper risk-targeting variables before the introduction of digitized audit systems, which are improving scrutiny assessments. However, audits are risk-based and focused on sectors or firms where the audits will likely yield sizeable outcomes. Therefore, most firms have strong incentives to misreport VAT. One way of doing this is by underreporting their output (sales) and overreporting their inputs (purchases).

It is important to highlight that the level of misreporting is accentuated by the self-reporting of key variables, which is a common practice in most developing countries. Balboni et al. (2023), for instance, discuss a similar self-reportage of sales reporting in Pakistan. This pattern is now changing in developing countries, with reforms such as the reverse charge and implementation of fiscal devices that permit the tracking of intermediate firm activities that create loopholes in a typical VAT system (see, e.g., Adu-Ababio et al. 2023).

Additionally, due to the lack of electronic receipts from fiscal devices, VAT data is aggregated only for firms located in districts with a ZRA office, which are also districts with higher incomes and formal activities.[4] Although the VAT forms are digitally filled, the returns are collated at the district tax office. Through this, we benefit from access to a universe of about 12,000 taxpaying formal firms in Zambia between 2014 and 2020. The panel is more unbalanced at the month level than at the quarter level. ZRA's explanation for this is the small size of Zambian businesses, which causes sales to be very volatile per month, and their lack of managerial capabilities. Therefore, in some months, firms struggle to report sales above the threshold, but they compensate for reporting correctly in the quarter.[5]

The VAT data has information for 2014–20 on total firm (taxable) sales and for 2019–20 on total firm (taxable) purchases and total taxes paid. We merge the VAT data to aggregate pay-as-you-earn (PAYE) employee data for the total number of employees and the total amount of wages paid. All administrative data files contain firm demographics as the district and province in which the firm is based. One key improvement in the online filing was the inclusion of the variable taxable purchases, which is available only from 2019. Taxable purchase is a VAT input variable denoting the amount of taxes that firms can claim back when, in the course of production, they buy an input, the final price of which includes VAT.

Appendix Table A1 shows the descriptive statistics. The first important result of this table is that the data covers a wide range of formal firms in Zambia, with very small firms having monthly sales below US$1,000 and larger firms with monthly sales equal to US$1,885,109.50. This fact also highlights an essential characteristic of the Zambian economy, with a few firms in the extractive sector, namely copper mining, being much larger than the average Zambian firm. The average Zambian firm has monthly sales equal to ZMW3,934,530 (US$148,340.40), but the median firm sales are equal to ZMW293,369 (US$11,060.65).

Appendix Table A1 also shows that 18.6% of district–month pairs are affected by episodes of extreme rainfall, and 19.5% are affected by high-temperature events. Most of the Zambian firms are located in the two richest and most populous provinces, Lusaka (61.83%) and Copperbelt (27.18%). Most of the firms are in the wholesale and retail trade sector.

3 Methodology

3.1 Empirical strategy

Our empirical strategy leverages variation of temperature and rainfall by month and district to identify the impacts of climate shocks on Zambian firms and revenue collection. We create a measure of extreme rain (R_{dm}), which assumes a value of 1 if the rainfall in the month m and district d is one standard

[4] The implementation of Electronic Fiscal Devices (EFDs) was launched on a pilot basis in 2018, under which 2,194 taxpayers were trained on how to use the devices in Phase I. Engagements were held with major retailers, vendors, and other taxpayers who needed to use interface. Following the training, the 2,000 EFDs procured by ZRA were distributed to trained taxpayers for their use. In addition, 20 Electronic Signature Devices (ESDs) were also distributed to taxpayers intending to interface with the TIMS by way of ESDs for test purposes.. However, the usage of the EFDs was very poor, and ZRA decided to change the approach and introduce SMART invoicing effective from 1st July 2024, where all businesses are expected to register

[5] ZRA also informed that the sporadic audits often address the quarter-level reporting.

deviation ($sd(R)_d$) above the historical average ($\bar{r}_d$):

$$R_{dm} = 1 \textbf{ if } r_{dm} > \overline{r_d} + sd(R)_d \tag{1}$$

We also do the same for temperature:

$$T_{dm} = 1 \textbf{ if } t_{dm} > \overline{t_d} + sd(T)_d \tag{2}$$

Finally, we create an indicator equal to 1 if the extreme rainfall or temperature event happened in the previous two months.[6] Our preferred estimation is described in Equation 3:

$$\begin{aligned} Y_{im} = \beta_1 \text{Extreme Rain}_{dm} + \beta_2 \text{Extreme Rain}_{d,m-1} + + \beta_3 \text{Extreme Rain}_{d,m-2} + \\ \beta_4 \text{Extreme Heat}_{dm} + \beta_5 \text{Extreme Heat}_{d,m-1} + \beta_6 \text{Extreme Heat}_{d,m-2} + \\ \eta_i + \rho_d + \theta_{pm} + \varepsilon_{im} \end{aligned} \tag{3}$$

In all regressions, we include firm (η_i) and district (ρ_d) fixed effects. In addition, because of the quarterly variability of the rainfall and temperature by province, we also include a quarter by province fixed effect (θ_{pm}). The errors are clustered at the firm level. The econometric specification is very standard in the climate shocks literature (see, e.g., Rocha and Soares 2015).

The main assumption is that extreme rainfall and temperature are difficult to predict as they are exogenous events. The main concern in this specification is the possibility of confounding omitted factors correlated with rainfall, temperature, and firm location. We rely on the combination of having the exogenous measure of the shocks and the extensive number of fixed effects for firms, districts, and quarters by province.

To capture the accumulated effects of rainfall and temperature, we also estimate a modified version of Equation 3 as:

$$\begin{aligned} Y_{im} = \beta_1 \overline{\text{3 month Extreme Rain}}_{dm} + \beta_2 \overline{\text{3 month Extreme Heat}}_{dm} + \\ \eta_i + \rho_d + \theta_{pm} + \varepsilon_{im} \end{aligned} \tag{4}$$

where $\overline{\text{Extreme Rain}}_{dm}$ is a dummy equal to 1 if the average rainfall in the last three months is one standard deviation higher than the district historical average. A similar covariate was created for temperature.

Additionally, based on the shock measures created in Equations 1 and 2, we create dummies to identify if a firm is in a district d that in month m was affected by one, two, or three rainfall or temperature shocks in the past three months. Equation 5 shows this specification:

$$\begin{aligned} Y_{im} = \beta_1 \text{1month Ext-Rain}_{dm} + \beta_2 \text{2month Ext-Rain}_{dm} + \beta_3 \text{3month Ext-Rain}_{dm} + \\ \beta_4 \text{1month Ext-Heat}_{dm} + \beta_5 \text{2month Ext-Heat}_{dm} + \beta_6 \text{3month Ext-Heat}_{dm} + \\ \eta_i + \rho_d + \theta_{pm} + \varepsilon_{im} \end{aligned} \tag{5}$$

We provide some robustness checks in the Appendix. Appendix Table A3 shows the results when clustering the errors at the district level. Appendix Table A4 shows two additional regressions using only a quarter fixed effect and using firm-by-district fixed effect. One may also prefer an econometric specification using a continuous standardized measure of climate shocks instead of dummy variables identifying the shocks. Appendix Table A5 provides evidence replacing the shocks measured by the standardized temperature and rainfall based on the historical average and standard deviation. In all robustness checks, the main conclusions do not change.

[6] Appendix Table A2 provides estimates of an alternative specification, including five-month lags for rainfall and temperature. The main conclusions do not change.

Finally, to understand the distributional effects of climate shocks on firms, we estimate unconditional quantile regressions (Firpo et al. 2009) similar to Equation 3 using the same set of climate covariates and fixed effects.

4 Results

This section presents the main results of the impacts of climate shocks on firms' performance and revenue collection. Table 1 shows the results of Equation 3. Our preferred specification is presented in columns (2), (5), and (8). The results suggest that firms located in districts that experienced a rainfall one standard deviation above the historical average reduced their sales value by 4.6%, their purchases value by 5.6%, and their revenue collection by 4.4%. Firms were also affected by extreme rainfall in previous months. The results also suggest that extreme temperatures negatively impact firms, but only when they occur in the current month.

A potential explanation for the effects of extreme rainfall in the current and past months is that we could be capturing floods and flash floods. Contrary to heat waves, which may affect mainly worker productivity (Feriga et al. 2024), floods may disrupt roads, storage, and other infrastructure needed for production (Balboni et al. 2023; Grover and Kahn 2024; Rentschler et al. 2021). Panel B of Table 1 provides additional evidence by substituting the main explanatory covariates with an indicator equal to 1 if the average temperature or rainfall in the previous three months is higher than the historical average as described in Equation 4. The main conclusions do not change.

Panel C of Table 1 provides the estimation results of Equation 5. This panel shows the cumulative impact of having many months of extreme weather. The results suggest that many months with extreme rainfall increases the negative impacts on all outcomes. A firm that experiences three consecutive months of extreme rainfall has 12.9% less sales and tax collection and 17.1% less purchases. However, cumulative months with extreme heat do not significantly impact the outcomes.

Starting in 2019, ZRA changed its management system, which allows it to obtain information about tax on purchases to calculate VAT deductions. For instance, a firm that pays VAT on inputs they buy has the right to claim this VAT cost back. This information allows us to measure the VAT of each firm in Zambia. Table 2 shows the results of estimating Equation 3 using the sample between 2019 and 2020.

The results for tax on sales using this sub-sample are quantitatively similar to the entire sample in Table 1. Column (2) shows that high temperatures and precipitation increase the value of the VAT that firms should claim back, which may reflect disruption in the production chain or an increase in prices. This is not good in terms of government revenues because the costs of VAT refunds increases. Finally, column (3) shows the huge impact of climate shocks on the VAT of Zambian firms. This is explained by the reduction of taxes paid by firms and the increase in the VAT claims due to the higher costs of inputs.

Table 1: The effects of climate shocks on firms performance and revenue collection (2014–20)

	Log(sales)			Log(purchases)			Log(taxable sales)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: Monthly precipitation and temperature									
Extreme rainfall	–0.0244***	–0.0461***	–0.0417***	–0.0322***	–0.0558***	–0.0558***	–0.0243***	–0.0488***	–0.0444***
	(0.00537)	(0.00583)	(0.00613)	(0.0125)	(0.0136)	(0.0144)	(0.00723)	(0.00796)	(0.00848)
Extreme rainfall (*t*–1)		–0.0378***	–0.0299***		–0.0419**	–0.0396**		–0.0396***	–0.0303***
		(0.00747)	(0.00783)		(0.0178)	(0.0187)		(0.0104)	(0.0109)
Extreme rainfall (*t*–2)		–0.0623***	–0.0510***		–0.0649***	–0.0610***		–0.0631***	–0.0522***
		(0.00535)	(0.00607)		(0.0128)	(0.0148)		(0.00765)	(0.00877)
Extreme heat	–0.0136**	–0.0311***	–0.0356***	–0.00101	–0.0189	–0.0316*	–0.0108	–0.0276***	–0.0257***
	(0.00607)	(0.00658)	(0.00710)	(0.0134)	(0.0152)	(0.0164)	(0.00793)	(0.00896)	(0.00962)
Extreme heat (*t*–1)		–0.00681	0.00315		–0.00960	–0.0103		–0.0143*	–0.00707
		(0.00585)	(0.00699)		(0.0134)	(0.0164)		(0.00809)	(0.00981)
Extreme heat (*t*–2)		–0.00844	–0.00120		–0.00634	–0.00360		–0.00179	0.00431
		(0.00515)	(0.00567)		(0.0118)	(0.0132)		(0.00712)	(0.00789)
Panel B: Three months' average precipitation and temperature									
Accumulated rainfall	–0.0248***			–0.0334***			–0.0233***		
	(0.0054)			(0.0037)			(0.0073)		
Accumulated temperature	–0.0132**			–0.0037			–0.0116		
	(0.0061)			(0.0135)			(0.0079)		
Panel C: Effects of multi-month rainfall and temperature shocks									
1 month rainfall shock	–0.0500***			–0.0528***			–0.0539***		
	(0.00494)			(0.0116)			(0.00716)		
2 month rainfall shock	–0.0667***			–0.101***			–0.0752***		
	(0.0123)			(0.0279)			(0.0166)		
3 month rainfall shock	–0.129***			–0.171***			–0.129***		
	(0.0158)			(0.0376)			(0.0220)		
1 month temperature shock	–0.0179***			–0.0201			–0.0149*		
	(0.00603)			(0.0141)			(0.00807)		
2 month temperature shock	–0.0128			–0.0318**			–0.0233*		
	(0.00887)			(0.0201)			(0.0120)		
3 month temperature shock	–0.0234*			–0.00546			–0.00747		
	(0.0124)			(0.0276)			(0.0173)		
Observations	366,958	366,958	366,958	366,863	366,863	366,863	366,840	366,840	366,840
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
District FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Quarter by province FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Low temperature and rain			✓			✓			✓

Note: panel A of the table displays the baseline regression results of the estimation of Equation 3 of the firm's exposure to a climate shock in the district in which they are based for month *m* and *m–1*. The dependent variable in column (1) is the logarithm of total sales, column (2) is the logarithm of total purchases, and column (3) is the logarithm of total taxable sales. Panel B shows estimates of Equation 4 using the average rainfall and temperature of the last three months. Panel C shows the estimation of Equation 4 using dummies equal to 1 if the firm is in a district affected by at least one, two, or three extreme events in the last three months. Standard errors are clustered at the firm level. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: authors' calculations.

Table 2: The effects of climate shocks on revenue collection (tax years 2019–20)

	Log(taxable sales) (1)	Log(taxable purchases) (2)	Log(VAT) (3)
Extreme rainfall	–0.0652***	1.464***	–0.875***
	(0.0171)	(0.0259)	(0.0766)
Extreme rainfall (*t*–1)	0.0135	1.839***	–1.204***
	(0.0211)	(0.0493)	(0.107)
Extreme rainfall (*t*–2)	–0.0762***	1.139***	–0.723***
	(0.0136)	(0.0155)	(0.0529)
Extreme heat	–0.0150	1.433***	–0.726***
	(0.0197)	(0.0439)	(0.0878)
Extreme heat (*t*–1)	–0.00881	0.970***	–0.548***
	(0.0122)	(0.0127)	(0.0451)
Extreme heat (*t*–2)	0.0167	2.465***	–1.363***
	(0.0127)	(0.0268)	(0.0559)
Observations	126,073	122,272	122,288
Firm FE	✓	✓	✓
District FE	✓	✓	✓
Quarter by province FE	✓	✓	✓

Note: the table displays the baseline regression results of the estimation of Equation 3 of the firm's exposure to a climate shock in the district in which they are based for month *m* and *m–1*. The dependent variable in column (1) is the logarithm of total taxable sales, column (2) is the logarithm of the tax on purchases, and column (3) is the inverse hyperbolic sine of the value added because the value added may assume negative values. Standard errors are clustered at the firm level. Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: authors' calculations.

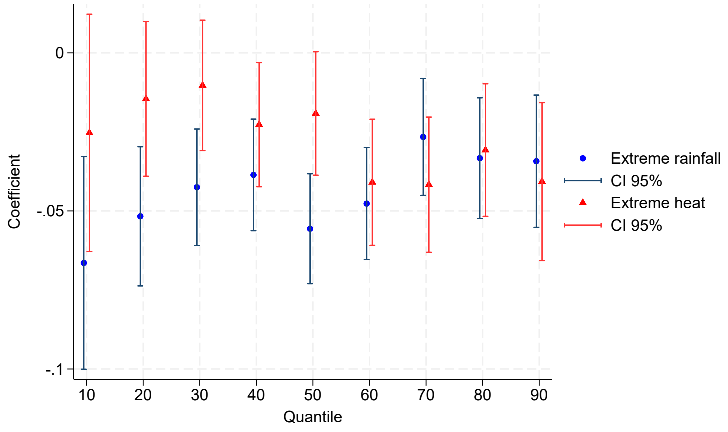
4.1 Heterogeneity

Climate shocks may have heterogeneous effects, depending on firm sizes and financial and managerial capacity to prepare, adapt, and mitigate shocks. To understand the heterogeneous impacts of climate shocks, we estimate the effects of climate shocks using unconditional quantile regressions versions of the average effect presented in Equation 3. Figure 2 shows two main patterns. First, extreme rainfall affects all types of firms but has a higher point estimate impact on the smaller ones. However, the confidence interval suggests that the effects might be statistically similar for all types of firms. Second, extreme heat affects only medium and large firms.

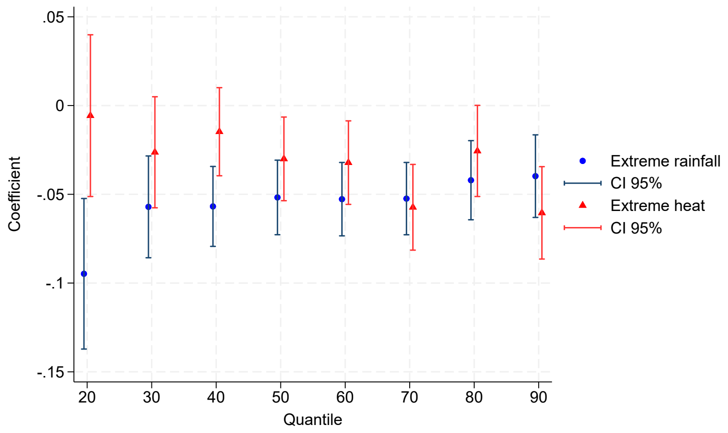
The effects of climate shocks may also differ by economic sectors. Appendix Tables A6–A8 show the results of our preferred specification on firms' sales and purchases and on revenue collection. The results suggest that tourism services, manufacturing, and wholesale and retail trade are the most affected sectors.[7] Finally, Appendix Tables A9–A11 show that the effects on firms' sales are distributed across the space, the effects on firms' purchases are concentrated in Lusaka province, and the effects on tax revenues are distributed across the space, but with higher impacts in the two big provinces, Lusaka and Copperbelt, and the south-east provinces.

[7] The tax data allows us to estimate the effects for 21 economic sectors. We provided the estimations for eight of them because they are the most relevant in Zambia. We can provide the estimations for the other sectors at your request.

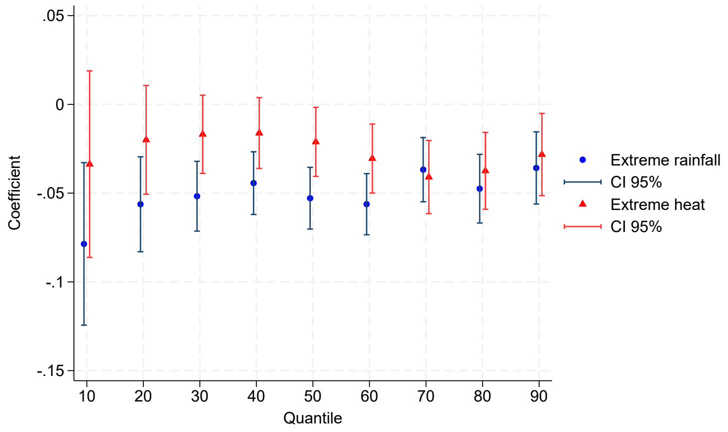
Figure 2: The effects of extreme rainfall and temperature in the current month on Zambian firms and revenue collection (tax years 2014–20)



(a) Sales



(b) Purchases



(c) Tax revenues

Note: the figure displays the baseline regression results of the estimation of the unconditional quantile version of Equation 3 of the firm's exposure to a climate shock in the district in which they are based for month *m* and *m–1*. Appendix Figure A2 shows the results for graph (b) including the quantile 10. We excluded this from the main graph because the high confidence interval makes it difficult to interpret the estimations for the other quantiles. Standard errors are clustered at the firm level. Confidence interval at 95%.

Source: authors' compilation.

4.2 Mechanism

As highlighted by recent literature reviews, there are many channels that explain how firms may be impacted by climate shocks and how they cope with them. However, due to data limitations, we can only explore the employment margins of adjustment. Columns 1 and 2 of Table 3 show that when firms have been impacted by extreme rainfall in the past, they reduce in the present their number of employees and their wage bill. It is important to highlight that we cannot disentangle the effects on total wages and hours of work because we do not have information at the individual level. Therefore, the observed reduction in wages can be a combination of firing some employees and temporarily reducing the worked hours of others.

Table 3: The effects of climate shocks on total employment, wages, and firm productivity

	Log(employees)	Log(wages)	Log(productivity)
	(1)	(2)	(3)
Extreme rainfall	0.00172	0.00416	–0.0519***
	(0.00240)	(0.00287)	(0.00635)
Extreme rainfall (*t*–1)	–0.00665*	–0.0262***	–0.0322***
	(0.00369)	(0.00408)	(0.00824)
Extreme rainfall (*t*–2)	–0.00443**	0.00128	–0.0619***
	(0.00224)	(0.00259)	(0.00583)
Extreme heat	–0.00271	–0.0386***	–0.0410***
	(0.00255)	(0.00312)	(0.00718)
Extreme heat (*t*–1)	–0.00173	–0.00176	–0.0121*
	(0.00219)	(0.00251)	(0.00633)
Extreme heat (*t*–2)	–0.0153***	–0.000759	–0.00195
	(0.00208)	(0.00274)	(0.00564)
Observations	289,890	283,113	289,890
Firm FE	✓	✓	✓
District FE	✓	✓	✓
Quarter by province FE	✓	✓	✓
Observations	289,890	283,113	289,890

Note: The table displays the baseline regression results of the estimation of Equation 3 of the firm's exposure to a climate shock in the district in which they are based for month *m* and *m–1*. The dependent variable in column (1) is the logarithm of total employees, column (2) is the logarithm of total wages, and column (3) is the productivity measured as sales per employee. Standard errors are clustered at the firm level. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: authors' calculations.

The potential explanations for that are twofold. First, the high informality in Zambia. As in many developing countries (Ulyssea 2018, 2020), Zambian formal firms also hire informal workers. However, when they report the number of employees and their salaries, the firms do not need to inform the type of contract each employee has. Second, employment contracts in Zambia are not strong. For instance, the Employment Code Act 2019[8] indicates that oral contracts are possible for short-term contracts and item 56 of division 3.3 specifies the conditions under which employers can terminate the contracts without a penalty, which includes situations of firms' economic loss. Column 3 of Table 3 shows that productivity is reduced by shocks in all periods, which may be explained by the destruction of the production infrastructure or by direct effects of the climate events on employees (Castro-Vincenzi et al. 2024; Feriga et al. 2024).

[8] https://shorturl.at/20DQW

5 Conclusion

This paper provides new insights into the interconnected challenges of climate change and revenue mobilization in low-income countries by examining the impacts of climate shocks on firms' performance and tax collection. We utilize unique firm-level administrative data from Zambia, combining monthly VAT and aggregate PAYE records from ZRA between 2014 and 2016 with granular temperature and rainfall data spanning 1980–2020.

Our results show that extreme weather events significantly reduce firms' sales, input purchases, and tax revenues. The impacts are particularly pronounced in the manufacturing, wholesale and retail trade, accommodation, and construction sectors, with rainfall shocks affecting all firm sizes but temperature shocks primarily impacting medium and large firms. We also find that firms reduce employment and payroll costs in response to climate shocks, reflecting a drop in productivity.

Our findings underscore the urgent need for policy attention in low-income countries where climate change poses a dual threat to economic stability and revenue generation. The evidence suggests that climate-induced shocks affect not only agricultural sectors but also non-agricultural businesses, challenging the conventional focus of climate impact studies. These results have crucial implications for developing countries with limited fiscal capacity to cope with climate shocks, highlighting the need for comprehensive strategies that integrate climate resilience into economic planning and revenue mobilization efforts.

Regarding practical policy in Zambia, the results suggest that when the Ministry of Finance sets the revenue targets for ZRA, they must consider the potential negative effects that climate shocks may exert on the economy.

References

Acevedo, S., M. Mrkaic, N. Novta, E. Pugacheva, and P. Topalova (2020). 'The Effects of Weather Shocks on Economic Activity: What Are the Channels of Impact?' *Journal of Macroeconomics*, 65: 103207. https://doi.org/10.1016/j.jmacro.2020.103207

Adhvaryu, A., N. Kala, and A. Nyshadham (2020). 'The Light and the Heat: Productivity Co-benefits of Energy-Saving Technology'. *Review of Economics and Statistics*, 102(4): 779–92. https://doi.org/10.1162/rest_a_00886

Adu-Ababio, K., A. Koivisto, A. Kumwenda, G. Chileshe, J. Mulenga, M. Mebelo, I. Mufana, and Y. Shamabobo (2023). 'Assessing the Impact of an Intervention to Withhold Value-Added Tax in Zambia'. Working Paper 2023/21. Helsinki: UNU-WIDER. https://doi.org/10.35188/UNU-WIDER/2023/329-1

Balboni, C., J. Boehm, and M. Waseem (2023). 'Firm Adaptation and Production Networks: Structural Evidence from Extreme Weather Events in Pakistan'. Available at: https://www.dropbox.com/s/8294vtvof2p5ne7/Pakistan_Floods_Paper_Draft.pdf?e=1&dl=0 (accessed 14 October 2024).

Barrios, S., L. Bertinelli, and E. Strobl (2010). 'Trends in Rainfall and Economic Growth in Africa: A Neglected Cause of the African Growth Tragedy'. *Review of Economics and Statistics*, 92(2): 350–66. https://doi.org/10.1162/rest.2010.11212

Brockmeyer, A., G. Mascagni, V. Nair, M. Waseem, and M. Almunia (2024). 'Does the Value-Added Tax Add Value? Lessons Using Administrative Data from a Diverse Set of Countries'. *Journal of Economic Perspectives*, 38(1): 107–32. https://doi.org/10.1257/jep.38.1.107

Carleton, T., A. Jina, M. Delgado, M. Greenstone, T. Houser, S. Hsiang, A. Hultgren, R.E. Kopp, K.E. McCusker, I. Nath, J. Rising, A. Rode, H.K. Seo, A. Viaene, J. Yuan, and A.T. Zhang (2022). 'Valuing the Global Mortality Consequences of Climate Change Accounting for Adaptation Costs and Benefits'. *Quarterly Journal of Economics*, 137(4): 2037–105. https://doi.org/10.1093/qje/qjac020

Castro-Vincenzi, J., G. Khanna, N. Morales, and N. Pandalai-Nayar (2024). 'Weathering the Storm: Supply Chains and Climate Risk'. Working Paper 32218. Cambridge, MA: NBER. https://doi.org/10.3386/w32218

Colmer, J. (2021). 'Temperature, Labor Reallocation, and Industrial Production: Evidence from India'. *American Economic Journal: Applied Economics*, 13(4): 101–24. https://doi.org/10.1257/app.20190249

Crick, F., S.M. Eskander, S. Fankhauser, and M. Diop (2018). 'How Do African SMEs Respond to Climate Risks? Evidence from Kenya and Senegal'. *World Development*, 108: 157–68. https://doi.org/10.1016/j.worlddev.2018.03.015

Davis, L.W., and P.J. Gertler (2015). 'Contribution of Air Conditioning Adoption to Future Energy Use Under Global Warming'. *Proceedings of the National Academy of Sciences*, 112(19): 5962–67. https://doi.org/10.1073/pnas.1423558112

De Mel, S., D. McKenzie, and C. Woodruff (2012). 'Enterprise Recovery Following Natural Disasters'. *The Economic Journal*, 122(559): 64–91. https://doi.org/10.1111/j.1468-0297.2011.02475.x

Dell, M., B.F. Jones, and B.A. Olken (2012). 'Temperature Shocks and Economic Growth: Evidence from the Last Half Century'. *American Economic Journal: Macroeconomics*, 4(3): 66–95. https://doi.org/10.1257/mac.4.3.66

Deschênes, O., and M. Greenstone (2011). 'Climate Change, Mortality, and Adaptation: Evidence from Annual Fluctuations in Weather in the US'. *American Economic Journal: Applied Economics*, 3(4): 152–85. https://doi.org/10.1257/app.3.4.152

Feriga, M., N.L. Gracia, and P. Serneels (2024). 'The Impact of Climate Change on Work: Lessons for Developing Countries'. *The World Bank Research Observer*. https://doi.org/10.1093/wbro/lkae002

Firpo, S., N.M. Fortin, and T. Lemieux (2009). 'Unconditional Quantile Regressions'. *Econometrica*, 77(3): 953–73. https://doi.org/10.3982/ECTA6822

Fuje, H., J. Yao, S.M. Choi, and H. Mighri (2023). 'Fiscal Impacts of Climate Disasters in Emerging Markets and Developing Economies'. IMF Working Papers, 2023(261). https://doi.org/10.5089/9798400262913.001

Grover, A., and M.E. Kahn (2024). 'Firm Adaptation to Climate Change'. Working Paper 32848. Cambridge, MA: NBER. https://doi.org/10.3386/w32848

Kala, N., C. Balboni, and S. Bhogale (2023). 'Climate Adaptation'. *VoxDevLit*, 7(1).

Maccini, S., and D. Yang (2009). 'Under the Weather: Health, Schooling, and Economic Consequences of Early-Life Rainfall'. *American Economic Review*, 99(3): 1006–26. https://doi.org/10.1257/aer.99.3.1006

OECD (2024). 'Global Revenue Statistics Database'. Paris: OECD.

Oliveira, R., G. Monteiro, and A. Hidalgo (forthcoming). 'The Distributional Effects of Climate Shocks in Zambia'. Working Paper. Helsinki: UNU-WIDER.

Reed, C., W. Anderson, A. Kruczkiewicz, J. Nakamura, D. Gallo, R. Seager, and S.S. McDermid (2022). 'The Impact of Flooding on Food Security Across Africa'. *Proceedings of the National Academy of Sciences*, 119(43): e2119399119. https://doi.org/10.1073/pnas.2119399119

Rentschler, J., E. Kim, S. Thies, S. De Vries Robbe, and A. Erman (2021). 'Floods and Their Impacts on Firms: Evidence from Tanzania'. Policy Research Working Paper. Washington, DC: World Bank. https://doi.org/10.1596/1813-9450-9774

Rocha, R., and R.R. Soares (2015). 'Water Scarcity and Birth Outcomes in the Brazilian Semiarid'. *Journal of Development Economics*, 112: 72–91. https://doi.org/10.1016/j.jdeveco.2014.10.003

Somanathan, E., R. Somanathan, A. Sudarshan, and M. Tewari (2021). 'The Impact of Temperature on Productivity and Labor Supply: Evidence from Indian Manufacturing'. *Journal of Political Economy*, 129(6): 1797–827. https://doi.org/10.1086/713733

Tol, R.S. (2018). 'The Economic Impacts of Climate Change'. *Review of Environmental Economics and Policy*, 12(1). https://doi.org/10.1093/reep/rex027

Ulyssea, G. (2018). 'Firms, Informality, and Development: Theory and Evidence from Brazil'. *American Economic Review*, 108(8): 2015–47. https://doi.org/10.1257/aer.20141745

Ulyssea, G. (2020). 'Informality: Causes and Consequences for Development'. *Annual Review of Economics*, 12(1): 525–46. https://doi.org/10.1146/annurev-economics-082119-121914

Xie, V.W. (2024). 'Heterogeneous Firms Under Regional Temperature Shocks: Exit and Reallocation, with Evidence from Indonesia'. *Economic Development and Cultural Change*, 72(2): 659–90. https://doi.org/10.1086/720776

ZAMSTATS (2024). *2022 Living Conditions Monitoring Survey Report*. Lusaka: Zambia Statistics Agency.

Appendix A

Table A1: Descriptive statistics

	Mean	Sd	Median	Min.	Max.
Sales (ZMW, million)	3.93	42.83	0.293	0.002	5,620.00
Purchases (ZMW, million)	2.11	24.86	0.139	0	2,750.00
Tax on sales (ZMW, million)	0.361	3.183	0.034	0	4.83
Employees	62.9	289.9	13	0	17,934
Total wages (ZMW, million)	0.541	6.399	0.040	0	9.65
		Share (%)			
Districts with extreme rain		18.6			
Districts with high temperature		19.5			
Share of firms in wholesale and retail trade		43.5			
Share of firms in manufacturing		9.23			
Share of firms in agriculture		4.19			
Share of firms in mining		2.18			

Note: the table displays the descriptive statistics for the main variables in the study. The values are in Zambian kwacha millions. The exchange rate in September 2023 is about 26 Zambian kwacha to 1 US dollar.

Source: authors' compilation.

Table A2: Regression results of rainfall and temperature using five-month lag

	Log(sales)	Log(purchases)	Log(tax sales)
	(1)	(2)	(3)
Extreme rain	–0.0307***	–0.0325**	–0.0410***
	(0.00694)	(0.0159)	(0.00952)
Extreme rain (*t*–1)	–0.0280***	–0.0324	–0.0320***
	(0.00864)	(0.0206)	(0.0122)
Extreme rain (*t*–2)	–0.0563***	–0.0617***	–0.0567***
	(0.00664)	(0.0157)	(0.00963)
Extreme rain (*t*–3)	–0.0168***	–0.00225	–0.0159*
	(0.00631)	(0.0146)	(0.00880)
Extreme rain (*t*–4)	–0.00953	0.0264	–0.0137
	(0.00765)	(0.0174)	(0.0114)
Extreme rain (*t*–5)	–0.00958*	–0.00957	–0.0115
	(0.00582)	(0.0132)	(0.00843)
Extreme heat	–0.0456***	–0.0291*	–0.0408***
	(0.00708)	(0.0162)	(0.00975)
Extreme heat (*t*–1)	–0.0182***	–0.0200	–0.0238***
	(0.00617)	(0.0141)	(0.00861)
Extreme heat (*t*–2)	–0.0187***	–0.0138	–0.01000
	(0.00581)	(0.0131)	(0.00814)
Extreme heat (*t*–3)	–0.0587***	–0.0589***	–0.0467***
	(0.00796)	(0.0179)	(0.0111)
Extreme heat (*t*–4)	–0.0163**	–0.0256	0.000100
	(0.00717)	(0.0165)	(0.0102)
Extreme heat (*t*–5)	–0.0244***	–0.00684	–0.0326***
	(0.00571)	(0.0139)	(0.00846)
Constant	12.73***	11.09***	10.19***
	(0.00672)	(0.0151)	(0.00983)
Observations	366,958	366,863	366,840
Firm FE	✓	✓	✓
District FE	✓	✓	✓
Quarter by province FE	✓	✓	✓

Note: the table displays regression results of firms' exposure to extreme climate shocks (rain and heat) at the district level in different lag periods (*t*–1, *t*–2, etc.). Fixed effects include firm fixed effects (Firm FE), district fixed effects (District FE), and quarter by province fixed effects. Standard errors are clustered at the district level. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: authors' compilation.

Table A3: Main results with errors clustered at the district level

	Log(sales) (1)	Log(purchases) (2)	Log(tax) (3)	Log(employees) (4)	Log(wages) (5)	Log(Pdt) (6)
Extreme rain	–0.0463***	–0.0576**	–0.0506***	0.00172	0.00416	–0.0519***
	(0.00855)	(0.0245)	(0.00830)	(0.00257)	(0.00649)	(0.0126)
Extreme rain (*t*–1)	–0.0377***	–0.0421	–0.0412***	–0.00665*	–0.0262**	–0.0322***
	(0.00883)	(0.0289)	(0.0128)	(0.00335)	(0.0115)	(0.00648)
Extreme rain (*t*–2)	–0.0624***	–0.0670***	–0.0649***	–0.00443**	0.00128	–0.0619***
	(0.00562)	(0.0237)	(0.00940)	(0.00206)	(0.00236)	(0.00645)
Extreme heat	–0.0322***	–0.0189	–0.0287***	–0.00271	–0.0386***	–0.0410***
	(0.00648)	(0.0185)	(0.00768)	(0.00347)	(0.00304)	(0.00595)
Extreme heat (*t*–1)	–0.00646	–0.00906	–0.0135*	–0.00173	–0.00176	–0.0121**
	(0.00496)	(0.00557)	(0.00769)	(0.00109)	(0.00167)	(0.00493)
Extreme heat (*t*–2)	–0.00874*	–0.00538	–0.00175	–0.0153***	–0.000759	–0.00195
	(0.00522)	(0.00840)	(0.00551)	(0.00153)	(0.0113)	(0.00629)
Observations	364,871	364,777	364,756	289,890	283,113	289,890
Firm FE	✓	✓	✓	✓	✓	✓
District FE	✓	✓	✓	✓	✓	✓
Quarter by province FE	✓	✓	✓	✓	✓	✓

Note: the table displays the baseline regression results of the estimation of Equation 3 of firms' exposure to a climate shock in the district in which they are based for month *m* and *m–1*. Standard errors are clustered at the district level. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: authors' compilation.

Table A4: Main results with only quarter fixed effects or with firm–district fixed effects

	Log(sales)		log(purchases)		Log(taxable sales)	
	(1)	(2)	(3)	(4)	(5)	(6)
Extreme rain	–0.0391***	–0.0462***	–0.0286**	–0.0568***	–0.0445***	–0.0489***
	(0.00584)	(0.00581)	(0.0137)	(0.0136)	(0.00820)	(0.00795)
Extreme rain (*t*–1)	–0.0253***	–0.0372***	–0.0309*	–0.0408**	–0.0347***	–0.0388***
	(0.00746)	(0.00745)	(0.0175)	(0.0177)	(0.0104)	(0.0104)
Extreme rain (*t*–2)	–0.0589***	–0.0629***	–0.0536***	–0.0655***	–0.0649***	–0.0632***
	(0.00542)	(0.00534)	(0.0129)	(0.0128)	(0.00791)	(0.00762)
Extreme heat	–0.0291***	–0.0306***	0.0275*	–0.0179	–0.0246**	–0.0264***
	(0.00702)	(0.00657)	(0.0162)	(0.0152)	(0.00961)	(0.00893)
Extreme heat (*t*–1)	–0.00657	–0.00700	0.0126	–0.00888	–0.00763	–0.0153*
	(0.00588)	(0.00582)	(0.0137)	(0.0134)	(0.00827)	(0.00806)
Extreme heat (*t*–2)	–0.0108**	–0.00847*	0.00937	–0.00579	–0.000824	–0.00223
	(0.00528)	(0.00514)	(0.0121)	(0.0118)	(0.00728)	(0.00713)
Observations	366,894	366,799	366,776	363,041	363,057	
Firm FE	✓		✓		✓	
District FE	✓		✓		✓	
Quarter FE	✓		✓		✓	
Province by quarter FE		✓		✓		✓
Firm-by-district FE		✓		✓		✓

Note: the table displays the baseline regression results of the estimation of Equation 3 of firms' exposure to a climate shock in the district in which they are based for month *m* and *m–1*. Standard errors are clustered at the firm level. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: authors' compilation.

Table A5: The effects of climate shocks using a continuous measure of shock

	Log(sales)	Log(purchases)	Log(taxes)	Log(sales)	Log(purchases)	Log(taxes)	Log(Sales)	Log(purchases)	Log(taxes)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Rainfall deviation	–0.0159***	–0.0199***	–0.0197***						
	(0.00273)	(0.00624)	(0.00372)						
Temperature deviation	–0.0148***	–0.00416	–0.0179***						
	(0.00258)	(0.00573)	(0.00361)						
Negative rainfall deviation				–0.0364***	–0.0327	–0.0471***			
				(0.00914)	(0.0200)	(0.0126)			
Negative temperature deviation				–0.0186***	–0.00850	–0.0238***			
				(0.00387)	(0.00890)	(0.00555)			
Positive rainfall deviation							–0.0168***	–0.0215***	–0.0196***
							(0.00338)	(0.00776)	(0.00457)
Positive temperature deviation							–0.0160***	0.00134	–0.0170***
							(0.00481)	(0.0101)	(0.00633)
Constant	12.66***	11.04***	10.13***	12.64***	11.02***	10.10***	12.68***	11.04***	10.14***
	(0.000430)	(0.000958)	(0.000588)	(0.00371)	(0.00814)	(0.00528)	(0.00304)	(0.00651)	(0.00404)
Observations	366,958	366,863	366,840	366,958	366,863	366,840	366,958	366,863	366,840
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
District FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Quarter by province FE	✓	✓	✓	✓	✓	✓	✓	✓	✓

Note: the table displays the baseline regression results of the estimation of Equation 3 of the firm's exposure to a climate shock in the district in which they are based for month *m* and *m–1*. Standard errors are clustered at the firm level. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Columns (1)–(3) use a standardized measure equal to the current rainfall (or temperature) subtracted by the historical average and divided by the historical standard deviation. Columns (4)–(6) try to capture the effects of negative deviations by normalizing all positive values to zero, and columns (7)–(9) try to capture the effects of positive deviations by normalizing all negative values to zero.

Source: authors' compilation.

Table A6: The effects of climate shocks on sales by sector

	Tourism	Agriculture	Construction	Energy	Financial	Manufacturing	Mining	Wholesale
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Extreme rainfall	–0.0974***	–0.0675	–0.0715**	0.0217	0.00579	–0.0505***	0.0143	–0.0484***
	(0.0258)	(0.0450)	(0.0303)	(0.145)	(0.0802)	(0.0155)	(0.0619)	(0.00771)
Extreme rainfall (*t*–1)	–0.143***	–0.203***	–0.00107	–0.0281	0.0143	–0.0126	–0.0501	–0.0226**
	(0.0366)	(0.0562)	(0.0372)	(0.151)	(0.106)	(0.0211)	(0.0566)	(0.00999)
Extreme rainfall (*t*–2)	–0.0184	–0.228***	–0.0339	–0.125*	–0.0742	–0.0625***	–0.136***	–0.0527***
	(0.0221)	(0.0409)	(0.0269)	(0.0648)	(0.0649)	(0.0147)	(0.0352)	(0.00744)
Extreme heat	–0.0456	0.0949*	–0.0332	–0.102	–0.0499	–0.0499***	0.0234	–0.0416***
	(0.0294)	(0.0540)	(0.0331)	(0.126)	(0.0921)	(0.0179)	(0.0525)	(0.00892)
Extreme heat (*t*–1)	–0.0541**	–0.0209	–0.00596	–0.0503	–0.191***	–0.0158	0.0468	–0.00239
	(0.0259)	(0.0446)	(0.0293)	(0.0716)	(0.0639)	(0.0144)	(0.0619)	(0.00779)
Extreme heat (*t*–2)	0.0168	–0.0925**	–0.0164	0.0713	–0.00715	–0.0101	–0.0447	0.00122
	(0.0204)	(0.0440)	(0.0272)	(0.0899)	(0.0752)	(0.0136)	(0.0432)	(0.00692)
Constant	12.26***	13.17***	12.45***	13.94***	14.21***	13.08***	14.38***	12.59***
	(0.0178)	(0.0275)	(0.0180)	(0.0732)	(0.0507)	(0.0101)	(0.0291)	(0.00500)
Observations	13,919	14,588	22,244	1,472	2,831	39,997	7,128	165,920
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓
District FE	✓	✓	✓	✓	✓	✓	✓	✓
Quarter by province FE	✓	✓	✓	✓	✓	✓	✓	✓

Note: the table displays the baseline regression results of the estimation of Equation 3 of firms' exposure to a climate shock in the district in which they are based for month *m* and *m–1*. Standard errors are clustered at the firm level. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: authors' compilation.

Table A7: The effects of climate shocks on firms' purchases by sector

	Tourism	Agriculture	Construction	Energy	Financial	Manufacturing	Mining	Wholesale
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Extreme rainfall	–0.140***	–0.00487	–0.128*	0.143	0.505**	–0.0811**	–0.0929	–0.0500**
	(0.0415)	(0.0923)	(0.0666)	(0.221)	(0.250)	(0.0350)	(0.0985)	(0.0196)
Extreme rainfall (*t*–1)	–0.0878*	0.239*	0.0583	–0.540*	–0.243	–0.126***	–0.105	–0.0507**
	(0.0523)	(0.126)	(0.0983)	(0.301)	(0.339)	(0.0445)	(0.130)	(0.0239)
Extreme rainfall (*t*–2)	–0.0446	0.0587	–0.101	–0.281	–0.129	–0.0574*	–0.211**	–0.0433**
	(0.0420)	(0.0807)	(0.0645)	(0.195)	(0.220)	(0.0311)	(0.0940)	(0.0180)
Extreme heat	–0.0569	0.177*	0.0502	0.105	0.240	–0.0252	–0.260**	–0.0669***
	(0.0549)	(0.106)	(0.0670)	(0.255)	(0.297)	(0.0415)	(0.116)	(0.0215)
Extreme heat (*t*–1)	0.0477	0.152*	0.157**	0.0891	–0.343**	–0.00323	0.0499	–0.0571***
	(0.0504)	(0.0855)	(0.0615)	(0.243)	(0.160)	(0.0345)	(0.101)	(0.0187)
Extreme heat (*t*–2)	–0.00465	0.0967	–0.0630	–0.170	–0.0296	–0.00315	–0.0797	0.00970
	(0.0478)	(0.0763)	(0.0579)	(0.224)	(0.168)	(0.0306)	(0.103)	(0.0170)
Constant	11.35***	10.50***	10.58***	12.83***	9.347***	12.09***	13.00***	11.25***
	(0.0317)	(0.0616)	(0.0458)	(0.166)	(0.154)	(0.0223)	(0.0646)	(0.0122)
Observations	13,916	14,585	22,241	1,471	2,830	39,991	7,126	165,892
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓
District FE	✓	✓	✓	✓	✓	✓	✓	✓
Quarter by province FE	✓	✓	✓	✓	✓	✓	✓	✓

Note: the table displays the baseline regression results of the estimation of Equation 3 of firms' exposure to a climate shock in the district in which they are based for month *m* and *m–1*. Standard errors are clustered at the firm level. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: authors' compilation.

Table A8: The effects of climate shocks on taxable sales revenues by sector

	Tourism (1)	Agriculture (2)	Construction (3)	Energy (4)	Financial (5)	Manufacturing (6)	Mining (7)	Wholesale (8)
Extreme rainfall	–0.125***	–0.117	–0.0484	0.0682	0.0120	–0.0566***	–0.0770	–0.0468***
	(0.0376)	(0.0726)	(0.0420)	(0.140)	(0.0959)	(0.0202)	(0.0766)	(0.00982)
Extreme rainfall (*t*–1)	–0.118***	–0.285***	0.0777	–0.0839	0.0200	–0.0247	–0.0189	–0.0171
	(0.0406)	(0.101)	(0.0609)	(0.151)	(0.160)	(0.0215)	(0.117)	(0.0129)
Extreme rainfall (*t*–2)	–0.0226	–0.358***	–0.0346	–0.181**	–0.190*	–0.0626***	–0.115	–0.0469***
	(0.0266)	(0.0824)	(0.0394)	(0.0859)	(0.0999)	(0.0168)	(0.0783)	(0.00943)
Extreme heat	–0.0409	0.122	0.0247	–0.0479	0.0727	–0.0568**	–0.155*	–0.0321***
	(0.0346)	(0.0772)	(0.0456)	(0.103)	(0.116)	(0.0233)	(0.0863)	(0.0114)
Extreme heat (*t*–1)	–0.0713**	–0.0788	0.0147	–0.0220	–0.0473	–0.0312*	–0.136	–0.0179*
	(0.0290)	(0.0622)	(0.0501)	(0.0968)	(0.0730)	(0.0174)	(0.0972)	(0.0101)
Extreme heat (*t*–2)	0.0375	–0.194***	0.00457	0.0490	0.0506	–0.0260	0.0141	0.0124
	(0.0251)	(0.0610)	(0.0367)	(0.0860)	(0.0858)	(0.0175)	(0.0863)	(0.00876)
Constant	10.18***	7.484***	10.04***	11.82***	11.40***	10.53***	11.21***	10.29***
	(0.0239)	(0.0450)	(0.0283)	(0.0695)	(0.0620)	(0.0123)	(0.0475)	(0.00652)
Observations	13,917	14,584	22,240	1,471	2,830	39,985	7,119	165,885
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓
District FE	✓	✓	✓	✓	✓	✓	✓	✓
Quarter by province FE	✓	✓	✓	✓	✓	✓	✓	✓

Note: the table displays the baseline regression results of the estimation of Equation 3 of the firm's exposure to a climate shock in the district in which they are based for month *m* and *m–1*. Standard errors are clustered at the firm level. Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: authors' compilation.

Table A9: The effects of climate shocks on firms' sales by province

	Central	Copperbelt	Eastern	Luapula	Lusaka	Muchinga	North	Northern	Southern	Western
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
rain_1sd	–0.0483	–0.0229**	–0.138**	–0.148	–0.0575***	0.00539	–0.0355	–0.0479	–0.0115	–0.116*
	(0.0549)	(0.0115)	(0.0562)	(0.162)	(0.00720)	(0.0963)	(0.0419)	(0.106)	(0.0272)	(0.0596)
lrain_1sd	–0.141*	–0.0123	–0.202***	–0.176	–0.0277***	0.0173	–0.112**	0.00423	–0.157***	–0.0759
	(0.0762)	(0.0168)	(0.0556)	(0.124)	(0.00909)	(0.129)	(0.0454)	(0.0826)	(0.0367)	(0.0764)
llrain_1sd	–0.0890**	–0.0423***	–0.107**	0.114	–0.0699***	0.162	–0.0678**	–0.0143	–0.159***	–0.0343
	(0.0445)	(0.00998)	(0.0471)	(0.0963)	(0.00676)	(0.109)	(0.0343)	(0.0832)	(0.0313)	(0.0604)
temp_1sd	–0.0903	–0.0292**	0.0262	0.230**	–0.0361***	0.0982	0.0435	–0.0453	0.0625	–0.118
	(0.0677)	(0.0125)	(0.0806)	(0.0892)	(0.00820)	(0.0922)	(0.0415)	(0.117)	(0.0383)	(0.0862)
ltemp_1sd	–0.0267	0.0173	–0.115**	0.00286	–0.00315	–0.139	–0.0728	0.338*	–0.0687**	–0.0728
	(0.0702)	(0.0166)	(0.0496)	(0.0858)	(0.00648)	(0.0978)	(0.0608)	(0.194)	(0.0275)	(0.0610)
lltemp_1sd	–0.0791	–0.0188*	0.0934**	0.250	–0.00319	0.363***	0.0362	0.0133	–0.0282	–0.0369
	(0.0628)	(0.0110)	(0.0446)	(0.154)	(0.00617)	(0.119)	(0.0391)	(0.130)	(0.0286)	(0.0563)
Constant	12.74***	12.68***	12.81***	12.80***	12.71***	12.63***	13.08***	12.22***	12.51***	12.60***
	(0.0331)	(0.00741)	(0.0347)	(0.0587)	(0.00460)	(0.0962)	(0.0279)	(0.0629)	(0.0172)	(0.0383)
Observations	9,940	96,698	6,368	1,031	226,706	661	5,133	1,140	17,084	2,159
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
District FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Quarter by province FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Note: the table displays the baseline regression results of the estimation of Equation 3 of firms' exposure to a climate shock in the district in which they are based for month *m* and *m–1*. Standard errors are clustered at the firm level. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: authors' compilation based on data.

Table A10: The effects of climate shocks on firms' purchases by province

	Central	Copperbelt	Eastern	Luapula	Lusaka	Muchinga	North	Northern	Southern	Western
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
rain_1sd	–0.0848	–0.00281	–0.0909	–0.490	–0.0959***	–0.187	–0.0470	–0.346	0.119**	–0.0368
	(0.0737)	(0.0290)	(0.0804)	(0.309)	(0.0168)	(0.108)	(0.135)	(0.299)	(0.0604)	(0.143)
lrain_1sd	0.324**	0.0111	–0.0902	–0.00530	–0.0827***	–0.256*	–0.104	0.00355	–0.0272	–0.213
	(0.126)	(0.0420)	(0.0796)	(0.163)	(0.0215)	(0.123)	(0.142)	(0.216)	(0.0789)	(0.166)
llrain_1sd	0.0658	–0.0394	0.000392	0.0404	–0.104***	0.0385	–0.0544	–0.175	0.0748	0.0912
	(0.0833)	(0.0252)	(0.0770)	(0.192)	(0.0162)	(0.0798)	(0.113)	(0.283)	(0.0591)	(0.149)
temp_1sd	0.135	0.0105	–0.0808	0.291	–0.0500***	–0.0617	0.0430	–0.00200	0.0883	–0.0380
	(0.114)	(0.0300)	(0.110)	(0.324)	(0.0188)	(0.209)	(0.113)	(0.353)	(0.0779)	(0.164)
ltemp_1sd	0.0801	0.00453	–0.0100	–0.112	–0.00870	–0.104	–0.0893	0.0574	0.00148	–0.0537
	(0.102)	(0.0382)	(0.102)	(0.214)	(0.0153)	(0.0964)	(0.177)	(0.229)	(0.0629)	(0.157)
lltemp_1sd	0.127	–0.00865	–0.00387	0.593*	–0.0199	0.145	0.0705	0.220	–0.0118	–0.0608
	(0.0989)	(0.0270)	(0.0822)	(0.318)	(0.0142)	(0.214)	(0.122)	(0.274)	(0.0519)	(0.130)
Constant	11.02***	10.68***	11.94***	12.16***	11.24***	12.40***	10.92***	11.16***	10.74***	11.45***
	(0.0663)	(0.0184)	(0.0513)	(0.0773)	(0.0108)	(0.0786)	(0.0921)	(0.159)	(0.0423)	(0.0912)
Observations	9,938	96,682	6,368	1,031	226,631	661	5,132	1,140	17,083	2,159
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
District FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Quarter by province FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Note: the table displays the baseline regression results of the estimation of Equation 3 of firms' exposure to a climate shock in the district in which they are based for month *m* and *m–1*. Standard errors are clustered at the firm level. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: authors' compilation.

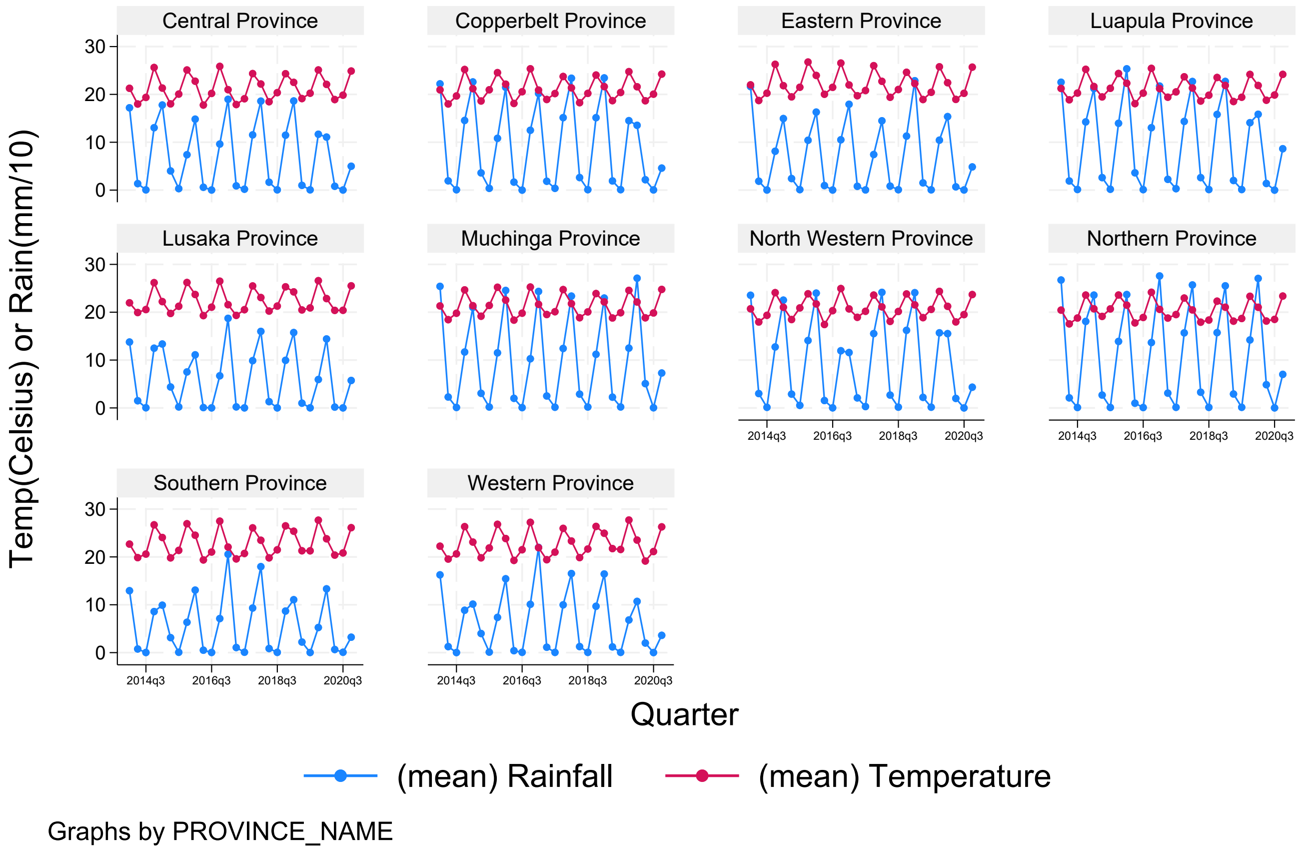
Table A11: The effects of climate shocks on tax revenues by province

	Central	Copperbelt	Eastern	Luapula	Lusaka	Muchinga	North	Northern	Southern	Western
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
rain_1sd	–0.0478	–0.0266*	–0.0841	–0.212	–0.0575***	–0.153	–0.0404	0.158	–0.0587	0.0127
	(0.0682)	(0.0152)	(0.0683)	(0.135)	(0.00997)	(0.175)	(0.0586)	(0.176)	(0.0421)	(0.114)
lrain_1sd	–0.313***	0.00278	–0.212***	–0.317**	–0.0275**	–0.0496	–0.0220	0.113	–0.265***	0.00254
	(0.110)	(0.0237)	(0.0682)	(0.118)	(0.0124)	(0.308)	(0.0587)	(0.193)	(0.0530)	(0.107)
llrain_1sd	–0.344***	–0.0380***	–0.0949	0.172	–0.0591***	–0.0268	–0.0182	–0.152	–0.225***	–0.0284
	(0.0868)	(0.0135)	(0.0595)	(0.188)	(0.00955)	(0.125)	(0.0621)	(0.183)	(0.0472)	(0.0967)
temp_1sd	–0.191*	–0.0390**	0.0863	0.250	–0.0294***	–0.118	0.0746	0.00712	0.134**	0.0305
	(0.116)	(0.0154)	(0.0986)	(0.270)	(0.0112)	(0.0999)	(0.0524)	(0.142)	(0.0641)	(0.101)
ltemp_1sd	–0.0752	–0.00996	–0.113	0.189	–0.00569	–0.349***	–0.0652	0.369*	–0.106***	–0.108
	(0.0956)	(0.0233)	(0.0721)	(0.222)	(0.00892)	(0.0962)	(0.0830)	(0.196)	(0.0387)	(0.0963)
lltemp_1sd	–0.0798	–0.00281	0.0904	0.203	0.000697	0.316**	0.0833	–0.196	–0.0380	0.113**
	(0.0921)	(0.0155)	(0.0561)	(0.191)	(0.00838)	(0.147)	(0.0824)	(0.291)	(0.0429)	(0.0552)
Constant	8.729***	10.25***	10.38***	10.27***	10.24***	10.64***	10.77***	9.516***	9.262***	9.715***
	(0.0599)	(0.00990)	(0.0456)	(0.139)	(0.00650)	(0.111)	(0.0393)	(0.0681)	(0.0281)	(0.0531)
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
District FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Quarter by province FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Note: the table displays the baseline regression results of the estimation of Equation 3 of firms' exposure to a climate shock in the district in which they are based for month *m* and *m–1*. Standard errors are clustered at the firm level. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: authors' compilation.

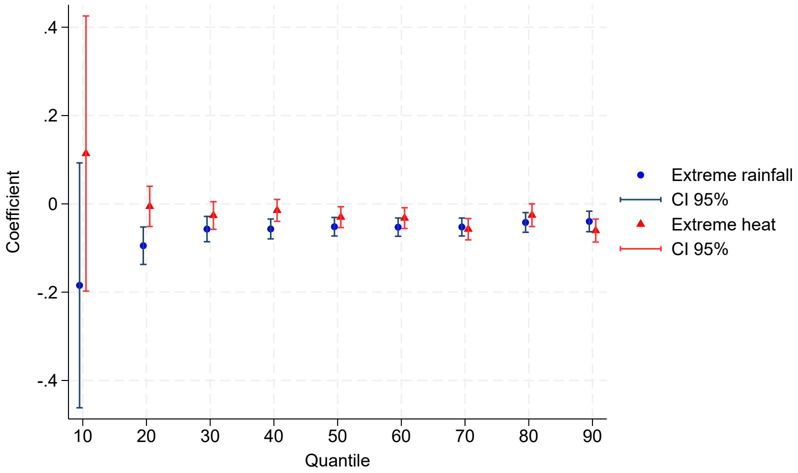
Figure A1: Average temperature and rainfall by quarter and province (2014–20)



Note: the figure displays Zambia's average temperature and rainfall by quarter and province. Each dot in the figure represents the temperature (or rainfall) in each quarter between the first quarter of 2014 and the fourth quarter of 2020.

Source: authors' compilation.

Figure A2: The effects of extreme weather events on firms' purchases, including the first quantile



Source: authors' compilation.