Development of a Mathematical Model to Analyze the Impact of Fuel Subsidy on Rice Production in Niger State, Nigeria

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ABSTRACT

This study develops a mathematical model to evaluate the impact of fuel subsidy policies on rice production in Niger State, Nigeria. Agriculture is crucial to Nigeria's economy, and rice is a staple food and source of livelihood for farmers. However, fluctuating fuel costs and evolving subsidy programs affect agricultural productivity. Using linear regression techniques, this study analyzes the relationship between fuel subsidy policies and rice production levels. Key variables include fuel price, rice price, and transportation costs. Data from the National Bureau of Statistics (NBS) enables a robust simulation of policy effects. The model's performance is assessed using R-square, Mean Square Error (MSE), and Root Mean Square Error (RMSE). Results indicate that approximately 59.8% of the variance in rice production can be explained by the independent variables. The findings highlight the critical role of fuel subsidies in shaping agricultural outcomes, particularly in resource constrained farming communities. This study underscores the need for evidence-based policy decisions to balance subsidy allocation with sustainable agricultural growth.

Keywords: Fuel subsidy, rice production, mathematical model.

INTRODUCTION

Agriculture remains a critical sector of Nigeria's economy, employing a large proportion of its labour force and contributing significantly to food security and economic stability (Obayelu, Edewor, Ogbe, and Oyedepo, 2024). Among the country's staple crops, rice holds a unique position due to its widespread consumption and economic importance (Chen and Zhao, 2023). Niger State, with its fertile land and favourable climate, is one of the leading rice-producing regions in Nigeria (Oduaro, Olawuyi, and Olatoye, 2024). However, the productivity of rice farmers in Niger State is influenced by various factors, including input costs, market dynamics, and government policies (Ojumu, Raji, Oyinloye, and Amao, 2024).

One major policy affecting agricultural productivity is the fuel subsidy program, which is designed to reduce the cost of fuel to enhance economic activities, including agricultural production (Zhang, Ma, and Liu, 2021). In Nigeria, diesel and petrol are essential inputs in agricultural operations such as irrigation, land preparation, and transportation of produce to markets (Nana, 2023). A reduction in fuel costs through subsidies is intended to alleviate cost burdens on farmers and enhance profitability (Nwachukwu and Tumba, 2023). Conversely, inconsistent or poorly implemented subsidy policies could increase input costs, reduce profitability, and, subsequently, affect production levels (Yang *et al*., 2022)

Despite the government's intention to use fuel subsidies to promote economic stability, the agricultural sector has often been constrained by rising energy costs, irregular subsidy programs, and challenges in their implementation (Bello, Yahaya, and Adamu, 2024). This has made it crucial to quantitatively understand the extent of the relationship between fuel subsidies and agricultural production (Idris, Kitabu, Musa, and Shehu, 2024). While several studies have examined the impacts of subsidies on various aspects of the economy, there

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is a noticeable gap in the literature specifically linking fuel subsidy policies to the production dynamics of key crops like rice, particularly in Niger State (Samuel and Talibu, 2024).

This study seeks to develop a mathematical model to analyze the effect of fuel subsidies on rice production in Niger State, providing insights into how subsidy policies influence agricultural outputs. The mathematical model will incorporates variables such as the cost of fuel, cost of produce, farm production levels, and cost of transportation. By establishing a quantitative framework, this research aims to provide evidence-based recommendations that inform better policy formulation, ensuring that fuel subsidy programs adequately support rice production and the broader agricultural economy in Niger State.

By exploring this critical topic, this study addresses significant questions about the role of subsidies in the agricultural sector, shedding light on ways to enhance food security and agricultural sustainability in Nigeria.

Statement of Research Problem

Agriculture is a cornerstone of Nigeria's economy, providing employment and contributing to food security, with rice being a staple crop of immense economic significance (Bello, Yahaya, and Adamu, 2024). Niger State, a leading producer of rice, faces challenges such as fluctuating fuel costs and inconsistent fuel subsidy policies, which increase operating costs and hinder agricultural productivity (Oduaro, Olawuyi, and Olatoye, 2024). While the Nigerian government's fuel subsidy program aims to stabilize energy costs and support farmers, inefficiencies and frequent policy changes have created uncertainties that strain farmers' profitability (Ogwuche, Adejor, Dabish, Garba, and Dole, 2024). Despite the evident impact of fuel costs on rice farming, limited research exists on the direct effects of subsidies on production. To address this issue, this research paper develops a mathematical model to analyze the effects of fuel subsidy policies on rice production in Niger State, offering evidence-based insights to enhance agricultural policies, support farmers, and improve rice productivity.

Research Objectives

The aim of this study is to develop a mathematical model to analyze the impact of fuel subsidy policies on rice production in Niger State, Nigeria, and to provide actionable insights for improving policy implementation to enhance agricultural productivity and sustainability. The objectives include:

1. To develop a mathematical model that quantifies the relationship between fuel subsidy and rice production levels.
2. To analyze the effects of varying fuel subsidy policies on rice production
3. To provide evidence-based recommendations to policymakers for optimizing fuel subsidy programs to better support rice production in Niger State.

MATERIALS AND METHOD

Method of Data collection:

Secondary data of fuel price per litre, price of local rice per kg and cost of transportation per drop were obtained and used for this research paper. The data set is a statistical records comprising of dependent variable (Agriculture GDP growth) that measures the economic impact of subsidy removal and independent variables (fuel price, price of rice and transportation cost).

The Data of 13 years (2012-2024) were collected from National Bureau of Statistics (NBS).

Data Presentation:

The data collected and used in developing the mathematical model to analyze the Impact of Fuel Subsidy on Rice Production in Niger State, Nigeria are shown in Table 1.

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Table 1: Prices and values of Model Parameters between 2012-2024

Year	Fuel Price (₦/lit)	Rice Price (₦/kg)	Transport Price (₦/drop)	Agric GDP Growth (%)
2012	97	135	60	2.2
2013	97	135	60	2.1
2014	97	135	80	2
2015	97	175	80	2.1
2016	145	275	135	2.1
2017	145	259.63	120	1.9
2018	145	279.53	100	2.3
2019	145	292.47	150	2.5
2020	130	363.35	200	2.2
2021	165	406.47	250	2.3
2022	175	463.37	300	2
2023	532.5	917.93	600	2.1
2024	941.24	1399.34	870	2.9

Source: National Bureau of Statistics (NBS)

Development of Mathematical Model

In this manuscript, the developed Mathematical Model contains three (3) variables and will represent the relationship between dependant variable (Agriculture GDP Growth) and the independent variables (fuel price, price of rice and transportation cost). However, in other to produce reliable and accurate results, the following assumptions are made in the development of the model;

1. Agriculture GDP Growth depends on the combined effects of fuel price, price of rice and transportation cost.
2. The relationship between these variables and AGDP growth is assumed to be linear
3. The independent variables are not perfectly correlated with each other (no multicollinearity)

Model Formulation:

To formulate the problem mathematically; the following variables and parameters are denoted as follows:

Variables:-

$\boldsymbol{Y}$: Agriculture GDP Growth ($\boldsymbol{dependent}$ variable)
$\boldsymbol{X_1}$: ⇄ $\boldsymbol{Fuel\,Price}$ (N/lit)
$\boldsymbol{X_2}$: $\boldsymbol{Rice\,Price}$ (N/kg)
$\boldsymbol{X_3}$: $\boldsymbol{TransportaionCost}$(N/drop)
$\boldsymbol{\varepsilon = Error\ term}$

Then, by assuming linear relationship between the variables and Agriculture GDP growth (Economic Impact); produce the model:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon \qquad (1)$$

Where:

β_0 Represents the intercept: the predicted economic impact of the fuel subsidy when all independent variables are zero

$\beta_1, \beta_2, \beta_3,$ $are\ coefficients\ for\ the\ lineareffects.$

$\varepsilon\ is\ the\ errorr\ term\ accounting\ for\ thefactors\ unobserved\ in\ the$ model

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Matrix Representation of Model

The model equation (1) can be represented in matrix form as:

$$Y = \beta(X) \ + \ \varepsilon \tag{2}$$

Consequently, the model coefficients can be determined using the normal matrix equation, which yields the least squares estimates of the coefficient:

$$\beta = (X^T X)^{-1} X^T y \tag{3}$$

Where:

X is the design matrix (input independent variables)

X^T is the transpose of X

$(X^T X)^{-1}$ is the inverse of the product $X^T X$

Y is the vector of observed value, and

β is the vector coefficient to be determined.

$$X = \begin{bmatrix} 1 & 97 & 135 & 60 \\ 1 & 97 & 135 & 60 \\ 1 & 97 & 135 & 80 \\ 1 & 97 & 175 & 80 \\ 1 & 145 & 275 & 135 \\ 1 & 145 & 259.63 & 120 \\ 1 & 145 & 279.53 & 100 \\ 1 & 145 & 292.47 & 150 \\ 1 & 130 & 363.35 & 200 \\ 1 & 165 & 406.47 & 250 \\ 1 & 175 & 463.37 & 300 \\ 1 & 532.5 & 917.93 & 600 \\ 1 & 941.24 & 1399.34 & 870 \end{bmatrix} \tag{4}$$

$$Y = \begin{bmatrix} 2.2 \\ 2.1 \\ 2 \\ 2.1 \\ 2.1 \\ 1.9 \\ 2.3 \\ 2.5 \\ 2.2 \\ 2.3 \\ 2 \\ 2.1 \\ 2.9 \end{bmatrix} \tag{5}$$

By Solving equation (3) using the matrix above; we obtained the coefficients of the model as follows:

$$\beta = \begin{bmatrix} 1.9083 \\ 0.0007 \\ 0.0027 \\ -0.004 \end{bmatrix} \tag{6}$$

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By substituting the values of the coefficients obtained in (6) into the model equation (1) produced the required model as follow:

$$Y \quad = 1.9083 \ + \ 0..0007X_1 \ + \ 0.0027X_2 \ - 0.004X_3 \ + \ \varepsilon \tag{7}$$

RESULTS AND DISCUSSION

The accuracy of this prediction model is measured using three (3) performance metrics to test and assess the validity and reliability of the developed model with empirical data. The metrics used includes: Coefficient of Determination (R-squared), Mean Square Error (MSE) and Root Mean Square Errors (RMSE). Table 2 shows the comparison between the predicted values and the actual values using the model while Table 3, shows the ANOVA analysis of the model.

Table 2: Residual analysis of the model

Actual Y	Predicted Y	Residuals
2.2	2.09424907	0.10575093
2.1	2.09424907	0.00575093
2	2.013930228	-0.013930228
2.1	2.120109306	-0.020109306
2.1	2.198617128	-0.098617128
1.9	2.218056949	-0.318056949
2.3	2.351199882	-0.051199882
2.5	2.184751709	0.315248291
2.2	2.161498636	0.038501364
2.3	2.099908266	0.200091734
2	2.057221096	-0.057221096
2.1	2.311817034	-0.211817034
2.9	2.794391627	0.105608373

Source: Author's computation, 2024

Table 3: ANOVA analysis of the model

Parameter Estimate	Coefficient	Est. Std. Error	T. Value	P. Value
INTERCEPT	1.908270	0.137473	13.881	2.21e-07 ***
X1	0.000707	0.001165	0.607	0.559
X2	0.002655	0.002054	1.292	0.229
X3	-0.004016	0.002566	-1.565	0.152

Source: Author's computation, 2024

Analysis from Table 2 shows that the R-square, Mean Square Error (MSE) and Root Mean Square Errors (RMSE) values were 0.598, 0.025 and 0.158 respectively. This indicates that approximately 59.8% of the variance in the dependent variable is explained by the independent variables in the model. It further reveals that the model's predictions are closer to the actual observed values which indicate a better fit of the model to the data.

Also from the ANOVA analysis the P-value is 0.035 meaning the overall regression is significant which implies that fuel subsidy removal as a significant effect on rice production in Niger state, Nigeria.

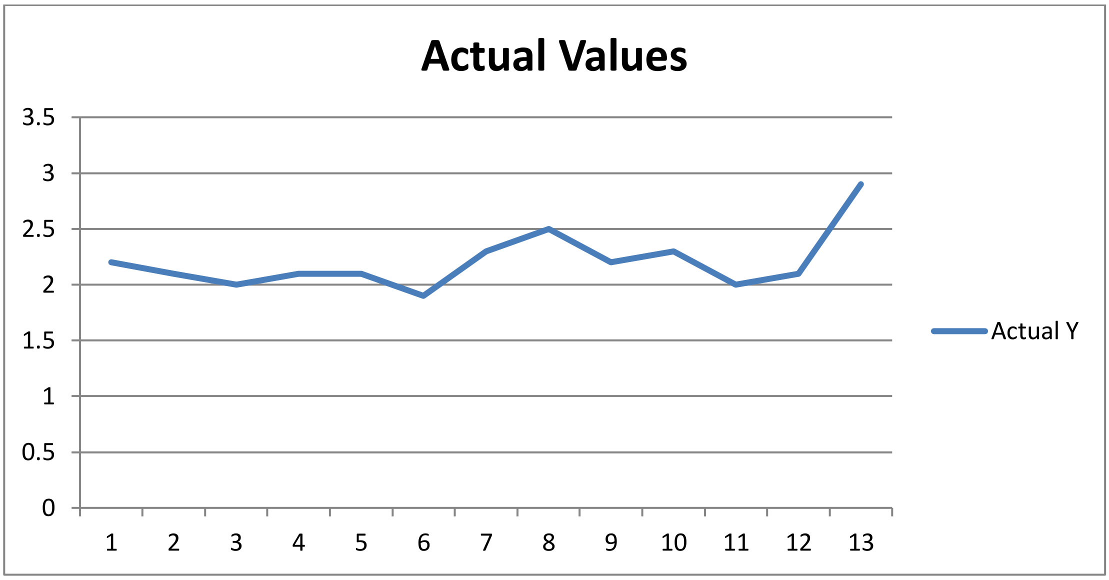

Fig. 1: Accuracy graph for actual values of AGDP growth

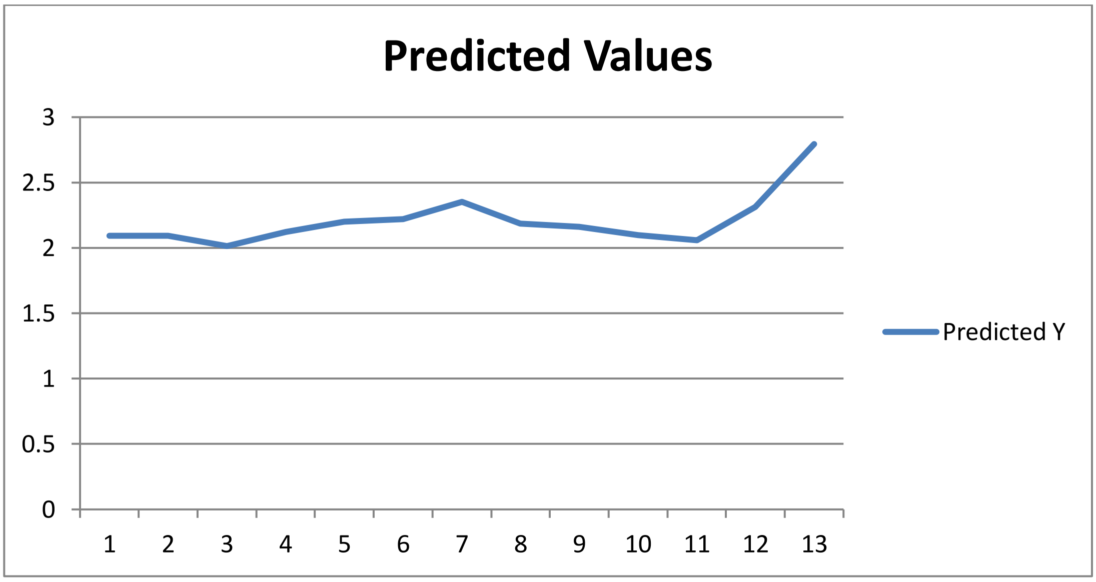

Fig. 2: Accuracy graph for predicted values of AGDP growth

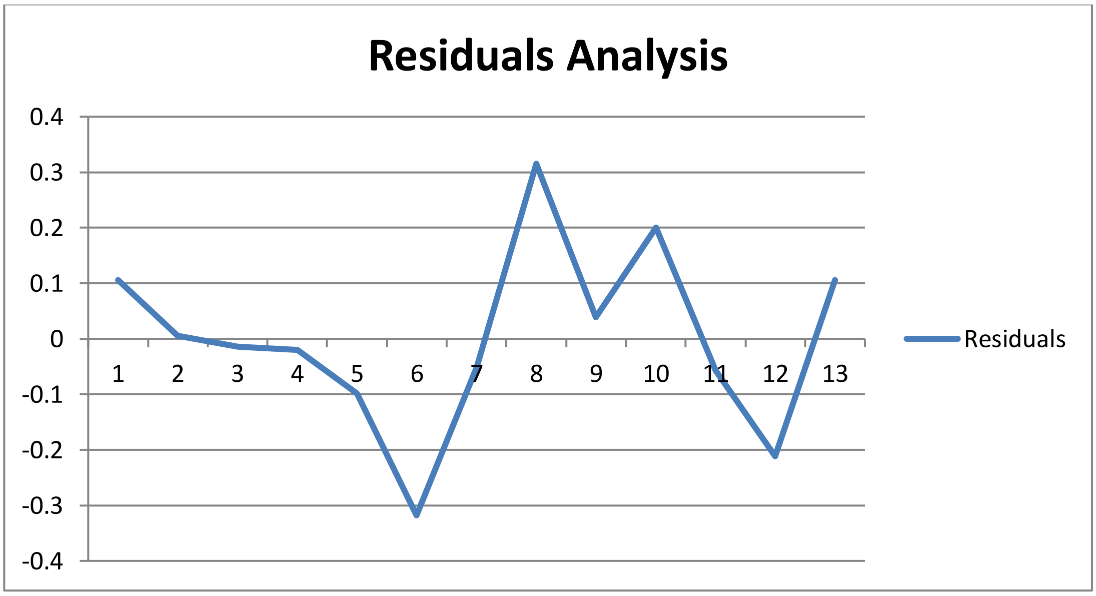

Fig. 3: Differences between the actual and predicted values of AGDP growth

CONCLUSION

The development of a mathematical model to analyze the impact of fuel subsidy on rice production in Niger State, Nigeria, provides valuable insights into the relationship between fuel price, rice price transportation cost and output levels. The study reveals that fuel subsidies play a significant role in reducing the cost of key production activities such as irrigation, mechanized farming, and transportation which in turn, enhances rice productivity and ensures affordability for both producers and consumers. Conversely, removing these subsidies leads to higher production costs, which can lower output levels and jeopardize food security in Niger State. The mathematical model offers a foretelling framework that aids stakeholders in understanding the undulate effects of policy decisions on agricultural productivity.

RECOMMENDATIONS

To sustain rice production and enhance food security in Niger State, the government should maintain stable and transparent subsidy policies, prioritize targeted subsidies for small and medium-scale farmers, and invest in renewable energy solutions to reduce long-term reliance on fossil fuels. Additionally, training programs and extension services should be provided to equip farmers with efficient resource management skills, while continuous monitoring and evaluation mechanisms should be implemented to assess the impact of subsidies and guide policy decisions effectively.

REFERENCES

1. Bello, M. M., Yahaya, J. U., and Adamu, I. (2024). An Analysis of Sustainable Agricultural Productivity and Food Security in Nigeria. Journal of Political Discourse, 2(1 (2)), 45-60.
2. Chen, W., and Zhao, X. (2023). Understanding global rice trade flows: Network evolution and implications. Foods, 12(17), 3298.
3. Idris, A., Kitabu, M. U., Musa, M. M., and Shehu, A. (2024). Effect of Fuel Subsidy Removal on Socio-Economic Development of Chanchaga Local Government Area of Niger State. Kashere Journal of Politics and International Relations, 2(2), 340-354.
4. Nana, O. M. (2023). A comparison of the use of diesel and solar energy in threshing and milling of maize: A case study of Oyo state, Nigeria (Master's thesis, Norwegian University of Life Sciences).
5. Nwachukwu, D., and Tumba, M. (2023). Price Unleashed: Examining the Ripple Effects of Petroleum Subsidy Removal on Consumer Buying Behavior in Nigeria (Systematic Literature Review). International Journal of Advanced Academic and Educational Research, 13(7), 40-51.
6. Obayelu, A. E., Edewor, S. E., Ogbe, A. O., and Oyedepo, E. O. (2024). Assessment of Agricultural Trade Flow and Food Security Status: Evidence from Nigeria. Agriculturae Conspectus Scientificus, 89(2), 175-186.
7. Oduaro, A. O., Olawuyi, T. O., and Olatoye, O. C. (2024). Effects of Utilization of Improved Rice Production Technologies on Productivity among Smallholder Farmers In Niger State. Badeggi Journal of Agricultural Research and Environment, 6(2), 59-68.
8. Ogwuche, D. D., Adejor, G. A., Dabish, N. D., Garba, R. I., and Dole, F. (2024). Assessing the Impact of Fuel Subsidy Removal on Economic Growth in Nigeria: A VECM Approach. Lapai Journal of Economics, 8(1), 1-13.
9. Ojumu, A. O., Raji, A. M., Oyinloye, O. D., and Amao, J. O. (2024). Cost and Return Analysis Of Rice Farming Among Smallholders Rice Farmers in Niger State, Nigeria. Technology (IJOSEET), 16(16), 88-98.
10. Samuel, A. T., and Talibu, O. (2024). Rice and Food Security in Shonga Emirate of Edu LGA of Kwara State, Nigeria, Since 1990s. Islamic University Journal of Social Sciences, 3(2), 75-96.
11. Yang, Z., Cheng, Q., Liao, Q., Fu, H., Zhang, J., Zhu, Y., and Li, N. (2022). Can reduced-input direct seeding improve resource use efficiencies and profitability of hybrid rice in China?. Science of The Total Environment, 833, 155186.
12. Zhang, R., Ma, W., and Liu, J. (2021). Impact of government subsidy on agricultural production and pollution: A game-theoretic approach. Journal of cleaner production, 285, 124806.