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Accounting for agricultural productivity growth in rice farming: Implication for agricultural transformation agenda in Nigeria

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ABSTRACT

This study engaged both Stochastic Frontier and Data Envelopment Analyses in estimating technical efficiency and productivity growth respectively among rice farmers in Nigeria. The underlying data for the study were derived from the households' panel survey conducted by NISER in collaboration with Lund University, Sweden under the African Food Crisis studies carried out in 2002 and 2007, respectively. The Stochastic frontier t technical efficiency analysis showed that all coefficients of the explanatory variables were significant between 1 and 5% but elasticity estimates showed the inelasticity of output with respect to land, labour, seed and fertiliser and a high gamma value of 0.835, signifying that much of the variation in the composite error term was due to inefficiency. The mean technical efficiency of the farmers under the assumption of constant returns to scale were estimated to be 0.66 and 0.53 respectively for periods 1 and 2 which indicated that the farmers fell short of the frontier by 34 and 47% in periods 1 and 2, respectively. The result further showed that technical efficiency of the farmers also declined by 16% between periods 1 and 2. Productivity growth analysis between the two periods suggested a decline as overall productivity reduced by 33% and the decomposition of the productivity into various components showed that only scale efficiency made significant contribution as the contribution of each of the other components is less than one. The result of the total factor productivity measure obtained by Fisher Index in period 2 was 0.85 in reference to period 1 which implied that rice farmers in period 2 have a productivity gap of 25% to match the technology of best production. The various analyses carried out in this study pointed to the fact that, in spite of various policies and programmes implemented between 2002 and 2007 to improve productivity in the agricultural sector in Nigeria, the expected result was constrained by inefficient use of resources and inability to minimize the cost of production which resulted in low technical efficiency. Therefore, achieving agricultural transformation in Nigeria will required more efforts at increasing the technical efficiency of the farmers and this can only be achieved through efficient utilization of productive inputs.

Keywords: Agricultural productivity, technical efficiency, growth, rice, transformation agenda.

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INTRODUCTION

Food security and agricultural productivity were twin issues central to Nigerian government economic policy between 1999 and 2008. During this period, the government launched a vast number of initiatives ranging from land reform to subsidized fertilizer and extension services. But the most notable among the initiatives was the Presidential Initiative (PI), designed to advance farmers' knowledge of farm technology and best practices. The main pillars of the initiative are: (1) farmers and private sector participation in developing agricultural development programs, (2) support for enhanced inputs and technology, (3) extension services that provide farmers with knowledge of idiosyncratic farm characteristics and requirements, and (4) advances in harvesting and product processing technology. The implementation of the initiative and other agricultural sector proprammes led to modest growth in the the sector during this period. The growth rate of agricultural GDP was found to have outpaced that of the aggregate GDP in recent times. Agricultural GDP growth rate rose from 4.2 in 2002 and reached an all time high of 7.4 in 2007 as against 4.6 and 6.2 for aggregate GDP growth for the same period respectively (CBN, 2003, 2008). In spite of this, available information showed that though this growth rate is well above targets set by the NEPAD Comprehensive African Agricultural Development Programme (CAADP), it is still below 10% growth rate set under the National Food Security Programme. Also, this growth rate fell below what is required to achieve the MDG1 of eliminating hunger and halving the proportion of people in poverty which is put at 65.6 in 1996 by 2015 in Nigeria (NBS, 2005). This in turn indicated that Nigeria has not fully tapped its agriculture potential. For example, Nigeria has 79 million hectares of fertile land but only 32 million hectares (46%) of these are cultivated. Further, more than 90% of agricultural output is accounted for by households with less than 2 hectares under cropping. Typical farm sizes range from 0.5 hectare in the south to 4 hectares in the north (FMA and WR, 2008).

From the Afrint II household micro survey, average area cultivated to maize in Kaduna (north) in 2006 season was 3.5 while it was 2.5 in Osun (south) and for cassava, it was 1.2 hectares in Kaduna and 2.7 hectares in Osun. Similar situation was observed for rice with 2.1 hectare in both Kaduna and Osun. Though recent growth trends show some modest increases in productivity over time, yield levels are generally below potentials. This reflects the fact that much of the growth or increase in output have come from expansion in the land area under cultivation. The indication that output growth was accounted for more by expansion in area cultivated than by productivity improvement is reinforced by the significant correlation between output and area harvested compared to the correlation between output and yield (Eboh et al., 2006). Aggregate data for major crops showed modest increases in productivity over time; however, the yield levels were far below potentials and still less than levels required for global competitiveness in agriculture. Yield levels for cassava, maize and rice either stagnated or only recorded marginal increases between 2002 and 2007. As a matter of fact, the yield level of cassava declined in 2004 and 2005 despite the implementation of the presidential initiatives on cassava. The objective of this research, therefore, is to determine sources of growth in agricultural productivity during the two periods for the purpose of drawing implications for agricultural transformation in Nigeria.

Concept and measurement of total factor productivity in agriculture

Productivity is defined as output per unit of input and productivity growth aims at capturing output growth not accounted for by growth in inputs (Fulginiti et al., 2004). Studies that measure productivity growth decompose total factor productivity (TFP) into two components, efficiency change and technical change. Efficiency measures the ability of a country to fully exploit its available agricultural resources in producing total output, relative to other countries and available technology represented by the best-practice frontier. Therefore, efficiency change measures the rate at which a country moves towards (catches up) or away (lags behind) from the best-practice production frontier. Technical change represents a shift in the production frontier through time; it is a measure of the level of innovation in agricultural production. Productivity statistics compare changes in outputs to changes in inputs in order to assess the performance of a sector. Two types of productivity measures are partial and multifactor indexes. Partial productivity indexes relate output to a single input, such as labor or land. These measures are useful for indicating factor-saving biases in technical change but are likely to overstate the overall improvement in efficiency because they do not account for changes in other input use. For example, rising output per worker may follow from additions to the capital stock, and higher crop yield may be due to greater application of fertilizer. For this reason, a measure of TFP relating output to all of the inputs used in production gives a superior indicator of a sector's efficiency than do indexes of partial productivity. TFP is usually defined as the ratio of total output to total inputs in a production process. In other words, TFP measures the average product of all inputs.

Let total output be given by Y and total inputs by X. Then TFP is simply:

$$TFP = Y/ X \qquad (1)$$

Taking logarithmic differentials of Equation 1 with respect to time, t, yields:

$$\partial In\frac{(TFP)}{\partial t} = \partial\frac{InY}{\partial t} - \partial\frac{InX}{\partial t} \qquad (2)$$

This simply states that, for small changes, the rate of change in TFP is equal to the difference between the rate of change in aggregate output and the rate of change in aggregate input. In agriculture, output is composed of multiple commodities produced by multiple inputs in a joint production process, so **Y** and **X** are vectors. Chambers (1988) showed that when the underlying technology can be represented by a Cobb-Douglas production function and where (i) producers maximize profits, and (ii) markets are in long-run competitive equilibrium (total revenue equals total cost), then Equation 2 can be written as:

$$In\left[\frac{TFP_t}{TFP_{t.1}}\right] = \sum_i RiIn\left[\frac{Y_{it}}{Y_{it-1}}\right] - \sum_j SjIn\left[\frac{X_{jt}}{X_{jt-1}}\right] \quad (3)$$

Where *Ri* is the revenue share of the *i*th output and *Sj* is the cost share of the *j*th input. Output growth is estimated by summing over the output growth rates for each commodity after multiplying each by its revenue share. Similarly, input growth is found by summing the growth rate of each input, weighting each by its cost share. TFP growth is just the difference between the growth in aggregate output and the growth in aggregate input. This measure of TFP growth is similar to the Tornqvist-Theil index since it is assumed that there will be variation in cost and revenue shares over time. Nevertheless in this study, the problem of variation in cost and revenue share over time is further circumvented as estimation was based on Malmquist index, which measures productivity using data on output and input quantities alone (Coelli and Rao, 2005). In summary, the theory underpinning the TFP productivity index assumes that producers maximize profits so that the elasticity of output with respect to each input is equal to its factor share. It also assumes that markets are in long-run competitive equilibrium (where technology exhibits constant returns to scale) so that total revenue equals total cost. If these conditions hold and the underlying production function is Cobb-Douglas, then this index provides an exact representation of Hicks-neutral technical change.

METHODOLOGY

The secondary data utilized for this study were derived from a household survey panel data which were collected by NISER in collaboration with Lund University, Sweden under the Afrint I and II projects. This panel data were collected at household levels in Kaduna and Osun States in 2002 now referred to as Afrint I and 2007 also referred to as Afrint II. The analytical method employed in this study was in two folds. The first involved the measurement of the technical efficiency while the second involved determination and disaggregation of productivity growth between the two periods. The stochastic frontier and data envelopment analyses were used to analyse technical efficiencies and productivity changes respectively. In analyzing the Stochastic Frontier (SFA) both Frontier 4.1 and DEA 2.1 software were employed. For the productivity changes, the Malmqiust index was used which employed the DEA software.

Construction of the panel data and description of variables

The sample data used for this analysis consist of cross sectional data set for a two year period (2002 and 2007). The data included quantity and prices of maize output as well as quantities and prices of inputs used in production. Four inputs were used in this analysis, namely, land, labour, seed and fertilizer. After accounting for missing data, we were left with 314 observations, of which 174 was for period one (2002) and the 140 for period two (2007). For the analysis, only 280 observations were used due to the fact that the DEA programmes used required balanced panel data sets. Thus, the sample data in period one was decreased by randomization to 140. Both outputs and input variables were normalized with the land variable to bring them to a common level, which is on a per hectare basis. This was necessary to correct for scale differences. The data description and the units of measurements are presented in Appendix Table 1.

Analytical methods

Stochastic frontier analysis

The Stochastic frontier is a parametric approach which imposes a production function on the frontier analysis to be employed (Aigner, et al., 1977; Meeusen and van den Broeck, 1977). The model can be described as:

$$\ln y_i = x_i \beta_i .TE_i \quad (4)$$

Where y_i is the observed output of the maize farmers, x_i, is the vector of N inputs used in the production. β is the vector of technology parameters and TE_i is the technical efficiency, that is the ratio of observed output to the maximum feasible output. TE_i = 1 if the farmer is operating on the frontier, that is, technically efficient. TE_i <1 is a measure of the technical inefficiency of the farmers. Thus we require $TE_i \leq 1$.

In adding a symmetric random error, the model becomes:

$y_i = x_i \beta_i .TE_i .\exp\{v_i\}$, where $\exp\{v_i\}$ is the random error term.

TE_i can also be written as an exponential $\exp\{-u_i\}$, where $u_i \geq 0$, since $TE_i \leq 1$

Therefore:

$$y_i = x_i \beta_i .\{\exp - u_i\}.\exp\{v_i\} \quad (5)$$

$$\ln y_i = x_i' \beta + v_i - u_i \quad (6)$$

Thus, assuming the stochastic frontier analysis takes on a Cobb Douglas Production function, it will be given as:

$$\ln y_i = \beta_1 \ln x_i^{\prime} + v_i - u_i \quad (7)$$

The stochastic frontier analysis is directed towards the prediction of inefficiency effect (Coelli et al, 2005) which is not the direct relevance of this study. The technical efficiency measure is the output of the ith farm relative to the output of the reference farm, that is, the fully efficient farm.

Data envelopment analysis

The data envelopment analysis is a non parametric measure of technical efficiency. The DEA involves the use of linear programming methods to calculate frontier estimates over the data (Coelli et al., 2005). The efficiency measures are then calculated relative to the frontier estimated. In assuming a constant return to scale efficiency, linear programming equation for the DEA is given by:

$$\begin{aligned} &\min_{\theta,\lambda} \theta, \\ &st, \\ &-q_i + Q\lambda \geq 0 \\ &\theta x_i - X\lambda \geq 0 \\ &\lambda \geq 0 \end{aligned} \quad (8)$$

where θ is a scalar and λ is a I x1 vector if constant. The θ is the efficiency score of the ith farm and satisfies the condition that θ ≤ 1. A farm with a score of 1 is said to be fully efficient, that is, operating on the frontier. The linear programming is carried out i times, for the number of farms in the analysis. It should however be noted that the DEA with a constant returns to scale assumption is a restrictive one. Thus, accounting for imperfect markets, financial market constraints and government interventions, a variable returns to scale DEA model might be appropriate. For the purpose of this study, however, both constant and variable returns to scale, are imposed on the model for analysis.

Malmquist total factor productivity measure

The Malmquist TFP index gives a measure of productivity growth by comparing two data points (periods 1 and 2) in which there are observed inputs and outputs. This TFP index measures productivity by comparing the observed outputs in periods 1 and 2 with the maximum level of outputs that can be produced using the inputs x_1 and x_2 under a reference technology. The Malmquist index makes use of a radial distance of the observed outputs and inputs in the two periods with respect to a reference technology. The distance measure could either be input orientated or output orientated, such that the index depends on the orientation used. This study made use of the input orientated Malmquist TFP index.

Input orientated Malmquist TFPI

The input orientated index focuses on the levels of inputs, x_1 and x_2 that can be used to produce the observed levels of outputs, y_1 and y_2 relative to the reference technology. Given that period 1 is the reference technology, the index is given as:

$$m_i^1(y_1, x_1, y_2, x_2) = \frac{d_i^1(q_2, x_2)}{d_i^1(q_1, x_1)} \quad (9)$$

Assume that there is technical efficiency in both periods, that is, $d_i^1(y_1 x_1) = 1$, then:

$$m_i^1(y_1, x_1, y_2, x_2) = d_i^1(y_2, x_2) \quad (10)$$

This can be similarly done if the reference technology is period 2. Therefore, the input orientated malmquist index is:

$$m_i\,(y_1, x_1, y_2, x_2) = \{\ m_i^1(y_1, x_1, y_2, x_2).m_i^2(y_1, x_1, y_2, x_2)\ \}^{0.5} \quad (11)$$

The above is a measure of productivity growth when technical efficiency is assumed in the two periods. However, if there is technical inefficiency, which is the most probable case, the observed productivity change can be given as follows:

$$m_i(y_1, x_1, y_2, x_2) = \frac{d_i^2(y_2, x_2)}{d_i^1(y_1, x_1)} \left[\frac{d_i^1(y_2, x_2)}{d_i^2(y_2, x_2)} \times \frac{d_i^1(y_1, x_1)}{d_i^2(y_1, x_1)} \right]^{0.5} \quad (12)$$

Equation 12 is composed of two ratios: the ratio on the outside is the measure of Efficiency change, while the ratio in the brackets is the technical change.

The results of the DEA measure of the Malmquist give the following change measures:

(i) Efficiency change
(ii) Technical change
(iii) Allocative (price) change
(iv) Scale efficiency change
(v) Total Factor productivity change

The efficiency change is equivalent to the ratio of the Farell technical efficiency in period 2 to the Farell technical efficiency in period 1 (Coelli et al., 2005). The technical change is the geometric mean of the shift in technology between the two periods under study. A value

Table 1. Maximum likelihood estimates of the Stochastic frontier analysis.

Coefficient (input vectors)	Estimates	Standard error	Z-statistics
Constant	2.069***	0.107	19.252
Land	0.145**	0.063	2.324
Labour	0.156*	0.055	2.827
Seed	0.427*	0.034	12.646
Fertilizer	0.742**	0.034	2.165
Gamma	0.835		
Log likelihood	-5.300*		
Technical efficiency (period 1)	0.987		
Technical efficiency (period 2)	0.847		

n = 280. LR test of the one-sided error = 0.26954716E+02 *, ** and ***: 10%, 5% and 1% significant levels respectively.

Table 2. Mean technical efficiency measures by periods from the DEA.

Period	Mean technical efficiency (CRS)	Mean technical efficiency (VRS)
1	0.658	0.856
2	0.532	0.570

greater than 1 implies a technical progress from periods 1 to 2. The allocative/price efficiency change measures the ratio of input prices between periods 1 and 2. Scale efficiency change measures the change in productivity as a result of the change in the scale of production of the farms and their movement towards the Technologically Optimum Scale. The numerical value of this change is bounded by 0 and 1. However, a value greater than 1 means that the farm is nearer the optimum scale of technology in the period under consideration as opposed to the reference period.

RESULTS AND DISCUSSION

Technical efficiencies in years 1 and 2 production periods

The panel data set consisted of the logged form of the normalized quantities of the output (maize in kg) and the inputs (land, seed, labour and fertilizer) over the time periods between 2002 and 2007. The functional form thus adopted is the Cobb Douglas production function. Table 1 presents the results of the analysis of SFA in two steps. First was the measure of Maximum likelihood estimates of the coefficients of the inputs used in the production of the maize while the second was the result of the mean technical efficiencies of the rice farmers in the two time periods.

The maximum livelihood estimate of the stochastic frontier analysis was found to be significant at 1%, showing that the model fits. The MLE when evaluated at the variable mean, showed that the estimated elasticity of the output with respect to land, labour, seed and fertilizer are 0.145, 0.156. 0.427 and 0.742, respectively. All the coefficients were significant at between 1 and 5% level of significance. The result showed that the highest contribution to productivity in the panel data was fertilizer, while land area cultivated had the lowest contribution to productivity of rice farmers. The gamma value is high (0.835), signifying that much of the variation in the composite error term was due to inefficiency.

The SFA technical efficiency measures for the two periods using Frontier 4.1 showed very high technical efficiencies. Period 1 farmers were reported by the SFA to have almost unity technical efficiency (0.987), while that of period 2 is also close (0.847) although less efficient to farmers of period 1. The high level of these two efficiency scores suggests that farmers in both periods seem to be supper efficient (that is, very close the frontier) which is less likely to be true as indicated by the high value of gamma. In order not to give a misleading interpretation of the result the analysis was repeated with the DEA for comparison. The DEA showed a more conservative and realistic measures of average technical efficiency for which this report later place more emphasis. This is not surprising given that the DEA method involves calculating separate frontier in each year while the SFA method use all the two years data to estimate the frontier of the two years with smooth changes in the frontier allowed via the time trend specification of technical change. Table 2 shows that the mean technical efficiency of farmers (using Constant return to scale) in period 1 was about 0.66 while for

Table 3. Productivity growth between period 1 and period 2.

Year (1 is base technology)	Efficiency change	Technical change	Price efficiency change	Scale efficiency change	Total factor productivity change
1	1.00	1.00	1.00	1.00	1.00
2	0.734	0.922	0.584	1.257	0.677

farmers in period 2 it 0.53. Suggesting that from a farm operating on the frontier, the rice farmers in both periods fell short from the frontier requiring a scope of about 34% in period 1 and 47% in period 2 to increase their maize output by adopting the technology of the best practice farmers who are on the frontier. Furthermore it can be observed from efficiency figures that the technical efficiency of the farmers dropped between the periods (2002 and 2007) by about 16%. This indicated that farmers were technically more efficient in period 1 than in period (result was consistent with that of SFA). Implying that over the years the technical efficiency of maize farmers in the country had gradually been declining a situation which might have arisen as a result of many factors.

Productivity growth (Malmquist TFP index) and total factor productivity measures

The Malmquist TFP index measure was used to examine the productivity changes from period 1 to period 2 for the rice farmers. The analysis was accomplished using the linear programming model of the DEA. The assumptions made for this analysis include constant returns to scale of production technology and input orientation. To assess the total factor productivity levels in the two periods the Fisher and Tornquist total productivity index were computed and used. In several analyses Fisher's index is preferred over Tornquist due to the fact that Fisher index exhibits self duality function and is able to handle zero quintiles in data sets. However, for this analysis it was found that both indexes gave the same numerical values. Tables 3 and 4 presents productivity growth and total productivity measures of rice farmers for the two periods under study.

From Table 3 it can be observed that there was a negative growth in productivity between the two periods with a value of 0.677, suggesting that relative to period 1 productivity declined in period 2. The overall productivity of rice farmers was reduced by about 0.33. Four major sources of productivity growth can be found in literature – Technical Change, Efficiency Change, Scale Efficiency Change and Input (or Output) mix effect. The combination of these factors gives the total factor productivity change. The decomposition of the total factor productivity change into the four components is also shown in Table 3. The table shows that beside the scale efficiency, all other factors were below unity (1),

Table 4. Total factor productivity measures.

Period	Total factor productivity
1	1.000
2	0.847

suggesting that relative to period 1 farmers in period two were less efficient. Notwithstanding the result show that framers were more scale efficient in period 2 than period 1.

Result of the total factor productivity measure obtained by Fisher index shown on Table 4, indicated that the result is consistent with that obtained with the Malmquist TFP estimates that showed a reduction in efficiency and productivity from period 1 to period 2. The TFP in period 1 was found to be Unity (it is assumed that the period 1 is the reference technology, that is, the farming period on the best practice Frontier), while in period two, it was 0.847. Thus with respect to all the inputs of production they led to about 85% productivity in period 2, implying that rice farmers in period 2 have a gap of 25% to match the technology of best production to be on the frontier.

CONCLUSION

The various analyses carried out in this study pointed to the fact that, in spite of various policies and programmes implemented between 2002 and 2007 to improve productivity in the agricultural sector in Nigeria, the expected result was constrained by inefficient use of resources and inability to minimize the cost of production resulting in low technical efficiency. The decomposition of productivity growth between the two periods under study showed that scale efficiency (increase in area cultivated) is the only significant factor accounting for productivity growth during this period. Output was inelastic with respect to land, labour, seed and fertilizer. Therefore, achieving agricultural transformation in Nigeria will required more efforts at increasing the technical efficiency of the farmers which can only be achieved through efficient utilization of production inputs.

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APPENDIX

Table 1. Description of variables used in determining productivity.

Variable	Description	Unit of measurement
Land	Land area used in cultivation of pure maize stands	Hectares
Labour	Number of adults working maize farm	Number/ha
Seed	Quantity of seed sown on maize plot	Kg/ha
Fertilizer	Quantity of fertilizer used on maize plots	Kg/ha
Output	Quantity of maize harvested for the given technology of production	Kg/ha
Output Price	Average price per kilogram of maize output sold.	USD/kg
Rent	Price per unit of land used	USD/Ha
Wage	Price per unit of labour used	USD/person
Seed price	Price per kilogram of seed used	USD/kg of maize seed
Fertilizer price	Price per kilogram of fertilizer used on maize plots	USD/kg of fertilizer