Analysing the Effect of Climate Change Variability on Livestock Productivity in Nigeria

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Abstract
This study investigates the impacts of climate change variability on livestock productivity in Nigeria, employing a Nonlinear Autoregressive Distributed Lag (NARDL) model to analyze time-series data from 1990 to 2023. The results reveal a significant asymmetry in the effects of climatic variables, particularly rainfall and temperature, on livestock production. Positive changes in rainfall were found to enhance livestock output, whereas negative changes significantly reduced productivity, especially during periods of drought. Similarly, temperature variations, both positive and negative, had detrimental effects on livestock productivity due to heat stress and forage quality deterioration. The findings underscore the lagged effects of climatic factors, revealing that past variations in rainfall and temperature exert more profound impacts than current changes. These results highlight the urgent need for adaptive strategies, including climate-resilient livestock systems, improved water and pasture management. This study recommends the adoption of drought-resilient livestock breeds to mitigate productivity losses in arid regions, alongside strengthening water and forage resource management through rainwater harvesting and sustainable rangeland practices among others.
Keywords: Climate change, Livestock, Livestock Productivity, Nonlinear Autoregressive Distributed Lag (NARDL) Model.
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1. Introduction

Climate change represents one of the most pressing global challenges of the 21st century, exerting profound and multifaceted impacts on ecosystems, human livelihoods, and economic activities. Characterized by shifts in temperature, precipitation patterns, and the frequency of extreme weather events, climate change has introduced unprecedented variability into global climatic systems (UN, 1992). These changes, compounded by anthropogenic activities such as industrialization and deforestation, have disrupted natural ecosystems, intensified resource depletion, and altered the functionality of climate systems, with far-reaching implications for agricultural and food production systems (Tol, 2013). In sub-Saharan Africa, where agriculture serves as the cornerstone of rural economies, the sector's vulnerability to climate change is particularly acute, with livestock production standing as one of the most affected subsectors (Gbenga, Fatimoh & Kehinde, 2020).

Livestock production plays a pivotal role in Nigeria's agricultural sector, serving as a vital source of income, employment, and food security for millions of rural households. The country's diverse livestock sector, encompassing cattle, goats, sheep, poultry, and pigs, contributes significantly to national GDP and cultural identity, providing essential resources such as animal protein, milk, hides, and manure for agricultural productivity (Nwosu & Ogbu, 2011). However, this critical subsector is highly sensitive to climate variability, which exacerbates existing production challenges. Rising temperatures, erratic rainfall, and increasing incidences of extreme weather events have disrupted traditional livestock production systems, reducing pasture availability, water resources, and feed quality (Okoro, 2023). Consequently, livestock health and productivity have declined, threatening the livelihoods of millions and undermining the resilience of Nigeria's agricultural landscape.

Empirical evidence underscores the severe implications of climate change on livestock production across regions with similar vulnerabilities. Megersa et al. (2014) documented significant declines in cattle populations in Ethiopia due to reduced rainfall, recurrent droughts, and heightened heat stress, which diminished forage quality and water availability. Similarly, Habte et al. (2022) observed that drought conditions and declining rainfall patterns in Ethiopia's Guji zone forced pastoralists to adopt adaptive strategies, including a shift to drought-tolerant livestock species such as camels and goats. These findings align with Rekwot, Ugo & Engo (2016), who highlighted that increasing drought frequencies and erratic rainfall in Nigeria have reduced forage availability, directly affecting livestock health and productivity.

In addition to direct climatic impacts, secondary effects such as the increased prevalence of vector-borne diseases and resource conflicts between farmers and herders have further destabilized the livestock sector. Chauhan and Ghosh (2014) emphasized the critical role of heat stress in impairing livestock reproductive efficiency and milk production in tropical regions, while Baumgard et al. (2012) linked climate-induced feed shortages to reduced livestock productivity globally. The Nigerian livestock sector, with its reliance on rain-fed systems and traditional husbandry practices, remains particularly vulnerable to these climatic stressors, as infrastructure limitations and suboptimal management practices constrain adaptive capacity (Gbenga et al., 2020).

Despite the wealth of global studies highlighting the impacts of climate variability on livestock systems, there remains a paucity of context-specific research for Nigeria. Existing studies have largely employed linear models that fail to capture the complex and dynamic interactions between climatic variables and livestock productivity. For instance, while Ayinde et al. (2011) and Gbenga et al. (2020) provide valuable insights into the effects of rainfall and temperature on agricultural outputs, their methodologies overlook asymmetric impacts and the nuanced responses of livestock systems to climatic shocks. Innovative approaches, such as the Nonlinear Autoregressive Distributed Lag (NARDL) model applied by Khurshid et al. (2023) in Pakistan, have demonstrated the value of capturing both short and long-term dynamics, providing a more comprehensive understanding of climate-livestock interactions.

This study aims to fill this critical gap by investigating the effects of climate change variability on livestock productivity in Nigeria, leveraging advanced econometric techniques to provide nuanced insights into the dynamic relationships between climatic factors and livestock outcomes. By focusing on a sector that is both economically vital and ecologically vulnerable, the research seeks to contribute to the development of targeted, evidence-based adaptation strategies and policies. These findings will serve as a crucial resource for stakeholders, including policymakers, farmers, and development practitioners, in fostering resilience and sustainability within Nigeria's livestock production systems amidst escalating climate challenges.

2. Literature Review

The extensive body of literature examining the impact of climate change on livestock production globally and regionally highlights diverse methodologies, findings, and implications for adaptation and policy. Megersa et al. (2014) provide an in-depth analysis of southern Ethiopia, where the integration of herders' perceptions with empirical data on rainfall, temperature, and cattle herd dynamics reveals a significant decline in precipitation and increasing drought cycles every 8.4 years. These climatic changes directly impacted forage quality and water availability, leading to reduced cattle populations through heightened mortality during severe droughts, such as the 2010/2011 event. Habte et al. (2022) corroborate these findings, reporting similar impacts in south eastern Ethiopia's Guji zone, where rising temperatures and declining rainfall patterns negatively affected livestock, especially cattle, while drought-resistant species like camels and goats demonstrated greater resilience. Both studies emphasize the urgent need for adaptive measures, including herd diversification and drought-resistant livestock strains.

Baumgard et al. (2012) expand the scope globally, analysing the systemic challenges posed by climate change to livestock production and pastoral livelihoods. The study underscores that rising temperatures impair livestock productivity by reducing dairy output, reproductive efficiency, and feed conversion rates while increasing the prevalence of vector-borne diseases. These impacts are particularly pronounced in dryland pastoral systems, where declining rangeland productivity exacerbates vulnerability. The study also highlights the importance of mitigation strategies, such as improved thermoregulation, feed systems, and disease control, to sustain livestock production under changing climatic conditions. This global perspective aligns with Nardone et al. (2010), who review the wide-ranging effects of climate change on livestock systems worldwide. They argue that while industrial livestock systems may mitigate some direct thermal effects through cooling and dietary interventions, they face challenges like increased costs, energy consumption, and environmental pollution. Developing regions reliant on rangelands and mixed farming systems are especially vulnerable, with significant losses in growth, reproduction, and immune health projected under worsening climatic conditions.

From an economic perspective, Thamo et al. (2016) employ a bioeconomic whole-farm optimization model to assess the impacts of climate variability on mixed cropping livestock systems in Western Australia. The study reveals substantial variations in farm profitability under different climate scenarios, with losses often exceeding gains, particularly in adverse conditions. Adaptation strategies, including reducing inputs, lowering livestock numbers, and altering land use, provided some economic relief but failed to fully offset extreme losses. These findings underscore the critical role of integrating adaptive strategies into climate impact assessments for more realistic and actionable insights. Similarly, Chauhan and Ghosh (2014) and Cheng et al. (2022) emphasize the dual role of livestock as contributors to greenhouse gas emissions and victims of climate variability. They advocate for innovative solutions, such as methane-reducing feed additives, genetic selection for resilient breeds, and improved manure management, to address the environmental and productivity challenges simultaneously.

In the Nigerian context, Ayinde et al. (2011) and Gbenga et al. (2020) highlight the adverse impacts of climate variability, including rainfall unpredictability and rising temperatures, on agricultural productivity. Using econometric techniques such as co-integration and Fully-Modified Least Squares regression, these studies reveal significant negative effects on both crop and livestock outputs, emphasizing the urgent need for climate-resilient agricultural technologies and enhanced irrigation systems. Okoro (2023) adds a more specific focus on rainfall variability, demonstrating its significant influence on livestock production through statistical analyses. The study identifies both positive and negative correlations depending on regional conditions and advocates for localized water management and forecasting systems to mitigate adverse effects. Rekwot et al. (2016) further explore the relationship between climate variability and livestock production in Nigeria, finding unidirectional causality from rainfall to livestock outputs. Their results highlight erratic rainfall and increasing drought frequencies as critical challenges, recommending climate-smart agricultural practices and farmer sensitization to promote adaptive behaviours.

On a global scale, Herrero and Havlík (2014) and Piao and Sitch (2016) project significant challenges for livestock systems under climate change. These studies highlight reduced feed supply, increased emissions, and heightened vulnerability in developing countries. Similarly, Thornton, Herrero & Boone (2022) synthesize global findings to identify critical vulnerabilities, such as declining feed quality, water scarcity, and heat stress, which disproportionately affect sub-Saharan Africa and South Asia. Methodological innovations such as the Non-linear Autoregressive Distributed Lag (NARDL) model, as employed by Khurshid et al. (2023) in Pakistan, offer valuable insights into the asymmetric impacts of climatic variables. The study reveals that increases and decreases in temperature, precipitation, and CO_2 emissions exhibit distinct short- and long-term effects on livestock productivity. This nuanced approach highlights the complexity of climate-livestock interactions and underscores the need for dynamic, context-specific adaptation strategies.

Despite the wealth of global and regional studies, significant gaps remain in Nigeria's context, particularly concerning the dynamic and nonlinear interactions between climate variables and livestock productivity. While existing studies, such as those by Ayinde et al. (2011) and Gbenga et al. (2020), provide valuable insights, they rely on linear models that fail to capture the asymmetric and dynamic responses to climate shocks. The application of NARDL in Nigeria would address these gaps by identifying how increases and decreases in key climatic variables asymmetrically affect livestock production. Additionally, it would provide critical insights into the short-term shocks versus long-term equilibrium impacts of climate variability, offering a more comprehensive understanding of the challenges and opportunities for sustainable livestock production in Nigeria. By addressing these gaps, this study contributes significantly to the global discourse on climate adaptation while providing actionable recommendations tailored to Nigeria's unique agricultural landscape.

3. Research Methodology

This section contains the methodology of this study. The methodology of this study emanates from the problem statement, objectives and identified gaps in the literature review

3.1 Model Specification

The model for the estimation of the impact of climate change on livestock production used in this study adapted the model of the study of Khurshid et al. (2023). The adapted model of the impact of climate change on livestock production used in this study is presented below:

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$$Live_t = f(Rain_t, Temp_t, Lab_t, Cap_t, AgrL_t) \quad (1)$$

Equation 1 above can be expressed in the econometric form as presented in equation 1 below:

$$Live_t = \alpha_0 + \alpha_1 Rain_t + \alpha_2 Temp_t + \alpha_3 Lab_t + \alpha_4 Cap_t + \alpha_5 AgrL_t + \mu_t \quad (2)$$

Where $live_t$ is output of livestock subsector of the Nigerian agricultural sector measured as percentage of Gross domestic product (GDP), $Rain_t$ is changes in mean annual rainfall (Measured in Millimetres), $Temp_t$ is changes in mean annual temperature (Measured in degree centigrade), Lab_t is the country's labour force as a percentage of total population, Cap_t is capital proxy by gross fixed capital formation annual growth rate measured in percentages, and $AgrL_t$ is agricultural land proxy by arable land as percentages of total land area while α_0 to α_6 are the parameters to be estimated.

Following Shin, et al. (2011), equation 2 can be presented in an ARDL framework as follows:

$$\begin{aligned} Live_t &= \beta_0 + \beta_1 Live_{t-1} + \beta_2 Rain^{+}{}_t + \beta_3 Rain^{-}{}_t + \beta_4 Temp^{+}{}_t + \beta_5 Temp^{-}{}_t + \beta_6 Lab_t + \beta_7 Cap_t + \\ &\beta_8 AgrL_t + \sum_{i=1}^{l} \rho_{1i} \Delta Live_{t-1} + \sum_{i=0}^{m} \rho_{2i} \Delta Rain^{+}{}_{t-1} + \sum_{i=0}^{n} \rho_{3i} \Delta Rain^{-}{}_{t-1} + \sum_{i=0}^{o} \rho_{4i} \Delta Temp^{+}{}_{t-1} \\ &+ \sum_{i=0}^{p} \rho_{5i} \Delta Temp^{-}{}_{t-1} + \sum_{i=0}^{q} \rho_{6i} \Delta Lab_{t-1} + \sum_{i=0}^{r} \rho_{7i} \Delta Cap_{t-1} + \sum_{i=0}^{s} \rho_{8i} \Delta AgrL_{t-1} + \mu_t \end{aligned} \quad (3)$$

All variables are as explained above, l, m, n, o, p, q, r and s are the respective lag order.

Where $Rain^{+}{}_t$ and $Rain^{-}{}_t$ are the partial sum of positive and negative changes in mean of annual rainfall which is expressed as:

$$Rain^{+}{}_t = \sum_{t=1}^{t} \Delta Rain_t^{+} = \sum_{t=1}^{t} \max(\Delta Rain_t, 0) \quad (4)$$

$$Rain^{-}{}_t = \sum_{t=1}^{t} \Delta Rain_t^{-} = \sum_{t=1}^{t} \max(\Delta Rain_t, 0) \quad (5)$$

While $Temp^{+}{}_t$ and $Temp^{-}{}_t$ are the partial sum of positive and negative changes in mean of annual temperature which can also be expressed as:

$$Temp^{+}{}_t = \sum_{t=1}^{t} \Delta Temp_t^{+} = \sum_{t=1}^{t} \max(\Delta Temp_t, 0) \quad (6)$$

$$Temp^{-}{}_t = \sum_{t=1}^{t} \Delta Temp_t^{-} = \sum_{t=1}^{t} \max(\Delta Temp_t, 0) \quad (7)$$

3.2 Data and Estimation Technique

This study employed annual time series data covering the time frame of 1990 to 2023. The data for this study were sourced from the Central Bank of Nigeria (CBN) Statistical bulletin, 2020 edition, World Bank Climate Change Portal and World Development Indicator (WDI) database of the United Nation Development Programme (UNDP).

The Nonlinear Autoregressive Lag (NARDL) model, also known as Asymmetric Autoregressive Distributed Lag, will be used in this study. The ARDL technique is chosen because it may be used effectively regardless of whether the data are stationary at level, at first difference, or mixed. Based on the claim made by Mendelsohn, Nordhaus, and Shaw (1994) that the link between climate change and the agricultural sector is nonlinear, NARDL is also relevant.

Asymmetric ARDL was used as a modelling tool for this study in part because to the benefits of non-linear modelling methods. For instance, linear models contain symmetry qualities that imply shocks experienced during a recession are just as durable as those experienced during an expansion of the business cycle. A nonlinear relationship between climate change and the agricultural sector has been established in the literature, and it is preferable to treat climate change's impact as nonlinear because it can result in either an increase or decrease in climatic variables like rainfall and temperature. As a result, linear models may be too limited in this situation. In order to determine the reliability or otherwise of the estimation techniques adopted for this study, some econometric tests such as unit root test and Wald test were carried out.

4. Presentation of Empirical Results

This section presents the results of the empirical investigations carried out in order to achieve the objectives of this study as well as the detail discussion of the results and their economic implications.

4.1. Unit Root Test Results

This study carried out unit root test to verify the time series properties of the data employed using standard Augmented Dickey-Fuller and Philip-Perron unit root test. The results obtained are reported in tables 1 and 2.

4.1.1.Augmented Dickey-Fuller Unit Root Test Results

The standard ADF unit root test is presented in the table 1. It revealed that AGL, CAP, LIVE, and Rain were stationary at first difference level while LAB and Rain are stationary at level.

Table 1: ADF unit Root Test Results

Variables	ADF Statistics at Level		ADF Statistics at First Difference		Order Of Integration
	ADF Statistics	Prob.	ADF Statistics	Prob.	
AGL	-2.4236	0.1444	-4.4286	0.0009	I(1)
LAB	-4.01822	0.0194	-4.6043	0.0013	I(0)
CAP	-0.0329	0.9480	-4.9601	0.0004	I(1)
LIVE	0.0951	0.9598	-3.0577	0.0413	I(1)
RAIN	-6.6550	0.0000	-12.8706	0.0000	I(0)
TEMP	-2.6442	0.0960	-4.2924	0.0025	I(1)

Source: Authors Computation

4.1.2. Philip -Perron Unit Root Test Result

Also, Philip-Perron Unit root test was carried out as a confirmation of the results of the ADF unit root test results presented in table 2. As contained in table 4.4 RAIN and TEMP were stationary at level [I(0)] while AGL, LAB, CAP and LIVE, were all stationary after first difference.

Table 2: PP Unit Root Test Results

Variables	PP Statistics Level		Pp Statistics At First Difference		Order Of Integration
	Test Statistics	Prob.	PP Statistics	Prob.	
AGL	-3.9758	0.0047	-23.1962	0.0001	I(1)
LAB	-2.5591	0.3000	-4.3004	0.0007	I(1)
CAP	-2.0729	0.5393	-4.7149	0.0039	I(1)
LIVE	0.8985	0.9941	-2.9829	0.0372	I(1)
RAIN	-6.5714	0.0000	-15.02447	0.0000	I(0)
TEMP	-4.0752	0.0170	-16.4698	0.0000	I(0)

Source: Authors Computation

Both ADF and PP unit root test results presented above confirmed that the time series data were either stationary at level or at first difference. With this result, the suitability of Nonlinear Autoregressive Distributed Lag (NARDL) technique for this study is confirmed.

4.2.NARDL Bound Test of Climate Change and Livestock Production

The result of NARDL bound test which is a test for the existence of long-run relationship is presented in Table 3.

Table 3: NARDL Bound Test Result

Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	5.342770	10%	2.03	3.13
K	7	5%	2.32	3.5
		2.5%	2.6	3.84
		1%	2.96	4.26

Source: Authors Computation

The result revealed that the F-statistic of 5.34 is greater than both the upper and lower critical values. This confirmed the existence of long-run relationship between climate change and livestock production and the appropriateness of NARDL for the estimation of the model of this study.

4.3. Short-Run Model of Climate Change and Livestock Production

Table 4 presented the results of the short-run NARDL model employed in this study to examine the impact of climate change on livestock production in Nigeria. The results indicated that positive indexes (current and lagged) of rainfall has a positive impact on livestock production. The impact of current value and lagged value of the positive index of rainfall is statistically significant at 5% level. A unit increase in the current positive index of rainfall resulted in ₦4.91 billion increase in livestock production. Also, a unit increase in the positive index of climate change is accompanied by ₦1.125 billion increase in livestock production. From these results, it can be inferred that increase in rainfall in the immediate past year has more impact on livestock production than that of the current year.

Negative indexes (current and lagged) of rainfall have negative impact on livestock production. However, the impact of current negative index of rainfall is not statistically significant, while the impact of lagged value of the negative index of rainfall is statistically significant at 5% level. A unit increase in the lagged value of the negative index of rainfall is accompanied by ₦2.440 billion decrease in livestock production. From this result, it can be inferred that decline in rainfall caused by climate change in the forms of drought and water shortages is detrimental to livestock production.

Both the positive and negative indexes of temperature have negative impact on livestock production. The impact of positive indexes (Current and lagged values) of temperature is also statistically significant at 5% level. A unit increase in positive indexes (current and lagged) resulted in ₦1.201 billion and ₦2.586 billion decrease in livestock production respectively. The negative indexes (Current and lagged values) of temperature is also statistically significant at 5% level. A unit increase in the negative indexes (Current and lagged) is accompanied by N3.499 billion and N3.786 billion decline in livestock production. These results revealed that livestock production response to climate change suffers from lag effects hence lagged value of indexes of rainfall and temperature have more impact and are all statistically significant at 5% level.

Table 4: Short-run Model of Climate Change and Livestock Production

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(RAIN_POS)	4.918036	1.898482	2.590509	0.0488
D(RAIN_POS(-1))	1.125841	0.259751	4.334305	0.0075
D(RAIN_NEG)	-1.084798	2.358743	-0.459905	0.6649
D(RAIN_NEG(-1))	-2.640393	0.313063	-8.434039	0.0004
D(TEMP_POS)	-1.200511	0.344165	-3.488184	0.0175
D(TEMP_POS(-1))	-2.586462	0.310160	-8.339123	0.0004
D(TEMP_NEG)	-3.499781	0.431208	-8.116208	0.0005
D(TEMP_NEG(-1))	-3.786390	0.592527	-6.390233	0.0014
D(LAB)	1.73E-05	2.08E-06	8.306079	0.0004
D(LAB(-1))	2.06E-05	2.21E-06	9.341653	0.0002
D(CAP)	5.49E-12	2.03E-12	2.705545	0.0425
D(CAP(-1))	1.36E-11	2.45E-12	5.550469	0.0026
D(AGRL)	0.014623	0.002159	6.771380	0.0011
D(AGRL(-1))	0.006232	0.001555	4.006542	0.0103
CointEq(-1)*	-0.085764	0.005995	-14.30513	0.0000
R-squared	0.968560	Mean dependent var		27.64993
Adjusted R-squared	0.934702	S.D. dependent var		22.67462
S.E. of regression	5.794170	Akaike info criterion		6.655755
Sum squared resid	436.4412	Schwarz criterion		7.369436
Log likelihood	-78.18057	Hannan-Quinn criter.		6.873934
Durbin-Watson stat	2.090909			

Source: Authors Computation

Again, from the results presented in table 4, it can be inferred that changes in temperature index arising from climate change is more detrimental to livestock production than changes in rainfall index. Labour, Capital and agricultural land have positive impact on livestock production and are all statistically significant at 5% level. The speed of adjustment is rightly signed and is statistically significant at 5% level and indicated that for every deviation from long-run equilibrium position, 8.5% is corrected annually. Therefore, shocks arising from climate change will last for about twelve (12) years before deviation from long-run equilibrium are totally eliminated and long-run equilibrium fully restored. The adjusted coefficient of determination revealed that this model explained 93.4% of systematic variation in livestock production and the Durbin-Watson Statistics of 2.09 indicated the absence of autocorrelation since this value is approximately equals to 2.

4.4. NARDL Long-Run Model of Climate Change and Livestock Production

Table 4.5 present the estimated coefficients for the long-run model capturing the impact of climate change on livestock production in Nigeria. The results revealed that both positive and negative indices of rainfall have negative impact on livestock production in the long-run, though both are statistically insignificant at 5% probability level. A unit change in positive index of rainfall leads to 4.8409 units decline in livestock production while a unit increase in the negative index of rainfall caused livestock production to fall by 2.1333 units respectively.

Also, both the positive and negative indices of temperature have a negative impact on livestock production, though only the positive index is statistically significant at 5% level of significance. A unit increase in the positive index of temperature leads to 3.494 decrease in livestock production while a unit increase in the negative index of temperature cause livestock production to drop by 1.0067 units. This according to Rowlinson (2008) is because heat stress is the major channel of transmission through which the impact of climate change affect livestock hence temperature instability is theoretically expected to have a negative impact on livestock production.

Table 4.5: NARDL Long-run Model of Climate Change and Livestock Production

Variable	Coefficient	Std. Error	t-Statistic	Prob.
RAIN_POS	-4.840914	11.46186	-0.422350	0.6778
RAIN_NEG	-2.133329	2.371264	-0.899659	0.3802
TEMP_POS	-3.493700	0.732217	-4.771399	0.0000
TEMP_NEG	-1.006739	1.152095	-0.873833	0.3937
LAB	1.41E-05	2.71E-05	0.520567	0.6090
CAP	1.463204	1.819790	0.804051	0.4319
AGRL	4.428783	42.84726	0.103362	0.9188

Source: Authors Computation

Hence, based on these results, in the long-run climate change has a negative impact on livestock production in Nigeria. Labour, Capital and agricultural land have positive impact on livestock production during the period under study, but none of these three variables are statistically significant at the 5% level of significance.

4.5.Stability Test Results

This study used NARDL CUSUM squares and NARDL CUSUM in checking for the stability of the estimated model.

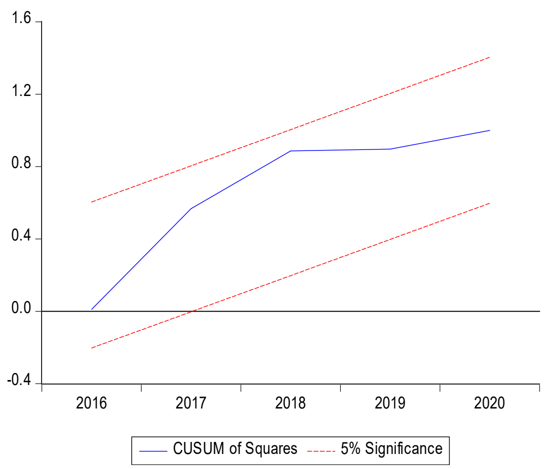

Figure 1: NARDL CUSUM Squares

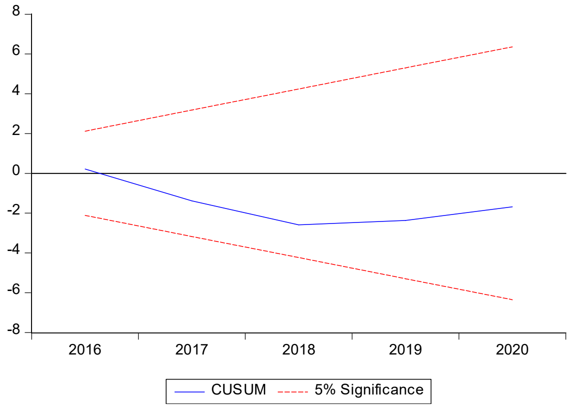

Figure 2: NARDL CUSUM

As revealed in figure 1 and 2, the results of the NARDL CUSUM square and CUSUM fall within the two straight lines confirming the stability of the model.

4.6. Wald Test

Wald test presented in Table 4.17 contain F-statistics and Chi-square with critical values of 17.08 and 34.16 respectively and probability values of 0.0001 and 0.0003 respectively. These statistics and their accompanying probabilities confirmed the existence of asymmetry.

Table 4.17: Wald Test

Test Statistic	Value	Df	Probability
F-statistic	17.07758	(2, 5)	0.0001
Chi-square	34.15515	2	0.0003

5. Conclusion

This study provides important insights into the impact of climate change on livestock productivity in Nigeria. The empirical analysis reveals both short-term and long-term negative effects of climate variables, especially temperature and rainfall, on livestock production. The results show that declining rainfall has an adverse impact, with droughts severely reducing livestock output. Increasing temperatures also consistently lower livestock production through effects, such as heat stress.

The findings confirm the vulnerability of livestock farming in Nigeria to the ongoing changes in climate and weather patterns. The analysis highlights the significant risks climate change poses to livestock rearing, which is a crucial agricultural activity, and source of livelihood for many rural communities across Nigeria. The results underscore the need for urgent actions to build resilience and adaptive capacity within the livestock sector to promote sustainability.

Overall, the study makes a vital contribution by providing empirical evidence on the relationships between climate change and livestock productivity specific to the Nigerian context. The findings can inform policymakers, agricultural agencies, livestock farmers and other stakeholders on critical impact channels and strategies for adaptation.

Based on the findings, the following recommendations were made:

I. **Promote Drought-Resilient Livestock Breeds:** Based on the findings highlighting the adverse effects of rainfall variability and heat stress on livestock productivity, the adoption of drought-resilient livestock species, such as camels and goats, should be prioritized. These breeds demonstrate higher adaptability to climatic stress and can help mitigate productivity losses in arid and semi-arid regions of Nigeria.

II. **Strengthen Water and Forage Resource Management**: With the study identifying reduced water and forage availability as major impacts of climate variability, implementing sustainable resource management practices is critical. This includes the establishment of rainwater harvesting systems, construction of reservoirs, and sustainable rangeland management techniques, such as rotational grazing and reseeding degraded pastures.

III. **Expand Veterinary Services and Disease Management:** Given the increased vulnerability of livestock to heat stress and vector-borne diseases due to climate variability, veterinary services should be expanded, particularly in rural areas. Programs providing affordable vaccines and treatments for climate-sensitive diseases, coupled with training for livestock farmers on disease prevention, will enhance livestock health and productivity under changing climatic conditions.

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