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ECONOMETRICS | RESEARCH ARTICLE

Differentials in technical efficiency among smallholder cassava farmers in Central Madagascar: A Cobb Douglas stochastic frontier production approach

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Abstract: This study employed the Cobb–Douglas stochastic frontier production function to measure the level of technical efficiency among smallholder cassava farmers in Central Madagascar. A multi-stage random sampling technique was used to select 180 cassava farmers in the region and from this sample, input–output data were obtained using the cost route approach. The parameters of the stochastic frontier production function were estimated using the maximum likelihood method. The results of the analysis showed that individual farm-level technical efficiency was about 79%. The study found education, gender and age to be indirectly and significantly related to technical efficiency at a 1% level of probability, and to household size at a 5% level. The coefficient for occupational status was positive and highly significant at a 1% level. The results show that the study’s cassava farmers are not fully technically efficient, showing a mean score of .79%, and suggesting that opportunities still exist for increasing efficiency among the farmers. There is a need, therefore, to ensure that these farmers have access to the appropriate inputs, especially land



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PUBLIC INTEREST STATEMENT

The results of this study reveal that technical efficiency in cassava production in Central Madagascar is relatively high. Although individual levels of technical efficiency range between 24 and 94% with a mean of 79%, it suggests that opportunities still exist for increased productivity of cassava farmers in the zone by increasing the efficiency with which resources are used at the farm level. Important factors indirectly related to technical efficiency are age, education, gender, household size and occupational status. Occupational status had a direct relationship with technical efficiency. The agricultural labour force is female dominated but ageing drastically with educated farmers diverting skills to non-farm livelihoods. Women play a significant role in cassava production in the study area. Therefore, policies designed to improve women access to land, fertilizer, credit, agricultural extension, new technologies and more education will be crucial in increasing technical efficiency.

and capital. The results also call for land reform policies to be introduced, aimed at making more land available, especially to the younger and full-time female farmers.

Subjects: Behavioral Sciences; Economics, Finance, Business & Industry; Environment & Agriculture

Keywords: technical efficiency; cassava; Madagascar

1. Introduction

Cassava (*Manihot esculenta* Crantz) is an important staple food and cash crop in several tropical African countries, where it plays a principal role in the food economy (Agwu & Anyaeche, 2007). Madagascar ranks 19th in terms of the production of cassava worldwide, with a share of 1.10% of the market, based on a total production figure of 3.11 m metric tonnes. The average farm size in the country is 4,750 ha and the average productivity, 6.55 t/ha (FAO Statistics, 2013).

Over 500 million people live on cassava throughout the world, eating its roots or tubers due to its high energy content, and also its leaves which are an abundant source of protein and both vitamins A and B (Kormawa, Tshiunza, Dixon, Udoh, & Okoruwa, 2001 and Tchabana, 2002). Cassava has the potential to become a key cash crop in many African countries (Qirschot, Ngendello, & Westby, 2004). In Madagascar, cassava is cultivated in virtually all regions; however, production levels are poor, taking into account the high demand for the product at local markets and the requirements of a variety of processing industries.

Cassava could be a powerful weapon in the fight against poverty in Africa, as the cash income derived from the crop is more egalitarian than other major staple crops due to its low cash input levels (Nweke, 2004). Compared to other major staples, cassava performs well across a wide range of ecological systems, and as a result, can benefit a broader range of farmers, those living across different zones. Cassava is also less expensive to grow, as it tolerates poor soil, adverse weather conditions and pests and diseases, more than other major staples (Nweke, 2004). The crop generates an income and provides food for the most vulnerable segments of Madagascan society. Cassava stores its harvestable portion underground until it is needed; therefore, it is also a classic food security crop (Asogwa, Umeh, & Ater, 2006).

Technical efficiency refers to the ability of firms to employ the best practices in their production processes, so that not more than the necessary amount of a given set of inputs is used in producing the “best” level of output (Carlsson, 1972). Olayide and Heady (1982) defined technical efficiency as the measure of a firm’s success in producing maximum output from a given set of inputs.

Farm efficiency, and the question of how to measure it, is an important subject within the agricultural sectors of developing countries (Hazarika & Subramanian, 1999; Shah, 1995). There are four major approaches to the measurement of efficiency (Coelli, Rao, & Battese, 1998): the non-parametric programming approach (Charnes, Cooper, & Rhodes, 1978), the parametric programming approach (Aigner & Chu, 1968; Ali & Chaudhry, 1990), the deterministic statistical approach (Afriat, 1972; Fleming, Fleming, Rodgers, Griffiten, & Johnston, 2004; Schippers, 2000) and the stochastic frontier approach (Aigner, Lovell, & Schmidt, 1977; Kirkley, Squires, & Strand, 1995). Among these, the stochastic frontier and non-parametric programming techniques known as data envelopment analysis (DEA) are the most popular approaches. The stochastic frontier approach is preferred when assessing agricultural efficiency because of the inherent stochasticity involved (Coelli, 1994; Ezeh, 2004).

Frontier efficiency studies over the last three decades have received attention among researchers and policy analysts, as evidenced by the proliferation of the methodology and its application across the globe (Thiam, Bravo-Ureta, & Rivas, 2001). Recent empirical findings by Thiam et al. (2001), Bravo-Ureta et al. (2007) and Ogundari and Brümmer (2011) have shown that mean efficiency

estimates of agricultural production reported in the primary studies vary across study attributes (or dimensions) such as methodology, data type, model specification and location. Given this, it will be interesting to understand what the literature reveals about the trends in agricultural efficiency levels in Africa and what drives these levels of efficiency over time. Such an understanding will provide an important input to agricultural policy decisions in the region

Given the various cassava programmes and policies implemented over the years to raise farmers' efficiency and productivity, it has become imperative to empirically analyse the relationship between technical efficiency and socio-economic variables among cassava farmers. Such an analysis will further guide policy-makers in developing policies aimed at improving the welfare of cassava farmers, and such an improvement will give them the potential to expand their cassava production activities. Thus, the broad objective of this study is to analyse the technical efficiency of Malagasy cassava farmers, so as to guide food security policy developments.

2. Methodology

2.1. The study area

Agriculture in Madagascar is heavily influenced by rainfall, which is generally abundant along the east coast, but decreases sharply across the highlands, falling to less than 500 mm per year in the south and south-west. The growing season starts with the first rains in October or November. The cropping calendar varies a lot from region to region according to the different climatic conditions, soils and altitudes. Food crop production is the most important agricultural sub-sector, accounting for around 75% of the cultivated area. Rice is the most common staple food grown, covering as it does 1.34 million hectares throughout the country—with the exception of some semi-arid areas in the south and south-west which use rain-fed and irrigated systems. Other food crops grown include maize (mainly grown in the south and central-east regions), cassava, sorghum (in the south), beans, groundnut, sweet potatoes and a wide variety of vegetables. Nonetheless, the risk-coping strategies used by farmers in the country, including the use of cassava as an energy-giving food, are insufficient to make the farmers food secure (Parikh & Shah, 1995; Ramaroson Rakotosamimanana, Arvisenet, & Valentin, 2014), and cassava farmers—similar to other farmers—suffer significant losses due to cyclones.

2.2. Sampling procedure

This participatory research study involved 180 farmers living across 12 rural communes selected from 6 districts: Moramanga, Betafo, Ambalavao, Soavinandriana, Analamanga and Vakinankara. The districts are located along the western coast, near to the Mozambique Channel, and along the transverse section of the country, through the central region and over to the eastern coast (Figure 1).

A multi-stage random sampling technique was used for the study. Primary data were collected with the aid of a well-structured questionnaire. Cassava collectors and agriculture service agents were interviewed and yield measurements were taken from the farmers' fields.

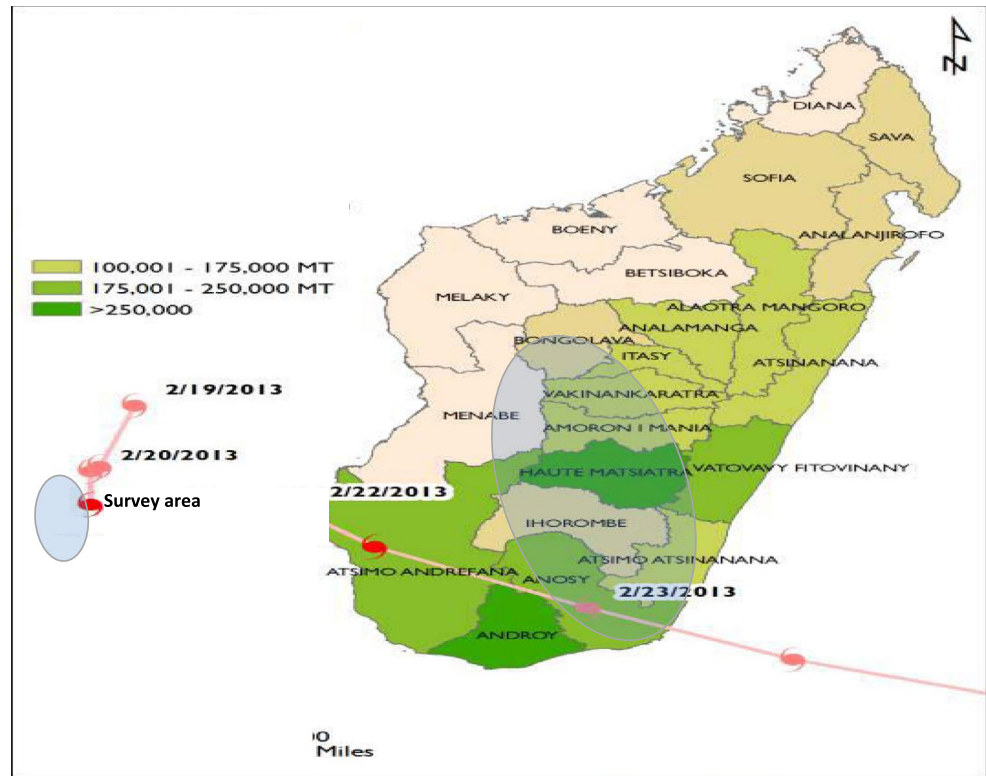
2.3. Specification of the stochastic frontier

A stochastic frontier production function is defined by:

$$Y_i = f(X_i; \beta) \exp(V_i - U_i), \quad i = 1, 2 \dots n \quad (1)$$

where Y_i —output of the i th farm, X_i —vector of input quantities used by the i th farm, β —vector of unknown parameters to be estimated, $f()$ —an appropriate function (e.g. Cobb–Douglas, translog, etc.), V_i —symmetric error, which accounts for random variations in output due to factors beyond the control of the farmer, e.g. weather, disease outbreaks and measurements errors and U_i —a non-negative random variable representing inefficiency in production relative to the stochastic frontier. The random error V_i is assumed to be independently and identically distributed as $N(0, \sigma^2)$ random variables independent of the U_i s, which are assumed to be a non-negative truncation of the $N(0, \sigma^2)$ distribution (i.e. half-normal distribution) or have an exponential distribution.

Figure 1. Map of Madagascar showing the survey locations.



This stochastic frontier model was independently proposed by Aigner et al. (1977) and Meeusen and Van den Broeck (1977). The major advantage of this method is that it provides numerical measures of technical efficiency. The technical efficiency of an individual farmer is defined in terms of the ratio of the observed output to the corresponding frontier output, given the available technology.

Technical efficiency of production for the i th farm at the t th observation is defined by equation (2), following Battese and Coelli (1995)

$$TE_i = Y_i/Y_i^* \exp(-U_i) = \exp(-Z_i\beta - W_i) \quad (2)$$

where Y_i —Observed output and Y_i^* —Frontier output.

The parameters of the stochastic frontier production function are estimated using the maximum likelihood method. The prediction of the technical efficiencies is based on its conditional expectation, given the model assumptions. This result is also given in the appendix of Battese and Coelli (1993).

2.4. Analytical framework

For this study, the production technology of cassava farmers in Central Madagascar is assumed to be specified by the Cobb–Douglas frontier production function, which is defined as follows:

$$\ln Y_i = b_0 + b_1 \ln X_1 + b_2 \ln X_2 + b_3 \ln X_3 + b_4 \ln X_4 + b_5 \ln X_5 + (v_i - u_i) \quad (3)$$

where Y —cassava output in kg, X_1 —labour (man days), X_2 —organic manure (kg), X_3 —Planting materials (bundles), X_4 —farm size (ha), X_5 —capital input in Ariari made up of depreciation charges on farm tools and equipment, interest on borrowed capital and rent on land, b_0, b_1, \dots, b_5 are estimated regression parameters, while v_i and u_i are as defined earlier.

In addition, u_i is assumed in this study to follow a half-normal distribution, as is the case in most frontier production literature.

2.5. Determinants of technical efficiency

Identifying the determinants of efficiency is a major task within efficiency analysis. In order to determine factors contributing to the observed technical efficiency of cassava production in the study area, the following model was formulated and estimated jointly with the stochastic frontier model in a single-stage maximum likelihood estimation procedure, and using the computer software Frontier Version 4.1 (Coelli, 1996).

$$TE_i = a_0 + a_1Z_1 + a_2Z_2 + a_3Z_3 + a_4Z_4 + a_5Z_5 + a_6Z_6 + a_7Z_7 + a_8Z_8 \quad (4)$$

where TE_i —technical efficiency of the i th farmer, Z_1 —gender (dummy variable; 1 = male, 0 = female), Z_2 —age (years), Z_3 —educational level (years), Z_4 —occupational status (dummy variable; 1 = full-time farmer, 0 = part-time farmer), Z_5 —household size, Z_6 —membership of farmer organizations (dummy variable; 1 = yes, 0 = no), Z_7 —farm size (ha), Z_8 —farming experience (years) and $a_0, a_1, a_2, \dots, a_8$ are estimated regression parameters.

We expect a_3, a_4, a_5, a_6, a_7 and a_8 to be positive, and a_1 and a_2 to be negative.

3. Results and discussion

3.1. Average statistics for cassava farmers in Madagascar

The averaged statistics for the sample cassava farmers are presented in Table 1. On average, a typical cassava farmer in Madagascar is 46.05 years old, spends 6 years in education and has 12 years farming experience. The average household size for such farmers is six people. The average cassava farmer cultivates .27 ha, uses about 268.89 kg of organic fertilizer and generates an output of about 2.7t of cassava. Table 1 also shows that an average cassava farmer in the region employs 420.03 mandays of labour, and has 13 years farming experience. Cassava production in the region is dominated by the use of female labour (56.05), the majority (73.88%) of whom work full-time. Only 16.32% of farmers have membership of farmer organizations.

3.2. Estimated production function

The maximum likelihood estimates using Cobb–Douglas stochastic frontier parameters for cassava are presented in Table 2. The coefficients for labour and organic fertilizer were negative and significant at 1 and 5% levels of probability, respectively. Planting materials was significant at a 10% level. These results imply that that any increase in labour, organic fertilizer and planting material would decrease output by .9748, .1515 and .9163%, respectively. This is in contrast to a priori expectations, probably due to the inefficient use of these inputs. The coefficients for farm size and capital inputs were positive and significant at a 1% level of probability. This implies that any increase in farm size and capital inputs would increase output by .4726 and .3576%, respectively. This is expected and in accordance with a priori expectations.

The estimated variance (σ^2) was statistically significant at a 1% level, indicating goodness of fit with the Cobb–Douglas Stochastic Frontier Model. The gamma (γ) was .5501 and significant at 1% level, indicating that only 55.01% of total variation in cassava output was due to technical inefficiency.

3.3. Sources of technical efficiency

The estimated determinants for the technical efficiency of cassava production activities are presented in Table 2. The coefficient for gender was negative and highly significant at a 1% level of probability. This implies that female cassava farmers are more technically efficient than their male counterparts, in line with the findings of Quisumbing (1996). However, women may be constrained by cultural factors from playing a more active economic role, plus they tend to have a lower level of education and technical development, resulting in lower input levels on the plots they farmed. This

Table 1. Statistics for Cassava Farmers in Central Madagascar

Variable	Mean	Std. deviation	Min	Max
Output (t/ha)	2.7	1.8	.06	12.3
Labour (MD)	420.03	224.94	182.00	1456.00
Organic fertilizer (kg)	268.89	230.99	10.00	1000.00
Planting materials (bundles)	92.45	164.42	10.00	160.00
Farm size (ha)	.27	.12	.10	8.00
Age (years)	46.05	13.54	19.00	87.00
Education (years)	6.26	3.25	.00	19.00
Household size	5.67	3.44	1.00	50.00
Farming experience	12.71	8.23	2.00	62.15
Gender (% males)	43.95			
Membership of farmer organizations	16.32			
Occupational status	73.88			

Source: Field Survey, 2011.

results in lower yields and casts doubt on Pareto efficiency assumptions (Adam, Wallace, & Scot, 2003).

The coefficient for age was also found to be negative and highly significant at a 1% level. This implies that an increase in age leads to a decrease in technical efficiency; that younger farmers are more technically efficient than their more elderly counterparts. This is because older farmers are less energetic, leading to lower productivity and lower technical efficiency levels. This result is in line with the findings of Mathijs and Vranken (2000), Bozoğlu and Ceyhan (2007), Ajibefun and Daramola (2003) and Ajibefun and Aderinola (2004).

The coefficient for education level was negative and highly significant to a 1% level. This shows that uneducated farmers are more technically efficient than their educated counterparts. This is not expected and is in contrast to the a priori expectation. The reason for this unexpected outcome is probably that the more educated farmers tend to work part-time on their farms and have other livelihood options. Simonyan, Umoren and Okoye (2011) suggested that for women, there is a strong competing effect in terms of diverting skills to off-farm employment opportunities as their education level increases.

The coefficient for occupational status was positive and highly significant at a 1% level. This implies that the full-time farmers are more technically efficient than their part-time counterparts. The productive effects of having an off-farm income (part-time farmers) are difficult to explain theoretically, but having off-farm incomes could imply that less time is spent on the farm, and so resources are used less efficiently (Tipi, Yildiz, Nargeleçekenler, & Çetin, 2009).

The coefficient for household size was negative and significant at a 5% level, indicating that large households will have lower technical efficiency levels. This is in contrast with a priori expectations, probably because with large households, a farmer may have to divert revenue away from farm activities towards looking after the children.

The coefficients for membership of farmer organizations and farm size were negative, but not significant. The coefficient for farming experience was positive but also not significant.

The frequency distributions for technical efficiency are presented in Table 3. Individual technical efficiency indices ranged from 24 to 94%, with a mean of 79%. In total, 35.56% of the cassava

Table 2. Estimated Cobb–Douglas Stochastic Frontier Production Function for Smallholder Cassava Farmers in Central Madagascar

Variables	Parameters	Coefficient	Std error	t-value
Constant term	b_0	4.3462	.3392	12.8098***
Labour	b_1	-.9748	.1245	-7.8236***
Organic manure	b_2	-.1515	.0609	-2.4854**
Planting materials	b_3	-.9163	.4880	-1.8775*
Farm size	b_4	.4726	.4737	9.9771***
Capital inputs	b_5	.3576	.0406	8.7919***
<i>Efficiency factors</i>				
Constant term	a_0	4.6047	.6688	6.8849
Gender	a_1	-3.6321	1.2298	-2.9532***
Age	a_2	-.1365	.0238	-5.7205***
Education	a_3	-.5051	.6427	-7.8599***
Occupational status	a_4	1.6408	.2718	6.0355***
Household size	a_5	-6.5406	2.5771	-2.537**
Membership of farmer organizations	a_6	-.4456	1.5935	-.2796
Farm size	a_7	-1.4644	6.7206	-.2179
Farming Experience	a_8	5.3595	5.4818	.9783
<i>Diagnostic statistics</i>				
Total variance (Sigma)	σ^2	.4596	.0552	8.3262***
Variance ratio (gamma)	γ	.5501	.0330	16.6552***
LR Test		71.8256		
Log likelihood function		-286.4442		

Source: Computed from frontier 4.1 MLE results/t-values marked

***Significant at 1.0% level.

**Significant at 5.0% level.

*Significant at 10.0% level.

Table 3. Frequency Distribution and Technical Efficiency Indices

Technical efficiency indices	Frequency	Percentage
<.41	8	4.44
.41-.50	12	6.67
.51-.60	31	17.22
.61-.70	23	12.77
.71-.80	42	23.33
>.80	64	35.56
Total	180	100.00
Max	.94	
Min	.24	
Mean	.79	

Source: Field Survey, 2011.

farmers were found to have technical efficiency indices greater than 80%. These technical efficiency levels are consistent with the low variance in farm effects found.

The estimates also show that if an average cassava farmer were to become the most technically efficient farmer in the sample, he or she would experience cost savings of 22.34% (1 - .79/.94). The least technically efficient farmers would also have to increase efficiency by 80.85% (1 - .24/.94).

4. Conclusion

This study has analysed the determinants of technical efficiency among smallholder cassava farmers in Central Madagascar. The results show that these cassava farmers are not fully technically efficient. Individual levels of technical efficiency were found to be in the range .24–.94%, with a mean of .79%, suggesting that opportunities still exist for cassava farmers in the country to increase their efficiency levels by improving the ways in which resources are used at the farm level. The study found that the most important factors indirectly related to technical efficiency levels are age, education, gender, household size and occupational status. Occupational status in particular has a direct relationship with technical efficiency. These results call for policies to be introduced aimed at encouraging young people who are agile and stronger than their older counterparts to enter the cassava-growing sector. The study also found that technical efficiency levels could be further increased by improving cassava farmers' access to inputs such as land and capital, especially among female, full-time farmers.

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