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Bayes Approach to the Estimation of Technical Efficiency and Returns to Scale in Agriculture: A Case of Nigeria

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Authors' contributions

Author TB handled the data and results presented in this paper. Author ODO prepared the introduction, made contributions in the methodology and prepared the final draft of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Most studies in Nigeria have focused on the classical approach to estimating technical efficiency. In this paper, we examine technical efficiency of small farms by estimating a stochastic production frontier model using the Bayesian methodology. The model is applied to farm household data from Nigeria. The results obtained show that farm size, fertilizer, hired and family labour are positive and significant at 5%. The estimated stochastic frontier function indicates that farms are technically inefficient. Efficiency was found to be positively influenced by the age, gender, education, extension visits and participation in off-farm activities. We also found that the farms in our sample exhibited increasing Returns to Scale. Our findings have significant policy implications as it draws attention to increasing agricultural productivity through improving the existing level of efficiency of small farmers.

Keywords: Agriculture; Bayesian stochastic frontier; Technical Efficiency; Nigeria.

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1. INTRODUCTION

The contribution of the agricultural sector to Nigeria's economy cannot be downplayed. Its role in employing the bulk of the nation's population and contribution to Gross Domestic Product (GDP) remains significant [1]. Despite its important role however, there have been very little expenditure on agriculture by government in Nigeria. [2] reported that between 2001 and 2005, less than 2 percent of total federal expenditure was channeled to agriculture.

Also of immediate concern is the huge food-import bill. According to a [3] there is expected to be a rise from $4.0 billion in 2011 to an estimated $5 billion by end of 2012 on total food and agricultural imports in Nigeria. Given this enormous expenditure, it is argued that substituting domestic food production with importation, government would not only save money but create jobs and give existing farmers a sustainable livelihood.

In Nigeria, agriculture is dominated by smallholder farmers [4] however these farmers have been categorized as the poorest of the poor [5,6]. Several authors drawing from the works of [7] have argued that farms in developing counties are poor but efficient. [7] argued that these poor farmers' productivity remains constrained due to limited available resources and necessary agricultural technologies. However, most agricultural policies in Nigeria have discriminated against smallholder farmers [8]. Successive policy makers dwelt on the assumption that large farms are more technically efficient than small scale farms without basing their conclusion on empirical findings.

Given the nature of the identified problems, this paper thus examines the level of technical efficiency of small farms in Nigeria. Specifically, the study identifies the significant determinants of technical inefficiency and estimates the elasticity of output and returns to scale.

1.1 Literature Review

Several terms have been used to describe 'technical efficiency' although all of these are consistent with the proposition of [9] in which technical efficiency is referred to as obtaining maximum output with a set of inputs by applying a given level of technology. In estimating technical efficiency, numerous methodologies have been proposed and different criteria have been advanced as the reason for adopting any given methodology. [10] and [11] have reported using a specific methodology based on its simplicity; while [12] and [13] have been driven by the type of data available. In a similar light, [14] reported that for most empirical studies, priority is accorded based on individual preference and the objectives of the research. However other empirical studies have proven that no single methodology clearly defeats the other or is adequately appropriate for all studies.

There are two main approaches to the stochastic frontier model: the Classical and Bayesian approach. While the basis of estimation is similar for both, there have been extensions and combinations of techniques. Notable among this is the half-normal and exponential developed by [15], the truncated normal developed by [16]; and [17] two-parameter gamma distribution.

Technical efficiency in agriculture has been shown to vary between and within countries particularly in developing countries. [18] in a cross-county review of studies on frontier in developing countries that dealt with analysis of farm level efficiency examined 30 studies from 14 different countries. They found that the average technical efficiency index from the studies reviewed ranged from 17 to 100 percent. This led the authors to conclude that output from agriculture in developing countries can be increased given the existing technology. More specifically, the summary of the results of a meta-analysis of technical efficiency in Nigeria agriculture by [19] which covered a total of 64 studies results showed an increase in mean technical efficiency in Nigerian agriculture increased significantly over the years. Characteristics peculiar to the different studies such as sample size, number of variables included in the model in addition to crop or livestock specific studies were reported to have significant impact on mean technical efficiency. Interestingly, compared to the other regions, studies carried out in the North-central, South-west, and South-south regions of the country reported higher mean technical efficiency.

Some author have examined the technical efficiency of crop (and) or livestock farmers in Nigeria and have come up with notable results. By adopting the cost route approach, [20] used stochastic frontier approach to analyze the determinants of technical efficiency in garden egg production in Uyo metropolis, Nigeria. In this study, with exception of capital, all production variables analyzed in the model were statistically significant which implied an increasing production function. They identified the main determinants of efficiency as farm size and gender; and smaller farms were found to be more efficient than larger ones as reported by [11] in a separate study. Along gender lines, women were reported more technically efficient than men and this was attributed to the smaller farm size owned by women. Overall the mean technical efficiency was 86%. This mean efficiency is similar to the findings of [21], [22] but notably higher than [5] whose result of rural and urban farmers of 66% and 57% show that rural farmers were more efficient than urban farmers.

[23] examined the technical and scale efficiencies in rice production by farmers in Ebonyi State Nigeria. They analyzed data using Data Envelopment Analysis (DEA) approach. From the results obtained, they reported about 70% of the rice farmers as operating with increasing returns to scale. In addition, their results showed only about 5% of the farmers were 100% technically efficient in resource utilization under variable returns to scale. Using the maximum likelihood estimation (MLE) technique on primary farm data, [24] examined the determinants of food crop production and technical efficiency in the guinea savannas of Borno State, Nigeria. Their results identified farm size, fertilizer and hired labour as the main factors that affect changes in the output of food crops. Factors which were reported to affect efficiency were age, education, credit, extension and crop diversification. Judging from their findings; given the current state of technology, technical efficiency in food crop production could be increased through better use of available resources.

Recent studies [25,26,27,28] have used the Bayesian approach in examining productivity and efficiency in agriculture. While the advantages of the Bayesian method is pointed out by Bayesian econometricians, [29] and [30] however reports little difference between Bayesian and classical procedures when the results were obtained from methods that depend on comparable assumptions. This study goes beyond most studies carried out particularly in Nigeria as it takes a step further to examine technical efficiency in Nigeria agriculture by employing a different estimation approach.

2. METHODOLOGY

2.1 Model Specification

We estimated the production technology of the farms by analysing the log-likelihood estimate of the Cobb-Douglas-type stochastic frontier model. The model is specified as:

$$Yi = \beta_{0\,1} + \sum_{j=1}^{J} \beta_j X_{ji} + \sum_{m=1}^{M} \delta_m Z_m + (z_i - u_i) \quad (3.1)$$

Where
Y = natural logarithm of the total value of output (in Naira)
X_1= farm size (hectares)
X_2= quantity of fertilizer used (kilogram)
X_3 = amount spent on other input (Naira)
X_4 = hired labour used (man-days)
X_5 = family labour used (man-days)
β is a vector of parameters that describes the frontier

And the inefficiency component in equation (3.1) is made up of:

$$\sum_{m=1}^{M} \delta_0 + \delta_m Z_m$$

U_{ji}= Technical inefficiency of the *i*th farm
Z_1 = Age of farmer
Z_2 = Gender
Z_3 = Education
Z_4 = Marital status
Z_5 = Access to extension and information network
Z_6= Ownership of Savings
Z_7= Access to Credit
Z_8= Land ownership
Z_9= Off-farm activities
δ's are unknown parameters to be estimated along with the variance parameters.

In order to analyse the data, the Bayesian software ‘MATLAB’ was used. To ensure that we present the production inputs in a standard unit (per hectare), data was normalised before being subjected to Bayesian stochastic frontier estimation. Results were generated from 10,000 ‘burn-in’ Gibbs samples using the Markov Chain Monte Carlo method before collecting same size samples.

The key justification for adopting the Bayesian approach (similar to reasons advanced by [27,28] is that Bayesian estimation allows for execution of models that were previously categorised as ’difficult to handle models’, and it provides precise small-sample empirical conclusions on efficiencies in addition to the possibility of including prior information in its estimation.

2.2 Data

The data is obtained from the Nigeria National Bureau of Statistics 2010-2011 panel survey which is a component of the revised General Household Survey (GHS-Panel). The survey consists of panel data on households, their characteristics, welfare and their agricultural activities and household consumption. To obtain the sample used for this study, purposive sampling was employed. Out of a total farm household, data from 1306 respondents who engaged in crop production were used for the study.

3. RESULTS AND DISCUSSION

3.1 Bayesian Stochastic Frontier

Estimates of technical efficiency for Nigeria agriculture are presented in Table 3.1. The results show that the elasticities of farm size, fertilizer, cost of other production inputs, hired and family labour are significantly positive. This corroborates the results of (31). The positive coefficient of farm size, fertilizer, cost of other production inputs, hired and family labour land implies that an increase in any of these variables will have a positive impact on production output.

Mean percent efficiency scores is estimated as 84%. The coefficient of sigma and omega parameters is statistically different from zero indicating that the distributional form assumed for the composite error term is correct thus implying that the appropriateness of the frontier method chosen.

Table 3.1. Bayesian Stochastic Frontier Estimation for Nigeria Agriculture

Stochastic frontier		**Coefficient**	**t-value**
Farm size	β_1	1.54***	11.71
Fertilizer	β_2	0.74 ***	10.13
Input cost-others	β_3	0.04*	1.86
Hired labour	β_4	0.60***	4.91
Family labour	β_5	1.24***	33.10
Inefficiency function			
Age	Z_1	-1.00**	-2.08
Gender	Z_2	-2.35**	-1.97
Education	Z_3	-0.75*	-1.82
Marital Status	Z_4	-6.29***	-2.81
Freq. of Ext. visit	Z_5	-0.05	-0.05
Savings	Z_6	-2.95	-1.51
Credit	Z_7	4.04***	2.79
Land ownership	Z_8	1.25	0.48
Off-farm activities	Z_9	-7.87***	-3.25
R-Square	R^2	0.74	
Sigma statistics		1.61***	3.31
Omega statistics		3.94***	2.82

**Significant at 10%, **Significant at 5%, ***Significant at 1%*

Source: Computed from 2010/2011 Nigerian General Household Survey dataset

3.2 Inefficiency Indices

The distribution of the inefficiency indices as presented in Table 3.2 shows that mean age of farmers is 49 years. This implies that farmers were in the economically active age range. The level of education ranged between no-education and adult education with primary education being predominant. This low level of literacy has its consequences on farm decision making. Majority of respondents are married and depends on personal saving. The implication of this is that such savings may not be large enough to meet farm expenditure and hence discourage expansion. Also we find that majority of farmers' farm on communal or borrowed land. This situation usually encourages tenure insecurity and determines to a large extent the type of crop that is cultivated.

Table 3.2. Distribution of the Inefficiency Indices

Variables	Mean	SD	Minimum	Maximum
Age	49	14.26	21	104
Education	21.8	16.42	0	61
Credit	0.30	0.46	0	1
Marital status	0.93	0.24	0	1
Freq. of Ext. visit	0.6	2.15	0	22
Savings	0.20	0.40	0	1
Land ownership	0.91	0.27	0	1
Off-farm activities	0.54	0.49	0	1

Source: Computed from 2010/2011 Nigerian General Household Survey dataset

The coefficient of age, gender, education, marital status and participation in off-farm activities are significant and negative while credit is significant and positive. Each significant inefficiency variable is discussed further.

Age: The negative estimated coefficient for age of farmer implies that efficiency is increased by age. Although this result corroborates [22] and [32] it however contradicts [33]. We argue here that up to a certain age, the older the farmer the more experienced he/she becomes and so does his efficiency level increase.

Gender: Male headed farm households are found to be more technically efficient. Similar results have been reported by [34,35] and [36]. In line with earlier literature we buttress the fact that smallholder farming in Nigeria is typically crude and involves significant exertion of energy thus male farmers are in better position to meet this farm energy demand.

Education: The negative sign of the estimated coefficient of education is consistent with literature [37,38,34] and indicates that the level of education affects decision-making ability and adoption of practices that increases technical efficiency.

Credit: Contrary to prior-expectations and findings from literature (including [35]) access to credit is significantly positive. This implies that greater access to credit decreases technical efficiency. We argue here that because majority of farm household are poor, diversion of credit to household consumption is widespread. More so, as poor small holder farmers improve their living standard, the less the incentive for them to farm as agriculture (especially in rural areas) in Nigeria is seen as a residual industry for the poor.

Off-farm participation: Similar to [39,40] off-farm activity clearly influences technical efficiency positively implying that farm household that engage in off-farm activities are likely to obtain higher technical efficiency. This relationship is attributed to augmenting farm income with extra income from off-farm activities thus enabling farmers afford additional inputs and improve their ability to cope with risk in agriculture.

3.3 Elasticity of Output and Returns to Scale

Table 3.2 is a presentation of output elasticity and returns to scale obtained from the coefficient of first order terms.

Table 3.2. Statistics of parameters of the Stochastic Frontier Model

Variables	Output Elasticity
Farm size	1.54
Fertilizer	0.74
Other inputs	0.04
Hired labour	0.60
Family labour	1.24
Returns to Scale	4.16

Source: Computed from 2010/2011 Nigerian General Household Survey dataset

The estimated output elasticity of all production inputs was positive and therefore consistent with economic theory. The highest elasticity (1.54) was recorded for farm size thus a 1% increase in farm size will increase production by 1.54% while the lowest (0.04) was for cost of other inputs. The Return to Scale (RTS) of 4.16 strongly suggest increasing returns which implies that each addition of input will lead to more than proportionate change in the output. This portrays farmers as being in stage 1 of production function thus implying that if all factor inputs are increased by 1%, farm output would increase by 4.16%. [41] reported slightly higher RTS in his study while [42] finding was lower than that obtained in this study. Thus the finding from this study corroborates that from earlier studies in Nigeria.

4. CONCLUSION

This paper contributes to the literature on Bayesian estimation of farm level efficiency by addressing the issue of technical efficiency and returns to scale in Nigeria agriculture. From the estimated results, we find that age, gender, level of education, extension visits and participation in off-farm activities had a positive effect on technical efficiency.

The paper further reports that there exists the possibility of improving technical efficiency in Nigeria farm by as much as 16% with the present resource endowment; without necessarily changing the existing level of technology. Factor identified to positively influence technical efficiency were age, gender, education, marital status and participation in off-farm activities. We find that majority of farms not at the efficient stage of production as they are operating in the first stage (stage 1) of the production function which reflects increasing returns to scale. Thus if all factor inputs are increased by 1%, farm output would increase by 4.16%. In other words a more-than-proportionate increase in output will be obtained from a proportionate increase in input. In line with our findings, support should be provided in form of farm production inputs rather than credit while farmers should be trained on entrepreneurial skills as returns from off-farm activities have been found to complement farm income and improve technical efficiency. Our findings have significant policy implications as it draws attention to increasing agricultural productivity through improving the existing level of efficiency of small farmers.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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