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Statistical modelling of permanent cropland availability and population growth with effect to crop production in Nigeria

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Abstract. This study investigates the long-run and short-run interplay between crop production, population growth and permanent cropland in Nigeria over a 61 year period spanning 1961–2021 using World Development Indicators (WDI) data and a vector autoregressive (VAR)/vector error correction model (VECM) framework. Unit root tests (ADF and Phillips-Perron) confirm that the series are integrated of order one or I(1), and the Johansen test for cointegration establishes the presence of at least one long-run equilibrium relationship. The VECM results reveal that cropland expansion significantly and positively impacts crop production, whereas population growth exerts a negative influence, emphasizing the dual role of demographic pressure as both a driver of demand and a constraint on supply. The VECM result further shows a high rate of adjustment from disequilibrium to long-run equilibrium. Diagnostic checks confirm model adequacy, while impulse-response analysis shows that shocks to crop production stimulate sustained cropland expansion, whereas shocks to population growth exert a negative pull. Overall, the findings underscore the importance of policies that balance land expansion and agricultural productivity with demographic management strategies, to secure long-term food security in Nigeria.

Keywords: cropland; crop production; food crisis; population growth; vector error correction model

1 Introduction

As the food crisis currently ravaging the world, and Nigeria in particular, continues its upward surge, population growth and insufficient permanent cropland have been identified as the two key factors exacerbating this trend. Aiyedogbon *et al.* [1] and Tavershima *et al.* [23] revealed that the land available for agricultural activities in Nigeria is insufficient to feed the ever-growing population. It is imperative to look holistically into this finding in order to ascertain its plausibility. Has the land size for crop production in Nigeria become so grossly insufficient that it can no longer be relied on to feed the country's population over time, or are there factors that have shrunk the cultivable land tremendously as revealed by Okeaya-Inneh [13] – factors such as land-use conflicts and communal clashes? Africa as a whole, and Nigeria in particular, is no stranger to violent conflicts and communal skirmishes surrounding land use, and it is not easy to quantify how much development and growth these conflicts have cost the people in these regions. Crop production has greatly been hampered by these incessant conflicts, as well. Furthermore, Sani *et al.* [18] posits that the *boko haram* (which means, western education is sin) insurgency continues its negative onslaught on food security in rural households. In another perspective, Headey and Hirnoven [9] believes that low food prices have led to decreased food production, as it is sufficient reason to demotivate farmers. The study then suggests higher prices as a stimulant for sustained crop production.

In this study, we investigate the postulate that insufficient permanent cropland and over-population are the key variables fuelling the food crisis in Nigeria, and also look into the veracity of claims by several studies, some of which have been referenced, that Nigeria's food crisis is as a consequence of the interplay of various factors already revealed. This is more so that [6] asserted that the gradual growth of Nigeria's population in the past did not impinge on food production, as there was so much food produced that the country could even export to other countries. Understanding the root of Nigeria's growing food crisis is important if any meaningful solution is to be achieved. It is thus the aim of this study to analyze the impact of permanent cropland and population growth on crop production in Nigeria, and investigate probable factors influencing this trend.

The rest of this study is partitioned as follows: In Section 2, we review relevant and related literature to this research, and then present the methodologies for the different tests performed in Section 3. Section 4 displays and discusses the results of the analysis carried out, and in Section 5, we conclude our study and make in-depth recommendations on the way forward.

2 Literature review

A critical assessment of how much land is available for the production of food crops and the rate of population growth are essential in determining whether or not a nation will produce enough food to feed her population, and also attain food security. Agricultural production and population growth are growing at par, globally, but at diverse rates in different geographical regions [16]. Population growth is experiencing a rapid increase, and this is in turn mounting immense pressure on food production [5]. There is growing emphasis on the extent to which population growth and permanent cropland availability are affecting crop production all over the world. Pressure continues to mount globally on the need for crop production and other agricultural activities to increase appreciably in order to meet the incessant food demand of the growing world population [22]. Also, Wang *et al.* [24] notes that there is heightened concern that increasing urbanization is eating up valuable cropland globally, thereby threatening food security. The study was however able to show, using spatial statistics and scenario analysis, that crop production increased with urbanization in China as a result of reclamation of rural land hitherto used for residential purposes which was converted and used for crop production.

Akanni *et al.* [2] observed that the quantity of crop production is essentially determined by the size of land used for cultivation. Their study looked at the causal relationship between the crop production index and permanent cropland availability using unrestricted Vector Autoregressive (VAR) modelling techniques, and the findings showed that Nigeria's crop production index is forecast by permanent cropland and vice versa. Recently, in the United States, cropland expansion has led to a sweeping conversion of grasslands and associated ecosystems with majorly unknown repercussions for agricultural production [11]. Ritchie and Roser [17] stressed that extensive variability is noticeable in the sizes of land that countries allocate for agricultural activities. This allocation ranges from less than 10 per cent (in mostly the Scandinavian regions) and rises up to 80 per cent in some other countries (including Uruguay, South Africa, Nigeria, Saudi Arabia, and the United Kingdom). A cropland expansion of 3.6 per cent leads to a 2 per cent enhancement in agricultural production globally [20].

Akpan and Ebong [3] examined the nexus between population growth rates and agricultural land use in Nigeria from 1961 to 2018. Findings from the study revealed that arable crop output increased mostly from land expansion than from land productivity. The study further revealed significant positive correlations between population and arable land utilization rates in Nigeria, and then concludes by recommending the institutionalization of policies to enhance farmland productivity. As demand for biomass continues to rise, the expansion and intensification of cropland for agricultural activities remains one of the surest ways to boost agricultural production. A major consequence of this cropland expansion is however the attendant decline in biodiversity. The continuous growth of farmland production is not likely to be sustainable; this is in spite of the anticipated sporadic increase in demand for food and agricultural products by the year 2050 [25]. However, cropland abandonment is becoming globally widespread in spite of the glaring land scarcity for crop production. Cropland expansion has been rising in tandem with population growth across several generations, and this has supported the availability of sufficient food and nourishment for the increasing world population. Unfortunately, this progress halted and began to experience a marked decline over the last decade, culminating in an alarming report in 2021 that 702 to 828 million people, representing 9.8% of the world population were suffering from malnutrition [26]. As such, future cropland expansion is inevitable, if there is any hope to continue feeding and nourishing the growing world population. Cropland expansion is expected to increase globally by a rate of 7% until 2050 [21]. With an estimated urban population growth of 2.5 billion people by 2050, an understanding of how this growth will affect urban land expansion is crucial [12]. This understanding is important in order for crop production and urban economic activities to be propelled in the right direction and sustained in the desired proportion.

6.5 million hectares out of Nigeria's 34 million hectares of arable land area is reserved for permanent crops, with 70 per cent of the country's households participating in different levels of crop production activity [19]. With agriculture accounting for 23 per cent of Nigeria's gross domestic product (GDP), just after oil, it is becoming increasingly important to give adequate attention to factors that contribute to its upscaling, paramount among which is permanent cropland availability. Sasu [19] laments that the population of Nigeria is growing at a worryingly high rate and this has shot up the demand for food tremendously. The study however stops short of indicating whether or not the available permanent cropland is sufficient to produce food that can sustain Nigeria's growing population, or if indeed Nigeria's population is growing at a rate that would have negative consequences on crop production. Consequently, this study will attempt to analyze the direction of influence between permanent cropland availability and population growth, and crop production in Nigeria, in view of the rapidly escalating food crisis in Nigeria. It is important to establish whether or not there exists a positive or negative correlation between the aforementioned variables in order to determine the interventions required. No study had previously considered these three variables together in order to establish any link between them; thus the novelty of this study. Evidence from this study will be used in mapping out whether or not Nigeria needs to scale up the land area used for agricultural cultivation and crop production, or if there are other justifiable factors other than the aforementioned hindering optimum crop production in Nigeria.

3 Methodology

3.1 Data

The time series data on the Crop Production Index, Permanent Cropland Availability, and the Population Growth Index used in this study span 61 years from 1961 to 2021. These data were lifted from the World Development Index, a World Bank publication, last updated in 2023.

3.2 Model specification

As with most econometric models which are expressed in the form

$$y = f(x_1, x_2, u).$$

The model specification for this research is

$$CPI = f(PCL, PGR). \tag{1}$$

Eq. (1) can be explicitly written as:

$$CPI_t = \alpha + \beta_1 PCL_t + \beta_2 PGR_t + u_t, \quad t = 1, 2, \dots, n, \tag{2}$$

where: CPI – crop production index, PCL – permanent cropland, PGR – population growth, α – constant term, β_1, β_2 – coefficients of estimates, and u_t – error term.

Eq. (1) is a conceptual model that links the CPI, PCL and PGR, whereas Eq. (2) is the detailed econometric regression specification that includes an error term (u_t), which serves as the empirical foundation for extending the analysis to the VAR system represented in Eqs. (3)–(5) and eventually the VECM represented in Eqs. (6)–(8).

3.3 Estimation procedure

3.3.1 Vector error correction model (VECM)

The VECM is preferred to other models since it yields more efficient estimators of the co-integrating vectors [8].

Eq. (2) provides the regression baseline, whilst Eqs. (3)–(5) as expressed below, represent the multivariate VAR system:

$$CPI_t = \sigma + \sum_{i=1}^{k} \beta_1 CPI_{t-1} + \sum_{j=1}^{k} \phi_1 PCL_{t-1} + \sum_{m=1}^{k} \varphi_1 PGR_{t-1} + u_{1t}, \tag{3}$$

$$PCL_t = \alpha + \sum_{i=1}^{k} \beta_2 CPI_{t-1} + \sum_{j=1}^{k} \phi_2 PCL_{t-1} + \sum_{m=1}^{k} \varphi_2 PGR_{t-1} + u_{2t}, \tag{4}$$

$$PGR_t = \tau + \sum_{i=1}^{k} \beta_3 CPI_{t-1} + \sum_{j=1}^{k} \phi_3 PCL_{t-1} + \sum_{m=1}^{k} \varphi_3 PGR_{t-1} + u_{3t}. \tag{5}$$

CPI is a function of its lagged values and the lagged values of other variables, and so are PCL and PGR, respectively. All variables are endogenous.

To specify the VECM, the difference operator (Δ) is applied, and the lag length k is reduced by 1, as shown in equations (6) to (8). However, it is essential that we conduct unit root tests and cointegration tests both for verifying VAR assumptions and for motivating the shift to a VECM framework; both VAR and VECM require stationary series.

$$\begin{aligned} \Delta CPI_t = \sigma &+ \sum_{i=1}^{k-1} \beta_1 \Delta CPI_{t-1} + \sum_{j=1}^{k-1} \phi_1 \Delta PCL_{t-1} + \sum_{m=1}^{k-1} \varphi_1 \Delta PGR_{t-1} \\ &+ \lambda_1 ECT_{t-1} + u_{1t}, \end{aligned} \tag{6}$$

$$\begin{aligned} \Delta PCL_t = \alpha &+ \sum_{i=1}^{k-1} \beta_2 \Delta CPI_{t-1} + \sum_{j=1}^{k-1} \phi_2 \Delta PCL_{t-1} + \sum_{m=1}^{k-1} \varphi_2 \Delta PGR_{t-1} \\ &+ \lambda_2 ECT_{t-1} + u_{2t}, \end{aligned} \tag{7}$$

$$\begin{aligned} \Delta PGR_t = \tau &+ \sum_{i=1}^{k-1} \beta_3 \Delta CPI_{t-1} + \sum_{j=1}^{k-1} \phi_3 \Delta PCL_{t-1} + \sum_{m=1}^{k-1} \varphi_3 \Delta PGR_{t-1} \\ &+ \lambda_3 ECT_{t-1} + u_{3t}, \end{aligned} \tag{8}$$

where: k – lag length; σ, α, τ – constant terms; λ_i – adjustment coefficient; $\beta_i, \phi_j, \varphi_m$ – short run coefficients; ECT_{t-1} – error correction term, and u_{it} – errors. Note that the error correction term displays the long-run information in the model, and also explains previous deviation from the long-run equilibrium.

3.3.2 Johansen's co-integration test

The valuable contribution of the concepts of unit root, co-integration, etc. is to force us to find out if the regression residuals are stationary. Granger [7] averred that co-integration can be thought of as a pre-test to avoid 'spurious regression' situations.

Co-integration describes a case whereby two or more time series advance together in the long run. Time series are co-integrated if they have a long term, or equilibrium relationship between them. If a stochastic process needs to undergo differencing j times in order to attain stationarity, then it is said to be integrated of order j, that is, $I(j)$. A time series y_t is said to be integrated of order 1 or $I(1)$ if Δy_t is a stationary time series.

To determine if two or more time series are cointegrated, Johansen's test is used [10]. Johansen's test, which is of two types (Trace and Maximum EigenValue) specifies if cointegration is present. The null hypothesis for both test forms is the same, that is;

H_0: There are r cointegrating vectors.

However, the alternate hypothesis, H_a, for both forms of the test is different. For the Trace test:

H_a: Number of cointegrating relationships is $> r$

whereas the alternate hypothesis for the maximum eigenvalue test states that:

H_a: There are $r + 1$ cointegrating vectors, where r – number of cointegrating relationships.

It is important to clarify how lag length was chosen. Before conducting Johansen's cointegration test, the optimal lag length for the underlying unrestricted VAR was determined using the Akaike Information Criterion (AIC) and the Schwarz Information Criterion (SIC). Both criteria selected an optimal lag of 2. Consequently, the Johansen test was implemented with a lag interval of 1 to 2, following the standard procedure where the VAR lag length is reduced by one when specifying the VECM. This approach ensures that residual autocorrelation is minimized, whilst avoiding over-parameterization given the relatively small sample size. To further check robustness, both Trace and Maximum Eigenvalue statistics were reported, acknowledging that these tests may yield different results due to their distinct power properties. A deterministic trend was also tested in the cointegrating relation, and the results remained consistent, confirming the stability of the long-run relationship among the variables.

The 1 per cent and 5 per cent significance levels are usually employed.

3.3.3 The Dickey-Fuller unit root test

The pioneering work on testing for a unit root in time series was done by Dickey and Fuller [4]. A time series characteristic that explains whether the time series is stationary or non-stationary is referred to as a unit root. A unit root is considered present in the following time series, with $\rho = 1$:

$$y_t = \rho y_{t-1} + \beta X_e + \varepsilon_t, \tag{9}$$

where y_t – value of time series at time t, X_e – exogenous variable, and ε_t – error.

If a unit root is present, it implies that the time series is non-stationary. The Dickey-Fuller test equation is given as

$$y_t = \alpha + \beta \cdot t + \rho y_{t-1} + \phi \Delta y_{t-1} + \varepsilon_t, \tag{10}$$

where y_{t-1} – lag 1 of the time series at time $t-1$, Δy_{t-1} – first difference of the time series at time $t-1$, and $\rho = 1$.

Eq. (10) can be extended to the Augmented Dickey-Fuller (ADF) case, given as

$$y_t = \alpha + \beta \cdot t + \rho y_{t-1} + \phi_1 \Delta y_{t-1} + \phi_2 \Delta y_{t-2} + \cdots + \phi_p \Delta y_{t-p} + \varepsilon_t. \tag{11}$$

This makes the test more robust, as it adds a higher-order regressive process to the model. The lag length (p) was selected using Akaike Information Criteria (AIC) to avoid residual autocorrelation. $\beta \cdot t$ is the deterministic trend component, and Δ is as earlier defined. A unit root is present if $\rho = 1$. The test statistic is described as:

$$t = \frac{\hat{\rho}}{s.e.(\hat{\rho})}. \tag{12}$$

For the Dickey-Fuller test, the null and alternative hypotheses are stated as follows:
H_0: y_t contains a unit root; against
H_1: y_t is stationary

3.3.4 Phillips-Perron unit root test

The Phillips-Perron unit root test, first introduced by Phillips and Perron [14], is a test that corrects the test statistic for serial correlation and heteroskedasticity using a non-parametric adjustment. It is a modified t-statistic for the estimate of ρ:

$$z_\rho = t_\rho - \frac{(\hat{\sigma}_u^2 - s^2)}{2s^2} \cdot \frac{T \cdot SE(\rho)}{s}, \tag{13}$$

where: t_ρ – conventional t-statistic for ρ; $\hat{\sigma}_u^2$ – consistent estimate of long-run variance of u_t, s^2 – variance of regression residuals; T – sample size, and $SE(\rho)$ – the standard error of ρ.

This correction ensures robustness against serial correlation and heteroskedasticity in u_t.

The null and alternate hypothesis for this test are stated as follows:
H_0: $\rho = 0$ (series contains a unit root)
H_1: $\rho < 0$ (series is stationary)
The null hypothesis is rejected if z_ρ is less than the critical value at 1% or 5%.

3.3.5 Jarque-Bera normality test

The Jarque-Bera (JB) test is a goodness-of-fit test of whether the sample data have the skewness and kurtosis matching a normal distribution. The test statistic is defined as:

$$JB = \frac{n - k + 1}{6} \left(S^2 + \frac{1}{4}(C - 3)^2 \right), \tag{14}$$

where n is the number of observations (or degrees of freedom in general), S is the sample skewness, C is the sample kurtosis, and k is the number of regressors. For this test, the null and alternative hypotheses are stated as follows:
H_0: errors are normally distributed
H_a: errors are not normally distributed
The null hypothesis is rejected if the p-value is less than the 5 percent level of significance.

3.3.6 Portmanteau autocorrelation test

The Portmanteau test, also known as the Ljung-Box Q test, is a statistical test used to detect autocorrelation in the residuals of a fitted time series model [15]. The Durbin-Watson test and the Breusch-Godfrey test are tests with similar applications. For the Portmanteau test, the null and alternative hypotheses are stated as follows:

H_0: the autocorrelations up to lag h are all 0

H_a: one or more lags have autocorrelations that differ from 0

The test statistic is given as:

$$Q_h = n(n+2)\sum_{k=1}^{h}\frac{\hat{\rho}_k^2}{n-k}, \tag{15}$$

where: n is the sample size, $\hat{\rho}_k$ is the sample autocorrelation at lag k, and h is the number of lags being tested. Under the null hypothesis, Q follows a $\chi^2_{(h)}$. For the level of significance, α, the critical region for rejection of the hypothesis of serial correlations is: $Q > \chi^2_{1-\alpha,h}$, where $\chi^2_{1-\alpha,h}$ is a quantile of the chi-squared distribution with h degrees of freedom.

The Portmanteau test is usually applied to the residuals of a fitted ARIMA model, and not the original series.

3.3.7 White test for Heteroskedasticity

Among the assumptions of the error term variances for a linear regression model are that they are constant and independent of one another. That is, $V(\varepsilon) = \sigma^2$ and $Cov(\varepsilon_{i,\varepsilon_j}) = 0$. Failure of this assumption being met indicates that the residuals are heteroskedastic. The null and alternative hypotheses for the heteroskedasticity test are stated as follows:

H_0: residual variances are homoscedastic

H_a: residual variances are heteroskedastic

The null hypothesis is rejected if the p-value is less than 0.05 significance level.

4 Results and discussion

4.1 Results

Figs. 1a, 1b, and 1c show the graphical display of CPI, PCL, and PGR at levels, whereas Figs. 2a, 2b, and 2c show the respective graphs of these variables at first difference. A unit root test for levels simply means that the time series is integrated of order zero, that is, it is $I(0)$, and for first differences it is integrated of order one, $I(1)$. For first differences, the graphs appear relatively stationary, in contrast to their frequently changing mean at levels.

From the ADF unit root test results for the time series at levels displayed in Table 1, none of the series appear stationary; this is evidenced by their p-values, which fall above the 0.05 significance level. The conclusion we draw is that all three time series have a unit root at levels. As a result, we carry out first differencing of each series, and the results in Table 2 show that all the time series are $I(1)$ stationary. The PP test results reported in Tables 3 and 4 corroborate the ADF findings, confirming

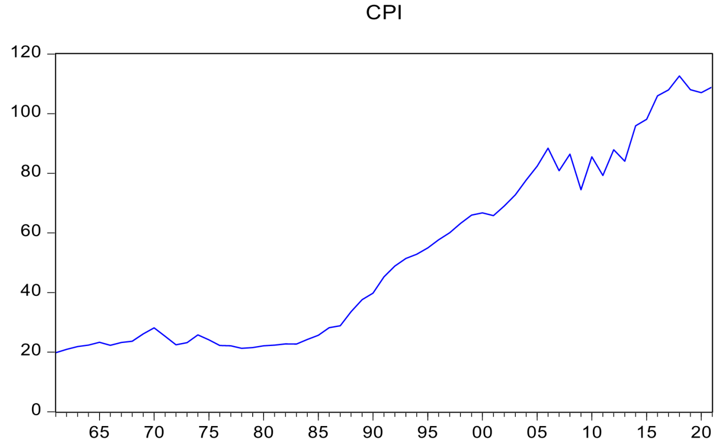

Fig. 1a. CPI level – y-axis: CPI; x-axis: time (years).

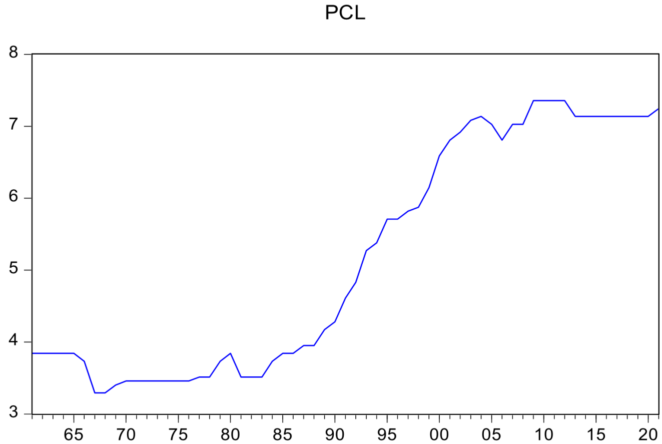

Fig. 1b. PCL level – y-axis: PCL (% land area); x-axis: time (years).

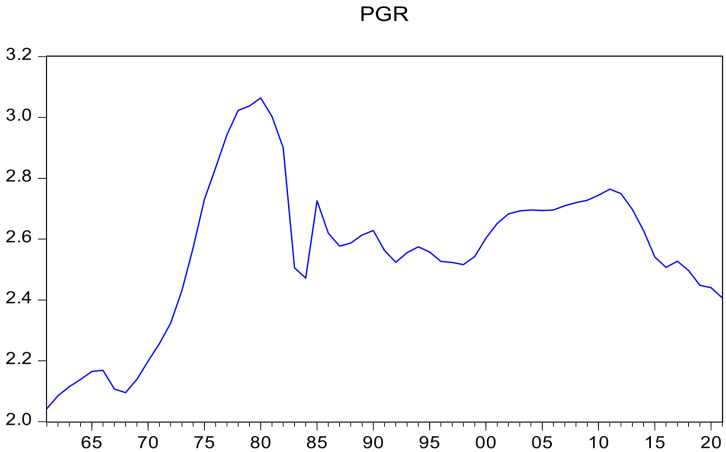

Fig. 1c. PGR level – y-axis: PGR (% annual growth); x-axis: time (years).

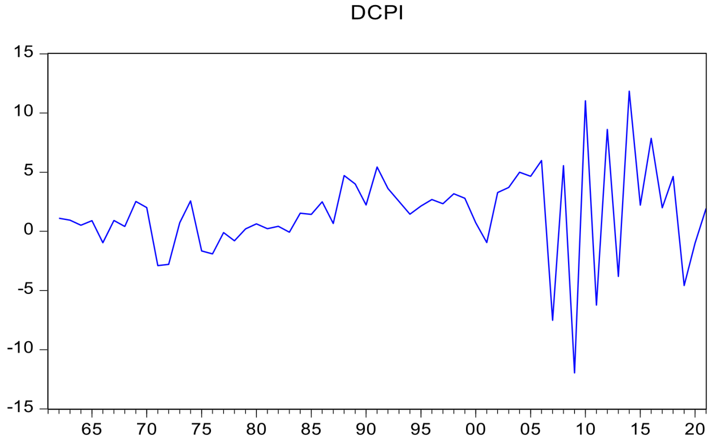

Fig. 2a. CPI first difference – y-axis: CPI; x-axis: time (years).

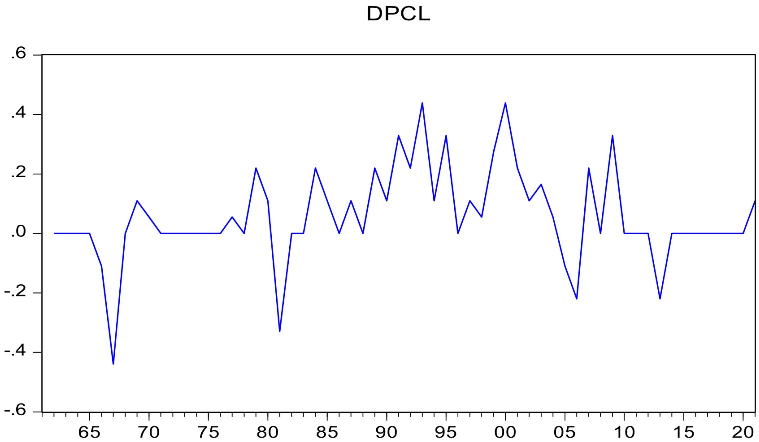

Fig. 2b. PCL first difference – Y-axis: PCL (% land area); X-axis: time (years).

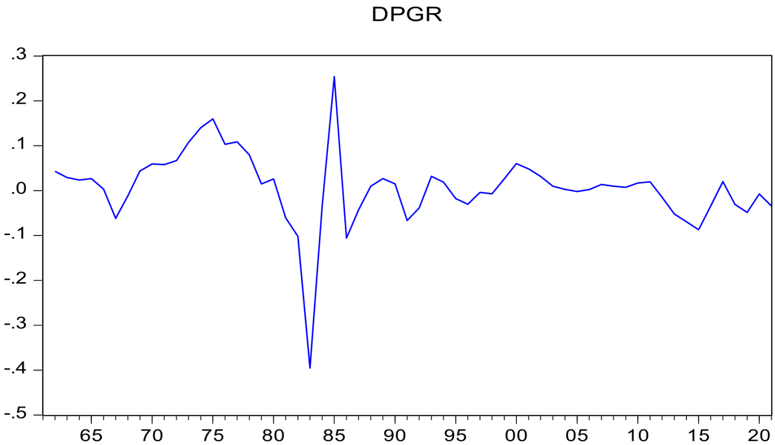

Fig. 2c. PGR first difference – Y-axis: PGR (% annual growth); X-axis: time (years).

Table 1. ADF unit root tests for levels.

Variable	ADF test statistic	Critical value (1%)	Critical value (5%)	Prob*	Integration order
CPI	0.243097	−3.548208	−2.912631	0.9731	I(1)
PCL	0.286876	−3.544063	−2.910860	0.9757	I(1)
PGR	−2.615252	−3.550396	−2.913549	0.0958	I(1)

Table 2. ADF unit root tests for first differences.

Variable	ADF test statistic	Critical value (1%)	Critical value (5%)	Prob*	Integration order
CPI	−3.305831	−3.548208	−2.912631	0.0191	I(0)
PCL	−5.482131	−3.546099	−2.911730	0.0000	I(0)
PGR	−5.155306	−3.546099	−2.911730	0.0001	I(0)

Table 3. PP unit root tests for levels

Variable	ADF test statistic	Critical value (1%)	Critical value (5%)	Prob*	Integration order
CPI	1.059087	−3.544063	−2.910860	0.9967	I(1)
PCL	0.003094	−3.544063	−2.910860	0.9548	I(1)
PGR	−2.264993	−3.544063	−2.910860	0.1865	I(1)

Table 4. PP unit root tests for first differences.

Variable	ADF test statistic	Critical value (1%)	Critical value (5%)	Prob*	Integration order
CPI	−10.76306	−3.546099	−2.911730	0.0000	I(0)
PCL	−5.424859	−3.546099	−2.911730	0.0000	I(0)
PGR	−5.213674	−3.546099	−2.911730	0.0001	I(0)

that all three series are non-stationary at levels but become stationary after first differencing (i.e., they are $I(1)$). The PP test is robust to heteroskedasticity and serial correlation, and its joint application with the ADF test provides a stronger basis for concluding that the variables are $I(1)$.

Having ascertained that the time series are stationary, we proceed to run a co-integration test to determine if there is a long-run relationship among the time series. The Trace test and Maximum Eigenvalue results of the Johansen co-integration test displayed in Tables 5a and 5b show three and one co-integrating equations at the 0.05 level, respectively. Hence, we display our co-integrating equation model drawn from Table 6, thus:

$$CPI + (-7.955930 * PCL + 18.51579 * PGR - 1.140119 * C) = 0. \tag{16}$$

We can also write Eq. (14) as:

$$CPI = 7.955930 * PCL - 18.51579 * PGR + 1.140119 * C.$$

Our model shows a positive relationship between PCL and CPI, while PGR is negatively related to CPI. In other words, a unit increase in the value of PCL will

Table 5a. Johansen co-integration test (trace).

Hypothesized number of CE(s)	Eigenvalue	Trace statistic	0.05 critical value	Prob.**
None*	0.303874	39.35077	29.79707	0.0030
At most 1*	0.204536	18.70399	15.49471	0.0158
At most 2*	0.094538	5.660684	3.841466	0.0173

Table 5b. Johansen co-integration test (maximum eigenvalue).

Hypothesized number of CE(s)	Eigenvalue	Max-eigen statistic	0.05 critical value	Prob.**
None	0.303874	20.64678	21.13162	0.0583
At most 1	0.204536	13.04331	14.26460	0.0773
At most 2*	0.094538	5.660684	3.841466	0.0173

Table 6. Co-integration result.

Cointegrating eq.	Estimate	t-Statistic	Standard error
CPI	1.000000		
PCL	−7.955930	−2.21463	3.59244
PGR	18.51579	2.51124	7.37318
C	−1.140119		

cause a 7.96 unit rise in the value of CPI, whereas a unit increase in PGR will lead to a decline of 18.52 units in the value of CPI. Although population growth is a flow variable, its inclusion alongside cropland and crop production indices is justified because sustained demographic expansion exerts long-term pressure on land resources and food output, thereby forming a meaningful equilibrium relationship with the stock variables. Thus, our estimated model produced the correct signs.

These results are economically intuitive. The positive effect of PCL reflects the direct role of land expansion in boosting agricultural output, consistent with the expectation that more cultivable land translates into higher crop production. Contrastingly, the negative effect of PGR can be attributed to multiple reinforcing factors. Firstly, rapid demographic expansion fragments farmland into smaller plots, reducing economies of scale in cultivation. Secondly, urban encroachment and land use competition shrink the area available for farming. Thirdly, population growth drives up food demand, which in the short run can depress per capita productivity when agricultural supply does not keep pace. These channels jointly explain why rising population growth exerts downward pressure on crop production in the Nigerian context. We also acknowledge that other variables, such as rainfall variability, food price dynamics, fertilizer application, and conflict intricacies, may further impact the relationship. Although data limitations precluded their inclusion in this study, we strongly recommend incorporating such controls in future work to provide an even more comprehensive snapshot.

The value of co-integrating equation 1 of the vector error correction model shown in Table 7, which is -0.922068, indicates that the speed of adjustment to long-run equilibrium in any case of disequilibrium is 92 per cent. In other words, past values of CPI have a feedback effect on itself in the short run, and this makes it clear that our model's performance is very commendable. The coefficient of determination (R^2) of 0.829057 shows that 83% of the total variations in CPI were accounted for by PCL and PGR.

Table 7. Vector error correction model.

Error Correction	Estimate	t-Statistic	Standard error
D(CPI)	−0.922068	−4.41621	0.20879
D(PCL)	0.013270	1.09934	0.00556
D(PGR)	−0.004070	−0.73171	0.02752

$R^2 = 0.829057$. Adj. $R^2 = 0.804637$.

To further explore the dynamic interactions among the variables, impulse-response analysis was conducted (Fig. 3). The results show that a positive shock to CPI generates a sustained positive response in PCL, suggesting that higher crop output stimulates land expansion. Conversely, a shock to CPI exerts a negative effect on PGR, but this effect gradually fades away and returns to equilibrium after about 7–9 years, with the response not statistically different from zero across horizons, given the ±2 S.E. bands. These results are consistent with the long-run relationship identified in the VECM, where cropland expansion supports production, whereas population growth pressure limits it. It is, however, necessary to add that further analysis with expanded data is required to obtain a more conclusive result.

Response to Cholesky One S.D. (d.f. adjusted) Innovations ±2 S.E.

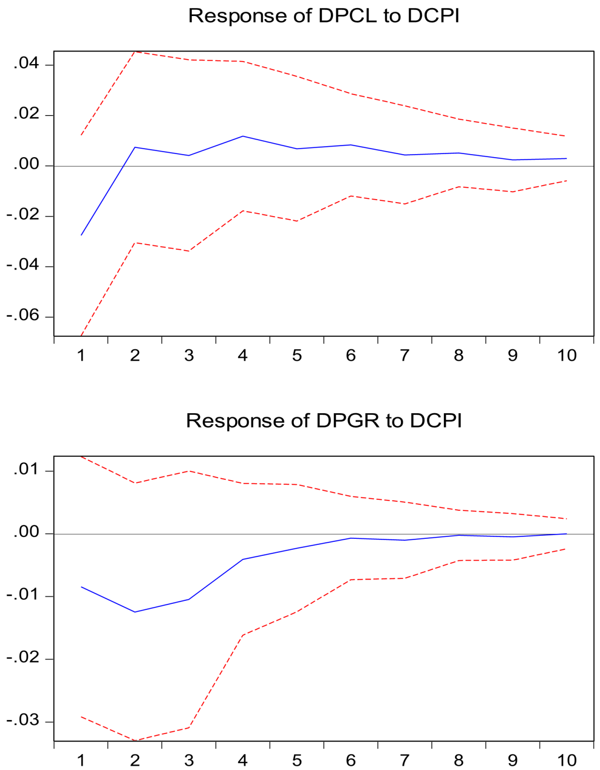

Fig. 3. Impulse-response function graph.

The impulse-response analysis highlights two key policy priorities for Nigeria. Firstly, since positive shocks to crop production stimulate further cropland expansion, government policies should sustainably support land development through improved irrigation, mechanization, and land security policies that reduce conflict and discourage unregulated land degradation. Secondly, given that PGR shocks exert a negative influence on CPI, complementary demographic policies, such as investment in family planning, rural education, and women's empowerment, are essential to moderate long-term pressure on the food system. Together, these approaches can balance the spiraling effect of cropland expansion with the dampening effect of population growth, creating a more resilient path to food security.

Table 8 shows the residual heteroskedasticity test result with a p-value of 0.0873, which is much higher than the 0.05 level. As such, we do not reject the null hypothesis at the 5% level of significance and conclude that the residuals are homoskedastic, which is ideal.

Table 8. VEC Residual heteroskedasticity tests (levels and squares).

Chi-Square	Degrees of freedom	Probability
102.0990	84	0.0873

The p-value of 0.6072 in Table 9, which is higher than the 0.05 significance level indicates that there are no serial autocorrelations among the time series. Consequently, we do not reject the null hypothesis of no autocorrelation.

Table 9. VEC residual Portmanteau tests for autocorrelation.

Lags	Q-Stat	Prob.*	Adj. Q-Stat	Prob.*	d.f.
1	1.001299	–	1.019180	–	–
2	5.395334	–	5.572998	–	–
3	12.37105	0.6508	12.93625	0.6072	15

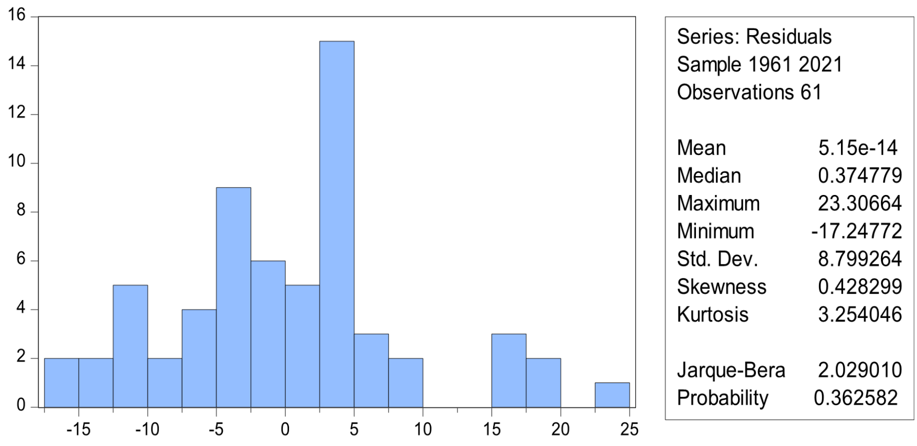

Fig. 4. Jarque-Bera normality test.

The Jarque-Bera normality test result (Fig. 4) gives a p-value of 0.362582, which is significantly higher than the 0.05 level of significance. This test stipulates that we reject the null hypothesis of normality if the p-value is less than the 5% significance level. In view of the p-value indicated in Fig. 4, the null hypothesis is not rejected, and thus, we conclude that the residuals are normally distributed.

5 Conclusion and recommendations

5.1 Conclusion

This study examined the long-run and short-run dynamics among PGR, PCL, and CPI in Nigeria, spanning a sixty-one-year period using VAR/VECM techniques. The following conclusions have thus been drawn:

i. All the time series data were stationary at $I(1)$, and exhibited at least one cointegrating relationship, justifying the use of the VECM approach.
ii. The Johansen cointegration test indicates a long-run, equilibrium relationship amongst the time series.
iii. There is a high rate of adjustment of any cases of disequilibrium to the long-run equilibrium.
iv. The co-integrating model displayed the correct signs; permanent cropland availability is positively related to crop production, whereas population growth and crop production have a negative relationship.
v. Our estimated model's performance was desirable. The residuals are normally distributed, not autocorrelated, and are homoskedastic.
vi. Impulse-response analysis further bolsters these findings by showing that positive shocks to crop production stimulate cropland expansion, while population growth exerts a negative drag on crop production. This dynamic interplay underscores the dual policy challenge: ensuring sustainable expansion of arable land and agricultural productivity while addressing the demographic pressures that threaten food supply.

5.2 Recommendations

In view of the study's findings, it is recommended that Nigeria adopt a two-tier approach that balances sustained cropland expansion with effective demographic management. On the supply side, the government should implement policies targeted at increased land development through irrigation, mechanization, while also promoting productivity-enhancing measures such as fertilizer subsidies, improved seed varieties, and agricultural extension services to raise yields per hectare. Synchronously, strategies to ensure safeguards against land degradation and deforestation must be put in place to ensure environmental sustainability.

From the demand angle, the negative long-run effect of population growth on crop production highlights the need for integrating demographic management into food security considerations through family planning initiatives, investment in women's education, and a rural employment drive. Given that shocks in the system can persist for several years, resilience measures such as food reserves, climate adaptation programs, and social protection schemes are vital to cushion short-run imbalances.

Finally, strengthening agricultural data systems to incorporate variables such as rainfall, fertilizer usage, conflict situations, etc., will provide a stronger evidence base for future policy interventions. Together, these strategies can potentially enable Nigeria to mitigate demographic pressure, enhance agricultural productivity, and ensure sustained long-term food security.

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REZIUMĖ

Nuolatinių pasėlių plotų ir gyventojų skaičiaus augimo bei jų poveikio augalininkystės produkcijai Nigerijoje statistinis modeliavimas

O. Ode, W. Mutah

Šiame tyrime, naudojant Pasaulio vystymosi rodiklių duomenis bei vektorinę autoregresiją ir vektorinės paklaidų korekcijos modelį (VPKM), tiriama ilgalaikė ir trumpalaikė sąveika tarp pasėlių produkcijos, populiacijos augimo ir nuolatinių pasėlių plotų Nigerijoje per 61 metų laikotarpį, apimantį 1961–2021 metus. Vienetinės šaknies testai (išplėstinis Dickey-Fuller ir Phillips-Perron) patvirtina, kad tiriamos laiko eilutės yra pirma eile integruotos arba I(1), o Johanseno kointegracijos testu nustatyta, kad egzistuoja bent vienas ilgalaikis pusiausvyros ryšys. VPKM rezultatai parodė, kad pasėlių plotų plėtra reikšmingai ir teigiamai veikia pasėlių produkciją, o gyventojų skaičiaus augimas daro neigiamą įtaką, ir tuo pačiu išryškino dvejopą demografinio spaudimo vaidmenį – paklausos variklio ir pasiūlą ribojančio veiksnio. VPKM rezultatai taip pat parodė didelį artėjimo prie ilgalaikės pusiausvyros greitį. Diagnostiniai patikrinimai patvirtina modelio tinkamumą. Impulsų ir atsako analizė rodo, kad pasėlių produkcijos šokai skatina tvarią pasėlių plotų plėtrą, o populiacijos augimo šokai daro neigiamą įtaką. Apibendrinant pabrėžiama, kad siekiant Nigerijoje užtikrinti ilgalaikį aprūpinimą maistu svarbu pasėlių plotų plėtrą ir žemės ūkio produktyvumą subalansuoti su demografinio valdymo strategijomis.

Raktiniai žodžiai: pasėlių plotas; augalininkystė; maisto krizė; gyventojų skaičiaus augimas