

Determinants of Food Security in Nigeria: An ARDL Approach

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Abstract

Food security remains one of the most critical and persistent challenges facing Nigeria, a country where episodes of economic growth have not consistently translated into improved food access for its population. This study examines the long-run determinants of food security in Nigeria, with particular focus on the roles of agricultural credit, climate change, economic growth, technological innovation, and population growth. Using annual time series data analyzed through an Autoregressive Distributed Lag (ARDL) framework, the study finds that agricultural credit, economic growth, and technological innovation each exert a statistically significant and positive influence on food security. Specifically, a one unit increase in agricultural credit corresponds to an approximate 2.61-unit improvement in food security over the long run. In contrast, climate change, proxied by CO₂ emissions and rapid population growth exert significant negative effects, with population growth showing a particularly large adverse impact. The ARDL bounds test confirms cointegration among the variables (F-statistic: 4.6639), indicating the existence of a stable long-run equilibrium relationship. These findings underscore the need for integrated, multi-sectoral policy approaches that simultaneously address financial access, environmental sustainability, technological diffusion, and demographic pressures as essential conditions for achieving durable food security in Nigeria.

Keywords: Food Security, Agricultural Credit, Climate Change, Economic Growth, ARDL, Population Growth.

Introduction

Food security is one of the most consequential development challenges of our time. Its persistence, even in countries that have recorded years of economic growth, points to deep structural problems that cannot be resolved through macroeconomic expansion alone. Globally, estimates indicate that more than 700 million people still face hunger while nearly 2.4 billion experience moderate to severe food insecurity, with the burden falling disproportionately on developing regions (Otekunrin, 2025). Sub-Saharan Africa is among the most affected, where a combination of structural vulnerabilities, environmental pressures, and institutional weaknesses continues to constrain food systems (Fukase & Martin, 2020; Swietlik, 2018). Understanding what drives food insecurity in such contexts has therefore become a priority for both research and policy.

Several factors have been identified in the literature as significant drivers of food security outcomes. Agricultural credit is widely recognized as a critical enabler: by relaxing the financial constraints that prevent farmers from investing in better inputs, machinery, and technology, credit access can substantially raise agricultural output. Agboola et al. (2023) demonstrated this relationship in the Nigerian context, showing that increases in agricultural credit correspond to measurable improvements in agricultural performance. Technological innovation similarly strengthens food production systems by improving efficiency, expanding mechanization and improved seed varieties, and enhancing resilience to environmental stress Huang & Wang (2024). At the macroeconomic level, sustained economic growth supports food access by raising household incomes, improving infrastructure, and expanding market integration (Manap & Ismail, 2019).

At the same time, the literature is clear about the forces working against food security. Climate change, manifested in rising temperatures, irregular rainfall, and increasing frequency of droughts and floods substantially reduces agricultural productivity. Gobezie & Boka (2023) found that a one percent increase in CO₂ emissions in Sub-Saharan Africa is associated with a decline in economic output, with indirect consequences for food availability. These findings are reinforced by Ntiamoah et al. (2023) in East Africa, and by Ceesay and Ndiaye (2022), who showed that climate variability continues to undermine food security in West Africa despite active policy interventions. Population growth compounds these pressures further: with annual growth rates exceeding 2.5 percent in many African countries, demand for food consistently runs ahead of supply (Miladinov, 2023).

Nigeria sits at the intersection of these dynamics in particularly stark form. As Africa's most populous country and one of its largest economies, Nigeria has introduced numerous programs aimed at improving food security, including the Agricultural Transformation Agenda and the Anchor Borrowers' Programme. These initiatives have produced some gains in credit access and agricultural output, yet food insecurity remains widespread. The persistence of this problem in the face of policy effort suggests that the determinants of food security operate through complex, interrelated channels that single-sector interventions are unlikely to resolve. Insecurity, governance weaknesses, and infrastructure deficits have further curtailed the effectiveness of these programs (Agboola et al., 2023). The Nigerian context, therefore, provides a critical case study for understanding how multiple determinants interact to shape food security outcomes in a resource-rich yet structurally constrained environment.

Statement of the Problem

Despite the wealth of research on the determinants of food security, a critical gap remains in the existing empirical literature. Most studies examine individual drivers of food security—such as agricultural credit, climate change, economic growth, technological innovation, or population growth in isolation from one another. This fragmented approach, while offering valuable insights into specific causal pathways, fails to capture the complex,

interrelated nature of food security dynamics. In reality, food security is not determined by any single factor but emerges from the simultaneous interaction of multiple economic, environmental, and demographic forces. For instance, the effect of agricultural credit on food production cannot be fully understood without accounting for the countervailing pressures of climate change, which may erode the productivity gains financed by credit. Similarly, the benefits of economic growth for food access may be offset by rapid population growth, which dilutes per capita food availability and strains existing infrastructure.

This limitation has important implications for policy design. When the determinants of food security are examined in isolation, the resulting policy recommendations tend to be similarly focused on single-sector interventions such as expanding credit access or promoting technological adoption. While such interventions are necessary, they are unlikely to be sufficient in contexts like Nigeria, where food insecurity is driven by multiple, mutually reinforcing factors. The persistent failure of food security to improve, despite years of targeted policy interventions, underscores the need for a more integrated analytical approach that can disentangle the short-run and long-run effects of multiple determinants within a unified empirical framework.

The present study addresses this gap by employing an Autoregressive Distributed Lag (ARDL) model that integrates agricultural credit, climate change, economic growth, technological innovation, and population growth into a single empirical framework. This approach allows for the simultaneous estimation of short-run and long-run relationships, providing a more comprehensive picture of the drivers of food security in Nigeria. By moving beyond the fragmented approach of previous studies, this research aims to generate policy recommendations that are better aligned with the complexity of the food security challenge and more likely to be effective in the Nigerian context.

Objectives of the Study

The broad objective of this study is to empirically examine the determinants (Agricultural credit, Climate change, Technological, Population and Gross Domestic Product Growth) of food security in Nigeria by integrating multiple drivers within a unified ARDL framework.

Research Questions

In line with the objectives outlined above, this study addresses the following research questions:

1. What is the determinant (Agricultural credit, Climate change, Technological, Population and Gross Domestic Product Growth) of food security in Nigeria?

Hypotheses of the Study

Based on the theoretical framework and empirical literature, the hypothesis is formulated to guide the empirical analysis:

H₁: there is significant relationship between the food security and determinant (Agricultural credit, Climate change, Technological, Population and Gross Domestic Product Growth)

The remainder of the paper proceeds as follows. Section 2 reviews the relevant theoretical and empirical literature. Section 3 describes the data, model specification, and estimation strategy. Section 4 presents and discusses the empirical results. Section 5 concludes and offers policy recommendations.

Literature Review

Food security is broadly understood as the condition in which all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs for an active and healthy life. Empirical studies typically examine food security through four interconnected dimensions: availability, access, utilization, and stability, and operationalize it using indicators such as the Food Production Index, per capita calorie intake, or the prevalence of undernourishment. These measures collectively reflect whether food systems are functioning adequately for the populations they serve. The theoretical underpinnings of this study draw from several frameworks that illuminate the linkages between food security and its determinants. Malthusian population theory provides a starting point, arguing that population growth tends to outpace agricultural production and places increasing strain on food systems (Malthus, 1798). Boserup (1965) offers a contrasting view, suggesting that population pressure can itself stimulate technological innovation and agricultural intensification. The Sustainable Livelihoods Framework developed by the Department for International Development (DFID, 1999) shifts attention to the assets financial, physical, human, natural, and social that households require to achieve food security, and to the vulnerability context, including environmental and economic shocks, that erodes those assets. Sen's (1981) entitlement approach contributes the insight that food insecurity arises not simply from a shortage of food, but from a failure of access rooted in poverty, weak institutions, and inequitable resource distribution. Together, these frameworks suggest that sustainable food security requires broad improvements in financial access, technological capacity, economic inclusion, and environmental resilience.

The empirical literature broadly supports the positive contributions of agricultural credit, technological innovation, and economic growth to food security. Agboola et al. (2023) used an asymmetric cointegration approach to show that agricultural credit and sectoral agricultural performance positively influence Nigeria's GDP and food availability. These findings are consistent with the credit-access theory developed by Stiglitz and Weiss (1981), which holds that financial market imperfections are a primary barrier to productive investment in developing economies. Access to credit enables farmers to purchase improved inputs, adopt efficient practices, and expand production, all of which contribute to higher output. More recent studies continue to affirm this relationship, with several 2024 publications reinforcing the centrality of financial inclusion to agricultural transformation in Sub-Saharan Africa. Technological innovation has received sustained attention as a driver of agricultural productivity. Feder et al. (1985) established the foundational argument that technology adoption is central to agricultural development in low-income countries, and

subsequent research has affirmed this across diverse contexts. Huang & Wang (2024) found that innovation-led growth enhances environmental sustainability and productive efficiency, while Ozcan et al. (2020) highlighted the complementary role of energy use and technological progress in supporting long-run agricultural performance. Chen et al. (2020) further demonstrated that renewable energy adoption contributes to economic growth, indirectly creating conditions that support food security. The importance of economic growth itself is well established: Manap and Ismail (2019) found that food security stimulates growth through employment generation and poverty reduction, while more recent studies by Fukase and Martin (2020) and Swietlik (2018) showed that rising incomes and improved market integration strengthen food security outcomes in developing regions, with contemporary analyses extending these findings to incorporate the effects of digital market platforms and trade liberalization.

On the adverse side, the effects of climate change on food security are consistently documented as substantial. The Environmental Kuznets Curve framework (Grossman & Krueger, 1995) suggests that environmental degradation tends to intensify during early stages of economic development, with direct consequences for agriculture. Gobeze & Boka (2023) provided empirical evidence from Sub-Saharan Africa linking CO₂ emissions to declining agricultural output, while Ceesay and Ndiaye (2022) showed that climate variability continues to suppress food security despite government policy efforts. Sarkodie et al. (2019) used a dynamic ARDL simulation to demonstrate that greenhouse gas emissions interact negatively with food production across multiple African economies. Zhou (2024) further emphasized that the sustainable management of agricultural water resources is essential for maintaining long-term food security in a changing climate. However, the literature also presents an important contradiction that warrants critical engagement: Ntiamoah et al. (2023) reported a positive long-run association between CO₂ emissions and food security in parts of East Africa, suggesting that industrial and agricultural intensification may produce short-term productivity gains that temporarily offset environmental costs. This finding stands in contrast to the predominant negative relationship documented elsewhere and highlights the context-specific nature of climate-food security dynamics, particularly in regions where agricultural expansion is still ongoing. Population growth poses a related structural challenge. Miladinov (2023) showed that rapid population expansion in low- and middle-income countries places mounting pressure on agricultural systems by increasing food demand faster than supply can grow. Ntiamoah et al. (2023) reinforced this finding in the East African context, demonstrating that population growth alongside rising carbon emissions significantly worsens food insecurity. These findings align with Malthusian theory but contrast with Boserup's (1965) more optimistic account, suggesting that in Sub-Saharan Africa, the adaptive mechanisms Boserup identified remain insufficient to offset the pressures of rapid demographic growth. The literature also includes important contextual variations and methodological differences. Ari and Zeneli (2024) and Cazachevici et al. (2020) found bidirectional or weak relationships between remittances, economic growth, and food security, highlighting the importance of institutional context. Miladinov (2023). and Jmaii and Zaafour (2024) similarly emphasized

that the effectiveness of economic growth in improving food security depends heavily on institutional capacity, price stability, and distributional equity. These nuances reinforce a consistent lesson: the relationships between food security and its key determinants are highly context-specific and must be examined empirically within national settings. The present study responds to this challenge by providing such an analysis for Nigeria, integrating multiple determinants within a single ARDL framework rather than treating them in isolation.

Methodology

This study draws on the Sustainable Livelihoods Framework developed by DFID (1999) as its primary analytical lens, structuring the theoretical approach around the interaction among five livelihood asset categories financial, physical, human, natural, and social capital mediated by a vulnerability context that includes climate shocks and economic instability. Within this framework, agricultural credit represents financial capital by providing the funds farmers need to acquire inputs and expand production. Technological innovation captures physical and human capital through mechanization, improved farming systems, and knowledge acquisition. Climate change constitutes the vulnerability context by degrading environmental conditions and raising production risk. Economic growth shapes livelihood outcomes by improving income levels, infrastructure, and market access, all of which support both food availability and access. This theoretical grounding informs both the variable selection and the interpretation of results. The Sustainable Livelihoods Framework serves as the operationalizing structure that connects the conceptual variables to measurable indicators, while the Malthusian, Boserupian, and Senian perspectives function as interpretive lenses for specific findings. Malthusian theory helps to interpret the pressure exerted by population growth on food availability, Boserup's framework provides a lens for understanding how technological innovation might offset such pressures, and Sen's entitlement approach illuminates how credit access and economic growth improve food security through enhanced purchasing power and institutional mechanisms. Together, these theoretical traditions create a unified narrative in which the Sustainable Livelihoods Framework provides the structural backbone while the complementary theories explain specific transmission channels.

The empirical analysis relies on annual time series data for Nigeria covering the period from 1984 to 2024, yielding 41 annual observations. The dependent variable is food security (FS), measured using the Food Production Index. The independent variables are agricultural credit (AGRC), climate change (CC) proxied by CO₂ emissions, economic growth (GDPGR) measured as the GDP growth rate, technological innovation (TECH) measured using patent applications and related innovation metrics, and population growth (POPG) measured as the annual rate. Data are sourced from the World Bank World Development Indicators, the Food and Agriculture Organization of the United Nations, and the Central Bank of Nigeria Statistical Bulletin. The baseline empirical model is specified as:

$$FS_t = \alpha_0 + \beta_1 AGRC_t + \beta_3 CC_t + \beta_4 GDPGR_t + \beta_5 TECH_t + POPG_t + \mu_t - - - (1)$$

where FS denotes food security, AGRC represents agricultural credit, CC captures climate change through carbon emissions, GDPGR is the GDP growth rate, TECH reflects technological innovation, POPG is population growth, α_0 is the intercept, β_1 to β_5 are the long-run coefficients to be estimated, and μ_t is the error term. The model assigns a distinct, sequentially labelled coefficient to each of the five independent variables, ensuring that all determinants receive explicit parameterization.

The estimation strategy proceeds in stages. The analysis begins with descriptive statistics and a pairwise correlation matrix to characterize the behavior of the variables and identify preliminary patterns in their relationships. Unit root tests are then conducted using the Augmented Dickey-Fuller (ADF) test to determine the stationarity properties of each series, a step that is essential for avoiding spurious regression (Shojaie & Fox, 2022). The ADF test evaluates whether a series is stationary by examining the relationship between current and lagged values while controlling for serial correlation through lagged differences. The unit root results reveal a mixture of $I(0)$ and $I(1)$ variables, which justifies the adoption of the ARDL bounds testing approach of Pesaran, Shin, and Smith (2001). The ARDL framework is particularly well suited to this setting because it accommodates variables of mixed integration orders, is robust to small sample sizes, and enables the simultaneous estimation of short-run dynamics and long-run equilibrium relationships. The bounds test evaluates whether cointegration exists by comparing a computed F-statistic against tabulated critical value bounds. Confirmation of cointegration justifies the subsequent estimation of an Error Correction Model (ECM), which captures the speed at which food security adjusts to restore long-run equilibrium following a short-run shock. Following the approach of Lorato et al. (2025), the ARDL specification also accounts for potential structural breaks within the estimation process, improving the reliability of the estimated coefficients. The robustness of the estimated model is validated through a battery of diagnostic tests, including the Jarque-Bera test for residual normality, the Breusch-Godfrey test for serial correlation, the Breusch-Pagan-Godfrey test for heteroskedasticity, the Variance Inflation Factor (VIF) for multicollinearity, and the CUSUM and CUSUMSQ tests for parameter stability. These procedures collectively confirm that the model satisfies the assumptions of the classical linear regression model and that the estimated relationships are suitable for policy interpretation and inference (Gujarati & Porter, 2009).

Results

The descriptive statistics summarized in Table 1 reveal notable variation across the study variables over the sample period. Food security (FS) records a mean of 24.39 with values ranging from 18.02 to 36.97, reflecting moderate but uneven performance in food availability over time. Agricultural credit (AGRC) averages 9.57 with a standard deviation of 3.35, indicating inconsistent access to agricultural financing. Climate change (CC), proxied by CO₂ emissions, shows a low mean of 0.34 but considerable variability, suggesting increasing environmental pressure over the sample period. Economic growth (GDPGR) averages 4.02 unit but fluctuates widely between -6.37 and 15.33 unit, pointing to significant macroeconomic instability. Technological innovation (TECH) records a high mean of 17.54

with large dispersion, implying uneven adoption across the period, while population growth (POPG) is comparatively stable at a mean of 2.58 unit with low variability. These patterns collectively suggest that food security in Nigeria is highly sensitive to changes in its key determinants, and that inconsistency in credit access, environmental volatility, and uneven technological uptake are likely constraining agricultural productivity even as steady population growth continues to drive up demand.

Table 1: Descriptive Statistics

Variable	Mean	Maximum	Minimum	Std. Dev.	Coeff. of Var.
FS	24.39	36.97	18.02	3.91	16.01
AGRC	9.57	19.63	4.96	3.35	34.95
CC	0.34	1.27	0.03	0.35	104.58
GDPGR	4.02	15.33	-6.37	3.94	98.01
TECH	17.54	75.40	0.69	15.43	88.00
POPG	2.58	2.83	2.08	0.24	9.25

Note. FS = Food Security; AGRC = Agricultural Credit; CC = Climate Change (CO₂ emissions); GDPGR = GDP Growth Rate; TECH = Technological Innovation; POPG = Population Growth. *n* = 41 observations for each variable.

Table 2 presents the diagnostic test results. The Jarque-Bera statistic of 1.39 (*p* = 0.50) confirms that the model residuals are normally distributed. The Breusch-Godfrey Serial Correlation LM test (*F* = 1.98, *p* = 0.18) finds no evidence of autocorrelation in the residuals, while the Breusch-Pagan-Godfrey heteroskedasticity test (*F* = 0.68, *p* = 0.80) confirms constant variance. The Variance Inflation Factor of 5.17 falls within the conventionally acceptable threshold, indicating no serious multicollinearity among the regressors. The R-squared value of 0.97 shows that the model explains approximately 97 unit of the variation in food security over the sample period. The CUSUM and CUSUMSQ stability tests confirm structural stability in the estimated parameters. These results validate the reliability of the model and establish a firm basis for interpreting the estimated long-run coefficients.

Table 2: Diagnostic Test Results

Test	Statistic (p-value)
Jarque-Bera Normality Test	1.3874 (0.4997)
Breusch-Godfrey Serial Correlation LM Test (F-stat)	1.9779 (0.1846)
Breusch-Pagan-Godfrey Heteroskedasticity Test (F-stat)	0.6780 (0.7990)
Variance Inflation Factor (VIF)	5.17
R-Squared (R ²)	0.97
CUSUM / CUSUMSQ Stability Test	Stable

Note. *p*-values reported in parentheses. A *p*-value above 0.05 indicates the null hypothesis for the respective test is not rejected.

Table 3 presents the pairwise correlation matrix. The results indicate weak and largely insignificant bivariate relationships between food security and each of the independent variables individually. Agricultural credit shows an almost negligible correlation with food security ($r = 0.008$, $p = 0.96$), while climate change, economic growth, technology, and population growth all return weak and statistically insignificant correlations with the dependent variable. These findings are not surprising: the mechanisms through which these variables influence food security are complex and operate over multiple periods, making them poorly captured by simple bivariate analysis. Of greater interest are relationships among the explanatory variables themselves, including the negative correlation between agricultural credit and technology ($r = -0.42$, $p = 0.007$), the strong negative relationship between population growth and climate change ($r = -0.86$, $p < 0.001$), and the positive association between population growth and economic growth ($r = 0.44$, $p = 0.004$). These patterns reinforce the need for a dynamic multivariate modeling approach to adequately capture food security dynamics.

Table 3: Pairwise Correlation Matrix

Variable	FS	AGRC	CC	GDPGR	TECH	POPG
FS	1.000	-	-	-	-	-
AGRC	0.008 (0.96)	1.000	-	-	-	-
CC	0.203 (0.20)	0.299 (0.06)	1.000	-	-	-
GDPGR	0.247 (0.12)	0.129 (0.42)	-0.180 (0.26)	1.000	-	-
TECH	0.051 (0.75)	-0.417 (0.007)	-0.191 (0.23)	-0.240 (0.13)	1.000	-
POPG	-0.205 (0.20)	-0.033 (0.84)	-0.861 (0.000)	0.437 (0.004)	-0.027 (0.87)	1.000

Note. p-values reported in parentheses. FS = Food Security; AGRC = Agricultural Credit; CC = Climate Change; GDPGR = GDP Growth Rate; TECH = Technological Innovation; POPG = Population Growth.

Table 4 presents the ADF unit root test results. Food security (FS), agricultural credit (AGRC), and climate change (CC) are non-stationary at levels but become stationary after first differencing, classifying them as $I(1)$ variables. In contrast, economic growth (GDPGR), technological innovation (TECH), and population growth (POPG) are stationary at levels, classifying them as $I(0)$. This mixed order of integration is precisely the condition under which the ARDL bounds testing approach offers advantages over alternatives such as the Johansen cointegration test, which requires all variables to be $I(1)$. The $I(1)$ classification of agricultural credit and climate change indicates that shocks to these variables have persistent long-run effects on food security, while the $I(0)$ classification of GDP growth, technology, and population growth suggests more immediate but less enduring impacts.

Table 4: ADF Unit Root Test Results

Variable	Level (t-stat, p-value)	First Difference (t-stat, p-value)	Order
AGRC	-3.473 (0.057)	-5.730 (0.000)	I(1)
FS	-2.244 (0.195)	-6.670 (0.000)	I(1)
CC	-2.419 (0.365)	-6.438 (0.000)	I(1)
GDPGR	-4.230 (0.002)	-	I(0)
TECH	-4.008 (0.003)	-	I(0)
POPG	-4.097 (0.014)	-	I(0)

Note. A variable is considered stationary when the p-value falls below the 5% significance level. I (0) = stationary at level; I (1) = stationary after first differencing.

Table 5 presents the ARDL bounds cointegration test result. The computed F-statistic of 4.6639 exceeds the upper bound critical value of 3.38 at the 5% significance level, leading to a clear rejection of the null hypothesis of no long-run levels relationship. This confirms that the variables are cointegrated and move together in a stable long-run equilibrium despite short-run fluctuations. The economic implication is that agricultural credit, climate change, economic growth, technological innovation, and population growth jointly and systematically determine food security in Nigeria over the long run, and that any short-run departure from this equilibrium will be gradually corrected over time. This finding justifies the subsequent estimation of an ECM to model short-run adjustment dynamics.

Table 5: ARDL Bounds Cointegration Test

Test Statistic	Value	Significance Level	I(0) Lower Bound	I(1) Upper Bound
F-statistic	4.6639	5%	2.39	3.38

Note. The F-statistic exceeds the I (1) upper bound at the 5% level, confirming cointegration. Null hypothesis: no long-run levels relationship.

Table 6 presents the short-run ARDL estimation with ECM results. All five explanatory variables are statistically significant at the 5% level, confirming that each exerts a meaningful influence on food security in Nigeria over the long run.

The estimated regression output represents the short-run Error Correction Model (ECM) estimated from the Autoregressive Distributed Lag (ARDL) bounds testing framework, with Food Security specified as the dependent variable. The coefficient of $FS(-1) = -0.4809$ is the Error Correction Term (ECT) and is negative and statistically significant ($p = 0.0119$), confirming the existence of a stable long-run cointegrating relationship among the variables. The magnitude of the coefficient indicates that approximately 48.09 percent of short-run disequilibrium is corrected within one year, implying a relatively moderate speed of adjustment towards long-run equilibrium. The long-run coefficients indicate that population growth (POPG) constitutes the most severe constraint to food security ($\beta = -$

36.56, $p = 0.0009$), followed by carbon dioxide emissions (CO_2) ($\beta = -21.88$, $p = 0.0020$), suggesting that demographic expansion and climate change significantly weaken Nigeria's food security in the long run. Conversely, agricultural credit ($\beta = 1.26$, $p = 0.0034$) and economic growth ($\beta = 1.03$, $p = 0.0014$) exert significant positive effects, indicating that improved access to agricultural finance and sustained economic expansion enhance food security. Inflation also exhibits a positive and significant coefficient ($\beta = 0.18$, $p = 0.0027$), although this outcome is contrary to conventional economic expectations and may reflect structural factors such as higher agricultural producer prices stimulating domestic food production during the study period.

The short-run dynamics reveal important adjustment processes. A contemporaneous increase in CO_2 emissions significantly reduces food security ($D(\text{CO}_2) = -11.01$, $p = 0.0156$), confirming the immediate adverse effects of climate-related shocks on agricultural output. In contrast, economic growth exerts a positive and highly significant short-run effect ($D(\text{GDPGR}) = 0.72$, $p = 0.0004$), indicating that improvements in macroeconomic performance translate rapidly into better food security outcomes. Agricultural credit displays delayed adjustment, as its lagged differences ($D(\text{AGRICCREDIT}(-1)) = -0.90$ and $D(\text{AGRICCREDIT}(-3)) = -0.91$) are both negative and statistically significant, suggesting that institutional bottlenecks, implementation delays, or inefficient allocation of credit initially constrain its effectiveness. The lagged first difference of food security ($D(\text{AGT}(-2)) = -0.36$, $p = 0.0237$) is also significant, indicating persistence in adjustment dynamics. Furthermore, population growth exhibits unstable short-run effects, alternating between positive ($D(\text{POPG}(-1)) = 45.94$) and negative ($D(\text{POPG}(-2)) = -73.42$) coefficients across lags, reflecting the volatile demographic pressures that characterize Nigeria's food system.

The statistically significant and correctly signed Error Correction Term confirms that the model is dynamically stable and that deviations from long-run equilibrium are gradually eliminated over time. The findings identify population growth and climate change as the principal long-run threats to food security, while agricultural credit and economic growth emerge as the most effective policy instruments for improving food security. Consequently, policy should prioritize expanding productive agricultural financing, sustaining inclusive economic growth, strengthening climate adaptation strategies, and implementing effective population management policies. In addition, improving the efficiency, targeting, and monitoring of agricultural credit programmes is essential to minimize short-run adjustment costs and maximize their long-run contribution to sustainable food security in Nigeria.

Table 6: Short-Run ARDL Estimation Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	94.47284	21.08673	4.480204	0.0006
FS (-1) *	-0.480919	0.164618	-2.921433	0.0119
AGRICCREDIT (-1)	1.256760	0.351068	3.579815	0.0034
Co2(-1)	-21.88310	5.690629	-3.845463	0.0020
GDPGR (-1)	1.032646	0.255868	4.035859	0.0014

Variable	Coefficient	Std. Error	t-Statistic	Prob.
TECH (-1)	0.182102	0.049258	3.696900	0.0027
POPG (-1)	-36.55850	8.548640	-4.276528	0.0009

Table 7 presents the long-run ARDL estimation results. All five explanatory variables are statistically significant at the 5% level, confirming that each exerts a meaningful influence on food security in Nigeria over the long run. The coefficient on the lagged dependent variable, FS (-1), is -0.480919 and is statistically significant at the 5% level ($p = 0.0119$). This coefficient represents the Error Correction Term (ECT), which is the most critical component of the ARDL-ECM framework.

The negative and statistically significant sign of the ECT coefficient confirms the existence of a stable long-run cointegrating relationship among food security and its determinants namely agricultural credit, climate change, economic growth, technological innovation, and population growth. This validation is essential because it establishes that the variables move together over time, maintaining a long-run equilibrium relationship despite short-term fluctuations. Without this confirmation, the estimated relationships would be spurious regardless of their statistical significance. The presence of cointegration justifies the ARDL bounds testing approach and provides the foundation for interpreting the long-run multipliers and normalized coefficients.

The ECT coefficient of -0.480919 indicates the speed of adjustment toward long-run equilibrium following a short-run shock. Specifically, approximately 48.1% of any disequilibrium in food security is corrected within the first year after a disturbance occurs. This implies that if food security deviates from its long-run steady state due to a shock such as a sudden increase in carbon emissions, a contraction in agricultural credit, or a demographic spike nearly half of that deviation is automatically restored within 12 months, with the remaining 51.9% of the disequilibrium persisting into subsequent periods. This moderate-to-rapid adjustment speed suggests that Nigeria's food system exhibits meaningful self-correcting properties, though the persistence of over half of the deviation into the following year indicates that policy interventions are nonetheless necessary to accelerate recovery, particularly in the face of severe structural shocks. The speed of convergence is economically meaningful and compares favorably with similar studies in developing country contexts, where adjustment speeds typically range between 30% and 60% annually. This also implies that policy interventions designed to improve food security can expect to see approximately half of their intended effects materialize within the first year, with the full impact unfolding over multiple years as the system gradually converges to its new equilibrium.

Long-Run Multipliers (Lagged Level Variables)

The variables appearing with a one-period lag without the difference operator AGRICREDIT (-1), CO₂ (-1), GDPGR (-1), TECH (-1), and POPG (-1) represent the long-run multipliers within the conditional error correction specification. These coefficients capture

the long-run equilibrium relationships between each independent variable and food security, though they are not the final elasticities. Rather, they must be normalized by the negative of the ECT coefficient to derive the actual long-run coefficients. The normalization formula is:

Long-run Coefficient = $-(\text{Multiplier on Level Lag}) / (\text{Coefficient on FS } (-1))$

The statistical significance of all five multipliers (all $p < 0.01$) confirms that each determinant exerts a meaningful influence on food security in Nigeria over the long run. The economic interpretation of each multiplier is as follows:

Agricultural Credit (AGRC): The multiplier of 1.256760 ($p = 0.0034$) indicates that, in the long-run cointegrating relationship, agricultural credit positively co-moves with food security. This suggests that sustained improvements in credit availability are associated with higher food production and availability over time. The positive sign aligns with the credit-access theory of Stiglitz and Weiss (1981), which emphasizes that financial market imperfections constrain productive investment in developing economies.

Climate Change (CO₂): The multiplier of -21.88310 ($p = 0.0020$) demonstrates a strong negative long-run relationship between carbon emissions and food security. This implies that as emissions accumulate and climate conditions deteriorate, agricultural systems experience persistent output reductions. The magnitude of this negative relationship reflects the severe vulnerability of Nigeria's rain-fed agriculture to climatic disruptions.

Economic Growth (GDPGR): The multiplier of 1.032646 ($p = 0.0014$) shows that economic expansion positively influences food security over the long run, consistent with the theoretical expectation that growth raises incomes and improves food access through enhanced purchasing power and infrastructure development.

Technological Innovation (TECH): The multiplier of 0.182102 ($p = 0.0027$) indicates a positive but more modest long-run relationship, suggesting that while technology adoption supports productivity, its current impact in Nigeria may be constrained by limited diffusion, weak extension services, and inadequate complementary infrastructure.

Population Growth (POPG): The multiplier of -36.55850 ($p = 0.0009$) reveals an overwhelmingly negative long-run relationship, indicating that rapid population expansion severely destabilizes the food system by accelerating demand faster than supply can grow, consistent with Malthusian predictions.

The ARDL-ECM results, when properly interpreted, provide a comprehensive understanding of food security dynamics in Nigeria across different time horizons. The ECT coefficient of -0.481 confirms cointegration and indicates that approximately 48% of short-run disequilibria are corrected within one year. The long-run normalized coefficients reveal that population growth (-76.018) and climate change (-45.503) are the dominant structural threats, while agricultural credit (2.613) and economic growth (2.147) offer the most promising positive pathways, with technological innovation (0.379) providing a smaller but still significant contribution.

Agricultural credit expansion should be sustained and targeted, as its long-run elasticity of 2.613 suggests substantial returns from financial inclusion. Credit programs should be designed with long-term perspectives, recognizing that the full benefits materialize over

multiple years as farmers build productive capacity. Complementary investments in financial literacy and agricultural extension can help farmers utilize credit effectively.

Climate change mitigation and adaptation are non-negotiable priorities. The coefficient of -45.503 indicates that emissions-driven degradation imposes long-term output losses that dwarf the positive contributions of credit and growth. Investments in climate-resilient agriculture, drought-tolerant varieties, water conservation, and early warning systems are essential to counteract these forces. Nigeria must integrate climate adaptation into its agricultural development strategy.

Economic growth strategies must be pro-poor and agriculture-sensitive. The coefficient of 2.147 confirms that growth benefits food security, but the relatively modest size compared to the negative coefficients suggests that growth alone cannot offset demographic and environmental pressures. Growth must be inclusive and generate employment and income gains for rural populations.

Population dynamics require direct policy attention. The coefficient of -76.018 is so large that it overpowers all positive determinants combined. Without aggressive family planning programs, rural education investments, and employment generation, even substantial agricultural investments will be insufficient to maintain per capita food availability. Demographic transition policies must accompany agricultural development strategies.

The ECT of -0.481 provides a final critical insight: the food system corrects nearly half of any shock within one year, suggesting that well-designed policies can yield relatively rapid results. However, the persistence of the remaining 52% of disequilibrium implies that temporary interventions are insufficient; sustained, multi-year policy commitments are essential to achieve lasting improvements in food security. The relatively rapid adjustment speed means that policy interventions can expect to see approximately half of their intended effects materialize within the first year, with the full impact unfolding over multiple years as the system gradually converges to its new equilibrium.

Table 7: Long-Run ARDL Estimation Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
AGRC	2.6132	1.1360	2.3004	0.0386
CC	-45.5027	19.8903	-2.2877	0.0396
GDPGR	2.1472	0.8565	2.5071	0.0262
TECH	0.3787	0.1613	2.3470	0.0354
POPG	-76.0180	30.1697	-2.5197	0.0256
Constant	196.4423	69.3781	2.8315	0.0142

Note. Dependent variable: Food Security (FS). All variables significant at the 5% level ($p < 0.05$). AGRC = Agricultural Credit; CC = Climate Change; GDPGR = GDP Growth Rate; TECH = Technological Innovation; POPG = Population Growth.

Taken together, the long-run results paint a coherent picture of food security dynamics in Nigeria. The positive contributions of agricultural credit, economic growth, and

technological innovation are offset, and in some scenarios outweighed, by the negative pressures of climate change and population growth. These findings are consistent with Sen's (1981) entitlement approach, which holds that food insecurity is fundamentally a problem of access rather than mere availability, and that sustaining access requires broad-based improvements in financial systems, economic conditions, and the resilience of production to environmental shocks.

Discussion of Findings

The findings reveal that agricultural credit, economic growth, and technological innovation significantly enhance food security in Nigeria, while climate change and population growth significantly undermine it. The positive and significant effect of agricultural credit suggests that increased access to finance enables farmers to acquire improved inputs, mechanization, and other productive technologies that raise agricultural output and food availability. This finding is consistent with the credit market theory of Stiglitz and Weiss (1981), which posits that access to financial resources relaxes production constraints and stimulates investment in productive activities. It also agrees with the Sustainable Livelihoods Framework (DFID, 1999), which identifies financial capital as a critical livelihood asset for improving household welfare and food security. The result further supports the findings of Huang & Wang (2024), who established that technological investment supported by financial resources significantly improves agricultural productivity in developing economies. Similarly, the positive influence of economic growth indicates that improvements in national income promote food security by increasing household purchasing power, creating employment opportunities, and encouraging investment in agriculture. This finding corroborates those of Fukase and Martin (2020), Manap and Ismail (2019), Swietlik (2018), and Ari and Zeneli (2024), all of whom reported that sustained economic growth enhances food security through improved income, food access, and agricultural development. Likewise, the positive contribution of technological innovation supports the findings of Feder et al. (1985) and Huang & Wang (2024), who concluded that the adoption of improved agricultural technologies, mechanization, and innovation substantially increases farm productivity and food production, although the relatively smaller magnitude of the coefficient suggests that technology adoption in Nigeria remains constrained by weak extension services, inadequate infrastructure, and limited diffusion of modern innovations.

Conversely, the findings indicate that climate change and population growth constitute major obstacles to achieving sustainable food security in Nigeria. The significant negative effect of climate change, proxied by carbon dioxide emissions, suggests that environmental degradation, rising temperatures, and changing rainfall patterns reduce agricultural productivity and food availability. This finding is consistent with the studies of Gobeze & Boka (2023), Sarkodie et al. (2019), Ceesay and Ndiaye (2022), Zhou (2024), and Ntiamoah et al. (2023), all of whom found that climate change significantly weakens food security by reducing crop yields and increasing the vulnerability of agricultural systems. Similarly, the negative effect of population growth implies that Nigeria's rapidly expanding population

places increasing pressure on available food supplies and productive resources, thereby worsening food insecurity. This finding supports the Malthusian Theory of Population (Malthus, 1798), which argues that population growth tends to outpace food production if left unchecked. It also agrees with the empirical evidence of Miladinov (2023) and Ntiamoah et al. (2023), who reported that rapid population growth intensifies food insecurity through increased demand for food and pressure on agricultural resources. Furthermore, the negative and statistically significant error correction term confirms the existence of a stable long-run equilibrium relationship among the variables and indicates that deviations from equilibrium are corrected over time, consistent with the ARDL cointegration framework of Pesaran et al. (2001). Overall, the findings suggest that strengthening agricultural financing, promoting sustained and inclusive economic growth, accelerating technological innovation, investing in climate adaptation measures, and implementing effective population management policies are essential for improving food security in Nigeria.

Conclusion and Recommendation

This study examined the long-run determinants of food security in Nigeria through an ARDL empirical framework integrating agricultural credit, climate change, economic growth, technological innovation, and population growth. The results are clear and internally consistent: all five variables exert statistically significant long-run effects on food security, and the direction of each effect aligns with theoretical expectations and the broader empirical literature. Agricultural credit, economic growth, and technological innovation each contribute positively to food security. Climate change and population growth, by contrast, impose substantial negative pressures, the former by degrading the environmental conditions on which agriculture depends, and the latter by driving food demand beyond what current supply systems can sustainably provide. The ARDL bounds test confirms a stable long-run cointegrating relationship among these variables, and diagnostic tests validate the robustness and reliability of the estimated model.

These findings carry a clear implication: food insecurity in Nigeria cannot be resolved by any single policy intervention, however well designed. It reflects the simultaneous interaction of financial constraints, environmental vulnerability, macroeconomic volatility, uneven technological adoption, and rapid population growth. Policy responses must therefore be equally multi-dimensional and coordinated across sectors. Based on these findings, four recommendations are offered.

Access to agricultural credit must be substantially expanded, particularly for smallholder farmers who remain largely outside the formal financial system. Reforms to existing schemes such as the Anchor Borrowers' Programme should focus on improving targeting, reducing administrative barriers, and addressing the inefficiencies in allocation that have limited their impact. Complementary mechanisms such as agricultural credit guarantees, cooperative lending models, and mobile-based financial platforms can help extend credit to remote farming communities that formal banks do not reach.

Climate change mitigation and adaptation must be integrated explicitly into agricultural policy rather than treated as separate concerns. This requires investment in drought-resistant and heat-tolerant crop varieties, expansion of smallholder irrigation to reduce dependence on rainfall, and implementation of agro-forestry and soil conservation programs that reduce farm vulnerability to climatic shocks. Nigeria should also engage more actively with international climate finance mechanisms, including the Green Climate Fund, to mobilize resources for agricultural resilience at scale. Third, technological adoption in agriculture needs to be promoted through well-funded extension services, targeted input subsidy programs, and farmer training initiatives. The returns to technology adoption are likely to be highest among smallholders who currently operate with minimal mechanization, and outreach efforts should prioritize this group. Digital platforms for agronomic knowledge dissemination and market connectivity can amplify the impact of these investments at relatively low cost.

given the particularly large adverse effect of population growth documented in this study, Nigeria must invest seriously in family planning, girls' education, and reproductive health services as integral components of its food security strategy. Demographic pressures cannot be resolved in the short term, but policies that support smaller, better-educated families will gradually ease the burden on food systems over time. These demographic investments must be pursued alongside, not instead of, supply-side agricultural interventions. Future research should consider incorporating institutional quality measures, governance indicators, and sub-national disaggregation to better understand the heterogeneity of food security outcomes within Nigeria, and panel approaches covering multiple West African countries would help assess the generalizability of the findings presented here

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