International Journal of Development and Sustainability
ISSN: 2168-8662 – www.isdsnet.com/ijds
Volume 3 Number 7 (2014): Pages 1538-1548
ISDS Article ID: IJDS14051201

Estimating technical efficiency and the metatechnology ratio using the metafrontier approach for cropping systems in Kebbi State,Nigeria

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Abstract

The study applied a metafrontier model, which is developed based on the idea that different groups of cropping systems use different technology set. The analysis is applied to the meta-cost efficiency of 98 monocroppers and 158 intercroppers. The results reveal that based on the metatechnology ratio, millet/cowpea group were more technically efficient followed by the sorghum/cowpea group. The sorghum groups were less technically efficient. This suggests that crop diversification in order to manage risk sources has the potential of improving crop productivity in Kebbi State. Crop combinations, however, prove to play an important role. Care should be taken to select the optimal combination of crops to include in the intercropping system.

Keywords: Cropping systems; Data envelopment analysis; Metafrontier; Metatechnology ratio.

Cite this article as: Jirgi, A.J., Grové, B., Jordaan, H., Viljoen, M.F. and Nmadu, J.N. (2014), "Estimating technical efficiency and the metatechnology ratio using the metafrontier approach for cropping systems in Kebbi State,Nigeria", *International Journal of Development and Sustainability*, Vol. 3 No. 7, pp. 1538-1548.

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1. Introduction

The two main cropping systems practiced in Nigeria are mono and intercropping system. The cropping systems considered in this study are practiced under rain-fed conditions. Generally intercropping involves the growing of rain-fed crops in mixtures, using available resources and permits farmers to maintain low but often adequate and relatively steady production. Monocropping generates vast amounts of corporate wealth, gives higher yields, is more efficient than intercropping, provides jobs, and gives higher economic returns (Nelson, 2006; Mmom 2009). The question is; can this type of system provide sufficient food to the ever increasing population in Nigeria and other parts of sub-Saharan Africa? Farmers in northern Nigeria practice both monocropping and intercropping. Intercropping is practiced as a means of diversification to safeguard against risk associated with agricultural production. The question of which cropping system is better in terms of technical efficiency in the context of monocropping and intercropping systems in Nigeria has not yet been answered. Should farmers continue with the monocropping system which gives high production yield in the short term; or continue with intercropping which gives low but often adequate and relatively steady production over the longer term? The increase in productivity in any of the systems will depend on how efficient resources are utilized by the farmers.

Research on the comparison of efficiencies in agriculture is scanty. The research that compared the efficiency of technologies used the highest average DEA score to indicate the decision making units (DMU) that are more efficient (Binici et al., 2006; Alene et al., 2006). Frey et al. (2012) argued that such comparison is inappropriate because high efficiency scores among a group of DMUs only gives a measure of relative homogeneity among the efficiency of the DMUs. Battese (2004) introduced the use of Metatechnology ratio (MTR) to compare efficiencies between different groups. The MTR is a more reliable approach of comparing efficiencies of different groups of enterprises.

The objective of the study is to compare the efficiencies of the monocrop and intercropping systems in order to know which technology is better and to know whether the technologies have equal efficiency.

2. Methodology

2.1. Sampling technique and data collection

A multi-stage sampling technique was used to select 256 farmers comprising of 98 monocrop farmers and 158 intercrop farmers. The reason for the sample size chosen is that there are more intercrop farmers than monocrop farmers in the State. In the first stage, the four agricultural zones were purposively selected in order to have a good representation of all the agro-ecological zones in the State. The second stage involved a random selection of two Local Government Areas (LGAs) from each of the four agricultural zones. In the third stage, four villages were randomly selected from each of the two LGAs. The fourth stage involved the random selection of the 98 monocrop farmers and the 158 intercrop farmers. Since the population of the LGAs is not homogeneous, the number of farmers selected from each of the selected LGAs was calculated using the formula:

$$P = \frac{S}{N} \times n$$

where, P = Proportion, S= Desired sample size, N= Total population, n= Population of LGA in question.

The survey was carried out in January to February, 2012; data were collected on production practices for the 2011 cropping season. The household heads were interviewed by the researcher and the trained enumerators. Data were collected on farmer's inputs, outputs and their prices.

2.2. Estimation procedure for the technical efficiency metafrontier

The objective of the study is to compare the technical efficiency of the mono and intercrop farms in order to know the differences between metafrontier and the group frontier. Following O'Donnell et al. (2008) the metafrontier production function was used to achieve this objective.

2.3. The basic analytical framework

The production theory and the concept of distance function form the basis of the efficiency measurement. O'Donnell et al. (2008) defined the metafrontier and group frontiers in terms of output sets and output distance functions.

2.4. The metafrontier

Let y and x be non-negative real output and input vectors of dimension M x1 and N x1, respectively. The *metatechnologyset* contains all input-output combinations that are technologically feasible. Then,

$$T = \{(x, y) : x \geq 0; y \geq 0; \ x \text{ can produce } \ y\} \quad (1)$$

The *metatechnologyset* is associated with input and output sets. The output set is defined for any input vector, x, given by:

$$P(x) = \{y : (x, y) \in T\} \quad (2)$$

The boundary of this output set is referred to as the output *metafrontier*. The output set is assumed to satisfy the standard regularity properties described by Färe and Primont (1995). When measuring efficiency, the technology using the output *metadistance* function, is defined as:

$$D(x, y) = \inf_{\theta}\{\theta > 0 : (y/\theta) \in P(x)\} \quad (3)$$

Given an input vector, this function gives the maximum amount by which a farm can radially expand its output vector. The distance function inherits its regularity properties from the regularity properties of the output set. An observation (x, y) can be considered technically efficient with respect to the metafrontier if and only if $D(x, y) = 1$.

2.5. Group frontier

Consider the case where the universe of the farms can be divided into $h(>1)$ groups, and suppose that a certain group is constrained by resources, regulatory and other environmental factors which may prevent the farms from choosing the full range of technologically feasible input-output combinations in the metatechnology set, T. Rather, the input-output combinations available to farms in the h^{th} group are contained in the group-specific technology set:

$$T^h = \{(x, y) : x \geq 0; y \geq 0; x \text{ can be used by farms in group } h \text{ to produce, } y\} \quad (4)$$

The H group-specific technologies can also be represented by the following group-specific output sets and output distance functions:

$$P^h(x) = \{y : (x, y) \in T^h\},\ h = 1,2,\ldots,H; \quad (5)$$

$$D^k(x, y) = \inf_\theta\{\theta > 0 : (y/\theta) \in P^h(x)\},\ h = 1,2,\ldots,H \quad (6)$$

The boundaries of the group-specific output sets are referred to as *group frontiers*. If the output sets, $P^h(x), h = 1,2,\ldots,H$, satisfy standard regularity properties then the distance functions, $D^h(x, y), h = 1,2,\ldots,H$, also satisfy standard regularity properties. For details of the standard regularity properties refer to O'Donnell et al. (2008) and Färe and Primont (1995).

2.6. Technical efficiencies and metatechnology ratios

An observation (x, y) is technically efficient with respect to the metafrontier if and only if $D(x, y) = 1$. Generally, an output orientated measure of technical efficiency of an observed pair (x, y) with respect to the metatechnology is represented by:

$$TE(x, y) = D(x, y) \quad (7)$$

Since the group-h output distance function, $D^h(x, y)$, can take a value no less than the output metadistance function, $D(x, y)$. In another way, the metafrontier envelops the group-h frontier. Whenever a strict inequality is observed between the group-h distance function and the metadistance function, we can obtain a measure of how close the group-h frontier is to the metafrontier. Specifically, the output-orientated *metatechnology ratio*[1] (MTR) for group-h farm is defined as:

$$MTR^{h}(x,y)=\frac{D(x,y)}{D^{h}(x,y)}=\frac{TE(x,y)}{TE^{h}(x,y)} \tag{8}$$

In this study the groups comprise of the sorghum farms (monocrop), sorghum/cowpea and millet/cowpea (intercrops).

The decomposition of the technical efficiency of a particular input-output combination is provided by equation 9:

$$TE(x,y)=TE^{k}(x,y)\times MTR^{h}(x,y) \tag{9}$$

Equation 9 shows that technical efficiency measured with reference to the metafrontier (representing the existing state of knowledge) can be decomposed into the product of technical efficiency measured with reference to the group-h frontier (representing the existing state of knowledge and the physical, social and economic environment that characterise group-h (which measures how close the group-h frontier is to the metafrontier).

2.7. Data Envelopment Analysis for the technical efficiency

For the DEA technical efficiency metatechnology frontier comparison, the estimates were done normally without using the bootstrapping approach. The DEA is a linear programming methodology that uses data on output and inputs of groups.

Using the input orientated and assuming constant returns to scale, the DEA problem is given by:

$$\begin{aligned} &\min_{\lambda x_i} \theta \\ &\text{Subject to } -q_i + Q\lambda \geq 0, \\ &\theta_{X_i} - X\lambda \geq 0, \\ &\lambda \geq 0, \end{aligned} \tag{10}$$

where, θ is a scalar and λ is a $I \times 1$vector of constants. $N \times 1$ input matrix X, $M \times 1$ output matrix, Q, q_i and x_i are the column vector of output and input respectively. The value of θ obtained is the efficiency score for the i*th*farm. The value satisfies; $\theta \leq 1$, with a value of 1 indicating a point on the frontier and hence a technical efficient firm (Coelli et al., 2005). Note that the linear programming problem must be solved I times, once for each farm in the sample. A value of θ is then obtained for each farm.

For each group-*h* the above linear programming is solved L_h times for each DMU. The metafrontier is constructed using DEA model based on the pooled data for all the cropping systems in the study area. Since there are a total of $L=\sum_h L_h$ cropping systems, the above equation 9 will be re-run with the inputs and outputs matrices with data for all the cropping systems in the Kebbi State. The outputs for the intercroppers

[1]Battese et al. (2004, p.94) refer to this measure as the “technology gap ratio”. However, increases in the (technology gap) ratio imply decreases in the gap between the group frontier and the metafrontier. In this study the “metatechnology ratio” is used.

were converted to their monetary value i.e. the farm income. The inputs used were labour, nitrogen, phosphorus and potassium as indicated previously. The variable seed was omitted because the conversion of seed to its monetary values will not be appropriate for use in the cost function (Data Envelopment Programme (DEAP), since the programme will not run when the input value is also the same as the input price. The DEAP 2.1 was used to obtain both the technical efficiency scores.

2.8. Wilcoxon Rank-Sum Test

In order to test for the differences in the technical efficiency and cost efficiency of the monocroppers and intercroppers, the Wilcoxon Rank-Sum Tests was used. The Mann-Whitney test is essentially identical to the Wilcoxon test even though it uses a different test statistic. Wilcoxon Rank-Sum test is a nonparametric statistical test based on the ranking of data (Copper et al., 2006). Wilcoxon tries to detect if there are local shifts in the distribution of the population of sample A to B. For small samples, independent groups, Wilcoxon for $n_1 \geq 10$ and $n_2 \geq 10$ is given by:

Test statistic:

$$Z = \frac{T_A - n_1(n_1 + n_2 + 1)/2}{\sqrt{n_1 n_2 (n_1 + n_2 + 1)/12}} \quad (11)$$

where, T_A is sum ranking.

The rejection region: one-tailed $Z > Z_\alpha$, two-tailed $|Z| > Z_{\alpha/2}$. Comparing the $Z-$statistic to $Z-$ value is equivalent to comparing the $P-$value to α .

3. Results and discussion

3.1. Comparison between the technical efficiency of the monocroppers and intercroppers metatechnology ratio (MTR), in Kebbi State

The comparison between metatechnology ratio of the technical efficiency of monocroppers and intercroppers was done for the purpose of comparing the technical efficiency for the different groups of cropping systems in Kebbi State; the results are presented in Table 1.

For metatechnology ratio (MTR); a higher value implies a smaller technology gap between the group frontier and the metafrontier. A value of 100% is equivalent to a point where the group frontier is equal to the metafrontier.

The results for the sorghum, sorghum/cowpea and millet/cowpea groups shows that on average, sorghum farmers produce output under the conditions that are more restrictive than the sorghum and millet/cowpea group. The average (MTR) for sorghum group (0.79) implies that the sorghum group could at best; produce 79% of the output that could be produced using the (unrestricted) metatechnology. Sorghum group has 0.79 MTR compared to the sorghum/cowpea and millet/cowpea groups who have MTR of 0.87

and 0.89. The high value of the MTR for millet/cowpea group suggests that the group is closest to the metafrontier. Sorghum farmers can borrow technology from millet/cowpea and/or sorghum/cowpea group.

Table 1. Data Envelopment Analysis estimates of technical efficiency and metatechnology ratios of the monocroppers and intercroppers, Kebbi State, January 2012

Enterprise group	Mean	SD	Minimum	Maximum
Technical efficiency with respect to the (DEA-h) group frontiers				
Sorghum	0.59	0.18	0.27	1
Sorghum/cowpea	0.52	0.17	0.18	1
Millet/cowpea	0.7	0.19	0.31	1
Metatechnology ratio (DEA-MTR)				
Sorghum	0.79	0.13	0.55	1
Sorghum/cowpea	0.87	0.08	0.66	1
Millet/cowpea	0.89	0.07	0.66	1
Technical efficiency with respect to the metafrontier (DEA-MF)				
Sorghum	0.46	0.16	0.21	1
Sorghum/cowpea	0.45	0.14	0.15	1
Millet/cowpea	0.62	0.16	0.28	1

DEA-h: Deta Envelopment Analysis for group, DEA-MTR: Data Envelopment Analysis for Metatechnology Ratio and DEA-MF: Data Envelopment Analysis for Metafrontier.

The high value of the MTR for the millet/cowpea group could be due to the fact that millet/cowpea cropping system (intercropping) under small holder setting is often superior to monocropping, because the former lends itself to better disease control, better use of available labour, reduced risk from natural calamities and better monetary income than monocropping (Beuerlien, 2001; Banik and Sharma, 2009). Palitza (2010) pointed out that the negative consequences of climate change can be addressed by increasing crop diversity (and a move away from monocropping) to diminish the risk of crop failure through intercropping. These advantages of the millet/cowpea intercropping system could have contributed to the high efficiency

The relatively low average MTR for sorghum group could be because the cropping system is associated with soil depletion and erosion, plant disease epidemics of enhanced severity, increased use of pesticides and nutrients and vulnerability to climate change (Saleem et al., 2000; Nelson 2006; Iyegha, 2000). These disadvantages of monocropping could have contributed to the lower technical efficiency of the sorghum group.

The variation in the DEA metafrontier (DEA-MF) of the three groups of cropping system suggests that there is a scope for increasing the technical efficiency in the cropping systems in Kebbi State. The maximum values of 1 for the DEA-MF show that there must have been at least one DMU that used an input-output combination that placed it at the point of tangency between their group frontier and the metafrontier[2].

Comparison of efficiency across different cropping systems is to ascertain the relevance of catching-up, i.e. of productivity gains attainable by increasing technical efficiency (Battese et al., 2004; O'Donnell et al., 2008; Moreira and Bravo-Ureta, 2010). The result from this study reveals that the sorghum and sorghum/cowpea groups can improve their technology by learning from the prevailing agricultural practices of the millet/cowpea group who are operating close to the metafrontier.

3.2. Comparison of the DEA technical efficiency metafrontier (MF) scores of the monocroppers and intercroppers using Wilcoxon Rank-Sum Test

Table 2 presents the Wilcoxon Rank-Sum Test for the differences between the metafrontier scores of the sorghum and sorghum/cowpea farmers.

Table 2. Wilcoxon Rank-Sum Test for the differences between the technical efficiency metafrontier scores of the sorghum and sorghum/cowpea farmers, Kebbi State, January 2012

Enterprise			**Ranks**	
	Count	**Wilcoxon sum rank**	**Mean of Wilcoxon**	**STD DEV of Wilcoxon**
Sorghum MF	42	2553	2436	172
Sorghum/cowpea MF	73	4117	4234	172
Ties	13			
Z	0.68			
P value	0.49			

The Wilcoxon Rank-Sum Test, which is used to test for the differences between technical efficiency metafrontier scores of the sorghum and sorghum/cowpea farmers, is not significant. The result shows that there is no statistical significant difference between sorghum and sorghum/cowpea farmers' technical efficiency metafrontier scores. Based on the average technical efficiency metafrontier scores of the sorghum (0.46) and sorghum/cowpea (0.45) farmers (Table 6.7), the sorghum farmers have the same efficiency in the utilisation of farm inputs as their counterpart sorghum/cowpea farmers. However the results suggest that there is opportunity for both groups of farmers to improve their technical efficiencies.

[2] Since the metafrontier and group frontiers are formed as the intersection of several hyperplanes, there is at least one DMU in the groups who operated at a point where the hyperplane of their group frontier touched a hyperplane of the metafrontier (O'Donnell *et al*., 2008).

Table 3. Wilcoxon Rank-Sum Test for the differences between the technical efficiency metafrontier scores of the sorghum and millet/cowpea farmers, Kebbi State, January 2012

Enterprise			Ranks	
	Count	**Wilcoxon sum rank**	**Mean of Wilcoxon**	**STD DEV of Wilcoxon**
Sorghum MF	42	1526	2268	157
Millet/cowpea MF	65	4252	3510	157
Ties	7			
Z	-4.73			
P value	0.00			

The results in Table 3 shows that the technical efficiency metafrontier scores for sorghum (monocrop) and millet/cowpea (intercrop), is significant Z = -4.73, P<0.01. This implies that there is statistical significant difference between the technical efficiency metafrontier scores of sorghum (monocrop) and their counterpart millet/cowpea (intercrop). The two groups have different technical efficiency metafrontier scores. The mean technical efficiency metafrontier scores for the sorghum and millet/cowpea is 0.46 and 0.62 respectively (Table 1). The results suggest that the millet/cowpea farmers are better in terms of resource utilisation than their counterpart sorghum farmers. The possible reason why the millet/cowpea farmer is better in terms of technical efficiency could be that the intercrop requires less fertiliser because cowpeas fix nitrogen into the soil and the crops are less exposed to infestation of pests and disease (Beuerlien, 2001; Banik and Sharma, 2009). Particularly, millet is drought tolerant, suffers less from pests and diseases than sorghum, maize and wheat NRC (1996), de Rouw (2004) and de Rouw and Winkel (1998).

4. Conclusion

Based on the levels of the technical efficiency of the two cropping systems in the study area, both mono and intercropping systems seem to have the potentials of improving crop production in Kebbi State. The result from this study reveals that the sorghum and sorghum/cowpea groups can improve their technology by learning from the prevailing agricultural practices of the millet/cowpea group who are operating close to the metafrontier. Policies towards enhancing farmer's performance should be promulgated.

Acknowledgements

The authors acknowledge the contribution of the Tertiary Education Trust Fund (TETFund) and Federal University of Technology Minna, Niger State, Nigeria for funding the research.

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