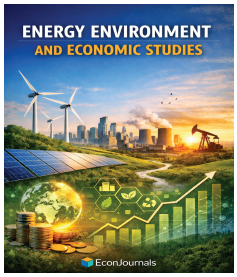

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Global Warming and Agricultural Output in Nigeria: A Threshold Analysis

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ABSTRACT

This study investigates the nonlinear relationship between global warming and agricultural output in Nigeria using a threshold regression framework. Annual time-series data covering 1990-2024 are employed to identify whether a critical temperature level exists beyond which warming exerts disproportionately adverse effects on agricultural performance. The results reveal a temperature threshold of 27.10°C, indicating that agricultural output responds positively to warming below this point but declines sharply once temperatures exceed it. This confirms the presence of a climatic tipping point in Nigeria's agricultural system. The analysis further shows that government agricultural expenditure exerts a weak and predominantly negative influence on output, particularly in high-temperature conditions, while labour productivity diminishes under thermal stress. These findings demonstrate that the climate–agriculture nexus in Nigeria is regimedependent and sensitive to temperature extremes. Strengthening climateresilient agricultural strategies, improving public investment efficiency, and enhancing adaptive capacity are essential for sustaining longterm sectoral performance under rising global temperatures.

Keywords: Global Warming, Agricultural Output, Temperature Threshold, Nonlinear Regression, Climate Change, Nigeria
JEL Classifications: C24, Q18, Q54

1. INTRODUCTION

Global warming, defined as the persistent rise in the earth's average surface temperature, largely driven by the anthropogenic greenhouse gas emission, has emerge as one of the most critical environmental challenges confronting the globe. Scientific evidence indicates that rising concentrations of carbon dioxide and other greenhouse gases have altered global climate systems, leading to increasing temperatures, changing precipitation patterns, and more frequent extreme weather events (IPCC, 2021). Although climate change is a worldwide phenomenon, its impacts are disproportionately severe in developing economies where production systems are heavily dependent on natural climatic conditions and adaptive capacity remains limited. Nigeria, as a climate-sensitive and agrarian-dependent economy, is particularly exposed to these risks.

Over the past few decades, Nigeria has experienced noticeable climatic shifts, including rising mean temperatures, increasing rainfall variability, and a growing incidence of floods and droughts (NIMET, 2022). These changes have heightened concerns about the sustainability of agricultural production, which remains a central pillar of the Nigerian economy. Agriculture contributes significantly to gross domestic product, employs a substantial proportion of the labor force, and provides livelihoods for the majority of rural households. The sector also plays a strategic role in ensuring food security and reducing poverty. Consequently, adverse climatic conditions associated with global warming pose a serious threat to agricultural development and broader economic stability in Nigeria.

Climate variability influences agricultural outcomes through multiple interconnected pathways. With rising temperatures

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affect crops, growth cycles are affected, soil moisture is reduced and evapotranspiration is increased, thereby lowering crop yields and land productivity (Adejuwon, 2004). In terms of altered rainfall patterns which is characterized by delayed onset and early cessation of rains, planting and harvesting schedules are disrupted, increasing the likelihood of crop failure. Also, extreme climate events such as flooding and drought further exacerbate land degradation, destroy farm infrastructure, and intensify pest and disease outbreaks (Apata et al., 2009). These effects are particularly severe for smallholder farmers, who dominate Nigeria's agricultural sector and often lack adequate access to irrigation, improved inputs, and climate-resilient technologies.

Beyond climatic factors, agricultural productivity in Nigeria is also shaped by macroeconomic conditions and public policy interventions. Variables such as government expenditure on agriculture, gross capital formation, exchange rate dynamics, and overall economic stability influence farmers' investment decisions, productivity, and capacity to adapt to climate-related shocks. In the context of climate change, the effectiveness of these macroeconomic and policy drivers becomes even more critical, as appropriate policy responses can either mitigate or exacerbate the adverse effects of climate change on agricultural performance. Weak policy coordination, insufficient funding, and limited institutional support have constrained Nigeria's ability to build climate-resilient agricultural systems.

Despite the growing body of literature on climate change and agriculture, empirical evidence on the dynamic and non-linear effects of global warming on agricultural output in Nigeria remains limited, particularly from a time-series perspective. Many existing studies focus on micro-level analyses or short-term impacts, thereby failing to capture the long-run dynamics, adjustment processes, and possible threshold effects inherent in climate–agriculture relationships. A time-series framework that allows for regime differentiation is therefore essential for understanding both the linear long-run and short-run effects of global warming on agricultural output, as well as determining whether a critical threshold level of global warming exists beyond which its impact on agricultural output changes significantly.

Against this background, the objective of this study is to investigate the non-linear effects of climate change on agricultural productivity in Nigeria. This paper also seeks to compare the regime-specific effects of climate change on agricultural outcomes below and above the threshold, thereby making policy recommendations for climate adaptation strategies Nigeria's agricultural sector.

2. REVIEWS OF RELATED LITERATURE

2.1. Conceptual Framework

The conceptual framework explains the theoretical and logical relationships between global warming, macroeconomic and policy variables, and agricultural development in Nigeria. It provides a structured understanding of how climate-related factors interact with economic and policy drivers to influence agricultural performance over time.

2.1.1. Definition of key concepts

2.1.1.1. Global warming

Global warming refers to the long-term and persistent increase in the average temperature of the Earth's atmosphere and surface, primarily resulting from the accumulation of greenhouse gases such as carbon dioxide, methane, and nitrous oxide due to human activities, including fossil fuel combustion, deforestation, and industrial processes. This rise in temperature alters climate systems, leading to changes in precipitation patterns, increased frequency of extreme weather events, and disruptions to natural and socio-economic systems (IPCC, 2021). Global warming is therefore a key driver of broader climate change and has significant implications for climate-sensitive sectors such as agriculture.

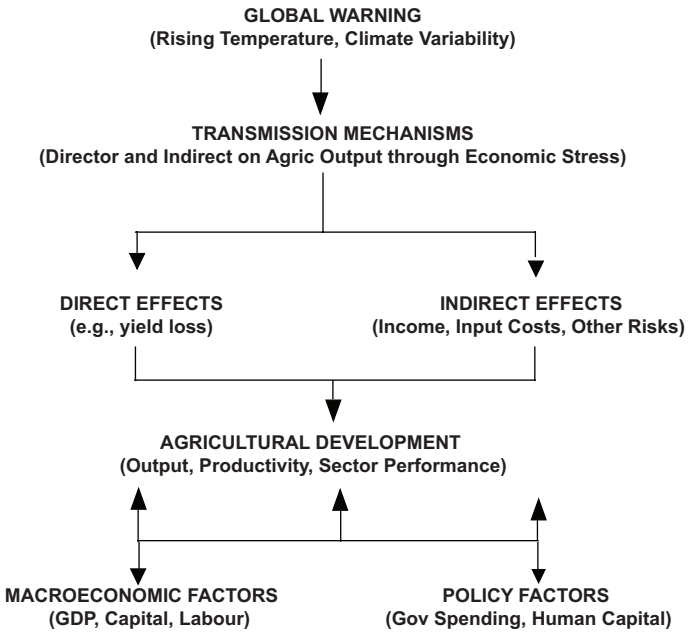
2.1.1.2. Agricultural development

Agricultural development is the process of improving the productivity, efficiency, and sustainability of the agricultural sector through enhanced use of inputs, technological advancement, institutional support, and policy interventions, with the ultimate goals of increasing output, ensuring food security, raising farm incomes, and promoting overall economic development. According to the Food and Agriculture Organization (FAO, 2018), agricultural development encompasses not only growth in agricultural output but also improvements in rural livelihoods, resource management, and resilience to environmental and economic shocks. In developing economies such as Nigeria, agricultural development is closely linked to poverty reduction, employment generation, and structural.

2.1.2. Conceptual flow

The conceptual flow, presented in Figure 1, illustrates the pathways through which global warming and macroeconomic and policy factors influence agricultural development in Nigeria. Global warming, represented by rising temperatures and climate variability, exerts a direct negative effect on agricultural

Figure 1: The conceptual flow diagram



Source: The Authors

development by reducing crop yields, increasing production risks, and degrading productive resources. In addition to this direct effect, global warming also has indirect effects by creating economic stress, such as reduced farm incomes and higher production costs, which further constrain agricultural performance.

Macroeconomic and policy drivers, including government expenditure on agriculture, capital formation, labour input, and human capital development, affect agricultural development directly by enhancing productive capacity and indirectly by moderating the adverse effects of global warming. Adequate policy support and investment improve farmers' ability to adopt climate-resilient technologies, thereby strengthening agricultural resilience. Agricultural development, measured in terms of output and productivity, therefore emerges as the outcome of the interaction between climatic conditions and macroeconomic and policy responses over time.

2.2. Theoretical Review

This study is anchored on relevant economic and environmental theories that explain how climate change interacts with agricultural productivity and long-term development. The major theories underpinning this study are discussed as follows:

2.2.1. Climate change and economic growth theory

The Climate Change and Economic Growth Theory, which may be referred to as Climate Growth Theory, explains how climatic conditions directly and indirectly influence economic performance, particularly in climate-sensitive sectors such as agriculture. The theory argues that rising temperatures, changing rainfall patterns, and increased frequency of extreme weather events negatively affect factor productivity, output, and income levels (Dell et al, 2012). In developing countries like Nigeria, agriculture is largely rain-fed and highly vulnerable to climate variability. Global warming leads to reduced crop yields through soil moisture loss, heat stress on crops and livestock, pest proliferation, and shortened growing seasons. These effects lower agricultural productivity, reduce farmers' incomes, and constrain agricultural development over time. Since agriculture plays a crucial role in employment generation, food security, and rural livelihoods in Nigeria, climate-induced shocks transmit directly into the broader economy. Time series analysis becomes relevant under this theory because climate change effects are cumulative and dynamic, meaning past climatic conditions influence current and future agricultural outcomes. Thus, long-run trends in temperature and rainfall can significantly explain variations in agricultural output and development indicators.

2.2.2. Environmental Kuznets curve (EKC) hypothesis

The Environmental Kuznets Curve (EKC) hypothesis posits an inverted U-shaped relationship between environmental degradation and economic growth (Grossman and Krueger, 1995). According to this theory, environmental degradation initially increases as economies expand due to intensive resource use, weak environmental regulation, and reliance on traditional production methods. However, beyond a certain income threshold, further economic growth leads to environmental improvement through technological innovation, better institutions, and increased environmental awareness.

In the Nigerian agricultural context, early stages of agricultural development often involve deforestation, bush burning, excessive fertilizer use, and land degradation, which contribute to greenhouse gas emissions and global warming. As income and development improve, the EKC suggests that farmers and policymakers may adopt climate-smart agriculture, improved irrigation systems, and sustainable land-use practices that reduce environmental damage.

This theory is relevant to the study because it helps explain whether agricultural development in Nigeria exacerbates global warming in the short run and whether long-run development can help mitigate environmental impacts. Time series analysis allows the investigation of whether Nigeria exhibits EKC-type behavior over time.

2.2.3. Solow-swan growth model with climate externalities

The Solow-Swan neoclassical growth model explains long-run economic growth through capital accumulation, labor growth, and technological progress. Recent extensions of the model incorporate environmental and climate factors as external shocks that affect total factor productivity (Barro, 2013). Within this framework, global warming is treated as a negative externality that depreciates natural capital and reduces productivity in agriculture. In Nigeria, rising temperatures and erratic rainfall reduce the effectiveness of labor and capital employed in farming, leading to lower steady-state agricultural output. Climate change can also accelerate capital depreciation by damaging infrastructure such as irrigation systems and rural roads.

By incorporating climate variables into a production function, this theory supports the inclusion of global warming indicators as explanatory variables in a time series model of agricultural development. It provides a strong theoretical justification for examining long-run relationships between climate change and agricultural growth in Nigeria.

2.2.4. Sustainable development theory

Sustainable Development Theory emphasizes meeting present development needs without compromising the ability of future generations to meet their own needs (WCED, 1987). The theory integrates economic growth, environmental protection, and social welfare, stressing that long-term development must be environmentally sustainable.

In relation to Nigerian agriculture, sustainable development requires adapting farming systems to climate change while preserving soil fertility, water resources, and biodiversity. Global warming threatens the sustainability of agricultural development by increasing land degradation, desertification, and food insecurity. Without climate-resilient agricultural practices, short-term gains in output may lead to long-term losses in productivity.

This theory underpins the study by highlighting the importance of long-run analysis. Time series methods are appropriate for

assessing whether agricultural development in Nigeria has been sustainable in the face of global warming and whether policy interventions have mitigated adverse climate effects over time.

2.3. Empirical Review: Climate Change as a Structural Determinant of Agricultural Output

Global warming is seen as one of the most significant challenges that tends to hinder agricultural productivity across the globe. It is not just a contemporaneous environmental disturbance; it represents a deep rooted and structural productivity shock which potentially has long run hampering effects on productivity.

In standard neoclassical framework, agricultural output can be represented thus:

$$Y_t = A_t F(K_t, L_t, M_t) \quad (2.1)$$

Where Y_t denotes total agricultural output at time t, K_t total capital stock (machines, equipment and infrastructure), L_t labour force used in production, M_t is the environmental or natural resources inputs (land, raw materials, climatic condition) and A_t total factor productivity (TFP). Based on this framework, climate variables like rainfall and other extreme weather condition creeps into the production function through the varaible A_t (as presented in equation 2.2).

$$A_t = g(T_t, R_t, E_t, Z_t) \quad (2.2)$$

Where Z_t represents institutional and technological determinants.

Under this schema, climate change is seen as being a non-systemic shifter of TFP, which re-arranges the marginal productivity of basic production inputs. However, this simplistic view do not capture the dynamic intrcacies of the complex relationship between climate change and agricultural producivity. Given the endogenous growth outlook, savings behaviour could be negatively impacted by worsening climatic condition. Similarly, investment in research and development as well as agricultural infrastructural buildup could suffer severe setback. It is therefore safe to conclude that climate change may not only affect current productivity but also capital formation and technical progress (Adebayo, 2021).

This theorectical analysis has led to the emergence of two dimetrically oppose oppinions on this subject. At one end, climate change is seen as having only contemporaneous effects on output without necessarily having impact on long term growth trajectory. In this perspective, climate change is seen as a level effect whch only temporarily reduces output without impacting long run growth. The second opinion admits that climate change could support growth by altering the slope of agricultural production in the long run. This framework admits that global warming could potentially discourage long term investment through hightened risk and uncertainty which could permanently teper-off growth.

It can aslo be argued that adaptation, characterized by irrigation development, credit market expansion and crop variety diversification could mitigate the long run effects of global warming on agricultural productivity. However, these structures are largely unavailable, especially in Nigeria and other developing countries as they are plagued with poor functional credit markets, poor extension services and lack of irrigational services (BenYishay et al, 2026).

Methodologically, the empirical literature on global warming and agricultural productivity has evolved from descriptive and cross-sectional data analyses to more sophisticated dynamic econometric approaches. Researchers tend to rely on Time-series techniques such as ARDL as it has the tendency to capture and distinguish between short and long run dynamic relationships. For instance, Ibrahim et al. (2025) applied an ARDL model and found significant short-run and long-run effects of temperature, rainfall, labour, capital, and fertilizer on maize yields. The ARDL model is appropriate when variables exhibit mixed integration orders and allow estimation of cointegrating relationships. However, some of the methodological challenges that can arise from this model include omitted variable bias, which happens when key and important macroeconomic variables that are determinants of agricultural productivity, such as agricultural credit, exchange rates, government spending on agriculture are not captured in the model. We could also have endogeneity concerns as farmers are more likely to be influenced by expected productivity outcomes. Furthermore, conventional linear models could be rendered ineffective or inadequate in capturing the dynamic relationship between global warming and agricultural outcomes due to structural breaks.

Cumulative evidence from literature establishes some important stylized facts. First, global warming exerts a statistically significant and economically meaningful effects on agricultural output. For instance, Apata et al. (2009) demonstrated significant crop yield responses to climate variability, showing high climatic elasticity in grain production. Their findings is in tandem with agronomic theory which suggest that when temperature increases beyond optimal thresholds photosynthetic efficiency is reduced and crop maturation is accelerated resulting in lower crop yields (Hatfield et al. 2015).

Second, the impacts differ across regions, crops, and agro-ecological zones. Ilesanmi et al. (2021), found non-symmetric responses of cassava, rice, and soybean under different warming scenarios. Such projections support the hypothesis that temperature increases may initially benefit some crops before hitting biological thresholds, resulting in nonlinear yield declines. Similarly, Nigeria's agro-ecological diversity introduces additional complexity. Regional studies indicate that climatic effects vary significantly across regions. Adetayo et al. (2025) reported rainfall-yield sensitivity in Oyo State, while Adeniyi and Yahaya (2029) documented adverse effects in Katsina State, particularly for certain crops like millet and sorghum.

Third, adaptation mechanisms play a critical role in mitigating the effects of global warming on agricultural output. Amankwah (2023) showed that climate variability increases the likelihood of farmers and other players in agro-industry adopting improved technologies. However, this adaptation may not fully compensate output losses. Finally, dynamic and non-linear analytical

frameworks are necessary to distinguish temporary disturbance associated with global warming and long-term structural transformations in agricultural productivity.

Despite these advances, important gaps remain. Existing studies are often fragmented, focusing separately on individual crops, regions or farmer perceptions, with limited integration into comprehensive macroeconomic production frameworks. Moreover, relatively few studies examine whether climate change exerts an independent structural effect on aggregate agricultural output after controlling conventional production inputs such as labor, capital and intermediate inputs.

Against this backdrop, the present study seeks to contribute to the literature by incorporating climate variables explicitly into an augmented agricultural production framework and examining the threshold effects of climate change on agricultural output in Nigeria.

3. METHODOLOGY

This section presents the systematic framework employed to investigate the nonlinear effects of climate change on agricultural output in Nigeria. It encompasses research design, theoretical framework, model specification, estimation techniques, variable definitions, data sources, and analytical procedures. The methodological approach is specifically designed to capture potential threshold effects in the relationship between global warming indicators and agricultural performance, consistent with the study's objective of identifying critical temperature thresholds beyond which the impact of climate change on agriculture fundamentally alters.

3.1. Research Design

This study adopts a longitudinal research design utilizing time series data covering 1990-2024 to examine the dynamic relationship between climate change variables and agricultural output in Nigeria over an extended period. The design is appropriate for capturing both the temporal evolution of agricultural performance and the potential structural breaks in its relationship with climatic factors. Specifically, the study employs a threshold regression framework that allows for the endogenous identification of critical temperature levels at which the impact of global warming on agricultural productivity undergoes significant change. This design is particularly suited to the research problem as it accommodates nonlinearities, and regime shifts inherent in climate-economy relationships.

3.2. Model Specification

Based on the theoretical framework, the functional relationship between agricultural output and its determinants, with particular emphasis on global warming indicators, is expressed as:

$$AGROUT_t = f(GLWAM_t, AGRLAB_t, GOVAGR_t) \quad (3.1)$$

Where *AGROUT* represents agricultural output, *GLWAR* captures global warming effects (proxied by average annual temperature), and the vector of control variables includes *AGRLAB* (Agricultural Labour Force) and *GOVAGR* (Government Agricultural Expenditure).

3.3. Threshold Regression Model Specification

Following Hansen (1999), the threshold regression model with two regimes defined by an endogenous threshold parameter γ is specified as follows. For a given threshold variable w_t (which in this study is the global warming indicator, GLWAR), the model can be expressed in its general form as:

- Regime 1 (Low Temperature Regime)

$$Y_t = X_t\beta + Z_t\delta_1 + \varepsilon_t \qquad \text{if } -\infty < w_t \leq \gamma \quad (3.2)$$

- Regime 2 (High Temperature Regime)

$$Y_t = X_t\beta + Z_t\delta_2 + \varepsilon_t \qquad \text{if } \gamma < w_t < \infty \quad (3.3)$$

- These two equations can be written compactly as:

$$Y_t = X_t\beta + Z_t\delta_1\, I(-\infty < w_t \leq \gamma) + Z_t\delta_2(\gamma < w_t < \infty) + \varepsilon_t \quad (3.4)$$

Where: Y_t is the dependent variable (agricultural output), X_t is a 1 × k vector of covariates with regime-invariant parameters, Z_t being a vector of exogenous variables with regime-specific coefficient vectors, δ_1 and δ_2. w_t is the threshold variable (global warming indicator), while γ is the threshold parameter to be estimated.

Adapting the general threshold model to the specific context of this study, the empirical model for examining the nonlinear effects of global warming on agricultural output is specified with global warming (GLWAR) serving both as a regressor and as the threshold variable. This approach allows the impact of temperature and other control variables to differ depending on whether the temperature lies below or above the estimated threshold.

$$(AGROUT_t = [\alpha_0 + \alpha_1 GLWAM_t + \alpha_2 AGRLAB_t + \alpha_3 GOVAGR_t] \cdot I(GLWAM_t \leq \gamma) + [\beta_0 + \beta_1 GLWAM_t + \beta_2 AGRLAB_t + \beta_3 GOVAGR_t] \cdot I(GLWAM_t > \gamma) + \varepsilon_t \quad (3.5)$$

3.4. Justification for Threshold Variable Selection

The selection of global warming (average annual temperature) as both the primary regressor of interest and the threshold variable is theoretically and empirically justified. From a theoretical perspective, climate science suggests that agricultural systems have adaptive capacities up to certain temperature ranges, beyond which physiological stress on crops, livestock, and agricultural labour leads to accelerated productivity losses (Schlenker and Roberts, 2009). Empirically, studies have documented nonlinear temperature-yield relationships, with critical thresholds varying across ecological zones and crop types. The endogenous estimation of the threshold parameter follows Hansen's (1999) approach, ensuring that the critical temperature level is statistically determined from Nigerian data rather than arbitrarily imposed, thereby providing an objective basis for identifying the point at which climate change effects intensify.

3.5. Variable Description and Measurement

3.5.1. The variables used in this study agricultural output (AGROUT)

This variable represents the total value of agricultural production in Nigeria, measured in millions of Naira (constant prices). It encompasses output from all agricultural subsectors, including crop production, livestock, fishery, and forestry. The use of aggregate agricultural output captures the overall sectoral performance and its sensitivity to climatic variations. Data are obtained from the Central Bank of Nigeria (CBN, 2024) Statistical Bulletin and the National Bureau of Statistics (2024).

3.5.2. Global warming (GLWAM)

Proxied by average annual temperature measured in degrees Celsius (°C). This variable serves dual roles in the model: As the primary climate change indicator and as the threshold variable that determines regime classification. Temperature data are sourced from the Nigerian Meteorological Agency (NIMET, 2024). The use of average annual temperature captures the gradual warming trend, while the threshold specification allows for the identification of critical temperature levels where impacts intensify.

3.5.3. Agricultural labour force (AGRLAB)

Measured as the economically active population engaged in agricultural activities (in millions). Labour is a fundamental input in agricultural production, and changes in labour availability affect output levels. Data are obtained from the National Population Commission and the International Labour Organization (ILO 2024).

3.5.4. Government agricultural expenditure (GOVAGR)

This variable represents government capital and recurrent expenditures allocated to the agricultural sector, measured as a percentage of total government expenditure (growth rate). It captures policy support for agriculture, including investments in research, extension services, irrigation, and input subsidies. Data is sourced from the Central Bank of Nigeria (CBN, 2024) Statistical Bulletin.

4. THRESHOLD AUTO REGRESSION (TAR)

The results of the threshold autoregression, estimated with data presented in Appendices 1 and 2, are shown in Table 1. It revealed a nonlinear relationship between global warming and agricultural output in Nigeria, with the model identifying two critical temperature thresholds at 27.1 and 27.2°C based on the lagged global warming variable, partitioning the sample into three distinct regimes where the relationships between agricultural determinants and output fundamentally transform. The model demonstrates strong explanatory power with an R-squared of 0.863, indicating that approximately 86% of the variation in agricultural output is explained by the threshold specification, and the highly significant F-statistic confirms the overall statistical validity of the approach. The distribution of observations across regimes shows that five observations fall below the first threshold, four observations lie in the middle regime between 27.1 and 27.2°C, and the majority of twenty-five observations reside in the high-temperature regime above 27.2°C, indicating that Nigerian agriculture has predominantly operated under thermally stressed conditions throughout the study period.

In the low-temperature regime below 27.1°, agricultural labour force emerges as a highly significant positive driver of output with a coefficient of 121.42, suggesting that under cooler conditions, labour serves as the primary engine of agricultural productivity, while the contemporaneous global warming variable shows a positive but insignificant coefficient, indicating that within this regime, temperature variations do not yet exert a detectable adverse effect on output. The middle regime between 27.1 and 27.2° presents a dramatic transition where all explanatory variables become statistically insignificant, including agricultural labour, government expenditure, and the global warming variable, suggesting that this narrow temperature band represents a transitional zone where the agricultural system is undergoing fundamental reorganization and the predictable relationships between inputs and output temporarily break down.

The high-temperature regime above 27.2°, which contains the largest share of observations, reveals a starkly different reality where agricultural labour becomes significantly negative with a coefficient of −11.57, indicating that under sustained high temperatures, labour transforms from a productive asset into a constraint on output, likely due to heat-induced productivity losses and physiological stress on workers. Government agricultural expenditure also becomes significantly negative in this regime with a coefficient of −0.519, suggesting that conventional agricultural policy interventions may prove counterproductive under thermal stress, while the global

Table 1: Threshold auto regression results (Threshold Variable: GLOWAM [−1])

Regime	Variable	Coefficient	Std. error	t-statistic	Prob.
Regime 1 (<27.10)	LNGOVAGR	−0.293	1.415	−0.207	0.838
	LNAGRLAB	121.416	44.171	2.749	0.012*
	GLOWAM	3.112	3.731	0.834	0.413
	Constant	−526.648	158.480	−3.323	0.003**
Regime 2 (27.10–27.20)	LNGOVAGR	0.687	0.987	0.696	0.494
	LNAGRLAB	−2.951	8.196	−0.360	0.722
	GLOWAM	0.252	2.708	0.093	0.927
	Constant	10.818	76.635	0.141	0.889
Regime 3 (≥27.20)	LNGOVAGR	−0.519	0.169	−3.068	0.006**
	LNAGRLAB	−11.567	1.902	−6.082	0.000***
	GLOWAM	−1.012	0.755	−1.339	0.194
	Constant	106.340	24.672	4.310	0.000***

Researcher's summary from estimation results presented as Appendix 3. Significance levels: *P<0.05, **P<0.01, ***P<0.001. Model fit statistics are: R^2=0.863, Adjusted R^2=0.795, F-statistic=12.61, (P<0.001)

warming variable shows a negative coefficient of −1.012, aligning with theoretical expectations that rising temperatures adversely affect agricultural productivity, though this effect falls just short of conventional significance levels. The constant term in the high-temperature regime is positive and highly significant, capturing the residual factors that sustain some level of agricultural output even as the effectiveness of conventional inputs and policy instruments diminishes under chronic thermal stress.

4.1. Discussion of Results

The findings, as presented, represent a significant contribution to the climate-economy literature, particularly for sub-Saharan African contexts where empirical evidence on temperature thresholds remains limited. The identification of these specific thresholds, the dramatic transformation of labour's role across regimes, and the finding that government agricultural expenditure becomes significantly negative in the high-temperature regime collectively challenge conventional assumptions about agricultural production functions and policy effectiveness under climate stress.

The Climate Change-Economic Growth Theory, which underpins this study, posits that climatic conditions exert both direct and indirect effects on economic performance, particularly in climate-sensitive sectors such as agriculture. The findings of this study both support and extend this theoretical framework in several important ways. The theory suggests that rising temperatures adversely affect factor productivity, reduce output levels, and constrain income growth. The results indeed confirm that in the high-temperature regime, labour productivity is significantly compromised.

However, the theory as originally articulated by (Dell et al. 2012) primarily emphasized linear and monotonic effects of temperature on economic outcomes. The findings of this study challenge this linear conceptualization by demonstrating that the relationship between temperature and agricultural output is not simply negative but rather regime-dependent, with the direction and magnitude of temperature effects varying fundamentally across different temperature ranges.

The identification of two distinct thresholds where the agricultural production function undergoes structural transformation extends the theoretical framework by introducing the concept of critical temperature tipping points. In the low-temperature regime below 27.1°, the theory's predictions about factor productivity hold in a positive sense, with labour serving as a strong driver of output. In the middle regime between 27.1 and 27.2°, the theory's predictions become temporarily suspended as all explanatory variables lose statistical significance, suggesting a zone of system reorganization where conventional relationships break down. In the high-temperature regime above 27.2°, the theory's predictions about adverse temperature effects are confirmed, but with the additional nuance that labour becomes a negative influence rather than merely a less productive factor. This regime-dependent pattern suggests that the Climate Change–Economic Growth Theory should be refined to incorporate threshold effects and the possibility that factor inputs may become counterproductive rather than merely less productive under extreme climatic conditions.

The finding that government agricultural expenditure becomes significantly negative in the high-temperature regime carries important implications for the theory's treatment of policy interventions. The theory implicitly assumes that policy instruments can be deployed to mitigate climate impacts, but the results suggest that under chronic thermal stress, conventional policy interventions may lose effectiveness or even exacerbate problems. This finding challenges the implicit policy optimism embedded in much climate-economy theorizing and suggests that the relationship between climate change and economic outcomes may be mediated by institutional and policy factors in ways that current theories inadequately capture.

The findings of this study align remarkably well with recent regional evidence from Iheonu et al. (2025), who investigated temperature thresholds for agricultural productivity across sixteen West African countries. Their study identified a temperature threshold of 24.39°C for agricultural productivity, with an even higher threshold of 25.27°C identified in countries where existing agricultural productivity levels are low. The thresholds identified in this study at 27.1 and 27.2°C are somewhat higher, which may reflect the specific agro-ecological conditions in Nigeria, the possibility that Nigerian agriculture has developed some adaptive capacity that shifts thresholds higher, or the methodological differences in threshold estimation. The consistency across independent studies in identifying the existence of critical temperature thresholds, even if the exact values differ, strengthens the validity of the threshold approach and suggests that nonlinear temperature effects are a robust feature of West African agricultural systems.

The finding that agricultural labour transforms from a positive to negative influence across temperature regimes finds support in the Nigerian literature. Ajiboye et al. (2025), examining maize and sorghum farmers in Nigeria's Guinea Savanna region, found that temperature increases raised yield risk for both crops while family labour share in farming increased yield variance for sorghum. This finding that labour introduces additional variability rather than certainty under thermal stress conditions is consistent with the threshold regression results showing labour's negative and significant coefficient in the high-temperature regime. The similarity between these independent findings strengthens the conclusion that labour productivity under thermal stress is a critical constraint in Nigerian agriculture and that policies focused on labour expansion may prove counterproductive under current and projected climate conditions.

The behaviour of government agricultural expenditure in this study presents both similarities and differences with previous Nigerian evidence. Adamu et al. (2025), investigating the moderating effect of corruption on agricultural financing effectiveness, found that government agricultural expenditure had a positive but statistically insignificant effect on productivity, while the interaction between expenditure and corruption exerted a negative and significant effect in both the short and long run. This previous finding that corruption undermines expenditure effectiveness is consistent with the negative coefficient for agricultural expenditure in the

high-temperature regime of this study, as corruption may become more consequential under the stress of thermal conditions. However, the finding that agricultural expenditure becomes significantly negative rather than merely insignificant in the high-temperature regime represents a departure from previous studies and suggests that under sustained thermal stress, agricultural spending may not merely be ineffective but actively harmful.

The finding that all explanatory variables become statistically insignificant in the middle regime between 27.1 and 27.2°C is a particularly novel contribution that has not been documented in previous Nigerian or West African studies. This transitional zone of statistical insignificance suggests that as temperatures cross the first threshold, the agricultural system enters a period of fundamental reorganization where the predictable relationships between inputs and output temporarily break down. This finding contributes a new conceptual dimension to the literature on climate thresholds by suggesting that the transition between production regimes may involve a zone of system instability rather than a sharp break, with implications for how adaptation policies should be timed and targeted.

Several findings from this study were unexpected and carry important implications for understanding climate-agriculture relationships in Nigeria. The most striking unexpected finding is that government agricultural expenditure becomes significantly negative in the high-temperature regime, with a coefficient of −0.519. This finding challenges the conventional assumption that public spending on agriculture, regardless of context, should have at least a non-negative effect on output. The negative coefficient suggests that under sustained thermal stress, agricultural policy interventions may actively harm rather than help agricultural productivity. Several mechanisms could explain this unexpected result. First, if agricultural expenditure is primarily allocated to recurrent rather than capital items, it may create dependency without generating productivity gains, and under thermal stress, such dependency may be particularly damaging as it diverts resources from adaptation. Second, if agricultural spending is pro-cyclical, increasing in response to poor agricultural performance, the negative coefficient may reflect reverse causality rather than a genuine negative effect. Third, and most concerning, corruption and governance challenges may be amplified under thermal stress, as the desperation created by climate impacts may make rent-seeking behavior more prevalent and more damaging. Fourth, agricultural expenditure may be allocated to inputs or technologies that are maladapted to high-temperature conditions, such as fertilizer applications that become less effective or even damaging under heat stress, or crop varieties that were suitable for cooler conditions but fail under warming.

Another unexpected finding is the existence of a narrow transitional zone between 27.1 and 27.2°C where all explanatory variables become statistically insignificant. This finding was not anticipated by the theoretical framework, which did not explicitly consider the possibility of a system reorganization zone between stable regimes. The existence of such a zone has important implications for understanding how agricultural systems respond to gradual warming. Rather than a smooth adjustment or a sharp break at a single threshold, the results suggest that as temperatures cross the first critical point, the agricultural system enters a period of fundamental reorganization during which conventional input-output relationships temporarily break down. This period of breakdown may represent the time required for farmers, markets, and institutions to adapt to new thermal conditions, and the duration and characteristics of this transition have important implications for policy timing. The finding that this transitional regime contains only four observations suggests that the system reorganization period is relatively short, perhaps reflecting the speed with which Nigerian farmers adapt or the narrow temperature range over which system instability occurs.

The finding that the contemporaneous global warming variable becomes negative but remains statistically insignificant in the high-temperature regime, despite labour and government expenditure showing significant negative effects, was also unexpected. One might anticipate that the direct effect of temperature would be most apparent in the high-temperature regime, yet the coefficient falls short of conventional significance levels. This may indicate that the impact of temperature on agricultural output operates primarily through indirect channels, particularly through its effects on labour productivity and the effectiveness of policy interventions, rather than through direct biological effects on crops. Alternatively, the use of average annual temperature may not adequately capture the thermal conditions that matter most for agriculture, with extreme temperatures during critical growing periods perhaps being more relevant than annual averages. The lagged threshold variable specification, which identified thresholds based on lagged temperature, suggests that the effects of temperature may operate with a delay, further complicating the direct estimation of contemporaneous temperature effects.

The dramatic transformation of labour's role from a highly significant positive coefficient of 121.42 in the low-temperature regime to a negative coefficient of −11.57 in the high-temperature regime represents another unexpected finding in terms of magnitude. The massive size of the coefficient in the low-temperature regime suggests that under favourable thermal conditions, labour has an extraordinarily high marginal product, likely reflecting the combination of abundant land, favourable growing conditions, and labour-intensive production techniques. The fact that this coefficient falls to a much smaller negative value in the high-temperature regime, rather than becoming moderately positive or zero, indicates that the transformation in labour's role is not merely a reduction in productivity but a fundamental reversal where additional labour actively reduces output. This reversal may reflect that under high-temperature conditions, labour adds to congestion, competition for limited water resources, or pressure on already stressed systems without contributing proportionally to production.

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

This study set out to investigate the nonlinear effects of climate change on agricultural output in Nigeria, employing threshold regression to identify critical temperature thresholds and

regime-dependent production relationships. The empirical findings provide evidence that the relationship between global warming and agricultural output is fundamentally nonlinear, characterized by two critical temperature thresholds at 27.1 and 27.2°C that partition the sample into three distinct regimes. The model demonstrates strong explanatory power with an R-squared of 0.863, and the distribution of observations reveals that majority of the study period falls within the high-temperature regime above 27.2°, indicating that Nigerian agriculture has predominantly operated under thermally stressed conditions throughout the period under investigation.

The findings reveal a dramatic transformation in the role of agricultural labour across temperature regimes. In the low-temperature regime below 27.1°, labour emerges as a highly significant positive driver of output, serving as the primary engine of agricultural productivity under favourable thermal conditions. However, once temperatures cross the first threshold, a narrow transitional zone between 27.1 and 27.2° emerges where all explanatory variables become statistically insignificant, representing a period of system reorganization where conventional input-output relationships temporarily break down. In the high-temperature regime above 27.2°, which contains the largest share of observations, labour transforms from a productive asset into a significantly negative influence on output, reflecting heat-induced productivity losses, physiological stress on workers, and the fundamental alteration of labour's role under chronic thermal stress.

The behaviour of government agricultural expenditure across regimes presents challenging findings. While expenditure shows positive but insignificant effects in the low-temperature regime, it becomes significantly negative in the high-temperature regime, suggesting that conventional agricultural policy interventions may prove counterproductive under sustained thermal stress. This finding challenges the conventional assumption that public spending on agriculture, regardless of context, should have at least a non-negative effect on output, and points to the need for fundamental reform of agricultural expenditure processes, including addressing governance challenges, implementation inefficiencies, and the misallocation of resources toward interventions that are maladapted to high-temperature conditions.

The conclusion, based on the findings of this study is that Nigerian agriculture is already operating under chronic thermal stress conditions that fundamentally alter the relationships between conventional inputs and agricultural output, and that the effectiveness of traditional policy instruments is compromised precisely when they are most needed. The identification of specific temperature thresholds provides actionable information for targeting adaptation interventions, while the breakdown of predictable input-output relationships in the high-temperature regime suggests that marginal adjustments to existing policies will prove inadequate. What is required instead is a fundamental transformation of Nigerian agriculture toward climate-resilient systems capable of maintaining functional integrity under thermal stress. For a country where agriculture remains central to employment, livelihoods, food security, and economic stability, the urgency of acting on these findings has never been greater.

5.2. Recommendations

Based on the empirical findings of this study, the following recommendations are proposed for policymakers, agricultural planners, development practitioners, and researchers concerned with climate change adaptation and agricultural development in Nigeria:

a. There is need to adopt a threshold-based agricultural policy framework that recognizes the fundamentally different production relationships operating below 27.1°C, between 27.1 and 27.2°C, and above 27.2°C. This requires mapping regions by temperature profiles and developing regime-specific policy packages, with regions below the first threshold receiving investments that enhance labour productivity; regions in the transitional zone receiving enhanced monitoring and rapid response capacity; and regions above the second threshold receiving transformative investments in climate-resilient systems including heat-tolerant crop varieties, drought-resistant livestock, water-efficient irrigation, and mechanization.
b. It is necessary to reorient agricultural labour policy away from increasing labour participation toward protecting labour from thermal stress, given that labour transforms from a highly significant positive driver in the low-temperature regime to a significantly negative influence in the high-temperature regime where most Nigerian agriculture operates. This reorientation requires shifting extension services to provide guidance on heat-safe work practices, developing occupational health standards for agricultural workers that account for thermal stress, and prioritizing research on affordable mechanization and labour-saving technologies appropriate for smallholder farmers under high-temperature conditions.
c. Comprehensive reform of agricultural expenditure processes is essential given the finding that government agricultural expenditure becomes significantly negative in the high-temperature regime, suggesting that conventional spending may prove counterproductive under thermal stress. The government should establish a Climate-Resilient Agriculture Fund dedicated to adaptation investments, prioritize audits of agricultural spending in high-temperature regions, strengthen oversight of agricultural expenditure to address corruption concerns, and shift resources from recurrent spending toward capital investments in climate-resilient infrastructure and adaptation-focused research and development.
d. Agricultural climate adaptation must be elevated to national emergency status because most of the observed years fall within the high-temperature regime above 27.2°C, indicating that Nigerian agriculture is already operating under chronic thermal stress requiring immediate rather than future action. It may therefore be necessary to declare agricultural climate adaptation a national emergency, integrate adaptation targets into Nigeria's Nationally Determined Contributions under the Paris Agreement, establish clear accountability frameworks across relevant ministries, and engage the private sector through incentives to invest in climate-resilient agricultural

value chains while supporting civil society organizations to help farming communities adopt resilient practices.

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Appendix 1: Data provided at absolute values

Years	AGRLAB	GOVAGR	GLOWAM	AGROUT	GOMEXL
1990		258,000,000.00	27.20	1.06627E+11	500700000
1991	50.60	208,700,000.00	27.00	1.23236E+11	618200000
1992	50.40	455,974,661.47	26.60	1.84116E+11	150160724.2
1993	50.40	1,803,806,483.65	27.00	2.95325E+11	3871600887
1994	50.30	1,183,290,794.06	26.75	4.45273E+11	2093983709
1995	50.20	1,510,400,000.00	27.10	7.90142E+11	3320700000
1996	49.90	1,818,400,000.00	27.20	1070514729	3175300000
1997	49.70	2,058,884,751.00	27.25	1211461962	3891098799
1998	49.40	2,891,704,579.15	27.55	1341040898	4742266721
1999	49.20	59,316,169,205.34	27.25	1426973811	16638772811
2000	48.80	6,335,778,522.04	26.95	1508408788	15218082128
2001	48.10	7,064,546,345.86	27.15	2015421533	24522272405
2002	47.10	9,993,553,736.06	27.35	4251520648	40621417132
2003	46.40	7,537,354,608.10	27.40	4585925698	33267982270
2004	45.60	11,300,000,000.00	27.45	4935263754	34200000000
2005	45.00	16,300,000,000.00	27.55	6032332406	55700000000
2006	44.30	17,919,034,311.00	27.50	7513297801	62253622008
2007	43.70	32,484,232,065.21	27.50	8551981399	81909366062
2008	42.90	65,399,012,695.14	27.15	10100325190	98219319420
2009	42.20	22,435,198,508.92	27.85	11625442333	90200000000
2010	41.40	28,217,947,498.53	27.95	13048892800	99100000000
2011	40.60	41,200,000,000.00	27.55	14037825838	2.318E+11
2012	39.50	33,300,000,000.00	27.40	15815997512	1.979E+11
2013	38.30	39,431,012,243.92	27.50	16816553012	1.8E+11
2014	37.50	36,700,000,000.00	27.65	18018612873	1.95977E+11
2015	36.90	41,270,000,000.00	27.40	19636969043	2.577E+11
2016	36.60	36,304,533,368.28	27.80	21523512499	2.00824E+11
2017	36.10	50,260,675,996.09	27.50	23952554203	2.45188E+11
2018	35.50	53,987,735,960.13	27.50	27371295758	2.96442E+11
2019	35.00	70,274,538,711.15	27.40	31904140863	3.88232E+11
2020	34.80	76,600,992,672.39	27.45	37241609159	4.23359E+11
2021	34.18	72,272,283,138.88	27.65	41126058437	3.86244E+11
2022	38.00	81,866,961,411.11	27.10	47944062797	4.37521E+11
2023	34.31	87,689,549,990.60	27.75	53273143682	4.68639E+11
2024	35.32	93,512,138,570.09	27.70	36735053016	4.3762E+11

Source: Central Bank of Nigeria (CBN) Statistical Bulletin, World Development Indicator (WDI)

Appendix 2: Date provided at growth rate

Years	AGRLAB	GOVAGR	GLWAR	AGROUT	GOMEXL
1991	50.60	−19.11	27.00	15.58	23.47
1992	50.40	118.48	26.60	49.40	−75.71
1993	50.40	295.59	27.00	60.40	2478.30
1994	50.30	−34.40	26.75	50.77	−45.91
1995	50.20	27.64	27.10	77.45	58.58
1996	49.90	20.39	27.20	−99.86	−4.38
1997	49.70	13.23	27.25	13.17	22.54
1998	49.40	40.45	27.55	10.70	21.87
1999	49.20	1,951.25	27.25	6.41	250.86
2000	48.80	−89.32	26.95	5.71	−8.54
2001	48.10	11.50	27.15	33.61	61.14
2002	47.10	41.46	27.35	110.95	65.65
2003	46.40	−24.58	27.40	7.87	−18.10
2004	45.60	49.92	27.45	7.62	2.80
2005	45.00	44.25	27.55	22.23	62.87
2006	44.30	9.93	27.50	24.55	11.77
2007	43.70	81.28	27.50	13.82	31.57
2008	42.90	101.33	27.15	18.11	19.91
2009	42.20	−65.69	27.85	15.10	−8.16
2010	41.40	25.78	27.95	12.24	9.87
2011	40.60	46.01	27.55	7.58	133.91
2012	39.50	−19.17	27.40	12.67	−14.62
2013	38.30	18.41	27.50	6.33	−9.04
2014	37.50	−6.93	27.65	7.15	8.88
2015	36.90	12.45	27.40	8.98	31.50
2016	36.60	−12.03	27.80	9.61	−22.07
2017	36.10	38.44	27.50	11.29	22.09
2018	35.50	7.42	27.50	14.27	20.90
2019	35.00	30.17	27.40	16.56	30.96
2020	34.80	9.00	27.45	16.73	9.05
2021	34.18	−5.65	27.65	10.43	−8.77
2022	38.00	13.28	27.10	16.58	13.28
2023	34.31	7.11	27.75	11.12	7.11
2024	35.32	6.64	27.70	−31.04	−6.62

Source: CBN: Central Bank of Nigeria Statistical Bulletin, WDI: World development indicator

Appendix 3: Threshold auto regression results (threshold variable: GLOWAM (−1))

Variable	Coefficient	Std. error	t-statistic	Prob.
GLOWAM (−1) < 27.099999 -- 5 obs				
LNGOVAGR	−0.292556	1.414747	−0.206790	0.8381
LNAGRLAB	121.4157	44.17116	2.748756	0.0117
GLOWAM	3.112035	3.731284	0.834038	0.4132
C	−526.6475	158.4800	−3.323117	0.0031
27.099999 ≤GLOWAM (−1) < 27.199999 -- 4 obs				
LNGOVAGR	0.687167	0.986727	0.696410	0.4935
LNAGRLAB	−2.950604	8.196110	−0.360001	0.7223
GLOWAM	0.252163	2.708457	0.093102	0.9267
C	10.81825	76.63462	0.141167	0.8890
27.199999 ≤GLOWAM (−1) -- 25 obs				
LNGOVAGR	−0.519237	0.169241	−3.068036	0.0056
LNAGRLAB	−11.56707	1.901895	−6.081862	0.0000
GLOWAM	−1.011799	0.755425	−1.339378	0.1941
C	106.3400	24.67219	4.310117	0.0003
R-squared	0.863084	Mean dependent var		23.49577
Adjusted R-squared	0.794627	S.D. dependent var		1.685478
S.E. of regression	0.763827	Akaike info criterion		2.569614
Sum squared resid	12.83551	Schwarz criterion		3.108330
Log likelihood	−31.68344	Hannan-Quinn criter.		2.753332
F-statistic	12.60753	Durbin-Watson stat		1.407078
Prob (F-statistic)	0.000000			