

EFFECTS OF EXTREME WEATHER ON PRODUCTIVITY OF MANUFACTURING FIRMS IN NIGERIA

**Joshua Olusegun Ajetomobi
Friday Ademola Ajagbe**

Working Paper 089-2026

Bringing Rigour and Evidence to Economic Policy Making in Africa

Effects of Extreme Weather on Productivity of Manufacturing Firms in Nigeria

Joshua Olusegun Ajetomobi

Department of Agricultural Economics

Ladoke Akintola University of Technology, Ogbomoso, Nigeria

E-mail: jsegun2002@yahoo.com

&

Friday Ademola Ajagbe

Department of Entrepreneurial Studies

Federal University of Agriculture, Abeokuta, P. M. B. 2240, Ogun State, Nigeria.

E-mail: ajagbefriday@yahoo.co.uk

AERC Research Paper 089-2026

African Economic Research Consortium,

Nairobi October 2026

Disclaimer: The findings, opinions and recommendations are, those of the author, and do not necessarily reflect the views of the Consortium, its individual members or the AERC Secretariat.

Published by: The African Economic Research Consortium

P.O. Box 62882 - City Square

Nairobi 00200, Kenya

© **2026**, African Economic Research Consortium

Table of Contents

List of Figures.....	5
Abstract	6
1.0 Introduction and Background to the Study	7
2.0 Stylized Facts on Nigerian Manufacturing Sector and Weather Conditions	8
2.1 Overview of the Nigerian Manufacturing Sector.....	8
2.2 Overview of Weather and Climate Conditions in Nigeria.....	10
2.3. Mechanisms of Temperature-Driven Output Losses in the Manufacturing Sector	12
3.0 Methodology	14
3.1 Data and Empirical Approach.....	14
3.1.1 Firm-Level Data	12
3.1.2 Weather Data and Matching Procedure	18
3.1.3 Empirical Strategy.....	19
3.1.4 Measurement of Key Variables.....	20
3.1.5 Labour Productivity Model	20
3.1.6 Structural Production Function and One-Stage TFP Estimation	20
3.1.7 Identification Strategy	21
3.1.8 Robustness Checks.....	21
4.0 Results and Discussion	23
4.1 Descriptive Statistics of Key Variables	23
4.2 The Effect of Extreme Weather on Labour Productivity.....	26
4.3 Effect of Extreme Weather on Total Factor Productivity of Manufacturing Industries	28
4.3.1 One Stage Structural Production Function Estimates	28
4.3.2 Temperature Effects	29
4.3.4 Role of Firm Characteristics	29
4.3.5 Model Comparison and Preferred Specification	29
4.5.6 Economic Interpretation.....	30
5.0 Conclusion and Policy Recommendations.....	31
5.1 Conclusion	31
5.2 Policy Recommendations.....	32

Appendix A: Deriving Cobb–Douglas as a special case of the Translog	34
Reference	35

List of Tables and Figures

Table 1: Manufacturing GDP between 2019 and 2023	8
Table 2: Regional Distribution of Manufacturing Firms in Nigeria	9
Table 3: Employment Distribution by Sub-sector in 2023	9
Table 4: Ecological Climate Zone and Characteristics in Nigeria.....	10
Table 5: Distribution of Nigerian Manufacturing Industries by Year	15
Table 6: Distribution of Manufacturing Industries by Geopolitical Zones.....	17
Table 7: Summary Statistics of Production and Weather Variables	24
Table 8: Effect of Extreme Weather on Labour Productivity	27
Table 9: Effect of Extreme Weather on Total Factor Productivity of Manufacturing Firms	30

List of Figures

Figure 1: Geopolitical Zones and their States in Nigeria.....	19
Figure 2 Distribution of Daily Temperature by Geopolitical Zone	26

Abstract

Rising global temperatures increasingly threaten economic productivity, yet micro-level evidence on how heat affects firms in developing countries remains limited. This study examines how temperature variability affects manufacturing productivity in Nigeria using firm-level data from the 2009 and 2025 World Bank Enterprise Surveys, matched with daily temperature records from the Nigerian Meteorological Agency. A pseudo-panel dataset of 2,075 firms was constructed and linked to regional weather exposure measured as annual counts of days in three temperature ranges: below 25 °C, 25–27 °C, and above 27 °C. Labour productivity is estimated using fixed-effects panel regressions, while total factor productivity (TFP) is analysed through a one-stage structural Cobb–Douglas production function that incorporates temperature directly into the productivity term and corrects for simultaneity using a control-function estimator. Descriptive evidence indicates that Nigerian manufacturing firms operate under persistent heat exposure, averaging about 197 days annually above 27 °C. Regression results show that extreme heat significantly reduces labour productivity: in the preferred specification, an additional hot day lowers productivity by approximately 2.4%. Structural production-function estimates reveal that materials are the dominant driver of output, while labour exhibits diminishing marginal productivity. Temperature effects on TFP are nonlinear, displaying an inverted-U pattern in which moderate warmth may initially raise output but excessive heat reduces it. Interaction results further indicate that labour acts as an adaptive margin, with larger workforces partially offsetting heat-related productivity losses, whereas capital intensity does not significantly mitigate temperature shocks. Overall, the findings demonstrate that temperature influences manufacturing performance primarily through short-run efficiency channels rather than long-run technological change. Persistent exposure to high temperatures therefore poses a structural constraint on industrial productivity, particularly in labour-intensive firms and regions with greater heat intensity. Policies aimed at improving workplace conditions, energy reliability, and firm-level adaptive capacity may be more effective for sustaining productivity under rising temperatures than strategies focused solely on capital accumulation.

Keywords: Labour Productivity, Total Factor Productivity, Extreme Temperature, Manufacturing, Climate Change, Nigeria.

1.0 Introduction and Background to the Study

Over the years, the increase in global surface temperature due to the emission of greenhouse gases from burning fossil fuels and land-use changes has become a major concern among scientists, educators, economists, and policymakers. There is a broad consensus among researchers that the average global temperature may rise by about 4°C before the end of this century if no significant climate change mitigation measures are implemented (Acevedo et al., 2020; Pachauri et al., 2014). Against this backdrop, nations worldwide continue to design and implement policy frameworks aimed at addressing the challenges posed by climate change. However, to formulate an effective climate policy, it is critical to understand how local climatic conditions influence productivity across various sectors of the economy (Sudarshan & Tewari, 2014).

A growing body of literature has documented a negative relationship between rising temperature and aggregate economic output across many countries (Acevedo et al., 2020; Burke et al., 2015; Chen & Yang, 2019; Hsiang & Jina, 2014; Zhang et al., 2018). Most of these studies are cross-country analyses based on aggregated data, which makes it difficult to unravel the mechanisms underlying temperature-induced output losses. Understanding these mechanisms is essential for designing appropriate policy responses. If temperature directly affects firm-level productivity, interventions should focus on technological adaptation and energy efficiency. Conversely, if the impact arises mainly through factor reallocation or supply chain disruptions, policy attention should shift toward improving resilience and adjustment capacity within firms.

Although the consequences of climate variability are likely to be felt across all sectors, empirical research has historically focused on agriculture (Ajetomobi et al., 2016; Deschênes & Greenstone, 2007; Mendelsohn, 2008; Schlenker & Roberts, 2009). However, the agricultural sector alone cannot explain observed GDP fluctuations, given the growing contribution of other sectors such as manufacturing, services, and mining to national output. In recent years, a few studies have begun to explore the effects of temperature and weather on firm performance (Cai et al., 2018; Huang et al., 2018; Somanathan et al., 2021; Sudarshan & Tewari, 2014b; Zhang et al., 2018), yet there remains limited evidence from developing economies such as Nigeria. Therefore, this study seeks to fill this gap by employing firm-level data on Nigeria's manufacturing sector to examine the relationship between weather variability and productivity performance. Specifically, the study aims to estimate the total factor productivity (TFP) of manufacturing firms in Nigeria and investigate the effects of temperature on the productivity of these firms. Given the sector's critical

role in Nigeria’s economic structure, understanding how climatic factors affect manufacturing performance is essential for achieving sustainable industrial growth.

2.0 Stylized Facts on Nigerian Manufacturing Sector and Weather Conditions

2.1 Overview of the Nigerian Manufacturing Sector

The manufacturing sector occupies a central position in Nigeria’s industrial and economic development agenda. It serves as a vital link between the primary and tertiary sectors—transforming raw materials into finished or semi-processed goods, generating employment, and contributing significantly to GDP and export earnings. Despite persistent structural challenges, the sector has demonstrated resilience and remains a major focus of government industrialization policies. As shown in Table 1, the sector’s contribution to national output has remained modest but stable in recent years. According to the National Bureau of Statistics (NBS, 2024), manufacturing accounted for an average of 8.8% of Nigeria’s real GDP between 2019 and 2023.

Table 1: Manufacturing GDP between 2019 and 2023

Year	Manufacturing GDP Share	Growth Rate (%)
2019	8.74	0.8
2020	8.59	-2.9
2021	9.17	3.4
2022	8.79	2.4
2023	8.98	2.9

Source: NBS (2024)

The sector is structurally diverse, comprising thirteen main sub-sectors as classified by the National Bureau of Statistics (2023). Among these, the food, beverage, and tobacco industry remains the largest, contributing about 35–40% of total manufacturing output. The regional distribution of manufacturing activities, presented in Table 2, shows a strong concentration in the South-West, particularly in Lagos, Ogun, and Oyo States, which host over half of the nation’s manufacturing establishments. This concentration reflects advantages in infrastructure, port access, and proximity to major consumer markets.

Table 2: Regional Distribution of Manufacturing Firms in Nigeria

Region	Estimated Share of Firms (%)	Major Sub-Sectors
South-West	55	Food, Beverages, Cement, Chemicals
South-East	15	Plastics, Cement, Furniture
South-South	10	Petroleum-based, Agro-processing
North-Central	8	Agro-processing, Building materials
North-West	7	Textiles, Leather, Metal works
North-East	5	Agro-processing, Basic metals

Sources: MAN (2023); CBN (2023)

Employment in the manufacturing sector remains significant, with NBS (2024) reporting about 2.5 million direct jobs—representing 7–10% of Nigeria’s total labour force (Table 3). Labour intensity varies across sub-sectors: industries such as textiles, garments, and food processing are labour-intensive, whereas cement, iron and steel, and chemicals are more capital-intensive.

Table 3: Employment Distribution by Sub-sector in 2023

Manufacturing Sub-Sector	Share of Total Employment (%)
Food, Beverage & Tobacco	40
Chemicals & Pharmaceuticals	15
Textiles, Apparel & Footwear	10
Cement	8
Basic Metals & Fabricated Products	7
Others	20

Source: NBS (2024)

In terms of performance, the sector has recorded mixed outcomes. While output has gradually recovered since the COVID-19 pandemic, structural bottlenecks persist—chief among them being inadequate power supply, high production costs, foreign exchange instability, and infrastructure deficits. These challenges have constrained capacity utilization, which averaged about 56% in 2023, compared to over 70% in the mid-2010s. Policy interventions such as the Nigeria Industrial Revolution Plan (NIRP) and the Central Bank of Nigeria’s Real Sector Support Facility have provided targeted support for selected manufacturing sub-sectors. Despite implementation gaps, these interventions underscore the government’s commitment to revitalizing industrial production and enhancing technological capability. Overall, Nigeria’s manufacturing sector presents a complex picture of potential and constraint. It remains a vital component of the national economy, offering opportunities for employment, export diversification, and structural transformation.

However, given its energy-intensive nature and exposure to climate variability, understanding the extent to which temperature changes affect firm productivity is crucial for designing adaptive and sustainable industrial policies.

2.2 Overview of Weather and Climate Conditions in Nigeria

Stylized facts about weather and climate conditions across Nigeria reveal a clear and systematic spatial structure shaped largely by latitude, proximity to the Atlantic Ocean, and atmospheric circulation systems. One of the most consistent empirical patterns is the pronounced north–south rainfall gradient, whereby annual precipitation increases steadily from less than about 500 mm in the far northern Sahelian belt to more than 3,000 mm along the southern coast. Rainfall variability is also spatially uneven, being considerably higher in northern Nigeria, where drought risk is recurrent, and relatively lower in the humid southern zones where precipitation is more stable. Closely linked to this gradient is the existence of distinct ecological climate belts, each with characteristic weather patterns, vegetation types, and agricultural potentials. These belts form a latitudinal sequence across the country as shown in Table 4.

Table 4: Ecological Climate Zones and Characteristics in Nigeria

Ecological Zone	North/South Region	Geopolitical Zone	Climate Traits
Sahel	North	North-West, North-East	Very low rainfall, frequent droughts
Sudan Savanna	North	North-West and North Central	Short wet season, high temperature
Guinea Savanna	North	North-Central	Moderate rainfall, longer wet season
Derived Savanna	South	South-West and North-Central	Transitional vegetation
Rainforest	South	South-West, South-East	High rainfall, humidity
Mangrove/Coastal	South	South-South	Very high rainfall, flood-prone

Source: Nigerian Meteorological Agency. (2020). *State of the climate in Nigeria*. NiMet.

Nigeria’s climate is also defined by strong seasonality, with two dominant seasons: wet and dry. The duration of the wet season increases progressively southward. Northern regions typically experience only three to four months of rainfall annually, while the Middle Belt receives about five to six months. In contrast, southern areas can experience eight to ten months of rainfall, with

coastal locations often exhibiting a bimodal rainfall pattern marked by peaks around June and September.

Temperature patterns further reinforce regional climatic contrasts. Although Nigeria is uniformly tropical and generally hot, the range and variability of temperature differ geographically. Northern areas exhibit the widest daily and seasonal temperature fluctuations, while southern regions maintain more stable thermal conditions due to higher humidity, cloud cover, and maritime influence. Average temperatures commonly fall between 25 °C and 35 °C, though extreme heat above 40 °C is not uncommon in the far north. Another defining climatic feature is the Harmattan, a dry and dusty northeasterly wind that blows from the Sahara between November and February. Its effects are most pronounced in northern Nigeria, where it causes sharp drops in humidity, reduced visibility, and cooler nighttime temperatures, though it can extend southward at varying intensity.

Humidity itself shows a strong spatial gradient, rising from roughly 20–30% during the northern dry season to as high as 80–95% in the coastal south. This gradient contributes to differences in vegetation, human comfort levels, and disease ecology. In terms of extreme weather, southern and riverine regions are more prone to flooding—particularly along the Niger–Benue basin and coastal states—while northern Nigeria faces recurrent droughts and increasing heat stress. The Middle Belt often experiences both extremes intermittently.

Recent observations also suggest emerging climate change signals, including rising average temperatures nationwide, increased rainfall variability, more intense rainfall events even where totals decline, gradual desertification in northern areas, and growing sea-level rise threats along the coast. These climatic dynamics have profound implications for agriculture, since Nigerian farming systems depend heavily on rainfall. Planting decisions are closely tied to rainfall onset, especially in the north where delayed rains can significantly reduce yields.

Overall, the stylized evidence indicates that Nigeria's climate system is not only highly seasonal but also geographically structured and increasingly variable, producing systematic regional differences in environmental risk, agricultural potential, and vulnerability to climate shocks.

2.3. Mechanisms of Temperature-Driven Output Losses in the Manufacturing Sector

The Nigerian manufacturing sector, as earlier discussed, is characterized by a mix of small and medium-sized firms, high labour intensity, and dependence on power supply and agro-based raw materials. These structural features make the sector particularly vulnerable to climatic variations, especially temperature fluctuations. To understand the mechanism through which temperature influences firm-level output, this study adopts a standard Cobb–Douglas (CD) production framework that links output to capital and labour productivity (Limskul, 2018; Zhang et al., 2018). The model is expressed as:

$$Q = [TFP(P_L L)]^{\alpha_L} (P_K K)^{\alpha_K} \quad (1)$$

where P_L and P_K represent labour and capital productivity, respectively, while α_L and α_K denote their output elasticities. Taking logarithms gives:

$$\ln Q = \ln TFP + \alpha_L \ln L + \alpha_K \ln K \quad (2)$$

and the logarithm of total factor productivity (TFP) can be expressed as:

$$\ln TFP = \alpha_L \rho_L + \alpha_K \rho_K \quad (3)$$

where ρ_L and ρ_K capture productivity shocks associated with labour and capital. Temperature is hypothesized to affect output indirectly through its influence on these productivity components and, consequently, on TFP (Zhang et al., 2018).

In practice, temperature-driven output losses arise through three interrelated mechanisms — its effects on labour productivity, capital productivity, and production costs. First, several empirical and experimental studies show that high temperature adversely affects labour productivity through both physical and cognitive channels. Excessive heat increases fatigue, dehydration, and discomfort, reducing workers' physical efficiency, while also impairing concentration and decision-making (Hancock et al., 2007). Using observational data, Graff, Zivin and Neidell (2014) and Park (2016) found that heat exposure reduces output in labour-intensive sectors. Park (2016) reported that in the United States, each additional day with temperatures above 32°C reduces labour productivity by about 0.048%. Similarly, Sudarshan and Tewari (2014) observed that in Indian manufacturing, labour productivity declined by 4–9% per degree increase on days exceeding 27°C. Given that Nigeria's manufacturing sector is predominantly labour-intensive,

with sub-sectors such as food, textiles, and apparel absorbing large proportions of the workforce, such heat-related reductions can significantly constrain overall productivity.

Second, temperature variations affect capital productivity through their influence on machinery and material performance. Engineering studies (Collins, 1963; Lilja, 2005; Mortier et al., 2010) reveal that excessive heat reduces lubricant viscosity, increases mechanical friction, and accelerates equipment wear. Thermal expansion of materials can cause misalignment and component failure, while overheating may reduce the processing speed of computer-controlled systems. These effects raise maintenance costs and downtime, reducing capital efficiency. In Nigeria, where many firms rely on aging equipment and irregular maintenance schedules, these temperature-induced stresses can exacerbate production inefficiencies and capacity underutilization.

Third, higher temperatures also increase production costs through energy demand and input price channels. Hotter days drive up electricity consumption for cooling and ventilation. Since Nigeria's power supply depends heavily on hydropower, rising temperatures that lower stream flow can reduce generation capacity and aggravate power shortages (Kaplinsky & Morris, 2008). Frequent power outages, as highlighted by Ajagbe and Ajetomobi (2020), remain a leading constraint on manufacturing productivity in Nigeria. Temperature-induced power stress therefore compounds existing infrastructural bottlenecks and limits operating hours.

Moreover, higher temperatures can indirectly raise production costs by affecting input availability and prices. Evidence from sub-Saharan Africa shows that temperature increases negatively impact agricultural output, leading to higher prices of agricultural raw materials. For Nigeria's manufacturing sub-sectors such as food, beverage, and agro-processing, which rely on agricultural inputs, such climate-induced supply shocks translate into higher input costs, lower margins, and potential production cutbacks. In summary, temperature influences firm performance in Nigeria through both direct and indirect channels. Directly, it reduces labour and capital productivity by worsening working conditions and machine efficiency. Indirectly, it increases production costs by raising energy demand and input prices. Given the sector's structural dependence on labour and power, these mechanisms are especially relevant for Nigeria's manufacturing context and provide the conceptual foundation for the empirical estimation of temperature effects on productivity in subsequent sections.

3.0 Methodology

3.1 Sources of Data

3.1.1 Firm-Level Data

The firm-level data used in this study were primarily drawn from the 2009 and 2025 World Bank Enterprise Surveys (WBES) for Nigeria. Although a true panel dataset would have been preferable for tracking firm dynamics over time, the available WBES waves for Nigeria (2007, 2009, 2014 and 2025) cover substantially different geographic samples, making them unsuitable for constructing a consistent longitudinal panel. Among these waves, the 2009 survey provides the broadest coverage in terms of the number of cities sampled and the number of firms surveyed. To extend the temporal dimension of the analysis, a pseudo-panel structure was constructed by harmonizing comparable variables from the 2009 survey with the most recent WBES wave available for Nigeria (2025). The firms are not tracked individually across survey rounds; cohorts were therefore defined using stable characteristics (such as sector and location), allowing consistent comparison of group-level outcomes across time.

Using the International Standard Industrial Classification (ISIC Revision 3.1) framework, the 2009 World Bank Investment Climate Survey covers all major manufacturing subsectors. These include food and beverages; garments and textiles; machinery and equipment; chemicals; electronics; non-metallic minerals; wood, wood products and furniture; metals and fabricated metal products; and other manufacturing industries. The latter category comprises diverse or less common manufacturing activities that do not fall within the major high-sample sectors, such as printing and publishing, rubber and plastics, leather and footwear, recycling, and transport equipment manufacturing. The distribution of firms across these sectors is presented in Table 5.

Table 5 presents the distribution of manufacturing firms across industry categories in the 2009 and 2025 waves of the Nigerian World Bank Enterprise (WBE) Survey, as well as the combined sample. The pooled dataset consists of 2,075 firms, comprising 1,590 observations from 2009 and 485 from 2025. The table reveals notable differences in sectoral representation across survey rounds, reflecting both sampling design and structural shifts in survey coverage.

In the 2009 survey, the manufacturing sample was relatively diversified across subsectors. The largest share of firms operated in the wood and wood products industry, which accounted for 414 firms or 26.0% of the sample. This was followed by metal and fabricated metal products (16.5%),

food processing (15.2%), other manufacturing industries (14.7%), and non-metallic mineral products (13.2%). The garment sector also constituted a meaningful proportion at 10.6%. In contrast, several sectors had very small representation, including chemicals (1.9%), textiles (0.9%), machinery and equipment (0.8%), and electronics (0.1%). Overall, the 2009 distribution indicates a broad industrial spread, with both traditional resource-based industries and light manufacturing activities represented.

By comparison, the 2025 survey displays a markedly different sectoral composition, with a more concentrated distribution across fewer industries. Only five sectors are represented in this wave. The largest share is recorded under other manufacturing industries (26.6%), followed closely by food processing (25.4%), garments (25.2%), and metal products (22.9%). Notably, several industries present in 2009—such as chemicals, electronics, machinery and equipment, non-metallic minerals, textiles, and wood products—are absent in the 2025 sample. This absence likely reflects differences in sampling scope or sectoral targeting rather than actual disappearance of these industries from Nigeria’s manufacturing landscape.

Considering the overall pooled sample, the most represented industry is wood and wood products (20.0%), followed by metal products (18.0%), food processing (17.6%), and other manufacturing industries (17.4%). Garments account for 14.0%, while non-metallic minerals represent 10.1%. All remaining sectors individually contribute less than 2% of total observations, indicating relatively minor representation in the combined dataset. Taken together, the table suggests two important stylized observations. First, the manufacturing sector in the Nigerian WBE data is dominated by a small number of subsectors—particularly wood, metals, food, garments, and miscellaneous manufacturing. Second, there is clear structural asymmetry between survey waves, implying that comparisons across years must be interpreted cautiously. The pseudo-panel analysis therefore relies on harmonized industry groupings to ensure comparability and to minimize bias arising from differences in sectoral coverage across survey rounds.

Table 5: Distribution of Nigerian Manufacturing Industries by Year

Industry	Frequency (%)		
	2009 (N=1590)	2025 (N=485)	Overall (N=2075)
Chemicals	30 (1.9%)	0 (0%)	30 (1.4%)
Electronics	2 (0.1%)	0 (0%)	2 (0.1%)

Food	242 (15.2%)	123 (25.4%)	365 (17.6%)
Garment	169 (10.6%)	122 (25.2%)	291 (14.0%)
M&E	13 (0.8%)	0 (0%)	13 (0.6%)
Metal	263 (16.5%)	111 (22.9%)	374 (18.0%)
Non-Metalic	210 (13.2%)	0 (0%)	210 (10.1%)
Others	233 (14.7%)	129 (26.6%)	362 (17.4%)
Textile	14 (0.9%)	0 (0%)	14 (0.7%)
Wood	414 (26.0%)	0 (0%)	414 (20.0%)

Source: Author Computation 2026

In processing the WBE data, the problem of missing observations is addressed using a multiple imputation technique. The method has been applied in several studies that used WBE data (Escribano et al., 2010). The imputed values were computed using the mice R package (Köhler et al., 2015). Table 6 presents the distribution of manufacturing firms across six regions of Nigeria—North Central (NC), North East (NE), North West (NW), South East (SE), South South (SS), and South West (SW)—for the years 2009 and 2025, broken down by sector that features in the two years: Food, Garment, Metal, and Others. The figures are presented as frequencies with percentages in parentheses.

In 2009, the North West recorded the highest number of food manufacturing firms (61 firms, 25.2%), followed closely by the South West (53 firms, 21.9%) and South South (50 firms, 20.7%). By 2025, the North West’s share of food firms decreased sharply to 18 firms (14.6%), while the South West saw a notable increase to 39 firms (31.7%), making it the leading region for food manufacturing. The North Central, North East, and South South regions experienced declines in the number of food firms over the same period, indicating a shift in regional concentration toward the South West. In the garment sector, the North Central had the largest number of firms in 2009 (39 firms, 23.1%), but by 2025, its share dropped significantly to 19 firms (15.6%). Interestingly, the North East saw growth from 17 firms (10.1%) to 28 firms (23.0%), highlighting regional gains in garment manufacturing. The South East and South West maintained relatively high shares in garment production, although growth was moderate.

Metal manufacturing firms were most concentrated in the North West (57 firms, 21.7%) and North Central (52 firms, 19.8%) in 2009, but by 2025, these numbers fell substantially to 18 firms (16.2%) and 18 firms (16.2%), respectively. Conversely, the South West saw growth from 44 firms (16.7%) to 28 firms (25.2%), indicating a gradual shift of metal manufacturing toward the southern region. For the “Others” category, the North Central dominated in 2009 with 90 firms (38.6%),

followed by the South West (41 firms, 17.6%). By 2025, however, North Central experienced a steep decline to 21 firms (16.3%), while the South West increased its share to 33 firms (25.6%), suggesting a reallocation of diverse manufacturing activities to the southern regions.

Overall, the total number of manufacturing firms decreased from 907 in 2009 to 485 in 2025, with marked regional shifts. The South West emerges as the dominant region by 2025 across most sectors, while the northern regions—NC, NE, and NW—experience substantial declines in firm presence. In respect of likely implications of rising temperatures on regional firm performance, rising temperatures could disproportionately affect northern regions, where heat stress and climatic variability are more pronounced. Sectors like food and metal manufacturing, which often rely on stable environmental conditions, may face reduced productivity due to heat-related machinery failures, spoilage, or labour inefficiencies. In contrast, southern regions, which are seeing growth in firm numbers, may experience slightly better resilience if infrastructure, energy supply, and cooling technologies are adequate. Overall, rising temperatures may exacerbate regional disparities, further concentrating manufacturing in regions less exposed to extreme heat.

Overall, the data highlight Nigeria’s regional industrial heterogeneity—with resource-based industries concentrated in the northern and central zones, while market-oriented and technology-related activities are more dominant in the southern zones, especially the Southwest.

Table 6: Distribution of Manufacturing Industries by Geopolitical Zones

	Food		Garment		Metal		Others		Overall	
	2009	2025	2009	2025	2009	2025	2009	2025	2009	2025
NC	28	16	39	19	52	18	90	21	209	74
	(11.6)	(13.0)	(23.1)	(15.6)	(19.8)	(16.2)	(38.6)	(16.3)	(23.0)	(15.3)

NE	31 (12.8)	14 (11.4)	17 (10.1)	28 (23.0)	35 (13.3)	23 (20.7)	37 (15.9)	14 (10.9)	120 (13.2)	79 (16.3)
NW	61 (25.2)	18 (14.6)	20 (11.8)	16 (13.1)	57 (21.7)	18 (16.2)	13 (5.6)	32 (24.8)	151 (16.6)	84 (17.3)
SE	19 (7.9)	19 (15.4)	33 (19.5)	24 (19.7)	30 (11.4)	12 (10.8)	22 (9.4)	15 (11.6)	104 (11.5)	70 (14.4)
SS	50 (20.7)	17 (13.8)	31 (18.3)	15 (12.3)	45 (17.1)	12 (10.8)	30 (12.9)	14 (10.9)	156 (17.2)	58 (12.0)
SW	53 (21.9)	39 (31.7)	29 (17.2)	20 (16.4)	44 (16.7)	28 (25.2)	41 (17.6)	33 (25.6)	167 (18.4)	120 (24.7)
N	242	123	169	122	263	111	233	129	907	485

Source: Authors' Computation 2026

3.1.2 Weather Data and Matching Procedure

The weather data used in this study consist of daily temperature records for the years 2008 and 2024 obtained from the Nigerian Meteorological Agency (NIMET). The data were sourced from weather stations located in the cities covered by the World Bank Enterprise (WBE) Survey, with temperature observations recorded for each of the 365 days of the year. To capture variations in thermal exposure across locations, the daily temperature data were classified into three categories:

1. Days below 25°C, representing relatively cool conditions.
2. Days between 25°C and 27°C, representing moderate or optimal temperature conditions; and
3. Days above 27°C, representing periods of heat stress or extreme temperature exposure.

Some climate and health agencies define $\geq 27^\circ\text{C}$ daily mean or daytime temperature as a heat-stress or hot-day threshold for tropical populations because: (1) It marks the point where heat-related discomfort rises sharply; (2) Labour productivity begins to decline, especially for outdoor or non-air-conditioned work; and (3) Heat-related illnesses become more likely in vulnerable groups (Steadman, 1979; Kjellstrom et al., 2009) The counts of days falling within each temperature category were computed for each city and used as key explanatory variables in the analysis. Since the NIMET dataset does not include humidity or dew point information, temperature alone was employed as the primary indicator of weather variation.

The firm-level WBE data were merged with the temperature data by geopolitical zone, which is the smallest geographical identifier in the 2009 and 2025 WBE datasets. This procedure yielded a consistent, spatially matched dataset linking firm-level productivity indicators to localised temperature conditions across 6 Nigerian geopolitical zones. The map of the six geopolitical zones with their respective states is shown in Figure 1. Temperature variations are expected to influence manufacturing productivity through their effects on labour performance, machinery efficiency, and production processes. Extreme heat, in particular, can reduce worker concentration, increase equipment downtime, and disrupt energy supply, thereby lowering labour productivity and total factor productivity (TFP) across temperature-sensitive industries.

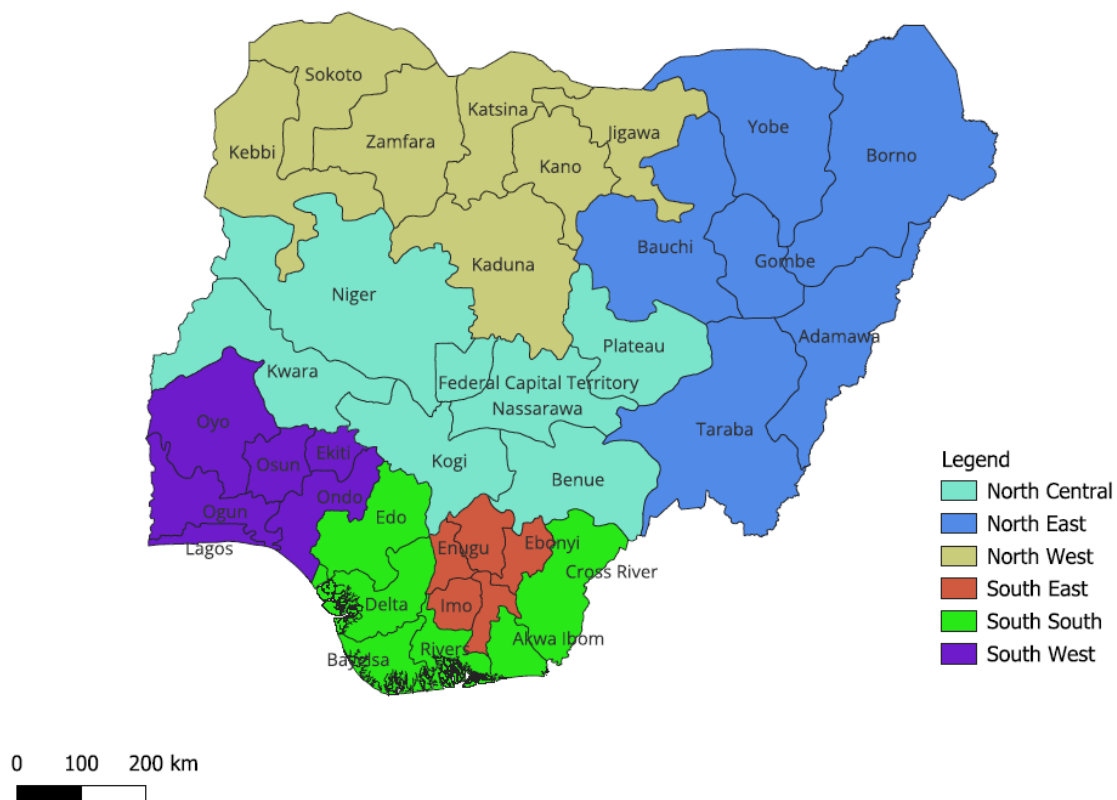


Figure 1: Geopolitical Zones and their States in Nigeria

3.1.3 Empirical Strategy

This study examines the effect of extreme temperature exposure on manufacturing firm productivity using two complementary outcome measures: labour productivity and total factor productivity (TFP). Extreme heat is defined as the number of days in a year in which daily temperature exceeds 27 °C, a threshold widely associated with heat stress and reduced economic

performance in tropical climates. The empirical strategy combines reduced-form panel regressions for labour productivity with a structural production-function framework for TFP estimation.

3.1.4 Measurement of Key Variables

Labour productivity is measured as the ratio of firm output to total employment:

$$LP_{it} = \frac{Y_{it}}{L_{it}}$$

where Y_{it} denotes real output and L_{it} represents the total number of employees of firm i in year t . The logarithm of labour productivity is used in estimation to reduce skewness and allow coefficient interpretation as elasticities.

Extreme weather exposure is constructed as the annual count of days in region r and year t for which temperature exceeds 27 °C:

$$Heat_{rt} = \sum_{d=1}^{365} I(T_{drt} > 27)$$

Firm-level control variables include capital stock, intermediate inputs, firm size, ownership structure, sector and year classification. Regional and year fixed effects are included to control for time-invariant regional characteristics and nationwide macroeconomic shocks.

3.1.5 Labour Productivity Model

The baseline specification for labour productivity is estimated using a fixed-effects panel regression:

$$\ln LP_{it} = \beta_0 + \beta_1 Heat_{rt} + \beta_2 X_{it} + \delta_r + \gamma_t + \varepsilon_{it}$$

where:

X_{it} is a vector of firm-level controls,

δ_r are region fixed effects,

γ_t are year fixed effects,

ε_{it} is the idiosyncratic error term.

Standard errors are clustered at the regional level to account for spatial correlation in weather shocks.

3.1.6 Structural Production Function and One-Stage TFP Estimation

To estimate the effect of extreme heat on TFP, a structural production function approach is adopted. Output is assumed to follow a Cobb–Douglas technology:

$$Y_{it} = A_{it}K_{it}^{\alpha}L_{it}^{\beta}M_{it}^{\theta}$$

Taking logarithms:

$$y_{it} = \alpha k_{it} + \beta l_{it} + \theta m_{it} + \omega_{it} + \varepsilon_{it}$$

where:

y_{it} is log output,

k_{it} , l_{it} , and m_{it} denote logs of capital, labour, and intermediate inputs,

ω_{it} represents firm-specific productivity,

ε_{it} is measurement error.

To directly estimate the effect of temperature on productivity without generated-regressor bias, the productivity term is modelled as:

$$\omega_{it} = \phi_0 + \phi_1 Heat_{rt} + \phi_2 Z_{it} + \eta_{it}$$

Substituting yields the estimable one-stage equation:

$$y_{it} = \alpha k_{it} + \beta l_{it} + \theta m_{it} + \phi_1 Heat_{rt} + \phi_2 Z_{it} + \delta_r + \gamma_t + \varepsilon_{it}$$

The model is estimated using a panel linear model with sector–region and year fixed effects, which is more appropriate for pseudo-panel data and allows us to control for unobserved heterogeneity at the cohort level. Specifically, rather than estimating total factor productivity (TFP) in a first stage and then regressing it on location variables, we estimate a single-stage production function in which temperature and fixed effects enter directly:

3.1.7 Identification Strategy

Identification relies on exogenous variation in temperature across regions and time. Daily weather fluctuations are plausibly exogenous to firm-level decision-making and therefore provide a natural experiment. Region fixed effects remove time-invariant locational differences such as infrastructure and geography, while year fixed effects absorb nationwide shocks such as macroeconomic conditions or policy changes. This approach isolates within-region intertemporal variation in heat exposure as the primary source of identification.

3.1.8 Robustness Checks

Several robustness tests are implemented to assess the stability and credibility of results.

First, nonlinear temperature effects are tested by including quadratic heat terms:

$$Heat_{rt}, Heat_{rt}^2$$

to capture potential threshold or accelerating productivity losses. Second, alternative heat measures include: number of days below 25 °C, average annual temperature, and cold-wave duration indicators. Third, sectoral heterogeneity is examined by interacting heat exposure with industry dummies to determine whether temperature sensitivity differs across manufacturing subsectors. Fourth, adaptive capacity mechanisms are tested by interacting heat exposure with firm characteristics such as ownership, firm size, and capital intensity. Fifth, estimator robustness is assessed by re-estimating the production function using alternative methods (fixed effects OLS, Levinsohn–Petrin) and comparing elasticities. Finally, sample sensitivity checks are performed by excluding extreme outliers, newly established firms, or regions with sparse observations.

All estimations are conducted using panel data techniques. Fixed-effects models are estimated using least squares with clustered standard errors, while the production-function model is estimated using the panel linear production function estimator implemented in R statistical software. Diagnostic tests for multicollinearity, serial correlation, and heteroskedasticity are performed to ensure model validity.

The firm-level data are recorded annually; therefore, the widely used approach to estimate the effects of daily temperature on output is to discretize the annual distribution into some fixed set of bins (Hsiang & Jina, 2014; Limskul, 2018; Zhang et al., 2018). The temperature bins represent the number of days falling into different bins for different cities in the firm data. The bin approach makes it easy to capture the effects of non-linear effects of temperature. To make the results of this study comparable to previous empirical works (Hsiang & Jina, 2014; Sudarshan & Tewari, 2014a), high temperature bin is defined as the number of days when the average temperature is greater than 27°C. The choice of 27°C as the breakpoint in this study appears good because the historical mean daily temperature for the period 1970-2008 in Nigeria is 27.16°C with a standard deviation of about 3.46. This means that the temperature shock breakpoint, 27°C, is 0.16 lower than the average and 3.62 standard deviations above the historical daily average temperatures. This study adopts three different temperature bins, namely, $T > 27^{\circ}\text{C}$, $25^{\circ}\text{C} < T < 27^{\circ}\text{C}$, and $T < 25^{\circ}\text{C}$. Generally, the optimum comfort in case of sedentary work is usually between 20°C and 26°C, depending on the time of the year and available clothing. When the temperature is above 27°C, cooling the air with fans becomes ineffective, and a better form of cooling is required, which comes at higher costs per unit for the firms.

4.0 Results and Discussion

4.1 Descriptive Statistics of Key Variables

Table 7 summarizes descriptive statistics for key firm-level and climate variables for 2009, 2025, and the pooled sample, providing insight into structural changes in manufacturing activity and exposure to temperature conditions over time. In 2009, the sample includes 1,590 firms, compared with 485 firms in 2025, yielding a pooled total of 2,075 observations. Average labour productivity (LP) declined markedly from 559 in 2009 to 164 in 2025, with very large standard deviations in both periods (16,563 and 2,100, respectively), indicating substantial heterogeneity in productivity levels across firms. The pooled mean of 466 confirms that productivity is highly dispersed, suggesting the coexistence of both very high- and very low-performing firms. Such wide dispersion often reflects structural differences in technology adoption, management efficiency, and scale of operation, which may amplify the sensitivity of firms to external shocks such as extreme weather.

Sales exhibit a dramatic increase in mean value from ₦145 million in 2009 to about ₦1.1 billion in 2025, although the extremely large standard deviation in 2025 (₦126 billion) indicates that this rise is driven by a small number of very large firms. This pattern suggests increasing concentration of output among a few dominant firms, while many others remain relatively small. The pooled mean of ₦2,698 million and large variability further support the presence of strong firm-size inequality within the manufacturing sector. Labour input rose from an average of 15 workers in 2009 to 85 workers in 2025, while capital increased from ₦80 million to ₦397 million and materials from ₦80 million to ₦819 million over the same period. These increases suggest expansion in production scale among surviving firms, possibly reflecting consolidation or exit of smaller enterprises. However, the large standard deviations for these variables indicate that production inputs remain unevenly distributed across firms.

Ownership structure appears relatively stable across periods, with mean values near 100, implying that most firms are domestically owned. The slight decline in the mean ownership index from 99 in 2009 to 95 in 2025 suggests a modest increase in foreign or mixed ownership participation, though domestic firms still dominate the sample.

Turning to climate exposure variables, firms experienced an average of 203 days above 27 °C in 2009 compared with 177 days in 2025, while moderate-temperature days (25–27 °C) increased

from 100 to 134. Cooler days below 25 °C declined slightly from 62 to 54. The pooled statistics show that, on average, firms face about 197 hot days annually, highlighting that high-temperature conditions are a persistent feature of the production environment. The higher standard deviation for hot days in 2025 suggests growing spatial variability in temperature exposure across regions. The descriptive patterns suggest that manufacturing firms operate under substantial climatic stress, given the high number of hot days recorded annually. Elevated temperatures can reduce labour efficiency, increase equipment overheating risks, and raise cooling and energy costs, all of which may depress productivity. The observed decline in average labour productivity between 2009 and 2025, despite increases in inputs such as labour, capital, and materials, may indicate diminishing efficiency possibly associated with environmental stressors. Moreover, rising dispersion in firm size and sales implies that smaller firms—typically with fewer adaptive resources—may be more vulnerable to heat exposure, potentially widening productivity gaps within the sector. Overall, the statistics point to a production environment where temperature variability is likely to play an increasingly important role in shaping firm performance, resource efficiency, and competitiveness.

Table 7: Summary Statistics of Production and Weather Variables

Year	2009			2025			Pooled		
Variable	N	Mean	SD	N	Mean	SD	N	Mean	SD
LP	1590	559	16563	485	164	2100	2075	466	14534
Sales	1590	145	1331	485	11071	126000	2075	2698	61055
Labour	1590	15	63	485	85	233	2075	31	129
Capital	1590	80	1880	485	397	4050	2075	154	2560
Material	1590	80	827	485	819	7129	2075	253	3533
Ownership	1590	99	10	485	95	21	2075	98	14
Day>27	1590	203	26	485	177	41	2075	197	32
Day<25	1590	62	35	485	54	32	2075	60	34
Day25-27	1590	100	50	485	134	64	2075	108	55

Source: Authors' Compilation 2026

Figure 2 presents a comparative bar chart showing the distribution of temperature exposure across Nigeria's six geopolitical zones for 2009 and 2025, grouped into three temperature categories: < 25 °C, 25–27 °C, and > 27 °C. Overall, the chart indicates that days above 27 °C dominate the annual temperature profile across all zones and both years, highlighting the prevalence of high-temperature conditions nationwide. In 2009, the number of days exceeding 27 °C ranged from about 159 days in the South-West to roughly 219 days in the South East. By 2025, this category remained the most frequent in most zones, though there was a slight decline in several regions,

such as the South-West (from about 159 to 113 days) and South-South (from about 206 to 152 days), suggesting some regional moderation in extreme heat exposure.

In contrast, days below 25 °C were consistently the least frequent category across all zones and years. For example, in 2009, most regions recorded fewer than 80 such days, with especially low counts in the South-East (18 days) and South-South (24 days). This pattern remained largely unchanged in 2025, indicating that cooler conditions are relatively rare and stable over time in Nigeria's climate system. The intermediate temperature range (25–27 °C) shows noticeable increases between 2009 and 2025 in several regions. The South West, for instance, rose from about 171 days to 217 days, while the South-South increased from 135 to 189 days. These shifts suggest that some extremely hot days may be transitioning into moderately hot days rather than cooler ones, reflecting possible redistribution within temperature bands rather than a uniform cooling trend.

Spatially, northern zones (North-Central, North-East, North-West) consistently display high counts of >27 °C days alongside moderate counts in the 25–27 °C range, indicating sustained heat exposure. Southern zones, particularly the South West and South-South, show larger temporal changes between 2009 and 2025, implying greater variability or evolving climatic conditions.

The dominance of high-temperature days across all regions suggests that firms operate in environments characterized by persistent heat exposure, which can affect labour efficiency, machinery performance, and energy costs. Regions with the highest counts of >27 °C days may face stronger productivity constraints, while zones experiencing increases in moderate-temperature days could benefit from slightly improved working conditions. Overall, the distribution indicates that temperature exposure is both regionally heterogeneous and temporally dynamic, factors that are likely to contribute to differences in firm productivity across locations and over time.

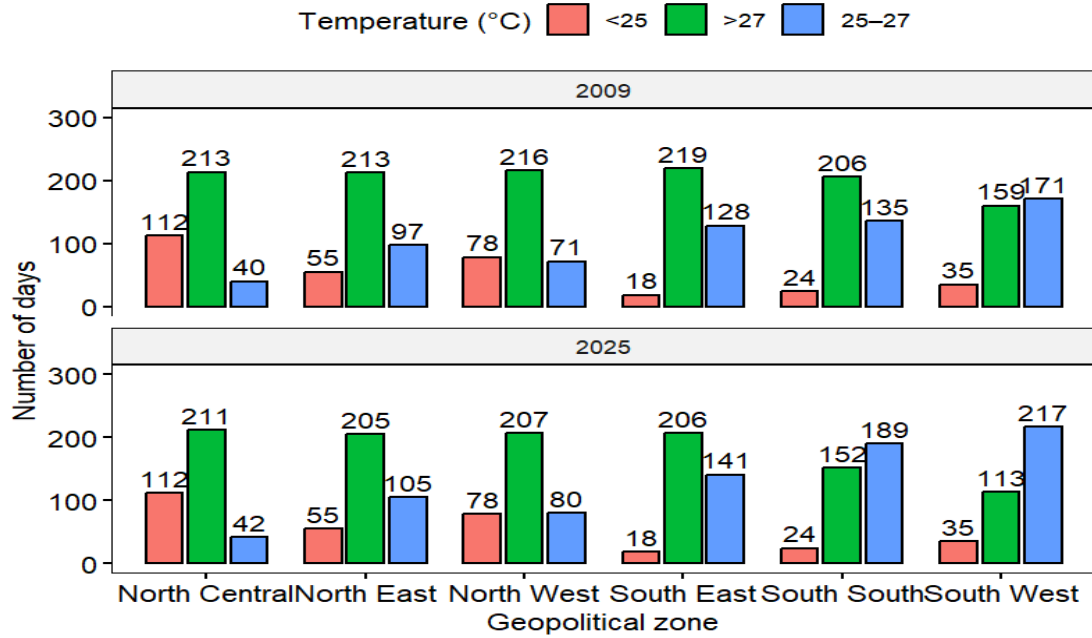


Figure 2 Distribution of Daily Temperature by Geopolitical Zone

4.2 The Effect of Extreme Weather on Labour Productivity

Table 8 shows the effect of extreme heat on firm-level labour productivity using panel data with two-way fixed effects (sector-region and year). Across all four specifications, extreme heat has a statistically significant negative effect on the log of labour productivity. In the preferred full model (Model 4), a one-unit increase in extreme heat is associated with a 2.4% decrease in labour productivity, holding all other inputs and firm characteristics constant. This robust negative effect indicates that higher temperatures materially reduce worker efficiency, consistent with empirical findings in climate and productivity literature.

Material inputs are positively associated with productivity and become statistically significant once firm size and ownership controls are included, suggesting that sufficient operational inputs can mitigate some productivity losses. Capital stock, in contrast, does not significantly affect productivity in any specification, implying that simply increasing physical assets may not shield firms from the adverse impacts of extreme heat. Interaction terms and quadratic heat effects are not significant, indicating that the productivity loss from heat is approximately linear and not mitigated by higher capital intensity. Firm size plays an important role: micro, small, and medium-sized enterprises display significantly higher labour productivity relative to large firms, which may

reflect more flexible labour allocation, tighter supervision, or more efficient use of limited resources. Ownership type does not have a statistically significant effect.

The overall model fits, as measured by within R^2 , are modest (38–40%), which is typical in firm-level panel regressions, reflecting the influence of unobserved heterogeneity and external shocks on productivity. The results underscore the vulnerability of labour productivity to extreme weather events and suggest that climate adaptation strategies—such as workplace cooling, altered working hours, or climate-resilient infrastructure—are crucial to protect output and efficiency in manufacturing firms.

Table 8: Effect of Extreme Weather on Labour Productivity

Variable	Dependent Variable: Labour Productivity			
	(1)	(2)	(3)	(4)
Heat	-0.023*** (0.003)	-0.034* (0.015)	-0.029*** (0.008)	-0.024*** (0.003)
log(capital)	-0.012 (0.018)	-0.012 (0.018)	-0.083 (0.098)	-0.008 (0.018)
log(material)	0.045+ (0.026)	0.043 (0.026)	0.048+ (0.026)	0.080** (0.030)
heat_sq		0.000 (0.000)		
heat × log(capital)			0.000 (0.000)	
firm_sizeMedium				0.864* (0.356)
firm_sizeMicro				1.239*** (0.364)
firm_sizeSmall				1.073** (0.356)
Own				-0.004 (0.003)
Num.Obs.	2075	2075	2075	2075
Sector-Region FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
R2	0.38	0.38	0.38	0.45

4.3 Effect of Extreme Weather on Total Factor Productivity of Manufacturing Industries

4.3.1 One Stage Structural Production Function Estimates

Table 9 presents the results of the one-stage structural production function models estimated with sector–region and year fixed effects. The inclusion of these fixed effects ensures that identification is based on within–sector–region variation over time, thereby controlling for time-invariant technological differences, regional production environments, and macroeconomic shocks common to all firms. Consequently, coefficient estimates capture short-run responses of firm output to changes in inputs and temperature conditions rather than cross-sectional structural differences.

Input Elasticities

Across all specifications, material inputs exhibit a consistently positive and highly significant elasticity, ranging from 0.534 to 0.580. This indicates that a 1 percent increase in materials raises output by approximately 0.53–0.58 percent, holding other factors constant. The magnitude and robustness of this coefficient suggest that production among the sampled firms is strongly materials-driven, implying relatively low value-added processing and a production structure dependent primarily on intermediate inputs rather than capital deepening or labour expansion.

Capital displays a small but positive elasticity in most specifications (≈ 0.03 – 0.04), indicating limited responsiveness of output to capital accumulation. Such modest capital elasticities are consistent with production environments characterized by underutilized machinery, technological rigidity, or infrastructure constraints that prevent firms from fully exploiting installed capital. The loss of significance in the interaction specification likely reflects multicollinearity introduced by interaction terms rather than a substantive absence of capital effects.

Labor enters with a negative and statistically significant coefficient in most models. For instance, the baseline estimate implies that a 1 percent increase in labour reduces output by approximately 0.08 percent. This counterintuitive result is commonly interpreted as evidence of diminishing marginal productivity or labour congestion effects, which may arise when firms operate beyond their efficient employment scale or when additional workers reduce average productivity due to coordination costs, limited workspace, or technological constraints. The substantially larger negative elasticity observed in the interaction specification suggests that labour productivity is particularly sensitive to environmental conditions, especially temperature fluctuations.

4.3.2 Temperature Effects

The baseline model indicates a weakly positive linear association between heat exposure and output. However, once nonlinear effects are introduced, temperature displays a statistically significant inverted-U relationship with productivity. Specifically, the positive coefficient on heat combined with a negative coefficient on its squared term implies that moderate increases in temperature initially enhance output but that further increases beyond a certain threshold reduce production. This pattern is consistent with physiological and operational mechanisms documented in climate–productivity studies, where mild warmth may improve efficiency in certain production processes, while excessive heat imposes physical stress on workers, disrupts machinery performance, and increases operational costs.

The interaction specification provides further insight into the transmission channel. The negative coefficient on heat indicates that higher temperatures reduce output on average, but the positive and significant interaction between labour and heat suggests that firms with larger workforces experience smaller productivity losses during hot periods. This implies that labour serves as an adaptive margin through which firms partially offset thermal stress. Possible mechanisms include task rotation, shift adjustments, or redistribution of workloads among employees. In contrast, the interaction between capital and heat is statistically insignificant, indicating that capital intensity does not systematically mitigate temperature shocks. This finding suggests that technological or mechanical adjustments play a smaller role in adaptation than human or organizational responses.

4.3.3 Role of Firm Characteristics

When firm-level characteristics are added, the direct effect of temperature becomes statistically insignificant, indicating that part of the temperature–output relationship is explained by structural heterogeneity across firms. Ownership status exhibits a positive and significant coefficient, suggesting that firms with formal ownership structures tend to achieve higher productivity levels. Similarly, firm size indicators are positive and significant, implying systematic productivity differences across size classes. These results highlight that structural firm attributes—such as managerial capacity, access to finance, or organizational efficiency—mediate how firms perform under varying environmental conditions.

4.3.4 Model Comparison and Preferred Specification

Model comparison statistics indicate that the interaction specification provides the best overall fit, as reflected in the highest R^2 and lowest information criteria values. This suggests that accounting

for heterogeneous temperature responses across input levels substantially improves explanatory power. The evidence therefore supports a framework in which temperature affects production not only directly but also indirectly through its interaction with factor utilization, particularly labour.

4.3.5 Economic Interpretation

Taken together, the results reveal three central findings. First, production is predominantly driven by material inputs, underscoring the importance of intermediate goods in firm output determination. Second, labour exhibits diminishing marginal productivity, indicating potential inefficiencies in workforce utilization. Third, temperature exerts a nonlinear and input-dependent effect on production, with labour acting as the primary adjustment channel through which firms respond to heat exposure. These patterns suggest that climatic conditions influence firm performance primarily through operational efficiency rather than through shifts in technological capacity.

Table 9: Effect of Extreme Weather on Total Factor Productivity of Manufacturing Firms

	Model 1	Model 2	Model 3	Model 4
Log(Capital)	0.036*	0.034*	-0.068	0.035*
	(0.015)	(0.015)	(0.094)	(0.014)
Log(Labour)	-0.083*	-0.079+	-1.161***	-0.116*
	(0.042)	(0.041)	(0.167)	(0.046)
Log(Material)	0.534***	0.544***	0.580***	0.534***
	(0.026)	(0.026)	(0.026)	(0.027)
Heat	0.004+	0.058***	-0.020**	0.001
	(0.002)	(0.012)	(0.007)	(0.002)
heat_sq		-0.000***		
		(0.000)		
Log(labour) × heat			0.006***	
			(0.001)	
Log(capital) × heat			0.000	
			(0.000)	
Own				0.005*
				(0.002)
firm_sizeMedium				0.937**
				(0.289)
firm_sizeMicro				0.890**
				(0.301)
firm_sizeSmall				1.373***

				(0.290)
Num.Obs.	2075	2075	2075	2075
Sector-region FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
R2	0.290	0.297	0.316	0.311
RMSE	1.37	1.36	1.34	1.34

5.0 Conclusion and Policy Recommendations

5.1 Conclusion

This study investigated the effect of temperature variability on the productivity of manufacturing firms using firm-level survey data matched with regional temperature exposure. By combining labour productivity regressions with a one-stage structural production function framework that controls for sector–region and year fixed effects, the analysis provides robust evidence on how heat conditions influence firm performance through both direct and indirect channels. The results consistently show that temperature is an economically meaningful determinant of productivity. In particular, extreme heat reduces labour productivity and shifts production efficiency, while moderate temperature increases may initially enhance output before declining beyond a threshold. This nonlinear relationship suggests that productivity responses to temperature are not uniform but depend on the intensity of heat exposure.

The structural estimates indicate that production is primarily driven by material inputs, whereas labour exhibits diminishing marginal productivity, implying inefficiencies in workforce utilization. Importantly, interaction results reveal that labour availability partially mitigates the adverse effects of heat, indicating that firms rely on workforce adjustments rather than capital or technology to cope with thermal stress. The absence of significant mitigation effects from capital suggests that existing machinery and equipment are not sufficiently adapted to high-temperature operating conditions. Furthermore, when firm-level characteristics are controlled for, the direct effect of temperature weakens, implying that structural heterogeneity—such as firm size, ownership, and organizational capacity—plays a mediating role in shaping vulnerability to heat exposure.

Taken together, these findings demonstrate that temperature shocks influence manufacturing performance primarily through short-run efficiency channels rather than long-run technological

changes. This implies that climate variability constitutes a binding operational constraint for firms, particularly in regions with sustained exposure to high temperatures. As climate change intensifies, such constraints may increasingly limit industrial growth and competitiveness if adaptive capacity remains weak.

5.2 Policy Recommendations

1. Given that productivity losses operate largely through labour efficiency, policies should prioritize interventions that reduce worker heat stress. These include incentives for firms to install ventilation systems, cooling technologies, insulated roofing, and heat-resistant production layouts. Occupational safety regulations should also incorporate temperature thresholds and guidelines for rest breaks, hydration, and shift restructuring during extreme heat periods.
2. Reliable electricity supply is critical for operating cooling systems and temperature-sensitive machinery. Investments in power infrastructure and support for decentralized energy solutions—such as renewable mini-grids or backup generation—would enhance firms’ ability to maintain production under high temperatures. Strengthening industrial energy resilience can significantly reduce productivity losses associated with heat-induced power disruptions.
3. The weak role of capital in mitigating temperature shocks suggests that existing equipment is not designed for high-heat environments. Industrial policies should therefore encourage adoption of heat-resilient technologies through tax incentives, subsidized credit, or technology transfer programs. Facilitating access to modern machinery that operates efficiently under high temperatures would improve long-term productivity resilience.
4. Firm characteristics significantly shape how enterprises respond to temperature shocks. Policies that expand access to finance, managerial training, and innovation support can enhance firms’ adaptive capacity. Small and medium enterprises in particular may benefit from targeted financial instruments that enable investments in climate-resilient infrastructure and production processes.
5. Regional differences in heat exposure imply that industrial policy should incorporate climatic risk into location planning and infrastructure development. Establishing industrial zones with climate-resilient design standards, green building requirements, and

environmental monitoring systems would help reduce temperature-related productivity losses and support sustainable industrial expansion.

Overall, the evidence underscores that rising temperatures represent not only an environmental challenge but also an economic productivity constraint. Addressing this challenge requires coordinated policy actions that combine climate adaptation, infrastructure development, and firm-level capability enhancement. Without such measures, increasing heat exposure may erode manufacturing competitiveness and slow structural transformation, particularly in heat-prone regions.

Appendix A: Deriving Cobb–Douglas as a special case of the Translog

Below is a concise derivation illustrating how the Cobb–Douglas (CD) production function evolves from the Translog (transcendental logarithmic) form, along with the associated assumptions and restrictions.

Translog production function (log form)

For n inputs $x_1, \dots, x_n$, the translog (log) specification is:

$$\ln Y = \alpha_0 + \sum_{i=1}^n \alpha_i \ln x_i + \frac{1}{2} \sum_{i=1}^n \beta_i \sum_{j=1}^n \beta_{ij} (\ln x_i)(\ln x_j).$$

The β_{ij} matrix is symmetric ($\beta_{ij} = \beta_{ji}$). The translog is effectively a second-order Taylor expansion (flexible form) for $\ln f(x)$.

The Cobb–Douglas in logs is:

$$\ln Y = \ln A + \gamma_i \sum_{i=1}^n \ln x_i.$$

Equivalently, in levels:

$$Y = A \prod_{i=1}^n x_i^{\gamma_i}.$$

So CD is linear in the log inputs — there are no quadratic or interaction terms.

If all second-order coefficients are zero:

$$\beta_{ij} = 0 \text{ for all } i, j,$$

the translog reduces to

$$\ln Y = \alpha_0 + \sum_{i=1}^n \alpha_i \ln x_i.$$

This is exactly the log form of Cobb–Douglas with $\ln A = \alpha_0$ and $\gamma_i = \alpha_i$. Hence:

$$Y = e^{\alpha_0} \prod_{i=1}^n x_i^{\alpha_i}.$$

Cobb–Douglas is the special case of the translog when all second-order (quadratic and interaction) terms vanish.

With three inputs L, K, M translog:

$$\ln Y = \alpha_0 + \alpha_L \ln L + \alpha_K \ln K + \alpha_M M + \frac{1}{2} \beta_{LL} (\ln L)^2 + \beta_{LK} \ln L \ln K + \frac{1}{2} \beta_{KK} (\ln K)^2 \\ + \beta_{LM} \ln L \ln M + \frac{1}{2} \beta_{MM} (\ln M)^2 + \beta_{KM} \ln K \ln M$$

Set $\beta_{LL} = \beta_{LK} = \beta_{LM} = \beta_{KM} = \beta_{KK} = \beta_{MM} = 0 \rightarrow$

$$\ln Y = \alpha_0 + \alpha_L \ln L + \alpha_K \ln K + \alpha_M \ln M,$$

so

$$Y = e^{\alpha_0} L^{\alpha_L} K^{\alpha_K} M^{\alpha_M}.$$

References

- Acevedo, S., Mrkaic, M., Novta, N., Pugacheva, E., & Topalova, P. (2020). The effects of weather shocks on economic activity: What are the channels of impact? *Journal of Macroeconomics*, 65, 103207.
- Ajagbe, F. A., & Ajetomobi, J. O. (2020). *Investment Climate Impact on Total Factor Productivity of Manufacturing Industries in Nigeria*.
- Ajetomobi, J., Abiodun, A., & Hassan, R. (2016). Economic impacts of climate change: A micro-level evidence from Nigerian rice agriculture. *Материалы Международной Конференции «ИнтерКарто/ИнтерГИС»*, 1(20), 358.
- Burke, M., Hsiang, S. M., & Miguel, E. (2015). Global non-linear effect of temperature on economic production. *Nature*, 527(7577), 235–239.
- Cai, X., Lu, Y., & Wang, J. (2018). The impact of temperature on manufacturing worker productivity: Evidence from personnel data. *Journal of Comparative Economics*, 46(4), 889–905.
- Chen, X., & Yang, L. (2019). Temperature and industrial output: Firm-level evidence from China. *Journal of Environmental Economics and Management*, 95, 257–274.
- Collins, J. G. (1963). On the calculation of the temperature variation of the coefficient of thermal expansion for materials of cubic structure. *Philosophical Magazine*, 8(86), 323–332.
- Deschênes, O., & Greenstone, M. (2007). The economic impacts of climate change: Evidence from agricultural output and random fluctuations in weather. *American Economic Review*, 97(1), 354–385.

- Escibano, A., & Guasch, J. L. (2005). *Assessing the impact of the investment climate on productivity using firm-level data: Methodology and the cases of Guatemala, Honduras, and Nicaragua* (Vol. 3621). World Bank Publications.
- Escibano, A., Pena, J., & Guasch, J. L. (2010). Empirical econometric evaluation of alternative methods of dealing with missing values in investment climate surveys. *World Bank Policy Research Working Paper*, 5346.
- Graff Zivin, J., & Neidell, M. (2014). Temperature and the allocation of time: Implications for climate change. *Journal of Labor Economics*, 32(1), 1–26.
- Hancock, P. A., Ross, J. M., & Szalma, J. L. (2007). A meta-analysis of performance response under thermal stressors. *Human Factors*, 49(5), 851–877.
- Hsiang, S. M., & Jina, A. S. (2014). *The causal effect of environmental catastrophe on long-run economic growth: Evidence from 6,700 cyclones*. National Bureau of Economic Research.
- Huang, H. H., Kerstein, J., & Wang, C. (2018). The impact of climate risk on firm performance and financing choices: An international comparison. *Journal of International Business Studies*, 49, 633–656.
- Kaplinsky, R., & Morris, M. (2008). Do the Asian drivers undermine export-oriented industrialization in SSA? *World Development*, 36(2), 254–273.
- Kinda, T., & Loening, J. L. (2010). Small enterprise growth and the rural investment climate: Evidence from Tanzania. *African Development Review*, 22(1), 173–207.
- Kinda, T., Plane, P., & Veganzones, M.-A. (2011). *Firm-level productivity and technical efficiency in MENA manufacturing industry: The role of the investment climate*.
- Köhler, C., Pohl, S., & Carstensen, C. H. (2015). Investigating mechanisms for missing responses in competence tests. *Psychological Test and Assessment Modeling*, 57(4), 499.
- Kjellstrom, T., Holmer, I., & Lemke, B. (2009). Workplace heat stress, health and productivity – an increasing challenge for low and middle-income countries during climate change. *Industrial Health*, 47(3), 1–8.
- Lilja, D. J. (2005). *Measuring computer performance: A practitioner's guide*. Cambridge University Press.
- Limskul, K. (2018). Climate change impact on labor productivity in Thai manufacture. *Asia-Pacific Journal of Regional Science*, 2(1), 195–209.

- Mayer, T., & Ottaviano, G. I. (2007). *The Happy Few: The internationalisation of European firms. New facts based on firm-level evidence. Bruegel blueprint series, Volume 3, November 2007.*
- Mendelsohn, R. (2008). The impact of climate change on agriculture in developing countries. *Journal of Natural Resources Policy Research*, 1(1), 5–19.
- Mortier, R. M., Orszulik, S. T., & Fox, M. F. (2010). *Chemistry and technology of lubricants* (Vol. 107115). Springer.
- Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., Church, J. A., Clarke, L., Dahe, Q., & Dasgupta, P. (2014). *Climate change 2014: Synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change*. Ipcc.
- Park, J. (2016). Will we adapt? Temperature shocks, labor productivity, and adaptation to climate change in the United States. *Unpublished. Harvard University, Cambridge, MA*, 4.
- Schlenker, W., & Roberts, M. J. (2009). Nonlinear temperature effects indicate severe damages to US crop yields under climate change. *Proceedings of the National Academy of Sciences*, 106(37), 15594–15598.
- Somanathan, E., Somanathan, R., Sudarshan, A., & Tewari, M. (2021). The impact of temperature on productivity and labor supply: Evidence from Indian manufacturing. *Journal of Political Economy*, 129(6), 1797–1827.
- Steadman, R. G. (1979). The assessment of sultriness: Part I – A temperature-humidity index based on human physiology and clothing science. *Journal of Applied Meteorology*, 18(7), 861–873.
- Sudarshan, A., & Tewari, M. (2014a). *The economic impacts of temperature on industrial productivity: Evidence from indian manufacturing*. Working paper.
- Sudarshan, A., & Tewari, M. (2014b). *The economic impacts of temperature on industrial productivity: Evidence from indian manufacturing*. Working paper.
- Zhang, P., Deschenes, O., Meng, K., & Zhang, J. (2018). Temperature effects on productivity and factor reallocation: Evidence from a half million Chinese manufacturing plants. *Journal of Environmental Economics and Management*, 88, 1–17.



Mission

To strengthen local capacity for conducting independent, rigorous inquiry into the problems facing the management of economies in sub-Saharan Africa.

The mission rests on two basic premises: that development is more likely to occur where there is sustained sound management of the economy, and that such management is more likely to happen where there is an active, well-informed group of locally based professional economists to conduct policy-relevant research.

Bringing Rigour and Evidence to Economic Policy Making in Africa

- Improve quality.
- Ensure Sustainability.
- Expand influence.

www.aercafrica.org

Learn More



www.facebook.com/aercafrica



www.instagram.com/aercafrica_official/



twitter.com/aercafrica



www.linkedin.com/school/aercafrica/

Contact Us

African Economic Research Consortium
Consortium pour la Recherche Economique en Afrique
Middle East Bank Towers,
3rd Floor, Jakaya Kikwete Road
Nairobi 00200, Kenya
Tel: +254 (0) 20 273 4150
communications@aercafrica.org