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Technical Efficiency of Small Scale Maize Production inMasaiti District, Zambia: A Stochastic Frontier Approach

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Abstract

Maize is a major staple food crop of Zambia dominantly produced by smallholder farmers. This paper examines technical efficiency of smallholder maize farmers in Zambia. Data were collected using a structured questionnaire administrated to 100 randomly selected smallholder maize farmers in Masaiti district in Zambia. The data were analyzed using descriptive statistics and a stochastic frontier production function approach. The estimated stochastic frontier Cobb-Douglas production function showed that maize land size and fertilizer were the significant factors that affected maize production. The efficiency analysis results indicated that farm level technical efficiency ranged between 52.2% and 93.2% with a mean of 79.6%. This indicates that overall, there is potential to increase maize production among smallholder farmers in the study area by 20.4% through efficient use of present technology. The results of the inefficiency model indicate that age of farmer, cooperative membership which implies access to fertilizer, and farm size, have significant positive effects of efficiency. The seed types used, rotation practices, and education level of the farmer had negative effects on technical efficiency. The policy implications are that to improve farm efficiency efforts should focus on access to improved inputs such as certified seed and fertilizer), information on agronomic practices, and farmer's education.

Keywords: technical efficiency, stochastic production frontier, smallholder, maize, Zambia.

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1. Introduction

The agricultural sector in Zambia is vital to the economy for incomes, employment and food security. In 2011 the sector accounted for 20% of Zambia's gross domestic product and 9 percent of total exports (World Bank, 2013). The sector is the largest employer in Zambia, absorbing some two-thirds of the labor force, making it the main source of income and employment for the majority of Zambians in rural and peri-urban areas. Attainment of food security in Zambia has been constrained by low agricultural productivity of smallholder maize farming. Since independence the Zambian government has made many attempts to improve productivity of smallholder agriculture in the country. For maize this has involved the development of high yielding varieties, subsidization of improved seed varieties and fertilizer, credit provision, liberalization of agricultural product prices and produce marketing, including encouraging private sector participation in agricultural marketing.

Despite the various past efforts, food security continues to be a challenge in Zambia as is the situation in a number of Sub-Saharan African countries. This is so because of low and stagnant agricultural productivity growth associated with major crops like maize which are predominantly produced by smallholder farmers under rain-fed conditions. Maize yield for example during 2000 to 2010, fluctuated between 1,037 Kg/ha and 2,250kg/ha (FAOSTAT, 2012) with no clear upward trend in yield per hectare. Total maize production had a similar trend to maize yield, with production varying between the lowest amount of 600,000 tonnes in 2002 and highest amount of 2,500,000 metric tonnes in 2010 (FAOSTAT, 2012). The wider fluctuations of maize yield and total production, reveals a presence of food insecurity over time, particularly in years of low production even when the country had favorable weather conditions. The low maize productivity and production in Zambia has been attributed to many factors, including: vulnerability to climate change; poor road infrastructure; inadequate access of support services and low maize productivity (see Jayne et al., 2006 Hanjra and Calus (2011), MACO (2006) and Chizuni (1994).

The less than optimal performance of the agricultural sector implies that a need exists for studies to examine efficiency of agricultural production in Zambia particularly the smallholder maize farming sector since it involves the majority of Zambian farmers and for food security reasons. One key to increasing food production in Zambia lies in raising agricultural productivity by improving technical efficiency of resource use in agriculture. Efficiency concerns relative performance of the processes used in transforming given input into output (Otieno et al., 2012).

Economic theory identifies three measures of efficiency, namely allocative, economic and technical efficiency

(Boris et al., 1997. The allocative efficiency (AE) reflects the ability of the farm to use inputs in optimum proportions given their respective prices and the production technology. Economic efficiency (EE) is defined as the capacity of a firm to produce a predetermined quantity of output at minimum cost for a given level of technology. Technical efficiency (TE) is the measure of the farm's success in producing maximum output from a given set of inputs. It is also referred to as the ability to operate on the production frontier or isoquant frontier (Effiong and Onyenweaku, 2006).

Measuring efficiency is vital because it can guide resource utilization and may lead to considerable resource savings, which have important implications for both policy formulation and farm management (Bravo-Ureta and Riegler, 1991). There are few existing empirical studies that have examined the productive efficiency of smallholder farmers in the Zambian agricultural sector. The few Zambian studies include: Mwape (1988) on relative economic and allocative efficiency of emergent and commercial maize farms; Kabwe (2012) who assessed technical, allocative and economic efficiency of smallholder maize producers in the Chongwe district and Chiona (2012)who studied technical and allocative efficiency of smallholder maize farmers. Thus, this study contributes to the analysis of the technical efficiency of maize production among smallholder farmers using data from another district in Zambia and identifies the factors influencing efficiency of smallholder maize farmers. The study used the stochastic production frontier approach to analyze efficiency of smallholder maize farming in the study area.

2. Methodology

2.1 Sampling and data collection

Data for this study were collected from smallholder maize farming households in Kafubu farm block in Masaiti district on the Copperbelt province in Zambia. Geographically, Masaiti district is located approximately 35 kilometers South West of Ndola town and30 kilometers South East of Luanshya town. The district and the province are found in agro-ecological region III of Zambia, which is a high rainfall zone, with 1000-1500mm of annual rainfall. There is tropical climate with two distinct seasons; the rainy season (late October- April) and the dry season (May to September). The region has good potential for the production of maize, sweet potatoes, cassava, sorghum, beans and groundnuts and vegetables. Agriculture is the main occupation of the people in the area. The farm block consists of the land demarcated into smaller farm plots and occupied by settlers most of whom are retirees from the copper mines.

The data for the study were collected using a structured questionnaire administered to a sample of 100 smallholder maize farmers comprising 50 members and 50 non-members of a local cooperative for purposes of accessing the Farmer Input Support Program (FISP). Masaiti has four areas and 25 farmers (i.e. 12 non-members and 13 cooperative members) were randomly selected for the interview in each area. Information collected include socio-economic aspects, farm characteristics, cropping pattern, data on maize production including farm size, labor input, fertilizer quantity, seed type and quantity, and maize output. The data collected covered cropping season 2009/2010 and should be noted that 2009/2010 cropping season was a normal agricultural year in the study area and the country in general.

2.2 Theoretical framework

The stochastic frontier production method was adopted to estimate the technical efficiency of small scale maize production in the study area. This model is appropriate because agricultural production in general exhibits shocks, and hence there is a need to separate the influence of stochastic variables (random shocks and measurement errors) from resulting estimates of technical inefficiency (Battese, 1992). The stochastic production frontier was independently proposed by Aigner et al., (1977) and Mueesen and Broeck (1977). The stochastic frontier model can be generally represented as:

$$Y_i = f(X_i;B) \exp (V_i - U_i) \quad \text{where } i = 1, 2,\ldots,n \qquad (1)$$

Where:

Y_i = output of the i^{th} farm

X_i = Vector of input quantities used by the i^{th} farm

B = Vector parameters to be estimated

V_i- U_i = Composite error term.

Vi denotes the random error not under the control of the famers, assumed to be independently and identically distributed as N $(0, \sigma_u^2)$, independent of U, which is the non-negative random variable associated with technical inefficiency and is identically and independently distributed as a truncated normal, with truncations at zero of the normal distribution (Battese and Coelli, 1995).

The technical efficiency (TE) of an individual farm is defined in terms of the ratio of the observed output (Yi) to the corresponding frontier output (Y*), conditioned on the level of inputs used by the farm and mathematically expressed as:

$$TE = Yi/Yi^* \qquad (2)$$

$$TE= f(X_i;B) \exp (V_i - U_i) \ / \ f(X_i;B) \exp (V_i) \qquad (3)$$

$$TE = \exp(-Ui) \quad (4)$$

Any farmer who is fully technically efficient will have a value of one and farmers with values lying between zero and below one are said to be technically inefficient. The frontier production function is estimated by the Maximum Likelihood technique which yields estimators for $\beta$and γ, where

$\gamma = \sigma_u^2/\sigma^2and\sigma^2 = \sigma_u^2 + \sigma_v^2$.

The parameter γ represents total variation of output from the frontier that is attributed to technical inefficiency and it lies between zero and one, thatis $0 \leq \gamma \leq 1$.

Battese and Coelli (1995), proposed a model in which the technical inefficiency effects in a stochastic production frontier are a function of other explanatory variables. The technical inefficiency model, Ui is defined as:

$$U_i = \delta_0 + \delta_i Z_{ij} \quad (5)$$

Where Z_i represents the vector of farm-specific variables and is a vector of unknown coefficients of the farm-specific inefficiency variables.

2.3 Empirical model

For the investigation of the technical efficiency and factors affecting efficiency of small scale maize producers in Masaiti District on the Copperbelt Province in Zambia, a Cobb-Douglas production function was adopted. Despite its well-known limitations, the Cobb-Douglas functional form was used to estimate the stochastic production frontier for the small scale maize producers in this study. It is argued by Binam et al. (2004) that as long as interest rest on efficiency measurement and not on the analysis of the general structure of the production technology, the Cobb-Douglas production function provides an adequate representation of the production technology. For this study the following Cobb-Douglas stochastic frontier production function was specified:

$$\text{Ln } Y_i = \beta_{oi} + \beta_1 \text{Ln}X_{1i} + \beta_2 \text{Ln}X_{2i} + \beta_3 \text{Ln}X_{3i} + \beta_4 \text{Ln}X_{4i} + V_i - U_i \quad (6)$$

Where Output (Y) is the value of maize output measured in local currency (Zambian Kwacha);
X_1 is planted land size (ha)
X_2 is the fertilizer (kg)
X_3 is the seed quantity (kg)
X_4 is the total labour (man days)

The inefficiency model based on Battese and Coelli (1995) was specified as:

$$U_i = \delta_0 + \delta_1 Z_{1i} + \delta_2 Z_{2i} + \delta_3 Z_{3i} + \delta_4 Z_{4i} + \delta_5 Z_{5i} + \delta_6 Z_{6i} + \delta_7 Z_{7i} \quad (7)$$

Where Z_1= age of the farmer; Z_2 = number of school years or level attained; Z_3= extension visits; Z_4= Used improved seed; Z_5= used rotation; Z_6= Cooperative membership; and Z_7= Farm size.

The maximum likelihood estimates of the Cobb-Douglas stochastic frontier cost function were estimated using the STATA software version 11. This software has the advantage of allowing simultaneous estimation of the production function coefficients and those of the technical inefficiency model. The parameter estimates and related statistical tests obtained from the stochastic frontier production function analysis are presented in Table 2.

3. Results and Discussion

3.1 Descriptive statistics of the surveyed farmers

Summary descriptive statistics for the variables used in the stochastic frontier model are presented in Table 1. The mean maize output per farm was 2,270 kg obtained from an average maize planted area of 1.20 hectares. The average farm size in the study area was 6.5 ha. Maize fields where prepared using the hand-hoe technology by majority farmers (96 percent) and only 4 percent of farmers used animal draft power. The main inputs used in the maize production were fertilizer, seed and labor. The mean quantity used was 335 kg for fertilizer, 24.9 kg of seed and 98 man-days labor.

The inefficiency model included six variables namely: age, education level, extension visits, used hybrid seed type rotation practiced, cooperative membership, and farm size. The summary statistics in Table 1 indicate that 60 percent of the respondents were male. The mean age of the farmers in the study area is 46 years, suggesting that most farmers are in the middle age category. The average education level for the farmers was 1.6, which translates into junior secondary (or grade 9) and implies that most farmers in the area have basic literacy and numeracy skills. This educational background is important in assisting the farmers to read and understand information on agricultural technologies and innovations which are necessary to enhance maize production in the area.

Table 1: Summary descriptive statistics of the variables in the model (n=100)

Variables	Mean	Standard deviation	Minimum	Maximum
Inefficiency variables:				
Gender 9male=1, female=0)	0.60	0.49	0.0	1.0
Age (years)	46.07	13.29	20.0	78.0
Education level (0=none, 1=primary; 2=secondary, 3=tertiary)	1.61	0.67	0.0	3.0
Household size	7.48	3.08	2.0	17.0
Hand hoe technology (yes=1, no=0)	0.96	0.20	0.0	1.0
Improved seed used (yes=1, no=0)	0.27	0.45	0.0	1.0
Cooperative member (yes=1, no=0)	0.50	0.50	0.0	1.0
Rotation used (yes=1, no=0)	0.52	0.50	0.0	1.0
Extension visits (number)	0.49	1.00	0.0	4.0
Production variables:				
Farm size (ha)	6.56	3.10	2.0	22.0
Maize area (ha)	1.20	0.92	0.2	7.0
Maize production (kg)	2270.5	2304.74	250.0	17500.0
Fertilizer (kg)	335.00	303.31	100.0	2000.0
Seed quantity (kg)	24.87	11.97	5.0	80.0
Total labour (man-days)	98.03	45.96	27.0	255.0

About half (50 percent) of the farmers survey were members of the local agricultural cooperative. The cooperative membership is a requirement for farmers to obtain subsidizedfertilizer and seed provided under the Farmer Input Support Programme (FISP) of the Ministry of Agriculture and Cooperatives (MACO). In addition, extension services tend to concentrate on recipients of inputs from FISP. The average number of extension staff visits received by famers was 0.49, which suggests that the farmers with cooperative membership had one visit while non-cooperative farmers were not visited by extension staff.

About 52% of farmers had practiced crop rotation to break away from maize mono-cropping on the same piece of land over many years. A small portion of farmers (27%) used improved maize varieties (i.e. open-pollinated varieties or hybrids) while the majority planted farmer saved (i.e. recycled) maize seed. Using farmer-saved seed instead of improved seed varieties could adversely affect productivity of maize production.Maize was the major crop (1.20 ha) planted by the surveyed farmers in the study area, it was accompanied by small plots of cassava (0.29 ha), sweet potatoes (0.32 ha), groundnuts (0.23 ha) and vegetables including tomatoes, onions, cabbage and rape. Farming activities were conducted using mainly family labor and in some cases hired labor especially during peak periods, for example, field preparation and weeding.

3.2 Estimates of stochastic production frontier model

The Maximum Likelihood Estimates of the stochastic production frontier parameters and those of the inefficiency model are presented in Table 2. The variance parameters for sigma square and gamma are 0.155 and 0.604, respectively. They are significant at 1% level. The sigma square indicates the goodness of fit and correctness of the distributional form assumed for the composite error term. The gamma estimate indicates the systematic variance that is unexplained by the production function and is the dominant source of random errors (Umoh, 2006). The estimate of γ= 0.604 or 60.4% means that the inefficiency effects make significant contribution to the technical inefficiency of maize farmers in the study area.

3.2.1 Stochastic production frontier parameters

The maximum likelihood estimates of the stochastic production (Table 2) indicate that input elasticities for maize planted area and fertilizer were positive and significant at 1% level of significance. Labor and seed quantity used had unexpected signs and were insignificant. The coefficient for maize planted area was 0.637, which implies that increasing land size by 10% will cause maize output to increase by 6.37%. The coefficient for fertilizer of 0.538 indicates that increasing the quantity of fertilizer by 10% will lead to a 5.38% increase in output. Thus, increases in maize production in the study area are driven mainly by area expansion and increased use of fertilizer.

Table 2: Estimates of the stochastic frontier Cobb-Douglas production function

Variable	Coefficient	StandardError	T-statistic	Significance
Production part:				
Constant	5.050	0.434	11.623	0.000
Lnmaizeha	0.637***	0.061	10.409	0.000
Lnfertilizer	0.539***	0.071	7.612	0.000
Lnseedqty	-0.056	0.096	-0.582	0.560
Lntotdays	-0.085	0.063	-1.340	0.180
Inefficiency effect (u):				
Constant	-6.980	5.492	-1.271	0.204
Age	-0.108*	0.063	-1.698	0.090
Education	1.929*	1.159	1.664	0.096
Extension	-1.250	0.872	-1.433	0.152
Seedtype	3.301*	1.733	1.904	0.057
Rotation	9.564**	4.646	2.059	0.040
Cooperative member	-3.661*	1.931	-1.896	0.058
Farmsize	-0.638*	0.373	-1.713	0.087
Variance parameters:				
Sigma_v (σ_v)	0.248	0.049	5.060	
Sigma_u (σ_u)	0.306	0.114	2.684	
Sigma Square (σ^2)	0.155	0.051	3.050	
Lambda (λ)	1.233	0.158	7.816	
Gamma (γ)	0.604			
Log likelihood =-12.553; Prob. Chi-square=0.0000				

***, **, and * Significance at 1%, 5% and 10% level.

The insignificant effect of seed quantity on maize output is surprising in that improved seed varieties are developed and disseminated to farmers so that yields can be improved. This result could indicate that farmers in the study area are not getting the benefits of using improved seed varieties; due to low usage of improved seeds and/or inappropriate seeding rate.The coefficient for labor is also insignificant and has a negative sign. This could be indicating that there is abundant household labor in the study area, such that any increase in labor input in maize production reduces the technical efficiency although the coefficient is not significant.

3.2.2 Sources of technical efficiency

In the inefficiency model, a negative coefficient means an increase in efficiency or a positive effect on productivity. While a positive coefficient means an increase in inefficiency or a negative effect on productivity. The estimates of the inefficiency model revealed that age, education, seed type, rotation, cooperative membership, and farm size were statistically significant at 10% level.

Farmer's age has a negative relationship with technical inefficiency. This implies that an increase in farmer's age would lead to a decrease in inefficiency. This result is consistent with those of Belbase and Grabowski (1985), Kalirajan and Shand (1985), and Bravo-Ureta and Pinheiro (1997) that age is positively related to technical efficiency.

Education has a positive relationship with technical inefficiency. This implies that an increase in the level of education would increase inefficiency or decrease efficiency. This contrasts the findings of Belbase and Grabowski (1985). Kalirajan and Shand (1985). And Bravo-Ureta and Pinheiro (1997) that education is positively related to technical efficiency.

The estimated coefficient on extension visits is negative as expected but it is statistically insignificant. This implies that more extension contacts with extension officers tend to have no significant effect on the inefficiency levels of smallholder maize farmers in the study area. The result contrasts findings of other researchers (Rahman,2003; Ali and Byerlee, 1991) because it is expected that more extension visits will increase the farmer's likelihood of adopting improved maize technologies which will eventually increase the efficiency level of the maize farmer. The result is not surprising in situations where the rate of adoption of land augmenting technologies such as improved seed and fertilizer is very low (Yiadom-Boakye et al., 2013). In the Masaiti district about 27% of farmers used improved seed and majority used recycled seed. Thus, knowledge on improved maize varieties disseminated by extension staff to maize farmers may not affect their output significantly.

Seed type has a positive coefficient of 3.301 in favor of those using recycled seed over improved seeds. This means that using unimproved seeds increases the chance of the farmer to increase technical inefficiency. This implies that the prevailing practice of using recycled seed is a source of technical inefficiency. This finding is similar that of Mignouna et al. (2010) among maize producers in Kenya.

Rotation had the unexpected positive effect on technical inefficiency. This finding is contrary to the finding of Dlamini et al. (2012). The implication of this result is that although farmers reported to be practicing some rotation to break away from maize mono-cropping, the rotations used are inappropriate because they are increasing technical inefficiency. Hence, farmers need to be trained and advised on the appropriate rotation techniques and the associated soil fertility improvement benefits.

Cooperative membership has a negative relationship with technical inefficiency. This implies that increased cooperative membership will lead to a reduction in technical inefficiency. This was expected in that cooperative membership is a requirement for a farmer to receive subsidized improved seed and fertilizer supplied under the Farm Input Support Program (FISP) in Zambia. If the cooperative members use the improved seed and fertilizer in their maize production as targeted, then technical efficiency could increase.

Farm size has a significant negative relationship with technical inefficiency. This result is similar to most findings in the literature which shows a positive relationship between land size or farm size and farm level efficiency and smallholder farmers (Bravo-Ureta and Pinheiro, 1997, and Kabwe (2012).

3.2.3 Distribution of technical efficiency

The technical efficiency estimates from the Cobb-Douglas production are shown in Table 3. The TE scores range from 52.2 percent to 93.2 percent with a mean of 79.6 percent. The presence of technical inefficiency indicates the possibility of raising output without increasing input use in the production process. The mean technical efficiency of 76.6 percent implies that smallholder farmers in the study area will have to reduce inefficiency by 20.4% in order to operate on the frontier. For the most inefficient smallholder household with the minimum technical efficiency of 52.2 percent, to be on the frontier they will need to achieve 47.8 percent more productivity. In the case of the most technically efficient smallholder with a maximum technical efficient score of 93.2 percent, they need to reduce inefficiency by 6.8 percent to be on the frontier.

More than 90 percent of the farmers were found to be more than 70 percent technically efficient and for 10 percent of the farmers their technical efficiency was between 50 percent and 70 percent.The estimated mean technical efficiency of 79.6 percent is similar to the mean of 78.2% estimated by Kabwe (2012) for smallholder maize farmers in the Chongwe district in Zambia.

Table 3: Technical efficiency scores

Class interval of TE	Farmers	Percent
0.50-0.59	4	4
0.6- 0.69	6	6
0.7 -0.79	29	29
0.8-0.89	55	55
0.90- 0.99	6	6
Total	100	

Minimum=52.2%, Maximum =93.2%; and Mean =79.6%

3.2.4 Returns to scale

The returns-to-scale parameter for the Cobb-Douglas production function is estimated by the sum of the elasticities for the four input variables and found to be 1.03. This means that the returns-to-scale for Masaiti maize farmers is 1.03. This estimate is approximately equal to 1, which indicates presence of constant returns to scale. This means that holding other factors constant, if all production inputs were increased by 1%, maize output would increase by 1%.

4. Conclusion

This study focused on estimation of the technical efficiency of smallholder maize production in Masaiti district in Zambia, applying the stochastic frontier approach and to identify factors influencing technical inefficiency of smallholder maize producers. A Cobb-Douglas functional form of the stochastic frontier model was used and the results indicated that maize land size and fertilizer have significant positive effects on maize production. Labor and seed were insignificant and have negative signs. The average technical efficiency of smallholder maize producers in the study area is 79.6%. This indicates that there is scope to further increase the output by 20.4% without increasing the levels of inputs.

The inefficiency effects model revealed that age of the farmer, cooperative membership or access to fertilizer (FISP) and farm size have positive effects on technical efficiency. While education of the farmer, seed type used and rotation practices, have negative effect on technical efficiency. Extension is one important function carried out by the Ministry of Agriculture in Zambia and is expected to raise agricultural productivity, but in this case it has no significant effect on technical efficiency and is evidenced by the low adoption of technologies such as improved maize varieties disseminated by extension staff.The policy implications are that to improve farm efficiency, efforts should focus on improving access to improved inputs such as certified seed and fertilizer, information on agronomic practices in particular crop rotations and to improve farmer's education through enhanced extension services. The issue of input availability and affordability also needs attention.

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