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Determinants of Technical Efficency of Smallholder Farming in Lukulu, Zambia

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***Abstract*—The study examines technical efficiency of smallholder rice farming in Lukulu district of Zambia. The study uses farm level data collected through a survey of 120 smallholder rice farmers selected using simple random sampling method. The data were analyzed using descriptive statistics and stochastic frontier production function approach. The estimated stochastic frontier Cobb-Douglas production function revealed that farm size, fertilizer and agrochemicals have statistically significantly positive effects on production of rice in the district. The results for technical efficiency analysis indicated that farm level technical efficiency ranged from 40.4% to 97.6% with the mean of 76.9%. This implies that there is potential to increase rice production for smallholder farmers in the district by 23.1% without increasing input usage but using available technology. The inefficiency model indicates that extension, credit, planting method and number of cattle owned were significant. The age, gender, household size and marital status were insignificant, meaning that they don't have any significant effect on technical efficiency. To improve efficiency of rice production in the district, extension, credit, adoption of improved planting methods and ownership of assets (cattle) should be encouraged.**

***Index Terms*—rice, technical efficiency, allocative efficiency, economic efficiency, smallholder, productivity, stochastic production frontier**

I. Introduction

For most developing countries, increasing food production and national productivity is a must and one of the major goals of their agricultural policy. The agricultural sector plays an important role in the national economies of most developing countries; it contributes to income generation, employment creation, food security and poverty reduction. In Zambia, the Agricultural sector contributed average of 9.8% of Gross Domestic product (GDP) in the period 2006 to 2015 ((Ministry of National Planning and Development (MNDP), 2017). An estimated 1.3 million smallholder farming households depend on agriculture for livelihood and the sector absorbs about 67% of the labour force and remains the main source of income and employment for both men and women (FAO, 2015).

Arable land covers 47 percent of the country's total land but only about 15 percent of this is under cultivation,(MA, 2016). Despite its important role in the national economy and its good endowment of fertile land and vast water resources and favourable climate, performance has been below full potential. Further, the sector has marginally contributed to an increase in rural incomes, food and nutrition security and the reduction in rural poverty (CSO, 2015); one concern that the national yields for most crops grown by smallholder farmers remained persistently low. The crops include key food and cash crops such as maize, sorghum, millet, and rice.

The Government of the Republic of Zambia (GRZ) has placed Agriculture as one of the key priority sectors for economic growth and development and poverty reduction. Therefore increasing agricultural production and productivity is of paramount importance to the government and its development partners (FAO, 2015). In fact, promoting the agriculture sector is one of the Government's priorities under the goal of diversifying the economy away from its over-reliance on its traditional products and exports, such as copper and cobalt. Two main strategic objectives for the sector included under the Seventh National Development Plan are: (i) improving productivity and production of crops and livestock, and (ii) diversification and promotion of small-scale agriculture (MNDP, 2017).

A. Rice Consumption and Demand Trends in Zambia, 2000-2014.

The Zambian Ministry of Agriculture and Livestock has designated rice as one of the strategic food and cash crops for Zambia, in addition to maize, cassava, sorghum and millet. Consumer surveys (SNV, 2014) have revealed that Zambians generally have a preference for the aromatic rice like Mongu, Nakonde and Chama rice hence the premium price paid for local rice varieties. In addition, Zambian consumers buy rice on the basis of quality that encompasses size of the grain, colour and free from grit and other impurities.

The total consumption of rice in Zambia increased from 15,926Mt in 2002 to 59,728 Mt in 2014. The per capita consumption increased from 1.4kg in 2002 to 4.11kg in 2014. The increase in demand for rice is driven by increases in urban population, rising incomes and change in tastes. The gap between production and consumption has been widening and this gap is filled by imports. In 2016 it is estimated that there was a rice deficit of 35,000 Mt (MFND, 2017). The deficit has grown because consumption has grown faster than production. The slow growth in production can be attributed to low productivity indicated by prevailing rice yields which are below potential yields.

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II .MATHODOLOGY

A. Study Area

Lukulu district is one of the 16 districts in the Western Province of Zambia. The topography of the district is mainly plain, with the temperature ranging from 20^{o} to 28^{o}. The district is situated in the northern part of Western Province.

. The district is bordering with Angola district on the western side. The district is bordering north-western province with Zambezi, Kabompo and Kasempa districts, Kabompo River being the boundary. On the southern side, the district borders Mongu and Kalabo and Kaoma districts, on the eastern side, the district borders with part of Kashempa and Kaoma district (MA, 2016). The district is in the agro-ecological region IIb, with rains ranging between 800mm and 1000mm. 90% of the smallholder farmers use hand-hoe cultivation, with less usage of modern inputs, 70% of the district is a plain, which gets flooded in the rain season, due to this, the district has got the potential for rice production, since rice does well in water logged areas. The district is second in the province for rice production after Limulunga district. The district has 6,000 smallholder farmers out of which 2,000 are smallholder rice farmers (MA, 2016).

B. Data Collection

Primary data were collected from sample respondents, comprising of 120 smallholder rice farmers. The data used in the study were collected through questionnaire that was administered to smallholder farming community at a household level. The information collected include socio-economic aspects, farm characteristics, cropping patterns, data on rice production including farm size, labour input, fertilizer quantity and rice output. The data collected covered cropping season 2016/2017 and it should be noted that 2016/2017 cropping season was a normal agricultural year in the study area and the country in general.

C. Analytical Approach

The study employed the Stochastic Frontier Analysis (SFA) Model to determine elasticities on the production part, compromising of farm specific characteristics and also the sources of technical efficiency of rice in small holder farmers in Lukulu district which comprised of the social-economic characteristics of the farmers. The SFA was independently proposed by Aigner et al. (1977) and Van de Broeck (1977) to measure the farm level technical efficiency by incorporating in the deterministic function, the error term that accounts for the statistical noise. SFA is based on an econometric specification of a production frontier. The specification of SFA allows for non negative random component in the error term to generate inefficiency, and is presented as below.

$Y_i=f(X_i{:}B)exp^{Vi-Ui}$ where $i=1,2,3……..n$ (7)

Where Y_i =output

X_i = a vector of inputs and

B=a vector of parameters to be estimated

$v_i–u_i$= Composite error term.

The error V_i is i.id≈N (0, $\square^2_v$) captures random variables beyond the control of farmers, such as the normal variation in weather, measurement error and other statistical noise. The error term u_i captures technical inefficiency in production, assumed to be farm specific non negative random variables i.i ≈N (u, $\square^2_u$). (Note: when u=0, distribution of u becomes half normal). A higher value of u_i implies an increase in technical inefficiency. If u_i is zero, the farm is perfectly technical efficient. Following Battese and coelli (1995), we assume the distribution of mean inefficiency (u_i) is related to the farmer's demographic variables by following heterogeneity in the mean inefficiency team to investigate sources of differences in technical efficiencies of the farmers. This model was proposed by Battese and coelli (1995) in which technical efficiency effects in the stochastic production frontier are a function of explanatory variables. The model of the technical inefficiency is expressed as follows.

$u_i=\square_0+\square \ \square \ z_i\square$
(8)

Z_i=Farmer specific variables.

$\square_i$ = Vector of unknown parameters be estimated.

Accordingly, the technical efficiency (TE) of the i^{th} individual farm is defined by the ratio of the mean output for the i^{th} individual farm, given the values of X_i and its technical inefficiency effect u_i (that is observed output) to the corresponding mean output if there were no technical inefficiency of production (that is frontier output).(Battese and Coelli 19988). In the description above, TE can be defined by;

$$TE=y_i/y_i^{*} \quad (9)$$

$$TE = f(\chi_i : \beta)\exp v_i - u_i \Big/ f(\chi_i : \beta)\exp v_i \quad (10)$$

Technical efficiency (TE) famers will have a value equal to 1, if there is no inefficiencies of among the small holder farmers. But if the value is between 0 and 1, then there are some inefficiencies among smallholder farmers (Battese and coelli, 1995).

The lambda λ shows the ratio between technical inefficiency (δ^2_u) and the statistical noise (δ^2_v). If the figure gotten from the lambda is 1, then it means that the inefficiency effects and the statistical noise contribute equally to the variance between the frontier and the observed out, if it's more than 1 then inefficiency contribute more than statistical noise and if it's less that 1, then the statistical noise contribute more to the variance than the inefficiency effect (Aiger et al, 1977).

$\lambda=\square_u^2/\square_v^2$
(11)

The gamma represent the total variation from the frontier, which is attributed by the technical inefficiency and it ranges from 0 up to 1 that is $0\leq\gamma\leq1$with a value closer to zero implying lesser of technical inefficiency contributing to the variance between the frontier and the actual or observed output on the other hand, the value closer to 1 indicates the high levels of technical inefficiency contributing to the variance between the frontier and the actual observed output,(Battese and coelli, 1995). The frontier production function is estimated by the maximum likelihood technique which yields estimator for γ andβ where;

$$\gamma=\square_u^2/\square^2 \text{and} \square^2=\square_u^2+\square_v^2 \quad (12)$$

D. Empirical Model

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To measure and determine the technical efficiency and factors affecting efficiency in Lukulu district of western province in Zambia, the Cobb -Douglas production function was adopted. Since the major interest of the study was technical efficiency measurement, Cobb-Douglass production function was employed because of its capacity to provide an adequate representation of the production technology (Binam et al., 2004). The Cobb-Douglass functional form was used to estimate the stochastic production frontier for smallholder rice farmers in the District despite its limitations (Battese, 1992) and it is specified as follow.

$InY_i = \beta_o + \beta_1 InX_1 + \beta_2 InX_2 + \beta_3 InX_3 + \beta_4 InX_4 + \beta_5 InX_5 + \beta_6 InX_6 + V_i - U_i$ (13)

Where

Y_i= rice output (kg), X_1=Farm size (ha), X_2=Total labour (Man days), X_3= seed (kg), X_4=fertilizer (kg), X_5=Agrochemicals (litres), $(V_i - U_i)$= Composite error term.

The technical efficiency model U_i is defined as;

$U_i = \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 Z_4 + \delta_5 Z_5 + \delta_6 Z_6 + \delta_7 Z_7 + \delta_8 Z_8 + \delta_9 Z_9$ (14)

Where

Z_1= Age of the farmer (years), Z_2=Formal education attained (years), Z_3=Planting method (years), Z_4= Gender, Z_5=Seed type, Z_6= Extension contacts, Z_7=Credit accessibility, Z_8=Number of cattle, Z_9= Family size (number of people), Z_{10} =Marital status

III. RESULTS AND DISCUSSION

A. *Descriptive statistics of the surveyed farmers*

Table 4.1 below represents the summary of the descriptive statistics for the variables used in the stochastic frontier model. Rice farmers in the district produce 1501.25Kg on average, on 0.94 ha of land. Farmers use on average 15.22 kg of rice seed, with 159 kg of fertilizer per hectarage. About 4.4 litres of pesticides and herbicides were applied by the smallholder farmers in a hectare. The majority of the smallholder rice farmers planted recycled seed (71%) and only 29% used certified seed.

Table: 4.1 Descriptive Statistics of the production variables in the model (n=120)

Variables	Mini	Max	Mean	Std.
Production Variables				
Rice production/ HH	200	4500	1501.2	1201.3
Seedquantitie s in Kg	9	20	15.22	2.25
Land in hectarage/HH	0	2	.94	.551
Fert/ per HH in Kg	35.00	400.00	159.00	89.78
Agrochemical s	0	10.00	4.4750	3.49
Total Man-days	25.64	245.22	92.36	39.03

Table 4.2 below presents social economical variables. On average, the age of rice smallholder farmers is at 43 years, which is very good, and indicating that, the majority of the smallholder farmers are in the middle age. Young farmers are believed to more energetic and more adoptive to the new technologies and farming pattern hence leading to improved yields. The education level among the smallholder rice farmers was at 1.6500, which translates into junior secondary education level (8 and 9). High educated farmers are believed be more efficiency, as education improves the managerial ability of a farmer. Farmers had on average extension 3 visits in 2015/2016 farming season, 50% of the farmers had access to credit, where as the other 50% of the farmers didn't have access to credit. The majority of the farmers were male with 60% whilst female farmers were at 40%, the family size per each house hold averaged at 6 members per household. The total man-days averaged at 92.36 per house hold in the district

Table: 4.2 Descriptive statistics of the social economic variables in the model (n=120)

Social economic variables	Mini	Max	Mean	Std
Improved seed used(yes=1, no=0)	0	1	.29	.63
Age per HH	22	67	42	13.8
Level of Education/farmer(0 =none,1=primary, 2= secondary, 3 Tertiary	0	3.00	1.6	.86
Number of visits by the Officer	0	10	2.6	2.77
Accessibility to credit(yes=1,no=0)	0	1	.50	.50
Sex of a house holds(male=1, 0=female)	0	1	.60	.49
Number of house holds	2	12	6.20	2.56
Marital status(yes=1,no=0)	0	1	.58	.50
Organization belongingness(yes= 1, no=0)	0	1	.45	.50
Other incomes apart from farming(yes=1, no=0)	0	1.00	.67	.474
Number of years in farming	3	12	6.65	2.15
Hand- hoe technology(yes=1, no=0)	0	1.0	.93	0.19
Row planting method (yes=1, no=0)	0	1.0	.13	0.15

58% of the family house hold head were married whilst 42% of the house hold head were single. The total man days on average were at 89 days with the 45% of them belonging to co-operatives and associations whilst 55% of the farmers were not belonging to any co-operative or association group. 67.5 % of the smallholder framer had other income generating activities apart from farming whereas only 27.7% of the farmers didn't have off-farm income generating activities. On average, the farmers had 7 years of farming experience, with 93% of them using hand-hole technology for preparing their land whilst only 7% used animal draft power. Only 13% of the farmers planted in rows and the 87% of the farmers planted using broadcasting method.

B. Estimates of the stochastic production frontier model.

The inefficiency model and those of the Maximum Likelihood Estimate of the stochastic production frontier parameters are presented in table 4.3. The variance parameters for the sigma square (δ^2), lambda (λ) and gamma (γ). The sigma square (δ^2) give the correctness of fit and the distributional form assumed for the composite error term which is 0.212. The lambda (λ), which is the ratio of random errors contributing to the inefficiency (δ_u) to that of the statistical noise (δ_v) is 1.414, it is from the lambda (λ) that the gamma (γ) can be formulated. The gamma (γ) estimate for the study is 0.665 or 66.5% which means that, the inefficiency effect makes a significant contribution to the technical efficiency of the rice farmers in the district, with the statistical noise contributing only 43.5%. We now reject the first (i) null hypothesis, which states that; their no technical efficiencies among the farmers in the district. We also reject the third (ii) null hypothesis, which states that; their no statistical noise in the production function in the model.

C. Stochastic production frontier parameters

Maximum likelihood estimates for the stochastic production function in Table 4.3 indicates that, the elasticities for area planted for rice, fertilizer applied and agrochemicals used were positive and significant at 1% level of significance. Labour and seed quantity had expected positive sign, but they were insignificant. The area planted had a coefficient of 0.558, implying that, a 10% increase in the rice area planted would lead to the increase of 5.58% in rice output. Fertilizer applied had a coefficient of 0.178, implying that, a 10% increase in fertilizer use would lead to 1.78% increase in rice output. Agrochemicals had a coefficient of 0.326, implying that, a 10% increase in agrochemical usage would lead to 3.26% increase in output of rice. An indication in the study area is that; the major contributors to the output increase of rice are increase in fertilizer usage, expansion in area planted and an increase in the agrochemicals

Table 4.3: Estimates of the stochastic frontier Cobb-Douglas production function

Variables	Coefficient	Standard error	T-Stat	Significance
Production Part:				
Constant	5.717	0.486	11.75	0.000
LnSeed Quantity	0.162	0.121	1.34	0.179
LnFarm size in hectarage	0.558***	0.099	5.65	0.000
LnFertilizer in Kg	0.178***	0.067	2.64	0.008
LnAgrochemicals	0.326***	0.046	7.06	0.000
LnTotal Labour	0.040	0.051	0.78	0.436
Variance parameters:				
Sigma v (δ_v)	0.266	0.036	4.676	
Sigma u (δ_u)	0.376	0.126	2.103	
Sigma square (δ^2)	0.212	0.017	3.172	
Lambda (λ)	1.414	0.148	8.136	
Gamma (γ)	0.665			
Log likelihood=-14.079; prob chi square=0.000				

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

Labor has a positive sign, which is an expected sign, even though it's not significant, but this indicates that, an increase labor input will lead to an increase in output in the area. Seed quantity is not significant and has unexpected sign (negative) which is very surprising, but this implies that, the farmers in the area are not getting the benefit of the improved seed and that, the majority still plants recycled seed. And unexpected sign for seed quantity can be due to the planting method of the farmers in the area, as majority uses broadcasting method of planting rice in the district, which leads to inappropriate seed rate, and this leads to intense competition of nutrients in the soil, leading to low output.

D. Sources of technical inefficiency

Results for the inefficiency model are presented in Table 4.4. In the inefficiency model, a negative sign implies an increase in efficiency, whilst a positive sign indicates an increase in inefficiency or a negative effect on productivity. The estimates in the inefficiency model revealed that, planting method by the farmers was significant at 1%, whilst number of cattle owned by a house hold was significant at 5% meanwhile; credit accessibility and extension services were insignificant at 10%.

Farmer's Planting method had negative relationship with technical inefficiency implying that increasing the broadcasting method of planting by the farmers would also increase inefficiency and it was significant at 1%, implying that a farmer's planting method has got significant effect on the smallholder rice farmers in the district. This contrast the findings of Belbase and Grabowski (1985), Kaliranjan and Shand (1985). And Bravo-Utera and Pinheiro (1997) which reported that, age is positively related to technical efficiency. The coefficient for the number of cattle owned by the household was negatively related to inefficiency as expected and it was significant at 5%, implying that, increasing the number of cattle of a farmer would increase the efficiency or decrease the inefficiency.

Table 4.4: Estimates of the Inefficiency effects model

Variables	Coefficient	Std error	T-Statistic	Significance
Constant	0.233	1.216	0.19	0.84
Age	0.006	0.013	0.43	0.66
Education	0.170	0.218	0.78	0.43
Extension	-0.120*	0.07	-1.82	0.06
Credit	-0.751*	0.425	-1.77	0.07
Household size	-0.120	0.087	-1.38	0.167
Marital status	-0.648	0.418	-1.55	0.121
Seed type	-0.173	0.470	-0.37	0.713
Planting method	-1.552***	0.511	-3.04	0.002
Number of Cattle per HH	-0.159**	0.066	-2.40	0.01

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

Extension had a negative relationship with inefficiency, and was significant at 10% implying that; an increase in the extension visits would lead to an increase in efficiency or decrease in inefficiency. This is in consistent with the findings of Kaliranjan (1981) Kaliranjan and Flinn (1983), Kaliranjan and shand (1985) and Bravo Utera et al., (1994) these studies reported a positive relationship between farm level efficiency and availability of extension services. Access to credit had a negative coefficient as expected and it was significant at 10% implying that, an increase in access to credit will lead to an increase in efficiency or the decrease inefficiency of the smallholder rice farmers in the district this is in disagreement with the findings of Okike et al. (2001), who showed that receiving credit contribute to farmer's inefficiency.

The coefficient for gender of the household was negative and insignificant, implying that the gender of a household has got no significant effect on efficiency of the farmers in the district. Household size had a negative sign as expected and it was insignificant, implying that, the house hold size has got no effect on technical efficiency. This is in contrast with the findings of Onyenweaku and Nwaru (2005) who noted that, large household size has an advantage on labor supply tremendously, meaning that, they have a positive relationship with technical efficiency. Marital status has positive relation with efficiency and insignificant, implying that, marital status has got no significant effect on efficiency. The coefficient for education had unexpected positive sign and insignificant, implying that, there is no relationship between education and technical efficiency, this is in contrast with the earlier findings by Page and John (1984) and Wang et al. (1996) these studies reported a negative relationship between technical efficiency and formal education.

E. The distribution of technical efficiency

The estimates of technical efficiency score range from 40.4% to 97.6% with the mean of 76.9%. The mean technical efficiency of 76.9 indicates that, the smallholder rice farmer will have to reduce inefficiency by 23.1% in order for them operate on the frontier. The distribution of farmers by technical efficiency classes is shown in figure 4.1.

For those operating on the minimum technical efficiency of 40.4% will have to reduce inefficiency by 59.6% in order for them to operate on the frontier, and for those operating on the maximum technical efficiency of 97.6% will need to reduce their inefficiency by 2.4% in order for them to operate on the frontier. 59.2% of the smallholder farmers operate above 70% technical efficiency whilst 40.8% of the farmers were found to operate between 40% and 70% technical efficiency.

The return to scale parameter for the Cobb Douglas production function was estimated by the sum of all the five elasticities of inputs variables. Implying that, the return to scale of smallholder rice farmers in Lukulu District is at 1.264. The estimate for the return to scale is approximately equal to 1implying the presence of a constant return to scale for the farmers in the district. This implies that, holding other factors constant, if the production inputs were to be increased by 1%, the rice output was also going to increase by 1%.

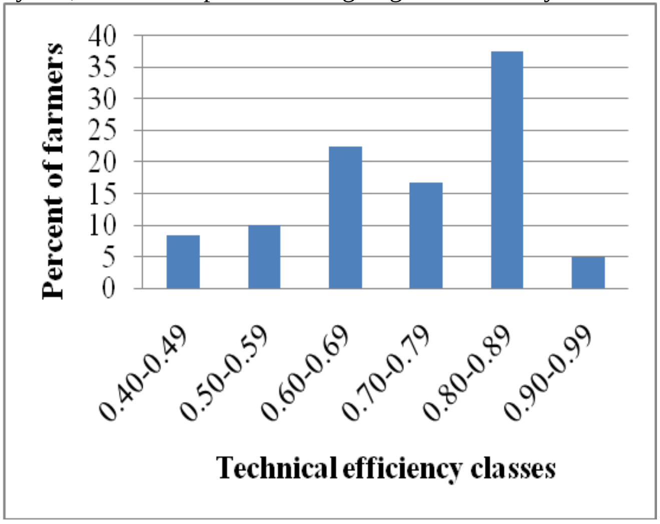

Figure 4.1: Technical efficiency scores

IV. CONCLUTION

The stochastic frontier approach was applied to identify factors affecting technical inefficiency among smallholder rice producers in the district. A Cobb-Douglas functional form of the stochastic frontier model was used and the results indicated that, estimates for rice farm size, fertilizer and Agrochemical have significant positive effect on rice production, meanwhile, seed quantity and, labor have positive sign but insignificant. The average technical efficiency of rice in smallholder farming is at 76.9% implying that, there is scope to further increase the output by 23.1% without increasing the levels of input usage.

The inefficiency effect model revealed that planting method, extension services, access to credit, and number of cattle owned by the farmer have positive effects on technical efficiency. While age, education, gender, household size, marital status and seed type, are insignificant.

The policy implications for this study are that; more affordable credit facilities be made available to the farmers as this will increase hectarage cultivated. Extension contact is very vital and significant to farmers especially on fostering the adoption of recommended rice planting methods and fertilizer application, if the government can recruit more extension officers in the ministry of agriculture so that services on crop management can be addressed in order to promote the technical efficiency of rice production in the district. There is need through extension services to sensitize the farmers on the importance of owning cattle by small holder farmers, as owning cattle encourages farmers to cultivate bigger farming area in specified time period using a plough as compared to hand –hoe method.

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