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RESEARCH ARTICLE

Evaluating the nexus between farm size, fertilizer input and technical efficiency of rice production in north west, Nigeria: A parametric approach

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Abstract

Rice contributes significantly to reducing food insecurity in sub-Saharan Africa, including Nigeria. This study evaluates the nexus between farm size, fertilizer input, and technical efficiency (TE) of rice production in Nigeria. Data covered 200 rice farmers proportionally distributed in Kano and Kaduna states. The TE levels were obtained using a parametric approach such as the stochastic production efficiency frontier model (SPEFM) and descriptive statistics. The production constraints of rice farmers were evaluated using PCA (Principal Component Analysis). The average TE score of rice producers is 53.13% leaving an efficiency gap of 46.87% for improvement. Inferential analysis showed that the significant predictors influencing TE of rice production include fertilizer, farm size, agrochemicals, seed, and family labour. The addition of the first-order of the production predictors, which is called the scale elasticity, shows increasing RTS (return to scale), which is estimated at 1.958. The sources of TIE (technical inefficiency) of rice production were age, experience in rice farming, education level, members of cooperatives, and amount of credit accessed. The coefficient of variance ratio open paren gamma close paren the gamma is 0.7827; this connotes that 78.27% of variations in rice output were due to differences in TE. The major production constraints facing rice producers include lack of access to farmland (1st), high cost of fertilizers (2nd), and lack of agrochemicals (3rd). The cost of fertilizers should be reduced and made affordable for increased rice productivity and efficiency. Secondly, easy access to farmland is necessary in terms of policy formulations and implementations.

Keywords: The Nexus; Farm Size; Fertilizer Input; Technical Efficiency; Rice Production; Nigeria.

1. Introduction

Rice (*Oryza species*) on the global level ranks the 3rd among the cereal produced with wheat as the first, while maize is the second (Miassi *et al*., 2023). In sub-Saharan Africa, in terms of importance rice ranks the 4th, millet is first, sorghum is second, and maize is third (Miassi *et al.*, 2023). Rice occupies 20% of cereal consumption in the world, and contributes significantly to food security in Africa. In sub-Saharan Africa, the demand and production gap of rice continues to grow, the consumption level is rising at a faster rate than the production level. In 2022, rice output in Nigeria is estimated at 8,502,000 tonnes, while in 2021, rice output in Nigeria is estimated at 8342000 tonnes (FAO, 2024). In 2022, the area harvested and yield of rice in Nigeria are estimated at 4,580,000 ha and 1856.3Kg/ha respectively (FAO, 2024). The

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world production of rice in 2022 and 2021 are estimated at 789,045, 342.64 tonnes and 776, 461,456.61 tonnes respectively (FAO, 2024). USDA (2016) reported that annual rice consumption in Nigeria was estimated at 5 million metric tonnes, while the quantity of rice supplied was 2.7 million metric tonnes, giving a supply and demand gap of about 2.3 million metric tonnes, which is completed by rice importation (Obih and Baiyegunhi, 2017). According to the Central Bank of Nigeria (CBN) (2019), 57 percent of the 6.7 million metric tons of rice consumed is produced locally; the 43% supply imbalance was filled in by imports. To make up for this gap, around 3 million tonnes of rice worth US$480 million are imported each year (Kamai *et al.,* 2020).

Kanu *et al.* (2014), estimates over 96% of African farmers are smallholders and in Nigeria, 90 percent of domestic rice is produced by peasant, small-scale, smallholders' farmers, and the remaining 10 percent is produced by commercial or corporate farmers (Adeyemi *et al.,* 2017). These smallholders practise low-input agriculture, which has low output and minimal input requirements (Africa Rice, 2019). Family labour, fertilizer input, and the size of the land are the three main factors that restrict smallholders' potentials to farm (Tittonell & Giller, 2013). Family labour, which is heavily reliant on household size for the majority of smallholders, is the primary source of production labour (Kanu *et al.,* 2014). According to FAO (2014), and Okello *et al*. (2020), there is evident of declining farm sizes in sub-Saharan Africa, the rising scarcity of land is a major constraint involving productive resource in agriculture, agricultural productivity encounters the new challenge of making sure that rising limited resources such as land becomes more and more productive. The increasing scarcity of land is due to rising population, thus, the future of agriculture relies to the efficient use of the productive inputs at our disposal. (World Bank, 2007). The research gap is that of technical efficiency of rice production. Evident suggest general inefficiency among smallholder farms, to improve the efficiency of small-scale farmers, the present levels of TE (Technical Efficiency) must be estimated (AGRA, 2014). Technical Efficiency is important for better farm planning and guiding decision making.

Technical efficiency (TE) estimates the potentials of a rice production sector to achieve the highest possible agricultural produce from a mixture of production resource inputs. A farm that operates on the production efficiency frontier is technically efficient, while a farm that operates below the production efficiency frontier is technically inefficient. In this study, the methods for estimating technical efficiency rely on the use parametric approach using the SPEFM (Stochastic Production Efficiency Frontier Model). Most empirical literatures show that the application of SPEFM in estimating TE of rice production is still scarce in Nigeria.

Objectives of the Study

The major objective is to estimate the nexus between the farm size, fertilizer input and TE of rice production in North West, Nigeria: A Parametric Approach. The specific objectives are:

(i) determine the TE scores of rice farmers,

(ii) evaluate the nexus between farm size, fertilizer input and TE of rice farmers

(iii) evaluate the socio-economic regressors influencing TE and TIE (Technical Inefficiency) of rice production, and

(iii) identify the constraints confronted by rice farmers.

2. Methodology

This work was carried out in Kano and Kaduna States, Nigeria. The population of Kano State is 15,462, 200 people with annual population change of 3.2%. The population of Kaduna state is about 8.9 million people as at 2021. (NPC, 2022). The people of the 2 states engaged in farming activities. Multistage method of sampling was employed, the fourth and last stage was the proportionate-random sampling of 200 rice farmers comprising of 100 rice farmers from Kano State and 100 rice farmers from Kaduna State. Primary sources of data were obtained using a questionnaire that is properly structured and of good design. The questionnaire was put through validity and reliability test. This research work use the formula suggested by Yamane (1967) in the evaluation of the sample size. The formula is given as:

$$n = \frac{N}{1+N(e^2)} = 200 \quad (1)$$

Where,

n = The Estimated Sample Size (Number)

N = The Sample Frame of Rice Farmers (Number for the 2 States)

e = Margin of Error (5%)

Data were analyzed using the following econometric tools:

2.1. *Stochastic Production Efficiency Frontier Model (SPEFM)*

The parametric approach follows the model suggested by Alabi *et al.* (2022), the SPEFM is given as:

$$Y_i = f(X_i, \beta_i)e^{v_i - u_i} \quad (2)$$

$$LnY_i = \beta_0 + \sum_{i=1}^{5} \beta_i LnX_i + \cdots \beta_n LnX_n + V - U_i \quad (3)$$

TE_i is estimated as follows:

$$TE_i = \frac{Y_i}{Y_i^*} \quad (4)$$

$$TE_{ij} = \frac{F(X_i,\beta)\exp(v_i - u_i)}{F(X_{i,}\beta)\exp(v_i)} \quad (5)$$

$$TE_{ij} = \exp(-u_{ij}) \quad (6)$$

where,

Y_i = Output of Rice (Kg)

Y_i^* = Unobserved Frontier Output of Rice (Kg)

X_i = Vectors of Regressor Inputs

β_i = Vectors of Parameters

V_i = Random Fluctuations in Rice Output

U_i= Error Term due to TIE

X_1 = Fertilizer (Kg)

X_2 = Farm Size (Ha)

X_3 = Agrochemicals (Litres)

X_4 = Seed (Kg)

X_5 = Family Labour (Mandays)

$$U_i = \alpha_0 + \alpha_1 Z_1 + \alpha_2 Z_2 + \alpha_3 Z_3 + \alpha_4 Z_4 + \alpha_5 Z_5 + \cdots \quad (7)$$

where,

Z_1 = Age (Years)

Z_2 = Experience in Farming (Years)

Z_3 = Education Level (Years)

Z_4 = Members of Cooperatives (1, Member, 0, Otherwise)

Z_5 = Amount of Credit Accessed (Naira)

α_0 = Constant Term

$\alpha_1 - \alpha_5$ = Estimated Parameters

U_i= Error Term due to TIE

2.2. *Principal Component Analysis (PCA)*

This model will reduce many interrelated constraints facing rice farmers into few ones that are not related. Those constraints withhold by the PCA will be those that have Eigen values greater than one. The constraints confronted by rice farmers was put through to PCA. The PCA is given as:

$$\alpha_K = (\alpha_{1k}, \alpha_{2k}, \alpha_{3k}, \ldots \alpha_{pk}) \quad (8)$$

$$\alpha_k^T X = \sum_{j=1}^{p} \alpha_{kj} X_j \quad (9)$$

The variance of each of the principal components are:

$$Var[\alpha_k^T X] = \lambda_k \quad (10)$$

$$S = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - \overline{X_i}\,(X_i - \overline{X}_i)^{\mathrm{T}} \quad (11)$$

Where,

X_i= Vector of p Random Variables

α_k = Vector p Components
λ_K = Eigen Value
T = Transpose
S = Covariance Matrix

3. Results and Discussion

3.1. Technical Efficiency (TE) Scores of Rice Farmers

Table 1 shows the summary statistics of TE scores of rice farmers. About 71.00% of rice farmers were between 21 to 80 % efficiency levels. The average TE in percentage was calculated by multiplying the mean TE by 100 calculated as [0.5313×100] and the result is 53.13 % leaving an inefficiency gap of 46.87 % for improvement. The inefficiency gap of 46.87% was estimated by subtracting the percentage score of mean TE from 100 (100.00 – 53.13). This signifies that the rice farmers are able to obtain 53.13% of potential output from a given combination of production resources. In other words, an average rice farmer is able to obtain 53.13% of the frontier output given the resources used under existing technology. Thus, opportunity still exists in the short term for increasing productivity of rice and income of farmers through increased efficiency using available inputs and by adopting new technologies and techniques used by the best performing rice farmers. Furthermore, the minimum TE score was 7.00 %, while the best accomplish rice farms had the highest TE of 98.00%. If the average rice farmers were to achieve the level of TE like most of its efficient counterparts, then the average rice farmers could make 45.78 % cost savings estimated as $\left[\left[1-\frac{53.13}{98.00}\right]\times 100\right]$. The estimated value for the most technically inefficient rice farmers reveal a cost savings of 92.86 % estimated as $\left[\left[1-\frac{7.00}{98.00}\right]\times 100\right]$.

Table 1. Summary Statistics of TE Scores of Rice Farmers

Efficiency Score	Frequency	Percentage
0.00 to 0.20	27	13.50
0.21 to 0.40	33	16.50
0.41 to 0.60	57	28.50
0.61 to 0.80	52	26.00
0.81 to 1.00	31	15.50
Mean	0.5313	
Standard Deviation	0.2521	
Minimum	0.07	
Maximum	0.98	

Source: Field Survey (2024)

This result is in consonance with Houngue and Nonvide (2020) who estimated the TE to vary from 42% to 99% and obtained an average TE score of 0.78 for rice farmers in Benin Republic.

3.2. The Nexus between Farm Size, Fertilizer Input and TE of Rice Production

The MLEs (Maximum Likelihood Estimates) using SPEFM in analyzing the nexus between farm size, fertilizer input, and TE of rice production is shown in Table 2. The partial derivatives of predictors in the TE components are the elasticity of production (Ep). The significant partial derivatives (significant elasticities of production) with positive signs increase the TE of rice production. The significant partial derivatives (significant elasticities of production) with negative signs decrease the TE of rice production. The coefficients and significant predictors influencing TE of rice production with their various level of probabilities were fertilizer (0.4531, P < 0.01), farm size (0.5312, P < 0.01), agrochemicals (0.2163, P < 0.05), seed (0.3935, P < 0.10), and family labour (0.3639, P < 0.05). All the regressors included in the TE component had positive signs. The coefficient of fertilizer is 0.4531, this signifies that a 1% increase in application of fertilizer to rice farms making all other regressors fixed will give rise to 45.31% increase in output of rice. The coefficient of farm size is 0,5312, this connotes that a 1% increase in the farm size of rice farms making all other predictors fixed will give rise to 53.12% increase in output of rice.

The RTS (Return to Scale) is the addition of the elasticities of production(EP) for all the predictors included in the TE component. The estimated RTS is 1.958, this means an increasing RTS. In other words, the addition of the first order estimates of the production predictors which is called the scale elasticity shows increasing RTS. In the frontier model adding up to 1.958, this connotes that an increase in all predictors at the sample mean by 1% will increased output of rice by 1.958% which is significantly different from zero. The increase RTS connotes that an increase in any of the predictors included in the TE components of rice production making all other predictors fixed will give rise to more than proportional increase in the output.

In the diagnostic statistics component, the coefficient of variance ratio (γ) also called gamma is 0.7827, this connotes that 78.27% of variations in the output of rice were due to differences in TE. Furthermore, this connotes that 78.27% of random fluctuation in the yield of the rice farmers were due to the farmers' inefficiency. Therefore, reducing the influence of the effect of gamma or variance ratio will improve the output of rice and greatly enhance the TE of the farmers. The coefficient of total variance (σ^2) also called Sigma Square is 2.7332, which is statistically significant at ($P < 0.01$). This means that the model used and data obtained were well fitted. The LLF (Log-Likelihood function) is -519.45. The outcome is in consonance with results of Ogundari (2008) who reported that farm size, fertilizer had positive coefficients and were significant predictors influencing output of rice farmers in Nigeria.

3.3. Socio-Economic Predictors Influencing TE and TIE of Rice Production

The MLEs (Maximum Likelihood Estimates) using SPEFM in analyzing the socio-economic predictors influencing TE and TIE of rice production is presented in Table 2. The socio-economic predictors significantly influencing TIE of rice production were age (P < 0.05), experience in rice farming (P < 0.05), education level (P < 0.05), member of cooperatives (P < 0.01), and amount of credit accessed (P < 0.05). All the socio-economic regressors included in the TIE components had negative coefficients, and this agrees with apriori expectations. The coefficient of experience in rice farming is -0.3718, this connotes that a 1% increase in experience in rice farming holding all other socio-economic predictors fixed will give rise to 37.18% increase in TE (decrease in TIE) of rice production. Also, the coefficient of education level is -0.3412, this connotes that a 1% increase in education level of rice farmers holding all other socio-economic predictors fixed will give rise to 34.12% increase in TE (decrease in TIE) of rice production. This outcome is in consonance with findings of Ojo *et al.* (2020) who estimate financial gaps in rice production in Southwestern, Nigeria reported that the significant socio-economic predictors influencing rice production include gender, age, farming experience, access to credit, household size, access to information, access to improved variety.

3.4. Constraints Confronted by Rice Producers

The constraints confronted by rice producers was put through PCA and is presented in Table 3. About 6 constraints with Eigen values more than 1 were retained by the PCA. Lack of access to farm land with Eigen value of 1.7205 was ranked 1st, and this interpret 14.02% of all constraints retained by PCA. High cost of fertilizers with Eigen value of 1.6201 was ranked 2nd, and this interpret about 13.07% of all constraints retained by PCA. Lack of agrochemicals with Eigen value of 1.2302 was ranked 3rd, and this interpret 15.01% of all constraints retained by PCA. All the constraints retained by the PCA interpret 70.43% of all constraints confronted by the rice farmers. The KMO (Kaiser-Meyer-Olkin) estimates of sampling adequacy is 0.7005 and Bartlett test of sphericity of 607.01 was significantly different from zero which manifested that the regressors were feasible for PCA. This result agrees with the outcome of Alabi and Anekwe (2023), and Aduba *et al.* (2013).

Table 2. MLEs (Maximum Likelihood Estimates) of the SPEFM

Variables	Parameters	Coefficient	Standard Error	t-Value
Constant	β_0	1.3462**	0.5472	2.46
Fertilizer	β_1	0.4531***	0.1189	3.81
Farm Size	β_2	0.5312***	0.1104	4.81
Agrochemicals	β_3	0.2163**	0.0924	2.34
Seed	β_4	0.3935*	0.2017	1.95
Family Labour	β_5	0.3639**	0.1378	2.64
RTS	1.958			
TIE Component				
Constant	α_0	1.8213**	0.7850	2.32
Age	α_1	-0.2548**	0.1031	-2.47
Experience in Rice Farming	α_2	- 0.3718**	0.1441	-2.58
Education Level	α_3	-0.3412**	0.1297	-2.63
Member of Cooperatives	α_4	-0.2521***	0.0644	-3.91
Amount of Credit Accessed	α_5	-0.2019**	0.0742	-2.72
Diagnostic Statistics				
Sigma Square				
Gamma	σ^2	2.7332***		
Log-Likelihood Function	γ	0.7827		
		-519.45		

Source: Data Analysis (2024) *-Significant at ($P < 0.10$), **-Significant at ($P < 0.05$), ***-Significant at ($P < 0.01$), MLEs-Maximum Likelihood Estimates

Table 3. The PCA of Constraints Confronted by Rice Producers

Constraints	Eigen-Value	Difference	Proportion	Cumulative
Lack of Access to Farm Land	1.7205	0.1004	0.1402	0.1402
High Cost of Fertilizers	1.6201	0.3899	0.1307	0.2709
Lack of Agrochemicals	1.2302	0.0800	0.1501	0.4210
Lack of Extension Officers	1.1502	0.1200	0.1611	0.5821
Bad Road Infrastructures	1.0302	0.0290	0.1017	0.6838
Lack of Improved Seeds	1.0004	0.0954	0.0205	0.7043
Bartlett Test of Sphericity				
χ^2	607.01***			
KMO	0.7005			
Rho	1.00000			

Source: Field Survey (2024), KMO – Kaiser-Meyer-Olken

4. Conclusion and Recommendations

In this study we evaluate the nexus between farm size, fertilizer input and TE of rice production as well as the socio-economic regressors influencing TIE of rice production, and the production constraints confronted by rice farmers. In achieving this, information on economic, social and technical characteristics of farmers and the TE of rice farms was collected.

Established on the result obtained from the stochastic production efficiency frontier method and PCA, the mean TE of the rice producers was estimated at 53.13% leaving an inefficiency gap of 46.87% for improvement. Factors such as fertilizer, farm size, agrochemicals, seed, and family labour significantly influence TE of rice production. The scale elasticity shows an increasing RTS in the frontier model adding up to 1.958. The sources of inefficiency in rice production were age, experience in rice farming, education level, members of cooperatives, and amount of credit accessed. However, it was observed that the most retained constraints confronted by rice farmers using PCA relate to lack of access to farm land, high cost of fertilizer, lack of agrochemicals, lack of extension officers, bad road infrastructures, and lack of improved seeds. These results show that there are still potentials for increasing or improving rice production. Thus:

(i) It is necessary to improve the efficiency of rice producers, and this depend on the use of agricultural technologies, it is important to enhance the access to these technologies by rice producers.

(ii) The cost of fertilizers should be reduced and made affordable for increased rice productivity and efficiency, and secondly, easy access to farm land is necessary in terms of policy formulations and implementations. Female farmers in terms of policy should be given access to farm land.

(iii) Efforts of the private organizations and government involved in the agricultural sector must be geared towards improving and promoting access to agricultural credit. This is key in the development of the agricultural sector.

(iv) It is important to organize training periodically on good rice production practices, extension agents can play a critical function in this instance.

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The authors disclosed no conflict of interest.

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