Estimating Technical Efficiency, Input substitution and complementary effects using Output Distance Function: A study of Cassava production in Nigeria

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Contributed Paper presented at the Joint 3rd African Association of Agricultural Economists (AAAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference, Cape Town, South Africa, September 19-23, 2010.

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Abstract

In this study, we estimate an output distance function in the context of a multi-output and multi-input production technology by stochastic frontier techniques. Unbalanced panel data for smallholder farms that grown cassava and other crops in Southwestern Nigeria covering 2006/07 to 2008/09 farming seasons is used for the analysis. The results show that the marginal rate of transformation (MRT) between "other crops" grown by the farmers and cassava produced relative to the output mix is negative and significantly different from zero. We observed also that increasing returns-to-scale as well as technical progress characterized cassava production in the region. Furthermore, fertilizer and pesticides are found to have significant substitution effects on cassava production in the sample. We also found evidence that, in pairs, farm size and pesticides, labour and fertilizer as well as fertilizer and pesticides jointly exhibit significant complementary effects on cassava production in the region. An average technical efficiency level of 72.1 percent which implies approximately a 39 percent inefficiency level is observed from the study. Over the seasons, we found significant evidence of an increasing trend in technical efficiency level of the farms. Extension, credit and, occupation (i.e., full time farming) are indentified as efficiency increasing policy variables from the study.

Key words: Cassava, technical efficiency, inputs substitution and complementary effects

1. Introduction

Cassava (*manihot esculenta crantz*) is a perennial, vegetatively propagated shrub, grown throughout the lowland tropics. African countries produce over 103 million metric tonnes cassava per annum with Nigeria accounting for approximately 35 million metric tons per annum (FAOSTAT, 2009).

Nigeria has the largest harvest in the world; three times more than the production level in Brazil and almost double the production level in Thailand and Indonesia. IITA (2005) attributed the large harvest in Nigeria to rapid population growth, internal market demand, availability of high yielding improved varieties of cassava tuber, and increase hectrage of farm land allocated to cassava in the country.

Traditionally, an average of three to five crops is often intercropped with cassava. The crops are selected on the basis of differences in growth habits and can be combined in either simple or complex mixtures. Cassava constitutes a major item in the crop combination of the most farmers and contributes significantly to total farm income in Nigeria (Bamire *et al.,* 2004).

This observation could offer reasons as to why the federal government of Nigeria launched the "Presidential Committee on Cassava Export Promotion" in 2001 with the aim of making cassava a major non-oil foreign exchange earner because of its comparative advantage in the country. Following this initiative, cassava production increased between 2000/2001 to 2005/2006 farming seasons while production has since then stagnated.

A lot factors have been linked to the sudden decline in cassava production in the country, key of which include lack of continuity of previous administration policies on the cassava expansion program by the current government in the country (Nigerian Tribune 2008). This however, is not surprising because policy discontinuity has become successive in the Nigerian government's culture.

Another factor which was resilient/echoed among the industry's experts/researchers is the level of productivity (i.e., input, output growth or input and output mix productivities) and the efficiency of the cassava industry in the country (Onu and Edon 2009, Edeh and Awoke 2009, Udoh and Etim, 2007).

Thiam *et al.* (2001) highlighted the importance of efficiency as a means of fostering the production process. However, in the context of cassava production, this observation implies that understanding of technical efficiency of cassava farms will provide policy makers with an important control mechanism for agricultural planning in the country.

This paper seeks to update literature on the efficiency of the Nigerian cassava industry while it will at the same time complement various efforts of research in improving cassava production in the country. Because cassava traditionally is grown with other crops, the present study examines the technical efficiency of cassava farms in Nigeria using a primal output distance function with unbalanced panel data covering three farming seasons, 2006/07-2008/09.

Therefore, the objective of the study includes: 1) to investigate input complementary and substitution effects on cassava production in the country and 2) to examine seasonal trends in technical efficiency of cassava farms in the country.

The outline of the paper is as follows. Section 2 introduces the theoretical framework of the output distance function. In section 3, we present the methodology and detailed information on the study area. Section 4 describes the results and discussion. Section 5 summarizes and concludes the findings.

2. Theoretical framework

2.1. *The Multiple outputs and Distance function*

Multi-outputs and inputs modeling of the production technology provide distinct effects of capturing different outputs and inputs in the production processes. According to Shephard (1970), when many inputs are used to produce many outputs, the distance function provides a functional characterization of the structure of the production technology. The concept and properties of the distance function are well documented in the literature (Färe 1988; Färe and Primont 1995; Kumbhakar and Lovell 2000; Coelli *et al.*, 2005).

However, in the distance function approach, the researcher chooses between the input and the output distance-oriented approaches and estimates the distance function of his/her choice depending on the direction/focus of the study (Daidone and D'Amico 2009). These primal functions represent a technical (substitution) relationship among and across the inputs and outputs - not economic optimization (Paul and Nehring 2005). A significant advantage of the distance function is that neither the input distance function nor the output distance function depends on any explicit behavioral assumptions such as cost minimization, revenue maximization, and profit maximization (Kumbhakar and Lovell 2000; Coelli *et al,* 2005).

The output distance function is constructed following the assumption that each observed point of production by the producer is scaled radially towards the boundary of production in order to operate on the production frontier. The input distance function on the other hand is constructed with the assumption that producer focuses mainly on reducing inputs to produce a fixed output by radically scaling down the input vectors in order to operate on the production frontier.

Considering the inability of traditional farmers in developing agriculture in most cases to meet the recommended input usage and timely access to these production inputs on their farms, the assumption of reducing inputs to produce at the frontier level seems plausible in this circumstance for farmers in developing agriculture such as Nigeria.

The output distance function takes an output–expanding approach to the measurement of the distance of a producer to the boundary of production possibility frontier (Kumbhakar and Lovell, 2000). It gives the minimum amount by which an output vector can be deflated by factor θ and still remain producible with a given input vector as

$$D_0(x,y,t) = \min\left\{\theta : y/\theta \in P(x)\right\} \qquad 1$$

The interpretation of Eqn.1 is that the output distance function seeks the largest proportional increase in the observed output vector given that the expanded vector $\left(y_m / y_{1i} \right)$ must still be an element of the original output set $P(x)$.

Using set notation, Eqn.1 could be described further as

$$D_0(x,y,t) \le 1 \Leftrightarrow y \in P(x) \qquad 2$$

$$D_0(x,y,t) = 1 \Leftrightarrow y \in \mathrm{IsoqP}(x) \qquad 3$$

$$P(x) = \left\{ y : D_0(\mathbf{x,y,t}) \le 1 \right\} \qquad 4$$

where $D_0(x,y)$ is non-decreasing, linearly homogenous, and convex in outputs ***y***, and non-increasing and quasi-convex in the inputs ***x***; $P(x)$ is the set of the output vectors ***y*** which can be produced using the input vector ***x***. $\mathrm{IsoqP}(x)$ is the boundary of the output set as $\mathrm{IsoqP}(x) = \left\{ y\text{:}\ y \in P(x) \Rightarrow \lambda y \in P(x), \lambda > 1 \right\}$. $D_0(x,y,t)$ takes a value of 1 whenever the output vector lies on the outer boundary of the output set.

Accordingly, $D_0(x,y,t)$ measures the inverse of the vector θ by which the production of all the output quantities could be increased while still remaining within the feasible production set $P(x)$ for the given input level (O'Donnell and Coelli 2005).

However, figure 2 described a typical multi-output production technology otherwise called the production possibility frontier (PPF) with two outputs and one input. The PPF describes the technically efficient points of production for various combinations of the output that could be produced using a given factor endowment ***x***. $\equiv P(x)$ represents the output set/vector which is bounded by the PPF.

In the present framework, we assumed that the distance of any firm from the frontier (boundary of output set) could be attributed to either - inefficiency or noise or both. The production at any point on the PPF other than ***B*** (i.e., the *frontier*) represents sub-optimal performances which include points ***A*** and ***C*** in the figure. For example, $\overline{\mathrm{AB}}$ represents the departure from the technically optimum point of production (i.e., the *frontier point*) associated with inefficiency. Meaning that location of firm in the neighborhood of ***A,*** with reference to the best practice ***B,*** signified the level of inefficiency in the firm's production process. Also, a firm located at point ***C*** implies departure from the technologically feasible point (***B***); this could be attributed to both inefficiency and noise (measurement error).

However, the proportional expansion of a firm operating at the point ***A*** towards the boundary of the output set ***B*** requires upward scaling of y_2^A and y_1^A by a vector θ which needs to be minimized. This process of upwards adjustment of the output set $\equiv P^{\mathbf{A}}(x)$ towards the frontier output set $\equiv P^{B}(x)$ while maintaining the same level of the inputs is called the output distance function $D_0(x, y, t)$.

By construction $D_0(x, y, t)$ is equal to

$$D_0(x,y,t) = \frac{OA^*}{OB^*} \leq 1 \qquad \text{i.e., } D_0(\mathbf{x,y,t}) \leq 1 \text{ .} \qquad 5$$

The output distance $D_0(x,y,t)$ gives the reciprocal of the maximum proportional expansion of the output vector **y**, given the inputs **x** and characteristics of the technology completely.

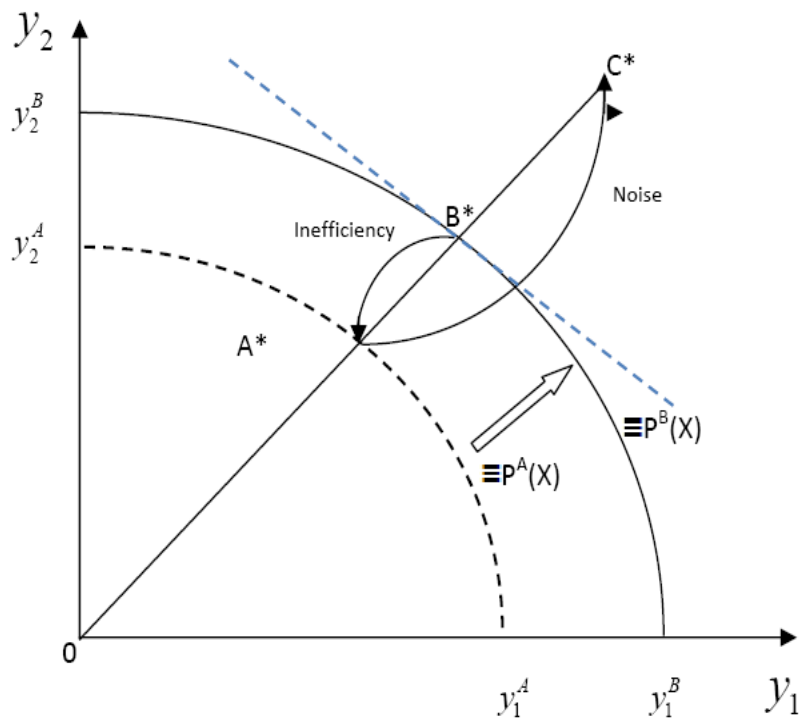

Figure 2: Illustration of Output Distance function (Adapted from Kumbhakar et al., 2007)

2.2. *Stochastic Frontier Output Distance function*

The pioneer work of Farrell (1957) and Debreu (1959) paved way for the understanding and measurement of firm level efficiency in the literature. Farrell's illustration of this concept theoretically provides the highly needed impetus to analyze technical efficiency in terms of a realized deviation from an idealized frontier isoquant (Greene, 2008).

Broadly, two quantitative approaches are developed to implement Farrell's definition of efficiency which includes: parametric (stochastic frontier analysis, SFA) and non-parametric (Data Envelopment Analysis, DEA) approaches. The main strengths of SFA over DEA are in its ability to deal with the stochastic noise and permit statistical testing of hypotheses pertaining to the production structure and the degree of the inefficiency. This observation suggests why the SFA is widely popular among researchers around the globe.

The stochastic frontier analysis (SFA) model was independently developed by Aigner *et al.,* (1977) and Meensen and van den Broeck (1977) to describe the production function technology, but the SFA's extension to dual and primal technology representations have become popular in the last two decades. The SFA has two error terms as earlier mentioned; the technical inefficiency error u_i and the white noise error component v_i. The v_i represents factors that might generate irrelevant noise in the data such as measurement error while u_i denotes unobserved inputs for eg., attributed to technical inefficiency in deterministic models as shown in the figure 1.

Based on the reasons highlighted in the section 2.1, the following discussion focuses on the stochastic frontier "Output Distance" function model as discussed in Färe and Primont (1995) and Kumbhakar and Lovell (2000).

We defined the stochastic frontier "output distance" relative to the output set P(x) as

$$D_0\left(x_j, y_m, t\right) = \min\left\{\theta : {y_m}/{\theta} \in P\left(x\right)\right\} \qquad 6$$

$$D_0\left(x_j, \theta y_m, t\right) = \theta \; ; D_0\left\{x_j, y_m, t\right\} \; \forall\, \theta > 0 \text{ for all } x \in \Re_+^j, \, y \in \Re_+^{\mathbf{m}} \qquad 7$$

Following Lovell *et al.,* (1994), one of the outputs is arbitrarily chosen while the reciprocal of the selected output is equal to the deflating vector θ. In this case, we choose output y_1 such that $\theta = {1}/{y_{1i}}$ which when substituted into Eqn.6 gives

$$D_0\left(x_j, {y_m}/{y_{1i}}, t\right) = {1}/{y_{1i}} \,.\, D_0\left\{x_j, y_m, t\right\} \qquad 8$$

Taking the log of both sides of Eqn.8 equal to

$$\text{In}D_0\left(x_j, {y_m}/{y_{1i}}, t\right) = -\text{In}y_{1i} + \text{In}D_0\left\{x_j, y_m, t\right\} \qquad 9$$

Re-arranging Eqn.9 yields

$$-\text{In}y_{1i} = \text{In}D_0\left(x_j, {y_m}/{y_{1i}}, t\right) - \text{In}D_0\left\{x_j, y_m, t\right\} \qquad 10$$

According to Brümmer *et al.,* (2006), the most useful property of the distance function is that the reciprocal of the distance function $D_0\left\{x_j, y_m, t\right\}$ has been proposed as a coefficient of resource utilization of Debreu (1959) and as a measure of Farrell (1957) output-oriented technical efficiency TE_0.

In this case, we defined TE_0 as

$$D_0\left\{x_j, y_m, t\right\} = \frac{1}{TE_0} \qquad \text{i.e., } D_0\left\{x_j, y_m, t\right\} \le 1 \text{ while } TE_0 \ge 1$$ [1] 11

Recall that at the frontier $D_0\left\{x_j, y_m, t\right\} = 1$ in the section 2.1. Therefore taking the log of Eqn.11 yields

$$\text{In}D_0\left\{x_j, y_m, t\right\} = \text{-In}TE_0 \qquad 12$$

And substituting Eqn.12 to Eqn.10 gives

$$\text{-In}y_{1i} = \text{In}D_0\left(x_j, \frac{y_m}{y_{1i}}, t\right) - \text{In}TE_0 \qquad 13$$

TE_0 is estimated from $TE_0 = \exp\left(\text{-}\hat{u}_{\mathbf{t}}^{+}\right)$, where $\hat{u}_{\mathbf{t}}^{+} = E\left[\text{-}u_{\mathbf{t}}^{+}\middle|\varepsilon\right]$ (Jondrowl *et al.,* 1982).

Since $TE_0 = \exp\left(\text{-}\hat{u}_{\mathbf{t}}^{+}\right)$ and taking the log of this expression in line with Eqn.13 gives $\text{In}TE_0 = \text{-}\hat{u}_{\mathbf{t}}^{+}$ which when substitute into Eqn.13 gives[2]:

$$\text{-In}y_{1i} = \text{In}D_0\left(x_j, \frac{y_m}{y_{1i}}, t\right) + \hat{u}_{\mathbf{t}}^{+} \qquad 14$$

To have a specification identical with the standard stochastic frontier production model proposed by Aigner *et al.,* (1977) and Meeusen and van den Broeck (1977), we multiply both sides of Eqn.14 by (-1) while adding another error term v_t to eliminate effects of "white noise" in the empirical model as earlier illustrated in the figure 2 as[3]

$$\text{In}y_{1i} = \text{-In}D_0\left(x_j, \frac{y_m}{y_{1i}}, t\right) \text{-}u_{\mathbf{t}} + v_{\mathbf{t}} \qquad 15$$

Rearranging Eqn.15 gives

$$Iny_{1i} = \text{-}InD_0\left(x_j, \frac{y_m}{y_{1i}}, t\right) + v_t \text{-} u_t \qquad 16$$

Since in a distance function context, the Cobb-Douglas functional form has the wrong curvature in the $\frac{y_m}{y_{1i}}$ space, $D_0\left(x_j, \frac{y_m}{y_{1i}}, t\right)$ of the Eqn.16 is, specified with the translog output distance

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1 It is important to mention here that for our result to be consistent with most output-oriented parametric efficiency studies, with technical efficiency bounded between zero and one, the study assumed the value of the output distance function as a direct measure of the technical efficiency which is bounded naturally between zero and one, since $TE_0 \ge 1$ by construction. In this regard, Kumbhakar *et al.,* (2007) referred to the index TE_0 as "natural technical efficiency" since it has the same orientation as the estimated output distance function $D_0\left\{x_j, y_m, t\right\}$ of Eq.11.

2 Equation 14 is simply $\text{In}D_0\left(x_j, y_m, t\right) = -\hat{u}_{\mathbf{t}}^{+}$ in Equ.10 and $0 < D_0\left(x_j, y_m, t\right) \le 1$, which implies that $-\infty < \text{In}D_0\left(x_j, y_m, t\right) \le 0$

3 It is important to mention here that, a transformation of the left LHS of Equa.12 from negative sign to positive sign in Equ.13 reverse the signs of the estimated coefficients corresponding to the usual output distance function.

function, where the presence of squared terms and interaction terms gives a high degree of flexibility , easy calculation and imposition of homogeneity is possible (Brümmer *et al.*, 2002; Brümmer *et al* ., 2006).

Therefore, we defined the translog output distance function as

$$-\text{In}D_0\left(x_j, {}^{y_m}\!/\!_{y_{1i}}, t\right) = \begin{cases} -\alpha_0 - \sum_{m=1}^{M-1}\psi_m \text{Iny}^*_{mit} - \sum_{j=1}^{J}\beta_j \text{Inx}_{jit} - \varphi_T A(t) - \frac{1}{2}\sum_{m=1}^{M-1}\sum_{s=1}^{M-1}\psi_{ms}\text{Iny}^*_{mit}\text{Iny}^*_{sit} \\ -\frac{1}{2}\sum_{j=1}^{J}\sum_{k=1}^{J}\beta_{jk}\text{Inx}_{jit}\text{Inx}_{kit} - \frac{1}{2}\varphi_{TT}A^2(t) - \sum_{m=1}^{M-1}\sum_{j=1}^{J}\tau_{mj}\text{Iny}^*_{mit}\text{Inx}_{jit} \\ -\sum_{m=1}^{M-1}\kappa_{mT}\text{Iny}^*_{mit}A(t) - \sum_{j=1}^{J}\phi_{jT}\text{Inx}_{jit}A(t)_t \end{cases} \quad 17$$

Substituting Eqn.17 into Eqn.16 gives Eqn.18 which is the stochastic frontier "Output distance" function specification used in the present study[4] as

$$\text{Iny}_{1it} = \begin{cases} -\alpha_0 - \sum_{m=1}^{M-1}\psi_m \text{Iny}^*_{mit} - \sum_{j=1}^{J}\beta_j \text{Inx}_{jit} - \varphi_T A(t) - \frac{1}{2}\sum_{m=1}^{M-1}\sum_{s=1}^{M-1}\psi_{ms}\text{Iny}^*_{mit}\text{Iny}^*_{sit} \\ -\frac{1}{2}\sum_{j=1}^{J}\sum_{k=1}^{J}\beta_{jk}\text{Inx}_{jit}\text{Inx}_{kit} - \frac{1}{2}\varphi_{TT}A^2(t) - \sum_{m=1}^{M-1}\sum_{j=1}^{J}\tau_{mj}\text{Iny}^*_{mit}\text{Inx}_{jit} \\ -\sum_{m=1}^{M-1}\kappa_{mT}\text{Iny}^*_{mit}A(t) - \sum_{j=1}^{J}\phi_{jT}\text{Inx}_{jit}A(t) + v_t - u_t \end{cases} \quad 18$$

where $y^*_m = {}^{y_m}\!/\!_{y_1}$ is the normalized output distance function by one of the outputs, which in this regard is y_1, to impose linear homogeneity property. By using linear homogeneity of output distance function, Eqn.17 can be transformed into an estimable regression model (Coelli and Pereman, 2000; Brümmer *et al*, 2002; Coelli *et al.,* 2005; Brümmer *et al.,* 2006).

Furthermore, O'Donnel and Coelli (2005) suggested that certain regularity conditions such as monotonicity (non-decreasing inputs and non-increasing outputs) and curvature (convexity in outputs and quasi-convexity in inputs) properties must theoretically hold for this function (Eqn.18). These conditions however, require the following Euler's restrictions.

Homogenous of order +1 in output restriction ensured that;

[4] We recognize an issue that arises from implanting output distance function models which include; problem of endogeneity bias and problem of which output might be used as normalizing factors. For the former, Coelli and Perelman (2000) argue that this should not present econometric problems because only rations of the outputs appear as regressions and these ratios may be assumed to be exogenous, since the distance function is defined for radial (proportional) expansion of all outputs, given the input levels and hence by definition output ratio are held constant for each firm. The second issue with regard to which output might used as normalizing factor, Coelli and Perelman stressed further that the final results are invariant to this choice.

$$\sum_{m} \psi_m = 1,\ m = 1, 2, \ldots\ldots\ldots M \qquad 19a$$

$$\sum_{\mathbf{s}} \psi_{ms} = 0,\ m = 1, 2, \ldots\ldots\ldots M$$

$$\sum_{\mathbf{j}} \tau_{mj} = 0,\ j = 1, 2, \ldots\ldots\ldots J$$

$$\sum_{m} \kappa_{mT} = 0,\ \ m = 1, 2, \ldots\ldots M$$

The imposition of the Eqn.19a ensures that output distances with respect to the boundary of the production set are measured by radial expansion.

Symmetry restriction ensured that;

$$\beta_{jk} = \beta_{kj},\ k{=}j\ = 1, 2, \ldots\ldots J \qquad 19b$$

$$\psi_{ms} = \psi_{sm},\ m = s = 1, 2, \text{--}M$$

As revealed by O'Donnel and Coelli (2005), the elasticities of the output distance with respect to the inputs and the outputs can be derived using the expression

$$\frac{\partial \mathrm{In} D_0(x,y,t)}{\partial \mathrm{In} x_{\mathbf{j}}} = \left(\beta_j + \sum_{\mathbf{j}=1}^{J} \beta_{jk} \mathrm{In} x_{kit} + \sum_{\mathbf{m}=1}^{\mathbf{M}-1} \tau_{mj} \mathrm{In} y^*_{mit} + \sum_{j=1}^{J} \phi_{jT} A(t) \right) \leq 0 \qquad 20a$$

$$\frac{\partial \mathrm{In} D_0(x,y,t)}{\partial \mathrm{In} y_m} = \left(\psi_m + \sum_{m=1}^{M-1} \psi_{ms} \mathrm{In} y^*_{sit} + \sum_{j=1}^{J} \tau_{mj} \mathrm{In} x_j + \sum_{m=1}^{M-1} \kappa_{mT} A(t) \right) \geq 0 \qquad 20b$$

According to Chamber (1988), production theory suggests that $D_0(x,y,t)$ is non-increasing in ***x*** $\left(\frac{\partial \mathrm{In} D_0(x,y,t)}{\partial \mathrm{In} x_j} \leq 0 \right)$, which is a condition for ensuring monotonicity in the inputs, and non-decreasing in ***y*** $\left(\frac{\partial \mathrm{In} D_0(x,y,t)}{\partial \mathrm{In} y_m} \geq 0 \right)$,which is also a condition for ensuring monotonicity in the outputs.

Chamber (1988) and O'Donnell and Coelli (2005) suggested that fulfilling curvature (i.e., quasi-convex in ***x*** and convex in ***y***) property in accordance with production theory implied that principal minors of bordered Hessian matrix (i.e., the coefficients of square terms of x_j in $D_0(x,y,t)$) must strictly be negative in sign for ***x***. Also for fulfillment of the curvature (i.e., convex) property in ***y***, it is expected that the principal minors of the Hessian matrix (i.e., the square terms of y* in $D_0(x,y,t)$) must strictly be positive in sign.

Because the objective of the study is, not only to estimate the output-oriented technical efficiency TE_0, but rather to, examine in addition how exogenous variables exert influence on the producer performance. In this case, we employed heteroskedasticity corrected inefficiency models proposed by Caudill *et al.,* (1993) to implement this as

$$\sigma_{ui}^2 = q(Z_i, D_i; \alpha_i) \quad 21$$

Also we corrected for the heteroskedasticity in the noise components using the relationship

$$\sigma_{vi}^2 = g(x; \tau_i) \quad 22$$

Equations (18, 21-22) were jointly estimated using the maximum likelihood estimation procedure in STATA10.

2.3. *Scope economies, inputs Substitution and Complementary (biases) effects*

The distance function is not only used to estimate the efficiency levels and the change in productivity, but it is also used to measure inputs substitution and complementary effects on the production process (Grosskopf *et al.,* 1995; Paul *et al.,* 2000).

Using Eqn.18 as an illustration, the *first-order* elasticities ($\varepsilon_{y_m, y_1} = \psi_m$ and $\varepsilon_{x_j, y_1} = \beta_j$) represents the input and the output elasticities contribution to the production of the output y_1, while the *second-order* ($\varepsilon_{y_m y_s, y_1} = \psi_{ms}$ and $\varepsilon_{x_j x_k, y_1} = \beta_{jk}$) elasticities (most especially the cross-effects) reflects complementary/ substitution (biases) effects of the inputs or the outputs jointness in the overall production or productivity.

Intuitively, ε_{x_j, y_1} is similar to the estimates from the parameters of the standard stochastic frontier production function models in y_1-x_j space frontier which indicates the contribution of the input x_j to the output y_1. In a similar way, ε_{y_m, y_1} of the y_1-y_m space frontier indicates a production possibility frontier (PPF) curvature which can be interpreted as the contribution of a change in y_m to productivity or shadow valuation of y_1 in the overall production or productivity (Paul and Nehring, 2005). Grosskopf *et al.,* (1995) defined y_1-y_m space frontier as marginal rate of transformation (MRT) between y_m and y_1 in terms of output production or shares to the overall production.

With regard to the manner with which Eqn.18 is specified, a negative ε_{x_j,y_1} elasticity is interpreted as an indicator of positive returns or the contribution of x_j to the production of y_1 which is consistent with economic theory (see foot note 4)[5]. Also, a positive ε_{y_m,y_1} elasticity implies a negative shadow share contribution of y_m relative to y_1 in the overall production (i.e., MRTS = the slope of PPF)[6].

For the *second-order* condition of cross-effects of the inputs, $\varepsilon_{x_j x_k,y_1} > 0$ implies input complementary effects while $\varepsilon_{x_j x_k,y_1} < 0$ implies input substitution effects between the input $\mathbf{x_j}$ and $\mathbf{x_k}$.

The cross-effect $\varepsilon_{y_m y_s,y_1}$ coefficient indicates that the PPF curvature which could be interpreted as the contribution of a change in $\mathbf{y_s}$ to the productivity or shadow valuation of $\mathbf{y_m}$ relative to its impact on the overall production, weighted by the implicit share or contribution of the production of $\mathbf{y_m}$.

However, various measures described above serve as the basis with which the present study examines the returns-to-scale, the inputs substitution and complementary effects as indicators of resource-productivity in cassava production in Nigeria.

3.0. Methodology

3.1. The Data and Study Area

The data used in this study came from a farm households' survey that was carried out in southwestern Nigeria. Southwestern Nigeria is the second leading cassava producing region in the country with the highest average national yield of about 14 metric tonnes/ha per annum (IITA 2005). The survey covered three farming years: 2006/07 to 08/09[7]. Five states in the region were adequately represented in the survey which includes: Ekiti, Ogun, Ondo, Osun and Oyo states.

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[5] If not computed in absolute value, scope economies otherwise called returns to scale in the traditional stochastic frontier production function equal $-\sum_j \varepsilon_{x_j,y_1}$. Note that the negative sign in the front of the summation is a reflection of the foot note 4.

[6] The shadow share/contribution of y_1 in the overall production/productivity could be obtained by using the homogeneity restriction of Equ.19a as $\varepsilon_{yD_0y_1} = 1 - \sum_m \varepsilon_{y_m,y_1}$

[7] Less than 10% of the farmers were repeatedly sampled within the seasons.

The respondents were randomly sample based on the list of farmers provided by the extension personnel of the states' agricultural development program, ADP. In all 282, 260, and 304 farms were sampled in 2006/07, 2007/08, and 2008/09 farming seasons, respectively. At the state level, 181, 206, 173, 141, and 145 farms were sampled in Ekiti, Ondo, Oyo, Osun, and Ogun states, respectively. An overall 846 observations consisting were used for the analysis in the region.

Food crops grown in the region includes: maize, yam, cassava, cocoyam, potato, melon, cowpea, among others under mixed cropping systems. But in the in the present study, five portfolios of crops were observed grown either solely or mixed by the farmers which include: cassava, yam, maize, cocoyam and potatoes. Detailed descriptions of the data used in the analysis are presented in the table A1 of the appendix.

3.2. *Empirical model*

The stochastic output distance function with two outputs and five inputs and time trend used in the empirical application of Eqn.18 is specified as

$$\mathrm{Iny}_{1it} = \begin{cases} -\alpha_0 - \pi_f D_{fit} - \pi_p D_{pit} - \psi_m \mathrm{In}\left(y_{2it} / y_{1it} \right) - \sum_{j=1}^{J} \beta_j \mathrm{Inx}_{jit} - \varphi_T A(t) \\ -\frac{1}{2}\psi_{mm}\mathrm{In}\left(y_{2it} / y_{1it} \right)^2 - \frac{1}{2}\sum_{j=1}^{J}\sum_{k=1}^{K}\beta_{jk}\mathrm{Inx}_{jit}.\mathrm{Inx}_{kit} - \frac{1}{2}\varphi_{TT}A^2(t) \\ -\sum_{j=1}^{J}\tau_{mj}\mathrm{Inx}_{jit}.\mathrm{In}\left(y_{2it} / y_{1it} \right) - \kappa_{mT}\,\mathrm{In}\left(y_{2it} / y_{1it} \right).A(t) \\ -\sum_{j=1}^{J}\phi_{jT}\mathrm{Inx}_{jit}A(t) - \sum_{s=2}^{6}\eta_s D_{states} - \sum_{n=2}^{3}\xi_n D_{FS} \end{cases} + v_{it} - u_{it} \quad 20$$

where y_{1it} represents value of cassava produced in naira by *i-th* farm at season *t*; y_{2it} is the normalized output which is equal to the "output ratio" of the value of other crops (i.e., maize, yam, cocoyam and sweet potatoes) relative to the value of cassava produced by *i-th* farm at season *t*. x_{jit} represents the *j-th* inputs used by *i-th* farm at season *t*. The inputs included in the model are land (x_1), labour(x_2), fertilizer(x_3) which is equal to $In\left[Max\left(fertilizer, 1-D_f\right)\right]$, pesticide($x_4$) which is equal to $In\left[Max\left(pesticide, 1-D_p\right)\right]$, and cost of planting materials(x_5). D_f is a dummy which has a value of 1 if fertilizer usage is positive and 0 if otherwise, and D_p is a dummy with a value of 1 if pesticide usage is positive and 0 if otherwise.

In an attempt to minimize bias in the coefficient of some of the variables in the equation 20, $In\left[Max\left(fertilizer, 1-D_f\right)\right]$ and $In\left[Max\left(pesticide, 1-D_p\right)\right]$ are included to account for zero usage of these variable inputs in the regression while D_f, *and* D_p account for intercept change (Battese, 1997).

$\mathrm{A}(\mathrm{t})$ represents the time trend which captures technological change. $\mathbf{D}_{\mathbf{states}}$ represents state dummies. This include; D_{ekiti}, D_{ondo}, D_{osun}, and D_{oyo}, which are dummies for Ekiti, Ondo, Osun, and Oyo states, respectively (D_{Ogun} is considered as the base). Seasonal dummies were also included in the production frontier which includes: D_{2008} and D_{2009} for 2007/08 and 2008/09 seasons, respectively (D_{2007} for 2006/07 as the base).

In this study, we assume v_{it} to be independently and identically distributed $N\left(0,\sigma_{vit}^2\right)$ with $\sigma_{vi}^2 = g\left(x;\tau_i\right)$ while u_i is assumed to be independently distributed $N^+\left(0,\sigma_{uit}^2\right)$ with $\sigma_{ui}^2 = \mathrm{q}\left(Z_i, D_i;\alpha_i\right)$.The specification of the heteroskedastic in both v_{it} and u_i are outlined as below.

For the heteroskedastic v_{it}, we include farm size to capture differences in the farm harvest while site specific location variables such as states dummies were included to capture size and location differences across the region. This choice however, is in line with work of Hadri *et al*., (2003) and Loureiro (2009) as

$$\sigma_v{}^2 = \exp\left(\tau_0 + \tau_1 InX_{landit} + \tau_2 D_{ekitit} + \tau_3 D_{ondot} + \tau_4 D_{osunt} + \tau_5 D_{oyot}\right) \qquad 21$$

where $\sigma_v{}^2$ represents the variance of the two-sided error (v_i), $In\mathrm{X}_{ji}$ is the logarithm for land while the state dummies are as indicated by the subscripts.

Following, the traditional technical inefficiency effect model in the literature, variance of the inefficiency error is, modeled as a function of the farmers' socio-economic variables, state and seasonal dummies as

$$\sigma_{\mathbf{u}}{}^2 = \mathbf{exp}\begin{pmatrix} \omega_0 + \alpha_1\mathbf{Z}_{\mathbf{age}} + \alpha_2\mathbf{Z}_{\mathbf{gender}} + \alpha_3\mathbf{Z}_{\mathbf{occupation}} + \alpha_4\mathbf{Z}_{\mathbf{family}} + \alpha_5\mathbf{Z}_{\mathbf{educ}} + \alpha_6\mathbf{Z}_{\mathbf{credit}} + \alpha_7\mathbf{Z}_{\mathbf{exten}} \\ +\alpha_8\mathbf{Z}_{\mathbf{nonfarm}} + \delta_1\mathbf{D}_{\mathbf{ekiti}} + \delta_2\mathbf{D}_{\mathbf{ondot}} + \delta_3\mathbf{D}_{\mathbf{osunt}} + \delta_4\mathbf{D}_{\mathbf{oyot}} + \delta_5\mathbf{D}_{2008} + \delta_6\mathbf{D}_{2009} \end{pmatrix} \qquad 22$$

where $\sigma_u{}^2$ represents the variance of one-sided error term (u_i), Z_{age}: age of the primary decision makers in the study area, $Z_{occupation}$: major occupation dummy of the primary decision makers in the study area (farming =1, 0 otherwise), Z_{gender}: gender dummy of the primary decision makers in the study area (male =1, 0 otherwise), Z_{family} : family size (this represents main family members), Z_{educ}: years of schooling the farmers, Z_{credi} : credit dummy (access =1, 0 otherwise), Z_{exten}: number of contacts with extension agents, $Z_{nonfarm}$,: non farm income dummy (participation=1, 0 otherwise), Z_{index}: crop diversification index. With respect to the states we includes: D_{ekiti}, D_{ondo}, D_{osun}, and D_{oyo}, which are dummies for Ekiti, Ondo, Osun and Oyo states, respectively (D_{Ogun} is considered as the base). Similarly, the states dummies are also included: D_{2008} and D_{2009} for 2007/08 and 2008/09 seasons, respectively and D_{2007} for 2006/07 as the base.

4.0. Results and discussions

4.1. *Results of Hypotheses*

The results of the likelihood ratio tests[8] carried out during the analysis are presented in the table 1. The null hypothesis of homoskedastcity v_i and u_i is rejected as revealed by the second row. The null hypothesis of homoskedasticity v_i with heteroskedasticity u_i is also rejected as shown in the third row. The last hypothesis of homoskedasticity u_i with heteroskedasticity v_i which also doubles as the test of the effect of technical inefficiency is rejected. The implication of this hypothesis is that, there is presence of technical inefficiency effects in the study.

Table 1: Results of Hypotheses

Null Hypotheses	Log likelihood	LR	Critical-value (5%)	Decision
Translog i.e., Full Heteroskedasticity preferred model	-460.14			
H_{01}: $\ell n\,\sigma_v^2 = \ell n\,\sigma_u^2 = const.$ i.e., Homoskedasticity in both v_i & u_i errors	-489.49	58.70	30.14	Reject H_0
H_{23}: $\ell n\,\sigma_v^2 = const$ i.e., Homoskedasticity in v_i error	-468.37	16.46	11.07	Reject H_0
H_{03}: $\ell n\,\sigma_u^2 = const$ i.e., Homoskedasticity in u_i error and No. technical effect	-482.47	44.66	23.69	Reject H_0

4.2. *Resource-Productivity in cassava production in the region*

The result of the maximum likelihood estimates of the elasticities of the output distance function is presented in the table A2 of the appendix while table 2 summarizes the first order (in absolute value) and the cross terms-effects elasticties to ease subsequent interpretation and discussion.

[8] We constructed the likelihood ratio test using the statistics $LR = -2\left[\ell n\left(\mathbf{LH_R} - \mathbf{LH_U}\right)\right]$, where $\mathbf{LH_R}$ is the value of the maximized log-likelihood for the restricted and $\mathbf{LH_U}$ represents that of unrestricted. This statistics follows a χ^2 distribution with $\mathbf{T_R} - \mathbf{T_U}$ denoting the degree of freedom, where $\mathbf{T_R}$ and $\mathbf{T_U}$ represents the number of variables in the restricted and unrestricted samples, respectively.

Before the estimation, the data was normalized at the sample mean, meaning that the *first-order* distance elasticities serve as the partial elasticity (the measure of resource-productivity) of production with respect to the inputs.

However, tables 2 shows that all input elasticities (land, labour, fertilizer, pesticide, and materials) are significantly different from zero and therefore, posses the expected signs at the sample mean. As noted by Brümmer *et al.,* (2002) distance elasticities for a "well-behaved" input must be negative as also revealed by table A2[9]. The implication of this is that estimated elasticities of the output distance function satisfy the property of monotonicity at the sample mean.

Using the homogeneity restriction in the output of Eqn.19a, the share of cassava in the total farm production is computed as 0.3816 which is equivalents to about 38% while the share of other crops stood at about 62% (see the lower panel of table 2). This result however, is consistent with the primary data (see table A1 of the appendix) where "other crops" appear to have a larger share of the total revenue relative to the value of cassava output.

In a related development, the -0.6184 coefficient of "other crops" at the sample mean could as well be interpreted as the slope of the production possibilities frontier, i.e., the marginal rate of transformation (MRT) between other crops and cassava produced relative to output mix. The coefficient is significantly different from zero.

Furthermore, higher distance elasticity with respect to labour (0.686) in absolute value reflects increasing share of this variable with respect to other variable inputs included in the distance function. Meaning that labour is an important variable input in cassava production in the region. This observation is consistent with the finding of Dvorak (1996) that a large share of labour is an indication that labour as a factor of production is generally of overwhelming importance and may take up to 90% of the costs of production in many Africa farming systems. This position is also upheld by Enete *et al.,* (2001) that cassava root yield responds positively to the use of labour in sub-Saharan Africa.

Färe and Primont (1995) shows that the scale elasticity otherwise called returns to scale (RTS) can be calculated as the negative sum of the input elasticities or simply sum of the absolute input elasticities. In this regard, the sum of the absolute input distance elasticities (table 2) gives a

[9] This assertion however, conformed to the present study because of the manner in which Eq.20 is specified (see foot note 4).

measure of the scale of 1.193 (0.068)[10], indicating increasing returns-to-scale in cassava production in the region. The economic interpretation of this is that, a 1% joint increase of the inputs increased the cassava production by about 1.2%. The RTS is significantly different from zero.

The coefficient of time trend which indicates technology change shows that there is a significant evidence of "technical progress" in cassava production in the region. This observation might possibly be due to the availability of improved cassava technologies to the farmers by the International Institute of Tropical Agriculture (IITA), Nigeria and Federal Ministry of Agriculture in Nigeria. These agencies have successfully distributed over 12 varieties of cassava tuber in the country for the past 15 years.

With regard to the violation of the monotonicity in output and inputs at the individual point estimate, we found evidence that 5% of the observation violates monotonicity i.e., $\left(\frac{\partial \ln D_0 (x,y,t)}{\partial \ln y_m} \geq 0 \right)$ in "other crops". For the inputs $\left(\frac{\partial \ln D_0 (x,y,t)}{\partial \ln x_j} \leq 0 \right)$, we found evidence that 3% of the observation violate monotonicity for land while it violates monotonicity for the other factors as follows: labour - 2%, fertilizer - 12%, pesticides - 23% and materials - 27%.

With regard to the curvature, quasi-convexity in inputs ($\boldsymbol{x_j}$) is rejected at the sample means. This is because the principal minors (the square terms of the $\boldsymbol{x_j}$) of the table 2A of the appendix are non-negative with the exception of land and pesticides.

In related development, we found evidence of convexity in the output at the sample mean for the "other crops" in the distance function as the square term of this variable is positive expected *a prior* in the table A2.

The positivity and significance of seasonal dummies is an indication of positive seasonal effects on cassava production in the study.

4.3. *Cross-terms effects (biases) of inputs*

The right panel of table 2 presents the summary result of the cross-term effects of the inputs. We found significant evidence of input complementary effects between land and pesticide, labour

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[10] The figure in parenthesis is the standard error computed by applying the delta formula: $\sqrt{\sum_{j=1}^{5} \left[Var\left(\hat{\beta}_j\right) \left|\hat{\beta}_j\right|^2 \right]}$ (Powell 2007)

and fertilizer, and fertilizer and pesticide. Economic interpretation of is that, joint effects of the pairs of these variables contribute significantly to cassava production in the region.

Also, we found significant evidence of input substitution effects between labour and pesticide. A plausible reason for this observation could be attributed to the high cost of pesticides (as most of the farmers indentified high cost of inputs such as fertilizer and inputs as a major production problem). Such development might force the farmers to substitute labour for pesticides to carryout basic post-planting operations such as weeding on the farms. Supporting this argument from the earlier findings in the study is the fact that labour appears to have the highest share of output distance elasticities while less than 60% of the farms used pesticides.

Table 2: Returns to scale in absolute value and cross-terms effects (biases) of the inputs

Inputs	*first-order* elastcities	Cross-terms effects of the inputs (*second -order* elastcities)			
		$\varepsilon_{x2,y1}$	$\varepsilon_{x3,y1}$	$\varepsilon_{x4,y1}$	$\varepsilon_{x5,y1}$
[a]Cassava $_{y1}$	**-0.3816**				
Other crops$_{y2}$	**-0.6184*** **				
Land$_{x1}$	0.1776**	0.0641	-0.0113	**0.1786*****	-0.0275
Labour$_{x2}$	0.6858***		**0.1005***	**-0.2056*** **	0.0324
Fertilizer$_{x3}$	0.1608***			**0.0368***	-0.0682
Pesticide$_{x4}$	0.1520***				-0.0083
Materials$_{x5}$	0.0169*				
[b]RTS	**1.1931**				

[b]$\varepsilon_{D0,y1}$=1- ε_{y2D0y1}; [b]RTS =$\sum \varepsilon_{xjy1}$; ***, **,* *denotes statistical significance at the 1%, 5%, and 10%, levels respectively.*

The result of the heteroskedasticity in the white noise v_i (table A2) shows that land size as well as dummies for Ekiti, and Osun states decreased the variance of the white noise while dummies for the Ondo and the Oyo states increased the variance of the noise. However, only land, dummies for Ekiti and Ondo states significantly different from zero.

4.4. *Technical inefficiency effect*

The result of the heteroskedasticity inefficiency error terms which double also as the technical inefficiency effects shows that gender, family size, occupation, education, extension, and credit decreased the variance of inefficiency (i.e., enhanced technical efficiency) of the cassava farmers in the sample. Only occupation (i.e., farming), credit, and extension were significantly different from zero. Also, age and non-farm income were found to increase the variance of the technical efficiency of the farmers. None of these variables were significantly different from zero.

The result of the state dummies shows that the Ekiti and the Oyo states dummies significantly decreased technical efficiency of cassava farmers in the region in reference to the Ogun state dummies. The coefficients of seasonal dummies shows that the technical inefficiency of the farmers in 2007/08 and 2008/09 farming seasons decreased significantly with reference to the 2006/2007 farming season.

4.5. *Technical efficiency*

Presented in table 3 is the deciles distribution of the estimated output-oriented technical efficiency scores by seasons as well as the pooled estimates. Figure A1 in the appendix on the other hand shows the density distribution of the pooled technical efficiency scores. The result shows that, the technical efficiency of the pooled sample ranged between 0.0921 to 0.9323 with an average efficiency of 0.7214 which implies a technical inefficiency level of 38.619% $\left(\frac{1 - 0.7214}{0.7214} \text{ x } 100\right)$. The economic interpretation of this is that, an average cassava farm in the region requires about 39% more resources to produce the same output (or meet the same objectives) as an efficient cassava farm on the frontier. The bottom line is that, there is still room for improvement in the cassava production in the country.

This observation however, attests to the poor performance of the cassava industry in the country despite being the largest harvest in the world. Presently, the average National yield of 8.8 tonnes/ha is far below the expected average of 25 tonnes/ha and 16.6 tonnes/ha in Barbados (Spore 2005).

The density plot helps shed more light on the distribution of the efficiency scores in the sample. The distribution shows that a large mass of the efficiency scores are distributed between 0.65 - 0.85 as also indicated in the fourth column of table 3.

Also, presented in the table 3 is the result of the technical efficiency by seasons. An average efficiency score of 0.665, 0.741 and 0.757 was obtained for 2006/07, 2007/08, 2008/09 farming seasons, respectively. A Cuzick's nonparametric test for trend across ordered groups with "*nptrend efficiency, by (seasons)*" command in STATA10 displays a **z** score of 6.74 and p-value of 0.000. The implication of this is that, there is significance evidence of increased trend in technical efficiency from 2006/07-2008/09[11,12].

Furthermore, the cumulative distribution function, CDF (Figure 3) offers an understanding on whether distribution of the seasonal efficiency scores is, robust across the sample. From the figure, it seems the 2008/09 CDF and 2007/08 CDF lie almost side by side while 2008/09 CDF is slightly located on the right side of 2007/08. The close proximity of 2008/09 CDF to 2007/08 could be attributed to marginal differences between the average efficiency scores (see Table 3).

From the figure, the 2008/09 CDF is located on the right hand side of the 2006/07 farming season while the 2007/08 CDF is located on the right side of that of the 2006/07 farming season. Since none of the distribution crosses each other, it suggest that the CDFs can be classified as first-stochastic dominance with the distribution of the technical efficiency for the 2008/09 farming season dominating the other two seasons as the distribution of the technical efficiency of 2007/08 farming season dominates the 2006/07 farming season.

A comparative analysis of the average technical efficiency obtained from the present study with previous efficiency studies with a focus on the Nigerian cassava industry is discussed as follows. The average score in the present study is higher than 66%, 61%, and 56% obtained by Adeleke *et al.,* (2008), Bamire *et al.,* (2004) and Ohajanya (2005), respectively while this is below 74% and 77% obtained by Udo and Etim (2007) and Iheke (2008), respectively[13].

The result of the efficiency score by states shows that Ogun state recorded the highest efficiency of 0.744. This however, is followed by Osun state: 0.742, Ondo state: 0.718, Oyo state: 0.717 and Ekiti: 0.695. With an exception of Ogun and Osun states, the results of the other states are barely different from each other at the sample mean.

[11] Supporting this observation also is the subscript a and b below table 3 which shows that at the sample mean, there is evidence of significant increase in the average efficiency score from the 2006/07-2008/08 farming seasons.

[12] A possible driver of the significance improvement in the technical efficiency could be linked to the earlier result of the positive impact of extension services on the technical efficiency. This is because accessibility to extension facilitates adjustment towards the technology prospect.

[13] It is important to stress here that these studies used the standard stochastic frontier production function

Table 3: Deciles Distribution of the technical efficiency

Range	2006/07		2007/08		2008/09		Pooled	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
0.00-0.10	1	0.35	0	0	0	0	1	0.12
0.11-0.20	6	2.13	0	0	1	0.33	7	0.83
0.21-0.30	9	3.19	3	1.15	4	1.32	16	1.89
0.31-0.40	12	4.26	4	1.54	6	1.97	22	2.60
0.41-0.50	23	8.16	2	0.77	13	4.28	38	4.49
0.51-0.60	29	10.28	14	5.38	18	5.92	61	7.21
0.61-0.70	55	19.50	41	15.77	37	12.17	133	15.72
0.71-0.80	76	26.95	96	36.92	86	28.29	258	30.50
0.81-0.90	65	23.05	95	36.54	129	42.43	289	34.16
0.91-1.00	6	2.13	5	1.92	10	3.29	21	2.16
Total	282	100	260	100	304		846	100
Mean	0.6645		0.7414[a]		0.7572[a,b]		0.7214	
Std.Dev.	0.1829		0.1404		0.1202		0.1549	
Min.	0.0921		0.1490		0.1917		0.0921	
Max.	0.9287		0.9252		0.9323		0.9323	

[a]Significant increase in this mean score compared to that of 2006/07; [b]Significant increase in this mean score compared to that of 2007/08.

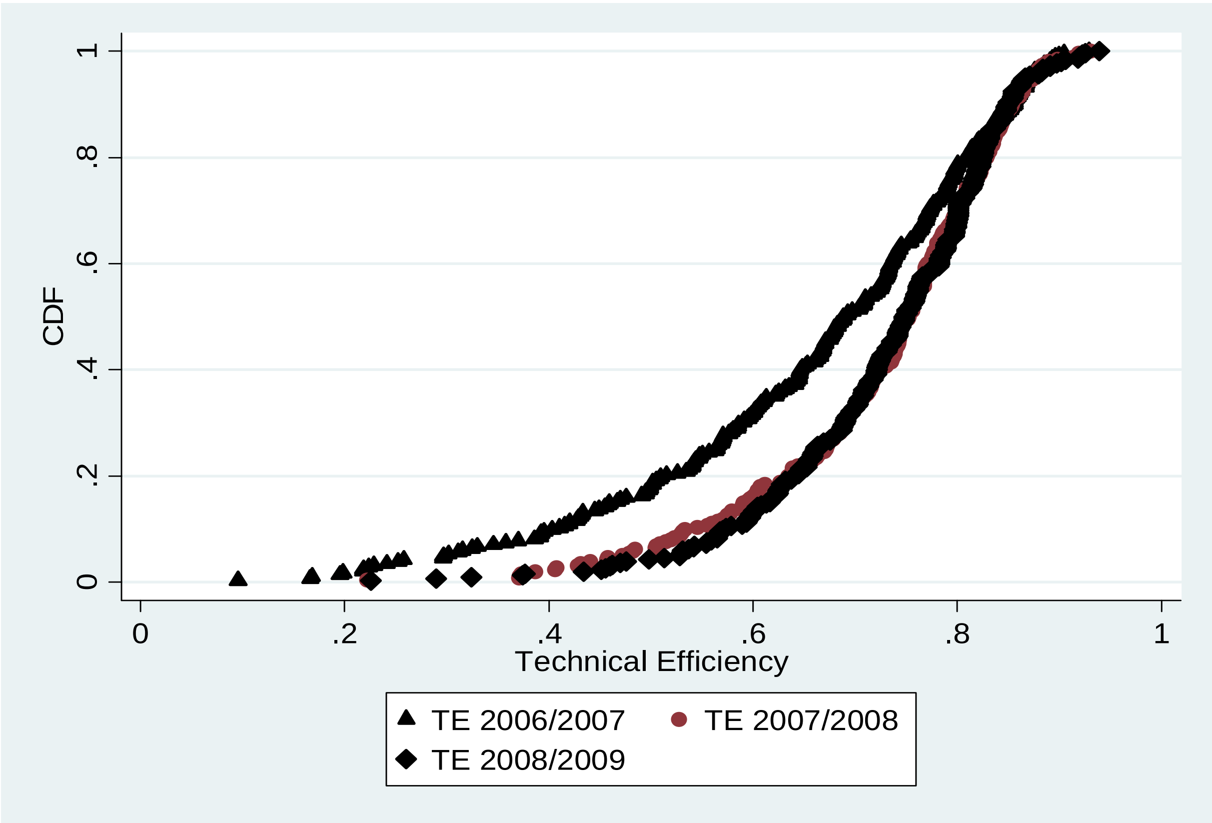

Figure 5.3: *Cumulative Distribution Function of the estimated Technical Efficiency scores by seasons; Kolmogorov-Smirnov test of equality-of-distributions indicates that the estimated seasonal technical efficiency scores do not have the same distributions with p-value of 0.073, 0.000, and 0.000 between 2007/08& 2008/09, 2006/07& 2007/08, and 2006/07& 2008/09, respectively.*

5.0. Conclusions

This paper estimate technical efficiency, inputs substitution and complementary effects using an output distance function with a focus on cassava farms in southwestern Nigeria. The study employed unbalanced panel data covering the 2006/07 to 2008/09 farming seasons with a total of 846 observations.

The results show that the marginal rate of transformation (MRT) between "other crops" grown by the farmers and cassava produced relative to the output mix is negative and significantly different from zero. Furthermore, the result of the partial elasticity of production with respect to the inputs shows that, farm size, labour, fertilizer, pesticides, and materials monotonicitly increased cassava production in the region. Similarly, we found evidence of increasing returns-to-scale as well as technical progress in cassava production in the sample.

The cross-term effects of the inputs indicate evidence of significant complementary effects between inputs which includes: farm size and pesticides, labour and fertilizer, fertilizer and pesticides on cassava production in the region. Also, there is evidence of significant substitution effects between labour and pesticides.

The result of the efficiency scores shows an average score of about 72% which implies that an inefficiency level of about 39% is observed from the study. This however, indicates ample room for improvement in cassava production in the country. Also, we found evidence of increasing trend in the technical efficiency from 2006/07 to 2008/09 farming seasons.

Extension, credit and occupation (i.e., farming) were policy variables increasing efficiency of the farmers in the sample.

Finally, the study suggests intensification of policies that will enhance technology transfer via effective and reliable extension services and farmer's access to credit as well as incentives that will encourage and increase the number of full time farmers entering cassava production. Such policies and incentives will provide the needed impetus to upwardly shift the frontier of cassava production in Nigeria from the present position.

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Appendix

Table A1: Summary statistics of variables in the regression

Variables	Description	Mean	Std. Dev.	Min.	Max
Total value cassava[a]	Total Revenue from cassava in Naira	780.425	708.319	0	6,282.276
Total value of Other crops[b]	Total Revenue from other crops[e] in Naira	1,731.318	1,939.93	0	11,777.9
Land	Total size of the farm in hectare	2.318	1.651	1	8.6
Labour	Total family and hired labour in manday	250.265	128.449	38	647
Fertilizer	Total quantity of fertilizer used in kilogram	219.81	135.595	0	1650
Pesticide[c]	Total quantity of pesticide used in litre	0.975	1.378	0	10
Materials[d]	Total costs of planting materials incurred in Naira	34,755.16	19,359.74	6,200	262,855
Time trend	2006/07=0,2007/08=1 and 2008/09=2	1.026	0.832	0	2
$D_{fertilizer}$	Equal to 1 if fertilizer usage is positive; 0 otherwise	0.728	0.445	0	1
$D_{pesticide}$	Equal to 1 if pesticide usage is positive; 0 otherwise	0.521	0.500	0	1
Age	Age of the primary decision maker in years	51.304	10.745	25	76
Gender	Equal to 1 if the primary decision maker is male	0.715	0.452	0	1
Household size	Total number of households members	5.382	2.369	0	15
Occupation	Equal to 1 if farming is major occupation	0.779	0.415	0	1
Education	Total years of schooling of the decision makers	9.515	5.371	0	16
Extension	Total number of contacts with extension agents	6.746	3.660	0	19
Credit	Equal to 1 if access to credit; 0 otherwise	0.667	0.471	0	1
Off-farm income	Equal to 1 if participated in non-farm income	0.387	0.487	0	1
State & Seasons Dummies					
D_{ekiti}	Equal to 1 if the farms are from Ekiti state	0.214	0.410	0	1
D_{ondo}	Equal to 1 if the farms are from Ondostate	0.243	0.429	0	1
D_{osun}	Equal to 1 if the farms are from Osun state	0.167	0.373	0	1
D_{oyo}	Equal to 1 if the farms are from Oyo state	0.204	0.404	0	1
$D_{2007/08}$	Equal to 1 if its 2007/08 farming season	0.333	0.471	0	1
$D_{2008/09}$	Equal to 1 if its 2008/09 farming season	0.359	0.480	0	1

[a,b] the total value of these items have been deflated by the 2008 consumer price index of 179.80 naira for food; [c]pesticide is expressed as weighted cost of herbicides and insecticides divided by the sum of their respective (Tornquist) price indices; [d]materials is the total costs of planting materials which include the cost of seeds, cuttings, and tubers planted by the farmers. [e]The other crops include aggregated total revenue from yam, maize, potato and cocoyam.

Table A2: Maximum Likelihood Estimates of the Stochastic Distance frontier model[a]

Variables	Parameters	Estimates	Std. Dev.	P-value
D_Fertilizer	π_1	0.2249***	0.0404	0.000
D_Pesticide	π_2	-0.0558**	0.0289	0.054
In Othercrops (y_2/y_1)	ψ_m	0.6184***	0.0370	0.000
In Land(x_1)	β_1	-0.1776**	0.0797	0.045
In Labour (x_2)	β_2	-0.6858***	0.0567	0.000
In Fertilizer (x_3)	β_3	-0.1608***	0.0457	0.000
In Pesticide(x_4)	β_4	-0.1520***	0.0472	0.001
In Materials (x_5)	β_5	-0.0169*	0.0091	0.083
Time trend	φ_T	-0.0471**	0.0023	0.036
0.5(In Other crops)^2	ψ_{mm}	0.0926***	0.0331	0.005
0.5(In Land x_1)^2	β_{11}	-0.2881***	0.0915	0.002
0.5(InLabour x_2)^2	β_{22}	0.1651*	0.0900	0.067
0.5(In Fertilizer x_3)^2	β_{33}	0.2517***	0.0931	0.007
0.5(In Pesticide x_4)^2	β_{44}	-0.1108	0.0555	0.842
0.5(In Materials x_5)^2	β_{55}	0.0542	0.0377	0.150
0.5(Time trend)^2	φ_{TT}	0.1272***	0.0322	0.000
In(Other crops) x In(Land x_1)	τ_{m1}	-0.0982**	0.0479	0.041
In(Other crops) x In(Labour x_2)	τ_{m2}	0.0629	0.0475	0.185
In(Other crops) x In(Fertilizer x_3)	τ_{m3}	0.1023***	0.0395	0.010
In(Other crops) x In(Pesticide x_4)	τ_{m4}	0.1145***	0.0388	0.003
In(Other crops) x In(Materials x_5)	τ_{m5}	-0.0651***	0.0249	0.009
In(Other crops) x Time trend	τ_{mT}	0.0641***	0.0233	0.006
In(Land x_1)x In(Labour x_2)	β_{12}	0.0642	0.0766	0.403
In(Land x_1)x In(Fertilizer x_3)	β_{13}	-0.0113	0.0743	0.879
In(Land x_1)x In(Pesticide x_4)	β_{14}	0.1786***	0.0642	0.005
In(Land x_1)x In(Materials x_5)	β_{15}	-0.0275	0.0418	0.510
In(Labour x_2)x In(Fertilizer x_3)	β_{23}	0.1005*	0.0561	0.086
In(Labour x_2)x In(Pesticide x_4)	β_{24}	-0.2056***	0.0747	0.006
In(Labour x_2)x In(Materials x_5)	β_{25}	0.0324	0.0426	0.446
In(Fertilizer x_3)x In(Pesticide x_4)	β_{34}	0.0368*	0.0186	0.052
In(Fertilizer x_3)x In(Materials x_5)	β_{35}	-0.0682	0.0490	0.281
In(Pesticide x_4)x In(Materials x_5)	β_{45}	-0.0083	0.0304	0.786
In(Land x_1)x Time trend	Φ_{1T}	0.0633	0.0403	0.116
In(Labour x_2)x Time trend	Φ_{2T}	-0.1565***	0.0409	0.000
In(Fertilizer x_3)x Time trend	Φ_{3T}	-0.0048	0.0376	0.899
In(Pesticide x_4)x Time trend	Φ_{4T}	0.0481	0.0361	0.183
In (Materials x_5) x In(Time trend)	Φ_{5T}	0.0006	0.0220	0.979
D_2008	Ξ_1	0.1275***	0.0539	0.018
D_2009	Ξ_2	0.1076**	0.0540	0.046
Constant	α_0	-0.1859***	0.0541	0.001
Variance of v_i				
InLand x_1	τ_1	-1.1474***	0.3785	0.002
D_Ekiti	τ_2	-0.4142**	0.2069	0.045
D_Ondo	τ_3	0.0841**	0.0430	0.051
D_Osun	τ_4	-0.2453	0.2995	0.412
D_Oyo	τ_5	0.1991	0.1324	0.133
Constant	τ_0	-2.2355***	0.1946	0.000
Variance of u_i				
Age	α_1	0.0062	0.0076	0.419
Gender	α_2	-0.1312	0.1475	0.374
Family Size	α_3	-0.0253	0.0338	0.455
Major Occupation	α_4	-0.3147*	0.1650	0.057
Education	α_5	-0.0116	0.0129	0.369
Extension	α_6	-0.0484*	0.0261	0.064
Off-farm income	α_7	0.0701	0.1367	0.608
Credit	α_8	-0.3805***	0.1479	0.010
D_Ekiti	δ_1	0.3878*	0.2235	0.083
D_Ondo	δ_2	0.2688	0.2317	0.246
D_Osun	δ_3	0.1486	0.2634	0.573
D_Oyo	δ_4	0.5753**	0.2654	0.030
D_2008	δ_5	-0.6199***	0.2009	0.002
D_2009	δ_6	-0.8474***	0.2150	0.000
Constant	ω_0	-0.4429**	0.1944	0.023
Average TE= 0.7214				

****, **,* denotes statistical significance at 1%, 5%, and 10% levels, respectively.*

Note: Because of non-significance of the coefficients of state dummies in the production frontier, these variables were not presented in the table to maximize the space.

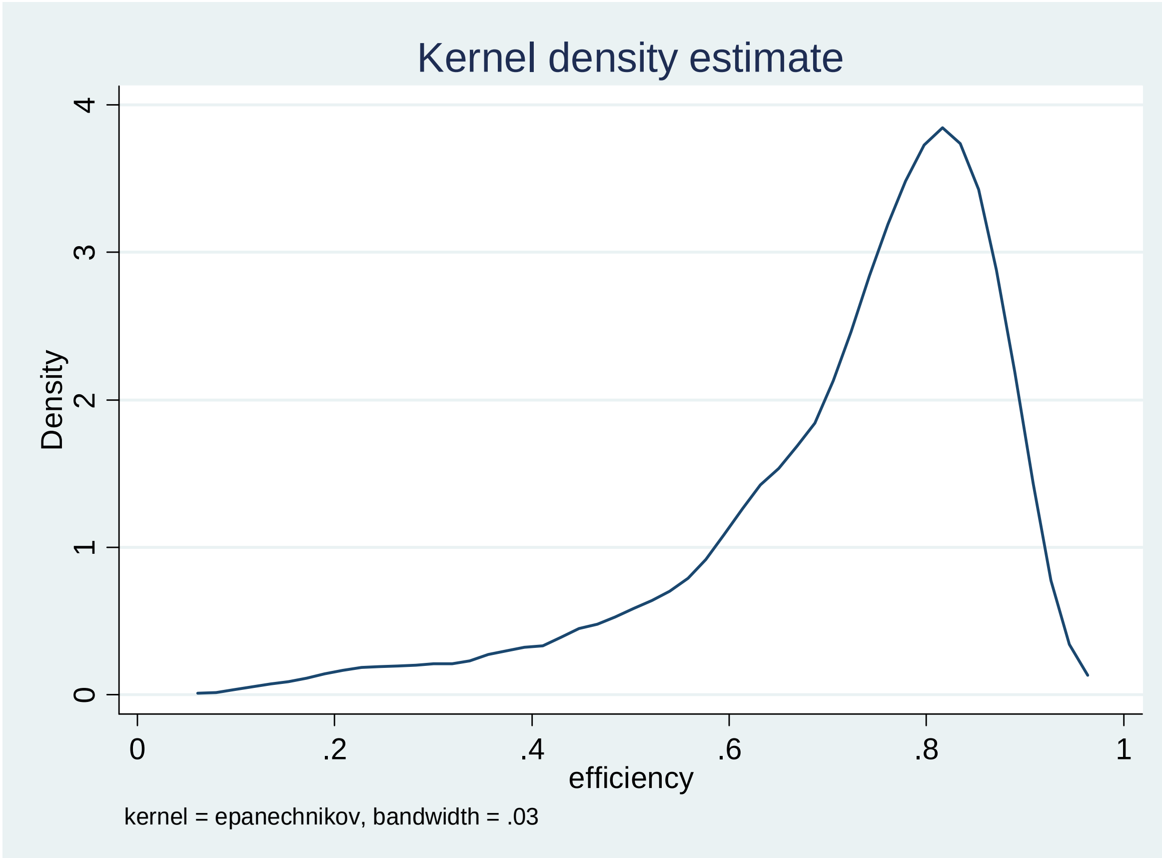

Figure A1: *Density distribution of the estimated technical efficiency*