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DOI: doi.org/10.64388/IREV9I3-1709523-596

Multivariate Time Series Analysis and Forecasting of Staple Food Prices in Kaduna State Using Vector Autoregression and Vector Error Correction Models

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Abstract- In Nigeria, staple food prices have been increasingly volatile, posing significant challenges to food accessibility and affordability. This study analyzes the dynamics of staple food prices in Kaduna State, Nigeria, focusing on rice, maize, soybeans, cowpea, and sorghum, using time series data from 2017 to 2023. The analysis reveals a statistically significant increase in food prices, with a notable surge and heightened volatility observed in 2023. Seasonal fluctuations, influenced by planting and harvest cycles, are also observed, with prices generally lower from January to March and higher from August to October. The unit root tests suggest stationarity at the first difference, while cointegration and Granger-causality were found in the time series. This suggests the suitability of the Vector Error Correction Model (VECM), which proved better than the baseline Vector Autoregression (VAR) model. The VECM provides more accurate forecast, with an overall average improvement of 4% in Mean Absolute Percentage Error (MAPE), 103 versus 131 in Mean Absolute Error (MAE) and 118 versus 150 in Root Mean Square Error (RMSE) for VECM and VAR respectively. The findings of this study contribute to a better understanding of staple food price dynamics in Kaduna State, providing valuable insights for policymakers and stakeholders seeking to enhance food security and affordability.

I. INTRODUCTION

Kaduna State is a vital agricultural center in Nigeria, with excellent crop production performance. The state is contributing an average of 22% of Nigeria's total annual maize production (Mani et al, 2021). It cultivates a wide variety of crops, with maize (31.8%), rice (12.4%), sorghum (9.0%), soybeans (8.4%), and cowpea (white beans) (7.6%) being among the most prominent in the country (AFEX, 2023).

In recent years a substantial increase in staple food prices have raised serious concerns starting in 2023. This surge, is attributed to multiple factors including the removal of fuel subsidies, the devaluation of the naira, escalating insecurity, and supply chain disruptions which has far-reaching implications for food security and economic well-being (Reporters, 2023)

Tunji (2024) reveal alarming price increases for various staple foods, with rice experiencing a 135.62% increase and other essential items like plantain, potatoes, and sweet potatoes also witnessing substantial price hikes.

To understand this changes in the context of Kaduna, this study aims to analyze the price trends and interrelationships between five primary staple foods produced in Kaduna State including maize, rice, sorghum, soybeans, and cowpeas. These staples were selected based on their prominence in the region's agricultural production and consumption patterns, as well as their critical importance for household nutrition and food security (Afex, 2020). The research will examine the relationships between the price levels of these staples, to discover whether they are linked, and make future forecast using a Vector Error Correction Model (VECM). The staple food price data was obtained from the Kaduna State Bureau of Statistics (KDBS) and spanning from 2017 to 2023. Price is recorded in Naira per Mudu (a traditional volumetric measure widely used in Northern Nigeria for grains and legumes, where one Mudu approximates 1.5kg).

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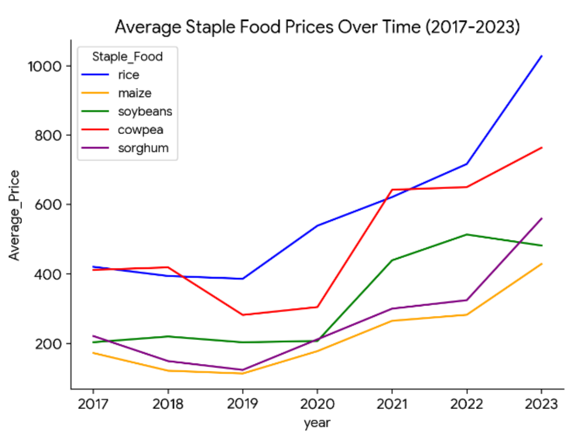
Staple price description

	mean	*std*	*min*	*25%*	*50%*	*75%*	*max*
rice	639.33	246.72	250	450	600	750	1500
maize	245.65	129.97	50	140	230	300	1100
soybeans	356.68	149.9	100	200	375	500	750
cowpea	534.31	225.21	150	350	500	700	1400
sorghum	301.37	187.21	70	180	260	350	1200

The greatest price variation is observed in rice with a standard deviation of ₦246.72 and stands at ₦639.33 as the average price. There was a single instance where rice price reaches a peak of ₦1500 which is considered an unusual market event (as at 2023). Maize remains the least expensive staple food with an average price of ₦245.65 and a minimum price of ₦50. Soybeans and cowpea prices sit between rice and maize prices because they are neither as expensive nor as stable as these staples. Sorghum shows a low average price of ₦301.37 but its wide standard deviation of ₦187.21 suggests frequent price-changes.



The chart shows that the prices of all the staple foods have been increasing over the years, with the most significant increase between 2022 to 2023. The price of rice has been the highest among all the staple foods, while the price of maize has been the lowest.

STATIONARITY TEST

Unit root test using Augmented Dickey Fuller (ADF) test for an autoregressive model of order p (AR(p))

$$y_t = \varphi_1 y_{t-1} + \varphi_2 y_{t-2} + \cdots + \varphi_p y_{t-p} + \varepsilon_t \ (1)$$

From (1) Let $y_{1t}, y_{2t},, y_{3t},, y_{4t}$ *and* y_{5t} represent a vector the prices of rice, maize, soybeans, cowpea, and sorghum respectively at time t. denoted as:

$$Y_t = y_{1t}, y_{2t},, y_{3t},, y_{4t} \text{ and } y_{5t}$$

Subtract y_{t-1} from both sides in (1)

$$y_t - y_{t-1} = \varphi_1 y_{t-1} - y_{t-1} + \varphi_2 y_{t-2} + \cdots + \varphi_p y_{t-p} + \varepsilon_t$$

$$\Delta y_t = (\varphi_1 - 1) y_{t-1} + \varphi_2 y_{t-2} + \cdots + \varphi_p y_{t-p} + \varepsilon_t \ (2)$$

- y_t: time series (dependent variable)
- $\varphi_1, \varphi_2, \ldots \varphi_p$: Autoregressive coefficients
- ε_t: White noise (independent and identically distributed: IID:$0, \sigma^2$)

Let $\delta = \varphi_1 - 1$ in (2)

$$\Delta y_t = \delta y_{t-1} + \varphi_2 y_{t-2} + \cdots + \varphi_p y_{t-p} + \varepsilon_t \ (3)$$

Adding lag difference to y_t in (3) will remove autocorrelation which might otherwise violates the ADF no autocorrelation assumption.

$$\Delta y_t = \delta y_{t-1} + \sum_{i=2}^{p} \varphi_i y_{t-i} + \sum_{j=1}^{m} \gamma_j \Delta y_{t-j} + \varepsilon_t \ (4)$$

Where $\sum_{j=1}^{m} \gamma_j \Delta y_{t-j}$ is the lagged first difference augmenting the test. (Hence, Augment Dickey fuller test)

If $\delta = 0$ then y_t has a unit root (non-stationary) else If $\delta < 0$ then the time series is stationary based on the t-statistics for the coefficient δ in the regression:

$$ADF = \frac{\hat{\delta}}{SE(\hat{\delta})}$$

Where: $SE(\hat{\delta})$ is the standard error $\hat{\delta}$

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COINTEGRATION TEST

The Johansen cointegration is used to determine whether a set of non-stationary time series variables are cointegrated. Thus:

$$y_{1t} = \varphi_{11}y_{t-1} + \varphi_{12}y_{t-2} + \cdots + \varphi_{1p}y_{1t-p} + \varepsilon_t$$

$$y_{2t} = \varphi_{21}y_{t-1} + \varphi_{22}y_{t-2} + \cdots + \varphi_{2p}y_{2t-p} + \varepsilon_t \quad (5)$$

$$\vdots \qquad\qquad \vdots \qquad\qquad \vdots$$

$$y_{5t} = \varphi_{5t}y_{5t-1} + \varphi_{52}y_{5t-2} + \cdots + \varphi_{5p}y_{5t-p} + \varepsilon_t$$

$$Y_t = \begin{pmatrix} \varphi_{11} & \cdots & \varphi_{1p} \\ \vdots & \ddots & \vdots \\ \varphi_5 & \cdots & \varphi_p \end{pmatrix} \begin{pmatrix} y_{1t-1} \\ \vdots \\ y_{5t-1} \end{pmatrix} + \varepsilon_t \quad (6)$$

$$Y_t = A_1Y_{t-1} + A_2Y_{t-2} + \cdots + A_pY_{t-p} + \varepsilon_t \quad (7)$$

Let (3) be a VAR(p) model for a vector of n time series variables Y_t, where:

- Y_t is an $n \times 1$ vector of non-stationary time series variables.
- A_i is an $n \times n$ coefficient matrices.
- ε_t is an $n \times 1$ vector of white noise.

Adding the lag difference yields the equation (8)

$$\Delta Y_t = \Pi Y_{t-1} + \Gamma_1 \Delta Y_{t-1} + \ldots + \Gamma_{p-1}\Delta Y_{t-p+1} + \epsilon_t$$

$$\Delta Y_t = \Pi Y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \, \Delta Y_{t-1} + \varepsilon_t \quad (8)$$

Where:

- $\Delta Y_t = Y_t - Y_{t-1}$ is the first difference.
- $\Gamma_i = -(I - A_1 - A_2 - \cdots - A_i)$ is the short run impact
- $\Pi = -(I - A_1 - A_2 - \cdots - A_p)$ is the long run equilibrium coefficient matrix

If $rank(\Pi) = 0$ no cointegration exist, else if $rank(\Pi) = n$ the system is stationary else if $0 < rank(\Pi) = r < n$, there are r cointegration relationships.

The hypothesis that the number of cointegrating relationship is at most r is determine by trace statistic test in (9) while the maximum eigenvalue statistics tests the null hypothesis of at most r cointegrated vectors against r+1 in (10):

$$\lambda_{trace}(r) = -T\sum_{i=r+1}^{n} \ln(1 - \hat{\lambda}_i) \quad (9)$$

$$\lambda_{max}(r, r+1) = -T\ln(1 - \hat{\lambda}_{t+1}) \quad (10)$$

$\hat{\lambda}_{t+1}$ *is the* $(r+1)th$ largest eigenvalue. Both (9) and (10) follow a non-standard distribution, and critical values are obtained from Johansen's table, if the test statistics exceeds the critical value H0 is rejected.

VECTOR ERROR CORRECTION MODEL (VECM)

VECM extends cointegration by decomposing the matrix Π

$$\Pi = \alpha\beta' Y_{t-1}$$

$$\Delta Y_t = \alpha\beta' Y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \, \Delta Y_{t-1} + \varepsilon_t \quad (11)$$

β and α are $n \times r$ matrix of cointegrated vectors which determined the long-run equilibrium relationship and the adjustment coefficient representing how quickly deviations from the equilibrium correct over time, respectively.

GRANGER CAUSALITY (GC) TEST

The test is based on the idea that if a time series X_t helps predict another time series Y_t, then past values of X_t should provide statistically significant information about Y_t, beyond what past values of Y_t alone can provide.

Let X_t^i be the staple food price at time t, where $i = 1,2 \ldots 5$ which represents the time series prices of Maize, Rice, Cowpea, Soybeans, and Sorghum respectively. Each series is modelled as

$$X_t^i = \sum_{j=1}^{p} \sum_{k=1}^{5} A_{j,k}^i X_{t-j}^t + \varepsilon_j^i \quad (12)$$

Where: X_t^i is the i^{th} time series, p is the number of lags, $A_{j,k}^i$ are the coefficients capturing the influence of the k^{th} series on the i^{th} series at lag j while ε_j^i is the error term. Written in matrix form as:

$$\boldsymbol{X}_t = \sum_{j=1}^{p} A_j \boldsymbol{X}_{t-j} + \varepsilon_t$$

Where $\boldsymbol{X}_t$ is a 5x1 vector of all series at time t, A_j is a 5x5 of coefficient for lag j.

By expressing each price series as a function of its own past values and the past values of all other series in a VAR(2) model.

$$\begin{bmatrix} Maize_t \\ Rice_t \\ Cowpea_t \\ Soybeans_t \\ Sorghum_t \end{bmatrix} = A_1 \begin{bmatrix} Maize_{t-1} \\ Rice_{t-1} \\ Cowpea_{t-1} \\ Soybeans_{t-1} \\ Sorghum_{t-1} \end{bmatrix} + A_2 \begin{bmatrix} Maize_{t-1} \\ Rice_{t-1} \\ Cowpea_{t-1} \\ Soybeans_{t-1} \\ Sorghum_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{maize} \\ \varepsilon_{rice} \\ \varepsilon_{cowpea} \\ \varepsilon_{soybeans} \\ \varepsilon_{sorghum} \end{bmatrix}$$

Each A_j matrix (for lag j) captures how past process of all five staple foods influence each other:

$$A_j = \begin{bmatrix} a_{11}^j & \cdots & a_{15}^j \\ \vdots & \ddots & \vdots \\ a_{51}^j & \cdots & a_{55}^j \end{bmatrix}$$

$$Maize_t = a_{11}^1 Maize_{t-1} + a_{12}^1 Rice_{t-1}$$

$$+ a_{13}^1 Copea_{t-1} + a_{14}^1 Soybeans_{t-1} + a_{15}^1 Sorghum_{t-1}$$

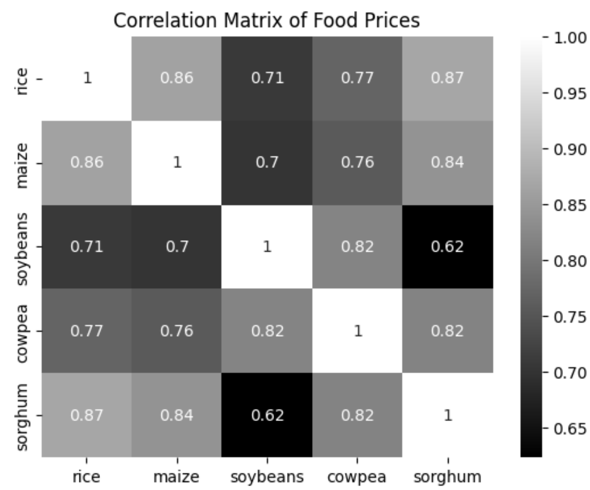
$$+ a_{11}^2 Maize_{t-2} + a_{12}^2 Rice_{t-2} + a_{13}^2 Copea_{t-2}$$

$$+ a_{14}^2 Soybeans_{t-2} + a_{15}^2 Sorghum_{t-2}$$

Similar equation exist for rice, cowpea, soybeans and sorghum respectively. We can determine the GC by testing the null hypothesis:

$$H_0 = A_{j,k}^i = 0, \quad \forall j$$

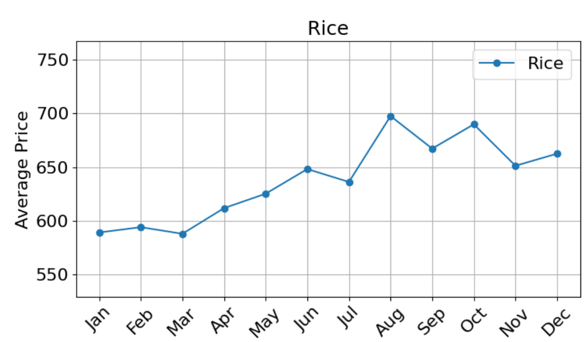
If these coefficients are significantly different from zero, we conclude the presence of GC relationship.



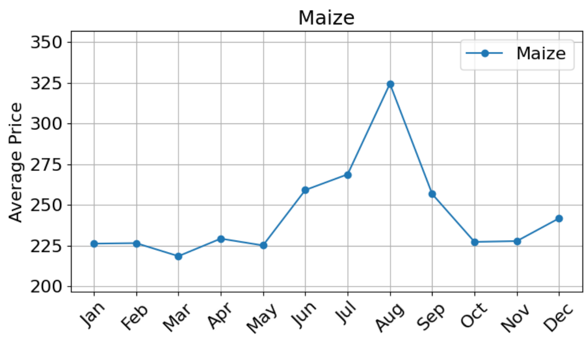
The strongest correlation is observed between rice and maize (0.86), suggesting a close relationship between theirs prices while the weakest is between soybeans and sorghum (o.62).

Price variation overtime

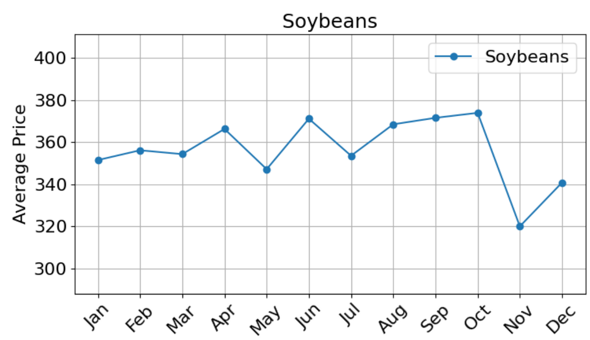
The following table presents the average monthly prices staple, calculated over the period from 2017 to 2023. This analysis reveals distinct seasonal patterns and variations in price trends across different staple foods.



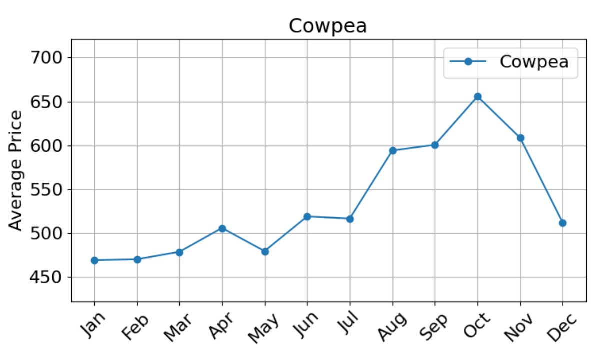
Rice: The highest average price for rice is observed in June (₦648.15), while the lowest occurs in March (₦587.86). This suggests that rice prices tend to increase during the planting season (May to July) and decrease during the harvest season (September to November).



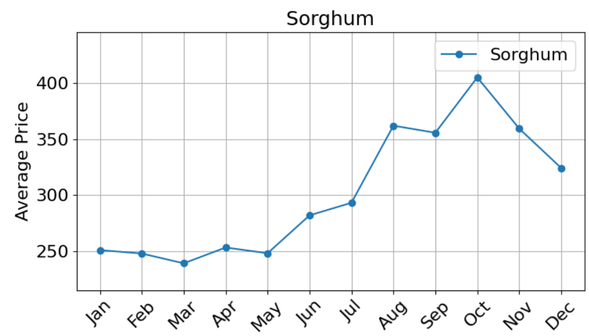
Maize: Maize exhibits a similar pattern, with the highest average price in August (₦324.51) and the lowest in March (₦218.52). This aligns with the planting and harvest cycles of maize in Kaduna State.



Soybeans: The highest average price for soybeans is observed in October (₦373.93), while the lowest occurs in November (₦319.97). This suggests a slight delay in the price peak compared to rice and maize, possibly due to differences in harvest times.



Cowpea: Cowpea shows a more pronounced price peak in October (₦655.67), with the lowest average price in February (₦470.27). This could be attributed to factors such as storage practices and market demand for cowpea.



Sorghum: Sorghum also exhibits a price peak in October (₦404.92), with the lowest average price in March (₦239.07). This pattern aligns with the general trend observed for other staple foods.

Unit Root test result

Testing the null hypothesis that time series data for staple food prices in Kaduna State is non-stationary. At alpha value = 0.05 we see that

Staple Food	ADF Statistic	p-value	Conclusion
Rice	-1.7199	0.4209	Fail to reject
Maize	-1.8806	0.3412	Fail to reject
Soybeans	-1.9305	0.3179	Fail to reject
Cowpea	-1.9219	0.3218	Fail to reject
Sorghum	-1.9742	0.298	Fail to reject

The ADF test shows the presence of a unit root by failing to reject the null , which indicates non-stationarity in all the series

Granger Causality test result

	rice	maize	soybeans	cowpea	sorghum
rice	1.00	7.22 E-78	2.83E-172	2.01E -05	3.12E-31

maize	9.19E-52	1.00	1.57E-146	6.43E-15	8.32E-51
soybeans	5.87E-132	2.95E-179	1.00	7.36E-21	3.06E-09
cowpea	1.29E-163	3.67E-48	1.32E-63	1.00	7.54E-28
sorghum	9.56E-36	1.50E-75	7.25E-151	1.37E-08	1.00

It can be observed that the p-values are significantly less than alpha (0.05). Therefore, it can be concluded that the null hypothesis of the Granger causality test, which states that past values of one staple food price do not have a significant impact on predicting the future values of other staple food prices, is rejected.

Cointegration test result

As the time series is determined to be non-stationary the Johansen cointegration test was conducted to assess the presence of long-run relationships between the prices of different staple foods. The trace statistic and the maximum eigenvalue statistic were determined, which are compared to critical values to determine the significance.

Trace test

Variable	Test Statistic	Critical Value (95%)	Significant
rice	329.01	60.0627	TRUE
maize	171.64	40.1749	TRUE
soybeans	70.41	24.2761	TRUE
cowpea	17.46	12.3212	TRUE
sorghum	0.29	4.1296	TRUE

Maximum eigen value test

Variable	Test Statistic	Critical Value (95%)	Significant
rice	157.37	30.4428	TRUE
maize	101.24	24.1592	TRUE
soybeans	52.95	17.7961	TRUE
cowpea	17.17	11.2246	TRUE
sorghum	0.29	4.1296	TRUE

The Johansen cointegration test confirmed the presence of cointegration among the prices of rice, maize, soybeans, and cowpea, indicating a long-run equilibrium relationship between these variables. While the Augmented Dickey-Fuller (ADF) test revealed that all the staple food price time series are non-stationary, the presence of cointegration allows for the valid application of a Vector Error Correction Model (VECM), even with non-stationary data. Furthermore, the Granger causality test identified significant causal relationships between the prices of several staple foods, suggesting that past values of one staple food price can help predict future values of others. Given these findings, the VECM is indeed the most suitable model for this dataset

Modelling

The training dataset comprised the of 4737 observations, while the testing set is 50 observations. This division ensures that the models are trained on a sufficiently large dataset. Most importantly the test data is taken from 2023 which has high fluctuation of prices.

Vector Autoregressive Model Evaluation

A VAR model was estimated as baseline for comparison to VECM. The Bayesian information criteria was used to estimate the lag order which was determined to be 7. Model was fitted and the accuracy metrics were determined.

	VAR				
METRIC	rice	maize	soybeans	cowpea	sorghum
MAPE	0.107742	0.064848	0.121434	0.179536	0.428559
ME	-15.7949	-17.7304	-72.7499	102.8643	252.2123

MAE	132.9338	36.54774	73.56618	146.7333	268.5701
MPE	-0.00415	-0.02782	-0.1198	0.135667	0.412201
RMSE	152.8153	41.74069	89.16739	169.9416	300.8901
CORR	-0.26263	0.041279	0.20667	0.29208	-0.35317

The model exhibits the most accurate forecasts for maize, as evidenced by the lowest values for MAPE (6.48%), MAE (36.55 ₦), and RMSE (41.74 ₦). This suggests that the it effectively captures the price dynamics of maize. The model also shows reasonable performance for soybeans and cowpea, with moderate MAPE values (12.14% and 17.95%, respectively) and positive correlations (0.21 and 0.29, respectively) between actual and forecasted prices.

However, the model struggles to accurately forecast sorghum prices, as indicated by the highest MAPE (42.86%), MAE (268.57 ₦), and RMSE (300.89 ₦). The negative correlation (-0.35) further suggests that the model fails to capture the price trends for sorghum. In the case of rice it also faces challenges in forecasting the prices, with a relatively high MAPE (10.77%) and a negative correlation (-0.26).

Serial correlation Checks using Durbing Watson

The serial correlation ensures that the model is sufficiently able to explain the variances and patterns in the time series. It is given by;

$$DW = \frac{\sum_{t=2}^{n}(e_t - e_{t-1})^2}{\sum_{t=1}^{n} e_t^2}$$

Where: e_t is the residual at time t, e_{t-1} is the previous residual and n is the number of observations

```
rice : 2.024742744172904
maize : 2.0157812614250457
soybeans : 2.017117087547231
cowpea : 2.0205319066690826
sorghum : 2.010272550957677
```

The value of this statistic can vary between 0 and 4. The closer it is to the value 2, imply that there is no significant serial correlation as in determined above (The closer to 0, there is a positive serial correlation, and the closer it is to 4 implies negative serial correlation).

Vector Error Correction Model (VECM)

$$\Delta Y_t = \alpha\beta' Y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \, \Delta Y_{t-1} + \varepsilon_t$$

Given the model in equation (11), beta (β) is the cointegration relationship (long-run equilibrium relations) while alpha (α) the speed of adjustment parameters which indicate how quickly variable adjust to long-run equilibrium and are determined as such.

```
              Alpha        Beta
rice      -0.000663    1.000000
maize     -0.001692    8.019753
soybeans   0.004925  -10.527486
cowpea    -0.007467    8.206471
sorghum    0.005668  -10.477937
```

- Soybeans and Sorghum are correcting deviations towards equilibrium.
- Maize and cowpea are pushing the system further from equilibrium

Short-run dynamic coefficients for lagged differences Γ is given below

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DOI: doi.org/10.64388/IREV9I3-1709523-596

```
               Lag 1     Lag 2     Lag 3
rice     -0.856665 -0.019162  0.031394
maize    -0.022968 -0.868681  0.005495
soybeans -0.023673 -0.040236 -0.758545 -
cowpea   -0.020834  0.014779 -0.031762 -
sorghum  -0.038349 -0.016997  0.062777 -

               Lag 7     Lag 8     Lag 9
rice     -0.077041  0.015267  0.040338 -
maize    -0.713017  0.004429  0.025742 -
soybeans -0.024177 -0.674871  0.002008
cowpea    0.028173 -0.068848 -0.631082 -
sorghum  -0.016621  0.002122  0.030415 -

              Lag 28    Lag 29    Lag 30
rice      0.078290 -0.005253  0.025941 -
maize     0.029408  0.005720  0.017516 -
soybeans -0.134731 -0.016722  0.030229 -
cowpea    0.100363 -0.260001 -0.005059 -
sorghum   0.060734 -0.049236 -0.237238 -

              Lag 34    Lag 35
rice      0.013795  0.033449
maize     0.000607 -0.018177
soybeans -0.003521  0.010973
cowpea   -0.121385  0.006167
sorghum  -0.011078 -0.128338
```

The performance of the VECM model in forecasting staple food prices is given below;

Evaluation of accuracy

	VECM				
	rice	maize	soybeans	cowpea	sorghum
MAPE	0.081375	0.044439	0.068266	0.178493	0.339341
ME	56.22257	0.433.67	-10.6258	110.2146	179.8449
MAE	97.95067	24.62701	39.74407	142.6478	214.1692
MPE	0.051569	0.003822	-0.0112	0.147486	0.304905
RMSE	117.8578	28.92706	49.0427	159.8228	238.9672
CORR	0.062399	0.59269	0.497529	0.355745	-0.561
MINMAX	0.07345	0.042705	0.065993	0.14551	0.238776

The model exhibits strong performance for certain staple foods. For maize, it achieves the lowest MAPE (4.44%) and the highest correlation (0.59) among all staple foods, indicating accurate forecasts and good alignment with actual price trends. However, it faces challenges in accurately forecasting sorghum prices, as indicated by the highest MAPE (33.93%) and a negative correlation (-0.56). This suggests that sorghum price dynamics might be influenced by factors not fully captured by the model, such as specific agricultural practices, regional market variations, or unique demand patterns.

DateTime	rice	maize	Soyb	cowpea	sorgh
2024-01-31	1060	470	450	960	670
2024-02-29	1110	470	500	970	720
2024-03-31	1140	440	480	1010	740
2024-04-30	1120	500	480	1010	740
2024-05-31	1140	490	500	950	750

The model was trained on six years of historical data (2017–2023). However, 2023 experienced a sharp price surge and heightened volatility. This period of unusual fluctuations may not be fully captured by the model and caution must be taken to due to potential concept drift.

As more data becomes available, the model can be retrained and updated to incorporate these fluctuations, enhancing its forecasting accuracy. With a larger dataset and a better understanding of the evolving price dynamics, the VECM is expected to provide more reliable forecasts in the future.

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DOI: doi.org/10.64388/IREV9I3-1709523-596

CONCLUSION

This study has shown that staple food prices in Kaduna State, Nigeria, exhibit distinct trends and variations, influenced by both seasonal factors and broader economic conditions. The main findings are that a general upward trend in prices is present for all five staple foods examined, with a notable price surge and increased volatility observed in 2023. This highlights the growing challenge of food affordability in the region and the vulnerability of vulnerable populations to price shocks. Additionally, the analysis revealed distinct seasonal patterns in staple food prices, linked to planting and harvest cycles, underscoring the influence of climatic conditions on food production and prices in Kaduna State.

This study has demonstrated that the Vector Error Correction Model (VECM) is a valuable tool for modeling and forecasting staple food prices, outperforming a baseline VAR model in forecasting accuracy for most staple foods, particularly sorghum. The VECM's ability to capture both short-term dynamics and long-run equilibrium relationships makes it particularly suitable for analyzing the complex interdependencies among staple food prices.

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