

Climate Change and Agricultural Commodity Prices: A Dynamic CGE Modelling

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Abstract: The main objective of the paper is to examine the effect of climate change on Nigeria's agricultural commodity prices from 2023 to 2032. The Dynamic Computable General Equilibrium (DCGE) Model is employed to investigate the variables of interest. The study finds that climate change exerts a positive influence on agricultural commodity prices in Nigeria. This suggests that climate change, which is anticipated to result from the untamed drive towards economic expansion would have positive agricultural commodity price effect in Nigeria. Premised on these findings, we recommended that government should expand adaptation and resilience initiatives to mitigate the adverse effects of climate change on farmers, fisherfolk, and other agricultural commodity producers and consumers. Additionally, transitioning from practices that emit higher levels of greenhouse gases to more sustainable methods of production and consumption is crucial.

Keywords: Climate change; agricultural commodity prices; rainfall; temperature; agriculture

JEL Classification: C68; G28; Q54; Q11; Q01

1. Introduction

There is a burgeoning body of literature indicating that the adverse effects of climate change extend to various facets of human well-being, including health and safety, food security and water resources, and sustainable development (Adeola et al., 2024; IPCC, 2021a; IPCC, 2021b; Kotz et al., 2023; Knight, 2023; Yüksel et al., 2021). Somewhat great attention has been given to international¹ and local collaboration to mitigate this threat (IPCC, 2023; Adeola *et al.*, 2024). However, anecdotal evidence shows that climate shock is exacerbating globally. Wagner and Weitzman (2015), acknowledged the likelihood of a ten per cent and three per cent temperature rise to 6 degrees Celsius and 10 degrees Celsius respectively.

Nigeria has encountered a range of challenges resulting from climate change, including high temperatures, drought, unseasonal rainfall, and a growing occurrence of severe climate phenomena². The factors contributing to these issues encompass a burgeoning population, rapid industrialization, human activities, limited knowledge on climate change, technological

¹ The World Climate Action Summit (WCAS) witnessed the announcement of the 'COP28 UAE Declaration on Sustainable Agriculture, Resilient Food Systems, and Climate Action' (the Declaration). This significant declaration not only tackles the issue of global emissions but also prioritizes the protection of farmers who are directly impacted by climate change. With 134 countries signing the Declaration, these nations collectively house a population of over 5.7 billion people and nearly 500 million farmers. These farmers play a crucial role in producing 70 percent of the world's food supply, while simultaneously being accountable for 76 percent of emissions stemming from global food systems or 25 percent of total global emissions.

² In Nigeria, the year 2022 witnessed a series of severe weather phenomena, particularly unprecedented floods that occurred in various regions. These floods were primarily caused by intense rainstorms and the discharge of water from the Lagdo dam in Cameroon (Rewane, 2022). The African Development Bank (ADB) has projected that the maximum temperature in Nigeria could increase by 3°C to 4°C between 2050 and 2070 (ADB, 2022). Furthermore, future estimations indicate a high probability of extreme rainfall events leading to widespread flooding throughout the country, except for the northeast Sahel zone, where a decline in rainfall is anticipated based on scenario analysis. See also Imadojemu (2022).

backwardness, monocultural economy, expansion of agricultural activities, inadequate monitoring, and a dearth of effective climate policies.

The economic implications of climate change are becoming increasingly well understood, as evidenced by empirical studies in Nigeria. These empirical analyses have revealed the influences of climate change on various sectors, including energy (Birrintsaba et al., 2021; Ogundipe et al., 2014; Jun et al., 2023), agricultural output (Akinbobola et al., 2015; Akomolafe et al., 2018; Ayinde et al., 2010; Ayinde et al., 2011; Ladan, 2014), food security (Ani et al., 2021; Emaziye, 2013; Igbokwe-Ibeto, 2019; Jun et al., 2023; Kralovec, 2020), security (Ani et al., 2021; Amusan et al., 2017; Folami & Folami, 2013; Fasona & Omojola, 2005; Onuoha & Ezirim, 2010; Ogele, 2020; Price & Elu, 2017; Wakdok & Bleischwitz 2021), tourism (Ijeomah & Aiyeloja, 2009), manufacturing (Foye & Benjamin, 2021), human capital development (Igbokwe-Ibeto, 2019), employment (Muritala et al., 2013) and human health (Adesiji et al., 2013; Foye, 2018; Omoruyi & Kunle, 2012; Raimi et al., 2018). Studies have also identified the impacts of climate change on aggregate economic output (Akpan et al., 2017; Akram, 2013; Bosello et al., 2011; Foye, 2018; Kalu & Mbanasor, 2016; Pendino, 2017). In a similar vein, climate change is expected to lead to significant welfare losses (Agbola, 2011; Ogbeide-Osaretin et al., 2022).

Notwithstanding the advancements made in comprehending the consequences of climate change, there exist a dearth of research concerning the effects of the aforementioned on agricultural commodity prices, especially in Nigeria. It is of utmost importance to further enhance this understanding to holistically evaluate the risks accompanying climate shocks. Escalating or volatile agricultural commodity prices not only jeopardize the economy (Asekunowo, 2016; Fasanya & Olawepo, 2018; Joiya & Shahzad, 2013; Mbah et al., 2022; Peersman, 2022) and human well-being (Díaz-Bonilla, 2016), but also political stability³(Bellemare, 2015).

The 2023 cost of living estimates serves as a prime illustration of the consequences at hand. According to estimates from the National Bureau of Statistics (NBS), the prices of essential agricultural items experienced a significant year-on-year increase. For instance, the average price of boneless beef, tomatoes, loose rice, onion bulbs, yam tuber, and vegetable oil increased by 27.43%, 19.08%, 19.30%, 18.99%, 28.45%, and 25.91%, respectively, in February 2023, compared to the value in the same period in 2022 (NBS, 2023). Consequently, the nation finds itself grappling with the pervasive issue of both food availability and affordability. This dire situation has pushed individuals and households below the acceptable food-energy thresholds, plunging them beneath the poverty line.

This underscores the necessity of considering the probable influence of climate shocks on agricultural commodity price dynamics, as it has progressively become more pertinent for monetary policy and the capacity of central banks to uphold price stability in the future (Saliu, 2021; Tule et al., 2019). Hence, conducting a wide-ranging assessment of the risks climate change poses to agricultural commodity prices is imperative in guiding government attempts in climate mitigation, adaptation and transition, as well as informing decisions pertaining to monetary policy. Following this frame of thought, a sparse number of topical research has begun to illuminate the linkages between climate change and agricultural commodity prices in Nigeria. This is commonly achieved by analyzing time series food prices data and employing climate fluctuations as

³ <http://www.bloomberg.com/bw/articles/2013-07-25/for-indias-inflation-crisis-see-onion-prices>.

exogenous shocks. In their study, Oluwasola et al. (2011) investigated the relationship between changing climatic elements, agricultural output, and food prices in Nigeria. The study gathered and analyzed secondary data from national institutions using the Correlation technique. Foye (2022), conducted a study with the aim of evaluating the nexus between climate change and macro prices (exchange rates, and interest rates) in Nigeria. In order to accomplish this objective, a nonlinear autoregressive distributed lag (NARDL) econometric technique was deployed on time series data spanning from 1960 to 2019.

Here, the study extends this emerging literature along two standpoints. First, we provide an empirical assessment of the impact of climate change on the prices of decomposed agricultural commodities, such as crop, livestock, forestry and fishing in Nigeria. This is in contrast to previous research, which focused on the impact of climate change on macro prices or food inflation. The approach adopted in this study is intended to eliminate the likelihood of masking the nexus between climate change and agricultural commodity prices. Moreover, the approach allows us to amenable account for the heterogeneity of impacts from climatic shocks across agricultural commodities.

The second key contribution is the utilization of a recursive dynamic CGE model to scrutinize the seeming climate-economy nexus in Nigeria. The previous research on the variable of interest utilized conventional econometric techniques. However, these econometric techniques are not suitable for long-term analyses of the economic impact of climate change, as they fail to account for growth effects, accumulation effects, or the transition path of the economy, where short-term and medium-term impacts may diverge significantly (Adenikinju & Chitiga, 2009). Furthermore, the utilization of a recursive dynamic CGE model explicitly integrates climate change into Nigeria's Social Accounting Matrix (SAM), resulting in a more precise representation of the relation between climate change and food prices. This approach is tenable with economic theory and is internally observable, rendering the outcomes of significant curiosity.

The remaining sections of this paper are organized as follows. In Section 2, a comprehensive empirical literature review is provided. Section 3 presents the methodology. Section 4 discusses the results. Lastly, in Section 5, the study is concluded by discussing the implications of the result and recommendations.

2. Empirical Literature Review

Since Amartya Sen's Poverty and Entitlement in 1981, there has been a division of academic opinion regarding the relative merits of two different explanations for contemporary agricultural prices in the Third World. The first theory, known as 'food availability decline' or FAD, suggests that agricultural commodity prices increase due to insufficient supplies of food. According to this theory, any factor that disrupts food production, such as temperature rise, extreme rainfall, drought, flood, or war, can lead to a decline in agricultural commodity prices (Milà-Villarroya et al., 2015; Oyelami, 2023). The reasoning behind this is that these disruptions result in crop failure and cattle death, which in turn reduces the availability of food in the affected region.

Consequently, a 'food availability decline' that falls below the subsistence needs of a significant number of people for an extended period of time leads to higher agricultural commodity prices. On the other hand, Sen's 'entitlements' approach presented a counterargument to supply-side

theories. He illustrated that numerous severe famines and subsequent rise in agricultural commodity prices in Africa and South Asia took place without any substantial decrease in the overall food supply or extreme weather condition at the national level (Milà-Villaruel et al., 2015; Oyelami, 2023).

Empirical research that reconnoiters the relationship between climate change and the economy is robust. These studies primarily focus on assessing the impact on welfare, income distribution, and economic consequences, with occasional consideration of the influence on agricultural commodity prices. An illustration of such a study is Tran et al. (2012), which conducted a robust examination by considering the consequences of climate change on prices, price volatility, storage, and social welfarism. To do so, they generated 1600 proposed yield pathways spanning 2000 to 2080, utilizing data from a global statistical analysis of weather and crop yields. The findings indicate that, as an outcome of climate change, the global crop price level is projected to double, and crop price volatility is expected to quintuple between 2000 and 2080.

Blake et al. (2018) investigated the consequences of extreme weather condition on prices in the global banana market. Utilizing weekly time series data, they analyzed the effects of extreme weather condition on both banana export volumes and import prices. The preliminary findings revealed that extreme weather events were the most frequently reported occurrences that influenced export volumes and consumer demand, thus confirming their significant role in price determination.

Moessner (2022), examined the impact of precipitation on food consumer price inflation (FCPI) using the dynamic panel estimation techniques. The study focused on 34 OECD members from 1985 to 2010. The findings of the study revealed that precipitation indeed has a significant nonlinear relation with FCPI. The coefficient of FCPI associated with the linear precipitation term was found to be significantly negative, indicating that as precipitation decreases, FCPI tends to increase. On the other hand, the coefficient of the quadratic precipitation term was significantly positive, suggesting that extremely high levels of precipitation also contribute to higher food CPI inflation. Interestingly, the study found that temperature did not possess any additional explanatory power for FCPI beyond that of precipitation.

Kotz et al. (2023) conducted a comprehensive analysis using an international dataset of consumer price indices (monthly frequency) to investigate the underlying effects of climate change on inflation in Europe. By considering the diverse effects across different climatic seasons and socio-economic conditions, the study discovered that rising mean temperatures lead to non-linear upward pressures on inflation, which persist for a duration of 12 months intervals in high- and low-income countries. Utilizing advanced climate models, the study projected that without unprecedented adaptation measures, future warming would result in global increases in annual food and headline inflation by approximately 0.92-3.23 and 0.32-1.18 percentage points per year, respectively, under the projected climate conditions for 2035. Additionally, the seasonal dynamics of inflation would also be altered as a consequence of future warming. Furthermore, the researchers estimated that the extreme heat experienced during the summer of 2022 led to a 0.67 (0.43-0.93) percentage point increase in food inflation in Europe. They also projected that the anticipated warming by 2035 would amplify the impacts of such extreme heat events by 50%.

Mutuc et al. (2012) utilized the yield impacts of Schlenker & Roberts (2009) which applied a global fiber model to examine the impact of temperature changes on food prices. The study findings reveals that extremely high temperatures (+5°C) will lead to a significant increase in cotton prices, reaching up to 17% compared to the baseline, due to a reduction in production by an average of 1.8% over the projection period of 2011-2020 in the United States. Moreover, a 5°C temperature rise in both the United States and the rest of the globe results in a substantial price increment of approximately 135% averagely during the forecast timeframe.

In a related study, Kaiser et al. (1995) conducted an examination of the potential impacts on the price of grains in the United States resulting from various climate change scenarios. The researchers utilized a comprehensive approach by integrating a tripartite agronomic, climatic, and economic model to form a cohesive model. The findings show that crop prices are significantly influenced by the presumed climate change scenarios. Specifically, under a mild climate change scenario, there is an observed increase in corn prices when adjusted for inflation, while wheat prices experience a decrease. Additionally, soybean prices exhibit an increase, albeit at a lower rate compared to the scenario without climate change. Conversely, in a more severe climate change scenario, soybean and corn prices demonstrated the most substantial increase over time.

Bandara and Cai (2014), employed a GTAP global dynamic computable general equilibrium model to investigate the repercussions of climate change-based variations in crop productivity on food prices and food security in South Asia. Their study focused on five prominent countries in the region, specifically India, Nepal, Pakistan, Bangladesh, and Sri Lanka. The findings of their research indicate that climate change-based shifts in agricultural productivity are projected to have a considerable detrimental effect on food prices and food production across all South Asian nations.

Kan et al. (2014) developed a practical model for allocating farmland by utilizing explicit profit functions that are connected to a market demand model in Israel. This empirical model considers corner solutions, allowing for estimation using disaggregated data and treating prices as exogenous. By integrating the model, it became possible to verify the impact of climate change on agriculture within the context of partial equilibrium in food markets, while considering the production responses of individual micro units. The findings reveal that climate change has a negative repercussive effect on farm profits, food prices, and consumer surplus in Israel. However, these effects are significantly lower when compared to scenarios where the price-feedback effects on agricultural supply are not taken into consideration.

In the same vein, Yüksel et al. (2021) investigated the effect of climate shocks on food prices in Turkey by employing the difference-in-differences estimation strategy. The findings highlight the notable impact of climate change on the prices of bread, cereals, and other food products. The results from the second phase of the analysis indicate that both the price and wealth effects on food consumption exhibit a greater increase in regions experiencing climate change compared to regions with minimal climate variations. However, no significant disparities in the wealth effect on non-food consumption are observed across the different regions.

Wong et al. (2019), examined the determinants of food prices considering both economic factors and climate change in Malaysia. To analyze this, non-linear time series analytical techniques, specifically the Engle-Granger (EG) cointegration test and Error Correction Mechanism (ECM),

were employed. The findings indicated that both economic factors, such as Real Gross Domestic Product, and climate factors have a significant combined impact on food prices.

In a similar study, Guerrero et al. (2014) investigated the impact of climate change on corn production, cultivated area, and prices in Mexico. To analyze this, they employed an empirical strategy based on a straightforward theoretical model that considers profit-maximizing farmers. These farmers make decisions regarding the allocation of land to various crops and the investment of inputs in each crop's cultivation. The results of their analysis indicated that climate change has a minimal but statistically significant effect on prices, with a 0.1% change. However, it leads to a decline in production ranging from 2.2% to 3.6%. Surprisingly, the cultivated area does not show any significant impact due to climate change.

Melo-Velandia et al. (2022) conducted a comprehensive analysis on the primary factors influencing the surge in food prices in Colombia from 1985 to 2020, with a specific focus on extreme weather events such as the formidable El Niño phenomenon. To achieve this, they employed a non-stationary extreme value model to estimate the impact of these weather variability on Colombian food prices. The research findings indicate that perishable food items are more susceptible to adverse weather conditions compared to processed foods. In fact, the escalation of prices in perishable goods can be solely attributed to an exceptionally low level of precipitation. The risk of soaring prices in perishable foods is significantly higher during periods of low rainfall (dry seasons) as opposed to periods of high precipitation (rainy seasons).

Similarly, Fajri et al. (2019) investigated the effect of climate change on the prices of essential food commodities, namely rice, maize, and soybean, in Indonesia. The study employed the static panel method to analyze the data. The cross-section data focused on the ten most affected provinces by the ENSO phenomenon, while the time series data spans from the first quarter of 2011 to the fourth quarter of 2016. The findings reveal that El Niño has a significant impact on the increase of rice and soybean prices, as well as the decrease of maize prices. On the other hand, La Niña is found to significantly contribute to the rise in rice prices. Overall, the study concludes that El Niño has a more pronounced effect on food prices compared to La Niña.

Sassi (2013) conducted a simulation to examine the relations between climate change and international prices uncertainty in the Sudanese sorghum market using a stochastic approach. This analysis was carried out considering various rainfall scenarios and the uncertainty in international market prices. The findings highlight an anticipated rise in sorghum prices due to the significant uncertainty in both precipitation levels and international market prices.

Mawejje (2016) focused on analyzing the implications of energy and climate shocks in the context of Uganda's food price dynamics. The study employed a single equation model that utilizes cointegration techniques and general-to-specific methods to explore these issues. The findings reveal a long-term cointegrating relationship between climate shocks, energy prices and food prices. Furthermore, the study highlights that temperature shocks hold greater explanatory power in understanding the variability of food prices compared to rainfall shocks. Ichoku et al. (2023) conducted an empirical study to investigate the association between climate change and food price inflation in Nigeria. The study employed a Nonlinear Autoregressive Distributed Lag (NARDL) methodology using dataset spanning January 2011 to December 2022. The results of their analysis

indicate a strong cointegrating relationship between climate change and food price inflation in Nigeria. Remarkably, the study found that climate change shocks had a significant impact on the increase in food prices during the examined period.

Additionally, the Error Correction Term (ECT) was estimated to be 52 percent, signifying that food price inflation adjusts by 52 percent in the current month to offset the preliminary shock experienced in the preceding month. Oluwasola et al. (2011) explored the relations between changing climatic factors, food production, and food prices in Nigeria. The findings of the study indicated that climate change is gradually transforming the fertile agricultural lands in the northern parts of Nigeria into unproductive areas. Moreover, Nigeria has experienced inconsistent rainfall patterns in recent years, resulting in droughts and floods that have negatively impacted crop yields. The study concluded that these factors significantly contributed to the surge in food prices observed in the country.

Bosello et al. (2018), demonstrated that climate change induces the increment of agricultural commodities prices. The result extracted from their study indicated that climate change will induce increment of 47.2 per cent for rice and 21.4 per cent for cassava by 2050 in Nigeria. Foye (2022) similarly found that climate change leads to food price inflation by 0.22 per cent in Nigeria. Ichoku et al. (2023) investigated the potential impact of climate change and insecurity on the rise of food inflation in Nigeria. The study used time series data from January 2011 to December 2022, while employing the ARDL approach to cointegration analysis. The results revealed that climate change and the level of insecurity significantly contribute to the upward trend in food prices in Nigeria. Furthermore, based on the estimation of the coefficient of the error correction term (ECT), it was determined that the adjustment mechanism in food price inflation, following an initial shock, would be corrected by approximately 23 percent on a monthly basis.

In retrospect, it is important to note that the literature, particularly in Nigeria utilized static econometric techniques, which are susceptible to issues such as heteroskedasticity, orthogonality, and autocorrelation. In order to circumvent the aforementioned prognosis, we employed the use of DCGE to examine the relations between climate change and food prices in Nigeria.

3. Methodology

In this research, we employed the dynamic computable general equilibrium model to analyze the impact of climate change (specifically, an increase in temperature and rainfall) on agricultural commodity prices from 2023-2032. The social accounting matrix (SAM) served as the database for this study, offering a comprehensive overview of the actual economy.

3.1 Data: Social Accounting Matrix

In this study, the Nigerian 2019 Social Accounting Matrix (SAM) developed by the Equilibria Consult⁴ was employed. The construction of the 2019 Nigeria SAM followed the methodology employed in Beyene (2020). Unlike the study conducted by Nwafor et al. (2010), which constructed the most widely acknowledged Social Accounting Matrix (SAM) for Nigeria based on outdated 2006 national accounts data, which no longer accurately represents the size and composition of the economy due to the rebasing of the GDP in 2010 and 2014, as reported by the National Bureau of Statistics (2014), the 2019 Nigeria SAM provides a more up-to-date and comprehensive reflection of the country's current structural peculiarities.

⁴ A Nigerian economic research consulting firm that operates from its offices in Ibadan and Oyo State.

Data for the 2019 Nigeria (SAM) was collected from a variety of sources and publications, such as the National Bureau of Statistics, 2010 supply-and-use table, Central Bank of Nigeria Statistical Bulletin, Federal Inland Revenue Services (FIRS), and World Integrated Trade Solutions of the World Bank. Noteworthy characteristics of the SAM includes its coverage of sectors, commodities, factors of production, economic agents, taxes, trade components (exports and imports), changes in inventories, and investment. In comparison to the national accounts, the SAM incorporates forty-seven sectors/activities and forty-eight commodities, whereas the national accounts consist of forty-six sectors and forty-six commodities. The description aggregates the SAM into six broad sectors⁵ namely agriculture, services, manufacturing, public administration, health and mining.

3.2 Model specification

This study used the recursive dynamic CGE models of the Partnership for Economic Policy (PEP 1-t) developed by Decaluwé *et al.*, (2013)⁶. The model incorporates two primary components of production, namely capital and labour. Capital is subdivided into tripartite distinct categories: land, physical capital, and non-physical capital. Additionally, labour is disaggregated based on skills, as outlined in our Social Accounting Matrix (SAM).

Domestic production function is hypothesized to be of constant returns to scale and depicted in a two-level nested production process. The first level is represented by equations (1) and (2) at the top-level bloc⁷. At the top level, output is represented as a Leontief function of value added and intermediate consumption. At the bottom level, it is presumed that composite labour and composite capital are close substitutes ensuing a constant elasticity of substitution (CES) function (See equation 3).

In conclusion, with regards to top level, specifically on the aspect of intermediate consumption, the total intermediate consumption is comprised of a multitude of goods and services. It is postulated that intermediate inputs are completely complementary and are amalgamated through the utilization of a Leontief production function (See equation 4). The price block comprises three discernible price classifications, namely those pertaining to production, global trade, and price indexes. In the total production block, total price accumulation is the weighted combination of the prices of its components. As a result, the unit cost of an industry's production is a sum of the weights of value added as well as total intermediate consumption prices (equation 5).

In accordance with the aggregation criterion, the price of aggregate output for nations that are export-oriented is determined by a weighted combination of national and international market prices. This relationship is expressed in equation (6). The GDP deflator (Fisher index) (equation 7) and the consumer price index (Laspeyres index) are the indexes in the price index block (equation 8). Agents in the model include households, firms, government, and the rest of the world (ROW). The household receivables include capital, labour income, and transfers. On the other hand, the income of Firms' is derivable from capital and transfers, while they expend on dividends, direct taxes, and savings. The government obtains income from taxes (direct, indirect

⁵ The comprehensive information regarding the 2019 SAM can be found in Beyene, L. M., Adenikinju, A., Decaluwe, B., Omoju, O. E., and Akande, A. (2021). "The 2019 Nigerian Social Accounting Matrix" which has not been published yet.

⁶ Decaluwé, B., Lemelin, A., Robichaud, V., Maisonnave, H. (2013). PEP-1-t: the PEP standard single-country, dynamic CGE model. Partnership for Economic Policy

⁷ The two cumulative inputs are hypothesised to be mutually exclusive, with no likelihood of substitution.

taxes, and import duties). The ROW derives its income from capital, labour, imports, and transfers, and expends on purchases of commodities (imports) and transfers (remittances).

$$VA_{j,t} = v_j XST_{j,t} \quad (1)$$

$$CI_{j,t} = io_j XST_{j,t} \quad (2)$$

$$VA_{j,t} = B_{j,t}^{VA} \left[B_{j,t}^{VA} LDC_{j,t}^{-\rho_j^{VA}} + (1 - B_{j,t}^{VA}) KDC_{j,t}^{-\rho_j^{VA}} \right]^{-\frac{1}{\rho_j^{VA}}} \quad (3)$$

$$DI_{i,j,t} = aij_{i,j,t} CI_{j,t} \quad (4)$$

$$PP_{i,t} = \frac{PVA_j VA_{j,t} + PCI_j CI_{j,t}}{XST_{j,t}} \quad (5)$$

$$PC_{i,t} = \sqrt{\frac{\sum_j PVA_{j,t} VA_{j,t}}{\sum_j PVA_{j,t} VA_{j,t}} \frac{\sum_j PVA_{j,t} VA_{j,t}}{\sum_j PVA_{j,t} VA_{j,t}}} \quad (6)$$

$$PIXCON_t = \frac{\sum_i PVA_{i,t} \sum_h C_{i,h,t}^0}{\sum_i PC_{ij,t}^0 \sum_h C_{ij,h,t}^0} \quad (7)$$

Climate shock Block

The primary focus of the climate change dynamic specifications revolves around the diverse impacts of climate on the agricultural sector, which we incorporated into the DCGE model. We make the assumption from (Equation 3) that, within a given time period, the total factor productivity parameter ($B_{j,t}^{VA}$) for each agricultural activity j exposed to climatic shocks is primarily influenced by the average exogenous annual depreciation rate ($\overline{\text{Climate}}_{j,t+1}$) and the effects of increased temperature or rainfall ($\overline{\text{Temp/Rain}}_{j,t+1}$) that occur arbitrarily over the course of ten years (2023-2032), based on estimates from literature⁸. This is expressed mathematically as:

$$B_{j,t+1}^{VA} = B_{j,t}^{VA} \left(1 - \overline{\text{Temp/Rain}}_{j,t+1} \right) - \overline{\text{Climate}}_{j,t+1} \quad \forall j \in \text{Agricultural activities exposed to climatic shocks} \quad (8)$$

Furthermore, the study considers (Equation. 9a, 9b, and 9c) which stipulates that when increased temperature or rainfall occurs, there is a higher annual depreciation rate ($\delta_{k,j,t}$) for land (indicating a decline or greater underutilization of land) and capital. This higher annual depreciation rate ($\delta_{k,j,t}$) persists for a period of two years following increased temperature or rainfall, after which a recovery phase ensues wherein annual depreciation rate ($\delta_{k,j,t}$) is set equal zero. The recovery phase follows climate mitigation efforts by economic agents.

$$\delta_{k,j,t+1} = \delta_{k,j,t} - \overline{\text{Temp/Rain}}_{j,t+1} \quad (9a)$$

$$\delta_{k,j,t+2} = \delta_{k,j,t+1} + \overline{\text{Temp/Rain}}_{j,t+1} / 2 \quad (9b)$$

$$\delta_{k,j,t+3} = \delta_{k,j,t+2} + \overline{\text{Temp/Rain}}_{j,t+1} / 2 \quad (9c)$$

⁸ See the estimates of Amare and Balana (2023) for clarity

Where:

- $VA_{j,t}$ is value added of industry j ;
 $XST_{j,t}$: Total aggregate output of industry j
 $B_{j,t}^{VA}$ is total Factor Productivity of industry j ;
 $Temp/Rain_{j,t}$ Annual effect on total factor productivity of activity j of increased temperature or rainfall
 $Climate_{j,t}$ Annual long run effect of climatic change on total factor productivity of activity j
 $LDC_{j,t}$ composite demand for labour of industry j ;
 $KDC_{j,t}$ composite demand for capital of industry j .
 PC_i : Purchaser price of composite commodity i (including all taxes and margins)
 $PIXCON_t$: Consumer price index
 $PP_{j,t}$: Industry j unit cost, including taxes directly related to the use of capital and labor, but excluding other taxes on production PT_j : Basic price of industry j 's output
 $PVA_{j,t}$: Price of industry j value added (including taxes on production directly related to the use of capital and labour)
 ρVA_j : Elasticity parameter (CES – value added); $-1 < \rho \leq 1$ $VA_j < \infty$
 io_j : Coefficient (Leontief – intermediate consumption)
 v_j : Coefficient (Leontief – value added)
 $DI_{i,j}$: Intermediate consumption of commodity i by industry j
 $CI_{j,t}$: Total intermediate consumption of industry j

In terms of closure rules, we assume that Nigeria is a small economy, therefore global prices are exogenous. The real exchange rate is adjudged to be flexible i.e., determined by market forces and the current account balance exogenous. The base-year level of the distribution of factor income and foreign institutions was maintained. For the PEP-1t CGE model (dynamic), capital was assumed to be mobile across sectors and employed at full capacity. Potential labour supply increases with the growth rate of the population. Elasticity values relating to gender disaggregation were obtained from Beyene et al. (2022).

3.4 Simulated climate change scenarios

The critical issue is how to incorporate agricultural commodity price shocks resulting from climate change into the CGE model. In the literature, two approaches are typically employed to model the consequences of climate change on agricultural production (Yalew, 2020). Climate change is either modelled as an exogenous change in technology that alters land productivity (Bezabih et al., 2011; Bosello et al., 2013), or total factor productivity (Robinson et al., 2012; Wiebelt et al., 2015). This study adopts the latter approach, as the policy implications of land productivity changes remain unclear.

We model three observed scenarios. Simulating the observed scenario has the following advantages:

1. Scenarios are premised on verifiable empirical estimates, so we are not exposing our assumptions to happenstance.
2. We can compare the results which we observe (e.g., agricultural commodity prices with the observed data), this scenario offers verifiable validation.

Table 1. Summarizes the climate change shocks simulated under the three scenarios

Scenarios	Details	Simulation Description
Simulation scenario 1	Increase in temperature	<ul style="list-style-type: none"> ▪ This simulation examines the overall effects of rising temperatures on the agricultural commodity prices. ▪ In particular, the simulation scenarios, referred to as SIM1, investigate the outcomes of a 15% temperature increase, which is equivalent to one standard deviation. As a result, there is a reduction of 5.22⁹% in total productivity.
Simulation scenario 2	Increase in Rainfall	<ul style="list-style-type: none"> ▪ This simulation investigates the impact of changes in rainfall patterns on agricultural commodity prices, as described in the SIM2 scenario. ▪ More specifically, SIM2 suggests a 15% departure from the average precipitation levels, leading to a decrease in total productivity by 1.23%.
Simulation scenario 3	Increase in both temperature and rainfall	<ul style="list-style-type: none"> ▪ The objective of this research was to analyze the consequences of simultaneous temperature and rainfall shocks on agricultural commodity prices through a simulation called SIM3. ▪ The simulation involved studying the effects of a 15% (one standard deviation) rise in precipitation, which resulted in a 1.23% decline in land productivity. Simultaneously, a 15% increase in temperature was examined, leading to a 5.22% decrease in land productivity. ▪ This scenario aimed to replicate the diversity in climatic conditions observed in Nigeria.

Source: Authors' Compilation

⁹ See Amare & Balane (2023) for clarity on estimates used for climate shocks.

4. Results

The simulation results are presented and discussed in this section. Prior to this the descriptive statistics detailing sectorial performance under the Business-as-usual scenario as evidenced in the 2019 Nigerian SAM is presented.

4.1 Descriptive Statistics

This section presents a comprehensive overview of the Nigerian economy as shown in the 2019 Social Accounting Matrix (SAM) employed in this study. Table 2 presents the GDP contribution of each re-aggregated sector, along with their respective shares. In 2019, the services sector, valued at ₦82,124,829.34 million and accounting for 57.24 per cent of the GDP, is the dominant component of GDP, followed closely by agriculture (22.07 per cent) and manufacturing (11.51 per cent), respectively.

Table 2: Sectoral Share of GDP

Code Name	Sector Description	GDP(₦*m)	Share of GDP (%)
AGR	Agriculture	31,660,311.80	22.07
MAN	Manufacturing	16,505,165.92	11.51
EXTI	Extractive Industry	12,671,832.82	8.83
ROIL	Refined oil	500,121.97	0.35
SER	Services	82,124,829.34	57.24
TOT	Total GDP Factor Cost	143,462,261.85	100

Source: Author's computation from SAM (2019)

The extractive industry and refined oil sub-sector, were previously the largest component of the Gross Domestic Product (GDP). However, according to the 2019 Social Accounting Matrix (SAM), their contributions to GDP were 8.83% and 0.35%, respectively. The current state of the economy is experiencing significant structural transformation, with renewed efforts to disentangle the growth process from the oil sector. This highlights the strategic importance of the agricultural sector, given its contributions to GDP, foreign exchange, and tax revenue.

4.2 Analysis of simulation results

Scenario 1: The implication of increasing temperature on agricultural commodity prices compared to Business As Usual (BAU) conditions.

This section presents the results of the impact of increasing temperature on agricultural commodity prices from 2023 to 2032. We discuss the agricultural commodity prices impact by decomposing the price variation in crops, livestock, forestry, and fishing.

The overall observation of the simulation results is that there is a positive effect from temperature rise on agricultural commodity prices, such as crops, livestock, fishing, and forestry (table 3). In Simulation 1, crop prices exhibited a consistent increase over a ten-year period, with an average annual increase of 5.97 per cent. Conversely, livestock prices have experienced an upsurge throughout the same period, with an average increase of 4.91 per cent. The prices of forest stock and fishes have also witnessed a substantial increase, reaching an average of 5.97 per cent and 4.14 per cent, respectively. A 15% increase in temperature causes food prices, which is the weighted sum of price increase in crops (5.97%), livestock (4.91%), forest products (5.97%), and fish (4.14%), to increase by 4.47%, when compared to the reference scenario in 2019.

Table 3: Agricultural Commodity Prices Impact-SIMI

T	CPN	LSK	FTY	FHY
1	6.07	4.97	6.07	4.14
2	6.04	4.95	6.04	4.14
3	6.01	4.93	6.01	4.14
4	5.99	4.92	5.99	4.14
5	5.97	4.90	5.97	4.14
6	5.96	4.89	5.95	4.14
7	5.94	4.88	5.93	4.14
8	5.93	4.88	5.92	4.14
9	5.91	4.87	5.90	4.14
10	5.90	4.86	5.89	4.15
Ave.	5.97	4.91	5.97	4.14

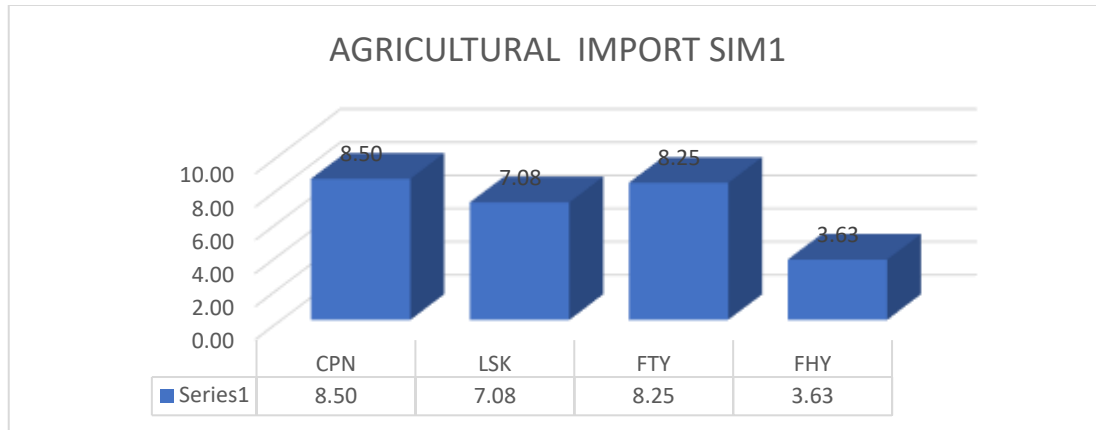
Source: Author's

Computation based on simulation results from GAMS

Note: Values in SIMI represent percentage changes from 2019 reference scenario T=Time period (from 2023-2032, with 2023 being the base-year), Ave=Average, CPN: Crop, LSK: Livestock, FTY: Forestry, FHY: Fishery

Moreover, the Consumer Price Index (CPI) experiences an increase of 1.14% in simulation 1. Since all prices are relative to the Consumer Price Index, the price of other commodities is expected to increase accordingly. Household consumption would reduce substantially when compared to baseline scenario with worsening effects over time, including a likely increase in the scourge of poverty, particularly among those with income just above the poverty line.

The main reason for the increase in agricultural commodity prices is associated with an annual decrease in agricultural output by 10.84 percent and increase in imports of agricultural commodities by 27.46 percent annually for the estimated period. It can be assumed that the performance of agricultural output is accompanied by deficit supply while an increase in agricultural import ensures a rise in global agricultural commodity price which is transmitted to the local economy.

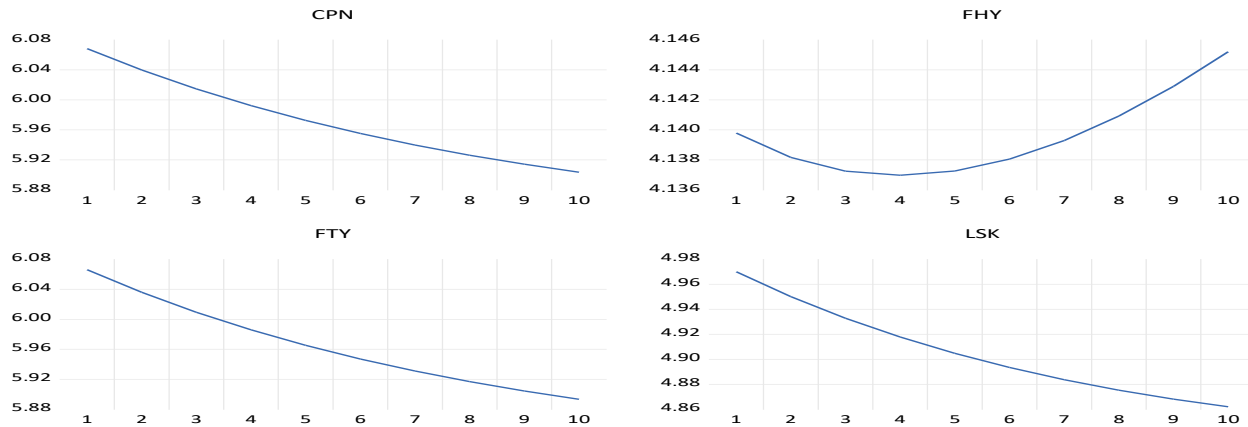


Source: Results from the CGE model

Note: Values represent percentage changes from base year value: CPN: Crop, LSK: Livestock, FTY: Forestry, FHY: Fishery

Figure 1: Agricultural Commodity Import (% deviation from baseline) (Increase in temperature)

It is a commonly held belief that efforts to mitigate temperature rise would have reached their peak and that farmers can counteract climate variability due to the variability of all production inputs in the long run. Thus, the trend analysis which showed that the prices of crops, livestock and forest stock was increasing, albeit at a decreasing magnitude with the exception of the prices of fishes which showed sign of exacerbating further in the long run (figure 2) remain profound. Apparently, the efforts to readjust factor inputs to counteract the impact of increasing temperature will be beneficial in the long run, nonetheless focal emphasis should be placed in the fish sub-sector.



Source: Results from the CGE model

Note: Values represent percentage changes from base year value: CPN: Crop, LSK: Livestock, FTY: Forestry, FHY: Fishery

Figure 2. Agricultural commodity price shocks with a 15% (one standard deviation) increases in temperature

Simulation Scenario 2: Agricultural Commodity prices effects of an Increase in the Rainfall.

This section presents the results of the impact of increasing rainfall on agricultural commodity prices from 2023 to 2032. We discuss the agricultural commodity prices impact by decomposing the price variations in crops, livestock, forest stock and fishes. Table 4 indicates the overall observation of the simulation results which shows that there is a positive effect from increased rainfall on agricultural commodity prices, such as crops, livestock, fishes, and forest stock.

Intuitively, the magnitude of food prices increase was lower compared to scenario 1. In Simulation 2, the average prices increase for the agriculture commodities, crops, livestock, forestry, and fishing were 3.83 per cent, 1.85 per cent, 1.55 per cent, and 1.09 per cent, respectively. Increasing rainfall has a substantial positive effect on agricultural commodity prices, which is a weighted sum of an increase in prices for crop (3.83%), livestock (1.85%), forest stock (1.55%), and fish (1.09%). Consequently, on average, a 15% increase in rainfall causes food prices to experience a notable rise of 2.08% when compared to the baseline scenario in 2019.

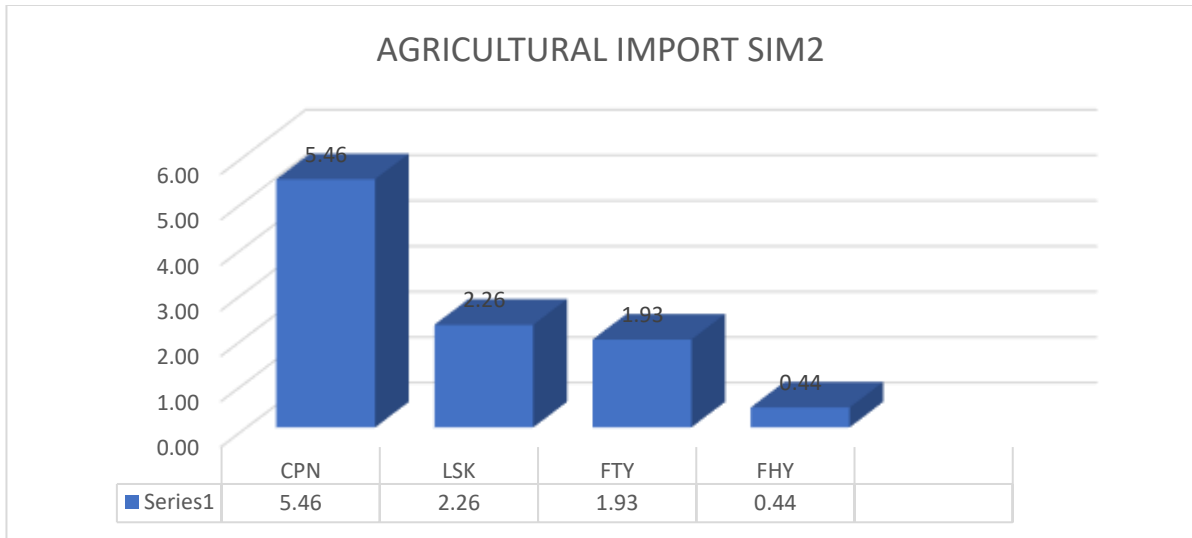
Table 4: Agricultural Commodity Prices Impact-SIM2

T	CPN	LSK	FTY	FHY
1	3.89	1.88	1.59	1.08
2	3.87	1.87	1.58	1.08
3	3.86	1.86	1.57	1.08
4	3.84	1.86	1.56	1.08
5	3.83	1.85	1.55	1.08
6	3.82	1.85	1.54	1.09
7	3.81	1.85	1.54	1.09
8	3.80	1.84	1.53	1.09
9	3.80	1.84	1.53	1.10
10	3.79	1.84	1.52	1.10
Ave.	3.83	1.85	1.55	1.09

Source: Author's Computation based on simulation results from GAMS

Note: Values in SIM2 represent percentage changes from 2019 reference scenario T=Time period (from 2023-2032, with 2023 being the base-year), Ave=Average, CPN: Crop, LSK: Livestock, FTY: Forestry, FHY: Fishery

Additionally, the Consumer Price Index (CPI) witnesses an increase of 0.95% in comparison to the reference scenario of 2019. Given that all prices are interconnected with the CPI, the price of other commodities also increases. At the end, household welfare at the aggregate level in 2032 would be lower than in the no-increased rainfall scenario as their purchasing power becomes constrained. The result is plausible since increasing rainfall causes the agricultural sector to increase wages, and thus raises the rental rate of capital and the value-added price. As a result, the price of agricultural commodities sold in the local market increase, making agricultural imports relatively cheaper and attractive (See Fig 3). Consequently, higher domestic prices discourage export for most agricultural commodities, including agricultural products.

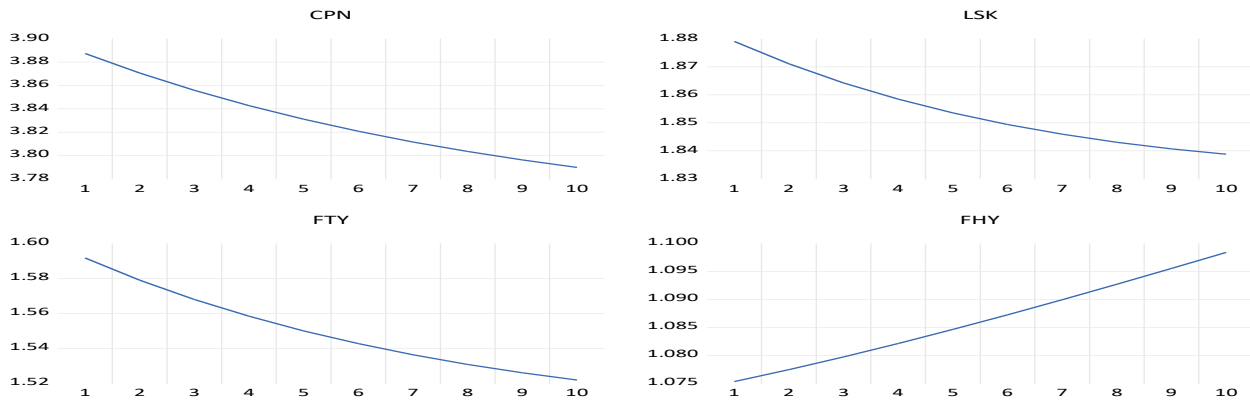


Source: Author’s Computation based on simulation results from GAMS

Note: Values represent percentage changes from 2019 reference scenario, CPN: Crop, LSK: Livestock, FTY: Forestry, FHY: Fishery

Figure 3: Agricultural Import (% deviation from baseline) (increase in rainfall)

It was found, that the increase in rainfall leads to rise in the prices of crops, livestock, and forest stock, albeit at a decreasing magnitude with the exception of the fishing subsector which experienced continuous increase overtime (figure 4). Since it is commonly believed that the efforts to mitigate increase in rainfall would have reached their peak and that farmers can counteract climate variability due to the variability of all production inputs in the long term. The result in the fishing subsector is a clear indication of the need for targeted climate mitigation policy to reverse this trend.



Source: Results from the CGE model

Note: Values represent percentage changes from base year value: CPN: Crop, LSK: Livestock, FTY: Forestry, FHY: Fishery

Figure 4. Agricultural commodity price shocks with a 15% (one standard deviation) increases in rainfall

Simulation 3: The impact of combined increase in temperature and rainfall on agricultural commodity prices

This section provides a litmus test to agricultural commodity price responses on the scenario replicating the diversity of climatic condition in Nigeria wherein the Northern region experiences high temperature while the southern counterpart is faced with intensifying rainfall.

The summary of the effects of this simulation scenario on agricultural commodity prices is shown in table 5. The simultaneous rise in temperature and rainfall increases agricultural commodity prices, which is the weighted sum of incremental price of agricultural commodities (crops, livestock, forestry and fish) by 6.58 percent in 2032. Specifically, the prices of crops, livestock, forestry, and fishes experienced significant increases over the ten-years horizon, with average growth rates of 7.49 per cent, 6.15 per cent, 7.48 per cent, and 5.19 per cent, respectively. Apparently, the magnitude of the change in this scenario is greater since the phenomenon makes mitigation more complex, while the readjustment of factor inputs is also severely constrained. Howbeit, a cursory examination of the result across the agricultural sub-sectors reveals that the prices of fishes is worst hit.

Table 5: Agricultural Commodity Prices Impact-SIM3

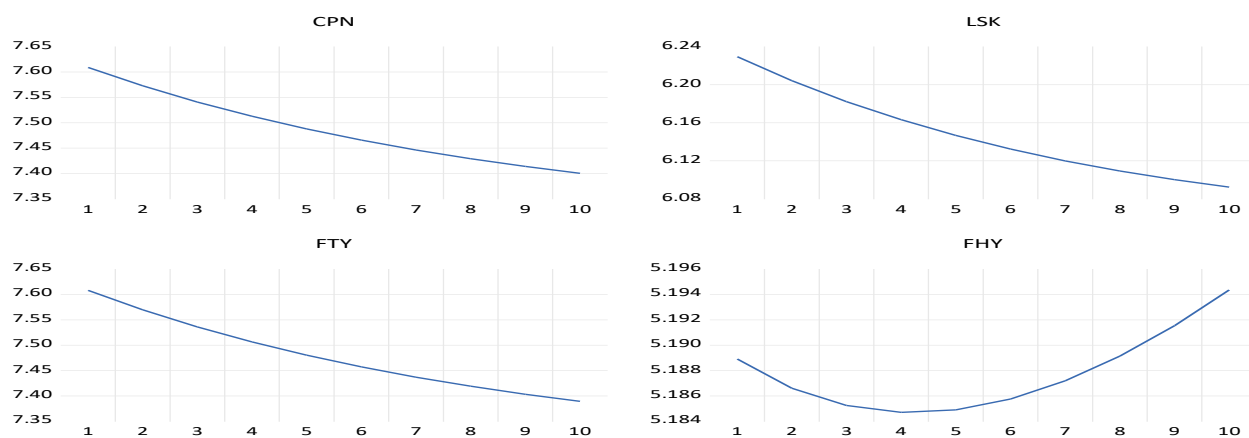
T	CPN	LSK	FTY	FHY
1	7.61	6.23	7.61	5.19
2	7.57	6.20	7.57	5.19
3	7.54	6.18	7.54	5.19
4	7.51	6.16	7.51	5.18
5	7.49	6.15	7.48	5.18
6	7.47	6.13	7.46	5.19
7	7.45	6.12	7.44	5.19
8	7.43	6.11	7.42	5.19
9	7.41	6.10	7.40	5.19
10	7.40	6.09	7.39	5.19
Ave.	7.49	6.15	7.48	5.19

Source: Author's Computation based on simulation results from GAMS

Note: Values represent percentage changes from 2019 reference scenario T=Time period (from 2023-2032, with 2023 being the base-year), Ave=Average, CPN: Crop, LSK: Livestock, FTY: Forestry, FHY: Fishery

Additionally, the Consumer Price Index (CPI) experiences an increase of 17.43% in contrast to the reference scenario. Given that all prices are interconnected with the CPI, the cost of other commodities also undergoes an increase. With agricultural commodity prices above baseline projections, the level of household consumption would likely decline. In a situation of a combined increase in rainfall and temperature, human welfare would experience significant negative effects. According to simulation results, combined increase in temperature and rainfall leads to an increase in agricultural commodity prices, albeit at a descending magnitude with the exception of the fishing subsector which exhibited an ascending magnitude (figure 5).

The findings of this study align with the arguments put forth by Bosello et al. (2018), and Foye (2022) that climate change crystallizes agricultural commodity prices increment. This is also in consonance with the food availability decline (FAD) theoretical framework, which posits that the decrease in per capita food supply is commonly instigated by various climatic factors such as (e.g., temperature rise, increased rainfall, droughts, floods, pest infestations) (Milà-Villaruel et al., 2015; Oyelami, 2023).



Source: Results from the CGE model

Note: Values represent percentage changes from base year value: CPN: Crop, LSK: Livestock, FTY: Forestry, FHY: Fishery

Figure 5. Food price shocks with a 15% (one standard deviation) increases in temperature and rainfall.

Despite providing some insight into Nigeria's vulnerability to future climate conditions, it is important to exercise caution when interpreting the absolute magnitudes of estimated agricultural commodity price shocks. The methodology used in this study does not fully account for the uncertainty surrounding the nature and magnitude of climate change or climate variability, and their respective impacts on agriculture. Additionally, the modeling framework employed does not consider all the collateral effects associated with new climatic conditions, such as health risks, conflicts over water, or external migrations. Furthermore, while the DCGE model does incorporate some autonomous adaptation responses to climate change, such as accumulation dynamics and intersectoral-labor migration, it is likely that the reality would be more flexible over the long-term. The methodology also fails to thoroughly examine the costs and benefits of planned adaptation strategies, including their exogenous supply effects on the agricultural sector or demand effects on other activities or their fiscal space effects.

Moreover, the critical question of funding for coping strategies is not addressed in this study. Unlike many low-income countries with weather-sensitive agricultural production and limited adaptive capacities, Nigeria has a unique position due to the expected windfall revenues from Liquefied Natural Gas. This raises an important policy question of how the country can utilize the increased income from natural resources to cope with new climate conditions, achieve sustainable growth, and reduce poverty over the long term.

5. Conclusion and recommendations

The objective of this paper was to examine the effect of climate change on agricultural commodity prices in the years ahead. The paper employed the use of the dynamic CGE models to achieve this lofty objective. The results of the simulations indicate that climate change would increase agricultural commodity prices in both the short- and long-runs. The study found positive effect of increasing temperature and rainfall (both individualistically and combined effect) on agricultural commodity prices, although the magnitude of variation differed. In view of the result, the conclusion is that climate change, which is envisaged to cause food price increase would be detrimental to households, particularly rural households who are net agricultural commodity

buyers and spend substantial part of their income in purchasing agricultural commodities. Put differently, climate change will cause an increase in the prices of agricultural commodities invariably reducing the purchasing power of households. In the absence of a heterogeneous market assumption in the model, all household categories were subject to identical agricultural commodity prices. Consequently, the adverse income effects associated with escalating agricultural commodity prices will further curtail the consumption capacity of rural poor households. In retrospect, the result should be taken with caution as the study did not consider the trends in inflation observed, increase in the price of imported goods in foreign currency or the impact of the nominal devaluation of the naira, and our model was thus unable to capture the nominal impact on domestic price level.

Based on the estimation of the likely implications agricultural commodity prices of the above simulated climate scenarios, we can recommend the following preliminary policies to enhance the government's climate policy strategy. The government should expand adaptation and resilience initiatives to mitigate the adverse effects of climate change on farmers, fisherfolk, and other agricultural commodity producers and consumers. This entails providing financial and technical assistance for sustainable solutions, enhancing capacity building efforts, improving infrastructure, and fostering innovations such as early warning systems. These measures aim to reduce the vulnerability of these stakeholders and promote sustainable food security, production, and nutrition. Additionally, it is imperative to prioritize the conservation, protection, and restoration of nature in these endeavors.

The government should also enhance the management of water in agriculture and food systems across all tiers to guarantee sustainability and mitigate detrimental effects on agricultural practices reliant on these interconnected domains. Efforts must be heightened to optimize the advantages for climate and the environment, while simultaneously mitigating and diminishing the detrimental effects, linked to agriculture and food systems. This can be achieved through the preservation, safeguarding, and rehabilitation of land and natural ecosystems, as well as the improvement of soil health and biodiversity. Additionally, transitioning from practices that emit higher levels of greenhouse gases to more sustainable methods of production and consumption is crucial. This includes reducing food loss and waste, as well as endorsing sustainable aquatic blue foods.

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