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A Stochastic Frontier Analysis of Technical Efficiency of Maize Production Under Minimum Tillage in Zambia

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Abstract

Minimum tillage and other conservation agriculture practices are not only associated with income gains but are also claimed to be the panacea to the declining agricultural productivity and soil degradation problems in Africa and across the world. The few studies on technical efficiency related to the agricultural sector performance in Zambia have not attempted to determine how technically efficient smallholder farmers that produce maize under minimum tillage are. This study used stochastic frontier analysis based on both the half-normal and exponential model distributions on 2008 cross-sectional nationally representative data of 160 smallholder maize farm households that adopted minimum tillage in Zambia. Results indicate that maize farmers face increasing returns to scale (1.074) implying that there were opportunities for them to improve their technical efficiency as they were operating in stage I of their production functions. The half-normal and exponential model distributions indicate average technical efficiency scores of 60 and 71.7 percent, respectively. Their respective lowest efficiency scores were 9.3 and 8.5 percent. The highest efficiency scores for the half-normal and exponential model distributions were 89.3 and 90.9 percent. Maximum likelihood estimation results show that marital status, level of education of household head, square of household size, off farm income, agro-ecological region III, distance to vehicular road and access to loans are statistically significant factors that affect technical efficiency of smallholder maize farmers that practice minimum tillage in Zambia. The study calls for increased infrastructural development through construction of improved road network, schools and colleges in remote areas as a means to increasing accesss to knowledge and other agricultural services in order to enhance their technical efficiency levels. It also recommends promotion of minimum tillage practices in recommended agro-ecological regions to improve their technical efficiency. The study further acclaims for increased access to loans by smallholder maize farmers that practice minimum tillage as this would in one way induce them to invest in improved varieties and equipment that would help enhance their technical efficiency in Zambia.

Keywords: minimum tillage, smallholder maize farmers, technical efficiency, stochastic frontier analysis, Zambia

1. Introduction and Background

Climate change is a global issue that has taken centre stage in discussions by many scientists and policy makers. Its perceived negative impacts on food production coupled with current decline in agricultural productivity have contributed to the promotion of many climate adaptation strategies across Sub-Saharan Africa (SSA) and the world over. One of the most notable of these climate change adaptation strategies in Zambia is minimum tillage (MT), a component of conservation agriculture (CA) (Kuntashula et al., 2014). MT and other CA practices are not only associated with income gains but are also claimed to be the panacea to the declining agricultural productivity and soil degradation problems in Africa (Pieri et al., 2002; Haggblade & Tembo, 2003; Kabwe & Donovan, 2005; Giller et al., 2009). As a result, many governments and international development institutions in Africa and Zambia in particular have invested substantially in the promotion of these improved technologies that are thought to result in efficient use of resources and improved productivity (Haggblade & Tembo, 2003; Kassie et al., 2008).

MT is a dry-season land preparation practice that mainly involves minimum soil disturbance, either through planting in basins or ripping. Pieri et al. (2002) contended that MT involves planting of the crop into the soil's vegetative cover or crop residue without any disturbance or with less breaking to the soil surface. The key principle of MT is that it requires restriction of soil disturbance to a precise area where the crop is sown resulting into a minimum soil turnover of around 10% of the area for farming (FAO, 2011). This improves soil structure, increases water infiltration thereby facilitating plant growth and root development and thus enhancing productivity (Haggblade & Tembo, 2003).

As earlier mentioned, farmers have an option to practice ripping as a form of MT. Ripping is restricted to farmers that have access to animal traction or mechanical power. A study by Siziba (2008) showed that a ripper is used to rip into the soil to make a single furrow where seeds and fertilizers can be placed manually. Haggblade et al. (2010) observed that the foundation of ripping technology in Zambia is based on earlier efforts in agricultural engineering that concentrated on the development of ox-drawn ripping equipment for animal draft low-tillage systems in Magoye, Zambia which led to the development of the Magoye ripper in 1986. The Magoye ripper was invented in a way to help facilitate animal draught low tillage systems and water conservation, an alternative to the commonly known ox-plow. Haggblade and Tembo (2003) pointed out that the Magoye ripper requires less animal draught power than the ox-plough as it contains smaller dishes and has no mold board that an ordinary ox-plough has.

According to a study by Haggblade and Tembo (2003), the origin of MT in Zambia dates back to the late 1980s and early 1990s. For example, one of the donor-financed non-governmental organizations (NGOs) called the Co-operative League of the United States of America (CLUSA) required its farmers to plant in CF basins as a pre-condition to receiving input credit in the early 1990s (Haggblade & Tembo, 2003). Since then, smallholder farmers in Zambia have continued to adopt MT though its adoption has remained low. For example, a countrywide study by Ngoma et al. (2013) observed that only about 3.9% among Zambia's population of smallholder farmers practiced MT in 2012. Furthermore, a study by Kuntashula et al. (2014) indicated an adoption rate of about 12% from six selected districts in Zambia's agro-ecological region (AER) II in 2012. Zambia has three AERs. AER I mainly covers the Southern part of the country and is characterized by rainfall patterns of between 400 mm to 800 mm per year. AER II covers the Central and Eastern parts of the country with rainfall patterns between 800 and 1000 mm per year. AER III covers the Northern parts of the country with rainfall above 1000 mm per year (Haggblade & Tembo, 2003).

The low adoption rates of MT have been in the midst of numerous compelling benefits that are claimed to arise from its adoption in relation to efficient use of resources. For example, Haggblade and Tembo (2003) pointed out that planting in basins and rip lines harvest water in years of sporadic rainfall and ensure the precise application of fertilizer and other inputs next to the plants. This facilitates plant growth and development contributing to improved productivity. Haggblade and Tembo (2003) further acknowledged that by allocating land preparation to the dry season, in advance of the rains, MT redistributes heavy labor as well as animal and mechanized draft requirements out of the peak planting period. A study by Haggblade et al. (2010) confirmed that increased attention to use of MT also offers high productivity gains. Furthermore, Kassie et al. (2010) observed that MT increases agricultural productivity particularly from its ability to conserve soil moisture in dry environments.

Since MT practices are associated with these productivity gains, there is compelling interest to measure and understand its technical efficiency in the face of declining agricultural productivity among smallholder maize farmers in Zambia. For example, the few studies on technical efficiency related to the agricultural sector performance in Zambia have not attempted to determine how technically efficient smallholder maize farmers that practice MT have been (see for example; Mwape, 1988; Chiona, 2012; Steven Kabwe, 2012; Michael Kabwe, 2012; Chiona, 2014; Musaba & Bwacha, 2014; Namonje, 2014). Mwape (1988) focused on the relative economic and allocative efficiency of emergent and commercial maize farms in Zambia while Kabwe (2012) assessed technical, allocative and economic efficiency of smallholder maize producers in the Chongwe district. Studies by Chiona (2012) and Kabwe (2012) focused on the technical and allocative efficiency of smallholder maize farmers and factors that affect allocative, technical and economic efficiecy of cotton smallholder farmers in Zambia, respectively. A study by Namonje (2014) on effect of late delivery of subsidized fertilizer on smallholder maize productivity and production also assessed the technical efficiency of smallholder farmers in Zambia.

Furthermore, a study by Chiona et al. (2014) focused on the technical efficiency of smallholder maize farmers of Central Zambia while Musaba and Bwacha (2014) studied the technical efficiency of smallholder maize farmers in Zambia's Masaiti district. In other countries, similar studies were done by Henderson and Kingwell (2001) in Australia, Gouse et al. (2006) in South Africa and Langemeier (2010) in the United States of America (USA). As mentioned before, none of the recent work in Zambia on technical efficiency has focussed on smallholder maize farmers that practice MT. This knowledge gap was the main motivation for this study.

Therefore, this study contributes to the analysis of technical efficiency of the agricultural sector in Zambia by determining the technical efficiency of smallholder maize farmers who practice MT using the stochastic frontier analysis (SFA). The study further identifies the factors that affect their technical efficiency. There is no doubt that evaluating technical efficiency of smallholder maize farmers that adopt MT in Zambia is vitally important because it could guide MT resource utilization and may therefore lead to considerable resource savings, which could have important implications for both policy formulation and farm management (Bravo-Ureta & Riegler, 1991).

1.1 The Conceptual Model

Technical efficiency is defined as the ability to operate on the production frontier or isoquant frontier (Effiong & Onyenweaku, 2006; Greene, 2008). To build on this definition, this study is underpinned by the model of Farrel (1957) that intuitively explains the measure of technical efficiency in simplicity. According to Farrel (1957), a firm is considered to have successfully achieved technical efficiency if it has produced a large amount of output given a correctly measured set of inputs. In his illustration, Farrel (1957) assumed that there is a given firm with a known efficient production function producing a single product while using two resources *X* and *Y* under constant returns to scale. These assumptions are necessary as they avail us with all the relevant information to be presented in a simple isoquant diagram shown in Figure 1. The point *P* represents the inputs of two resources per unit of output that the firm is observed to use. The isoquant *SS'* represents the various combinations of the two resources that a perfectly efficient firm might use to produce the unit output. Now the point *Q* represents an efficient firm using two resources in the same ratio as *P*.

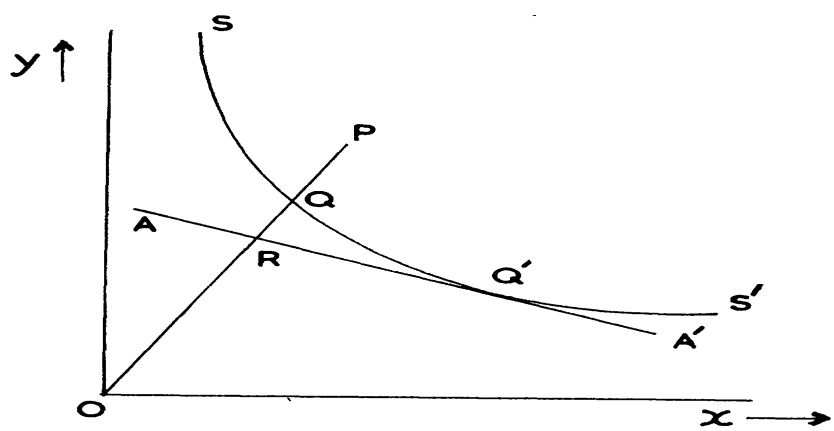

Figure 1. Farrel's measure of technical efficiency

Source: Farrel (1957).

As shown in Figure 1, the firm could produce the same output as *P* using only a fraction of *OQ/OP* as much of each resource. It could also be thought of producing *OQ/OP* times as much output from the same inputs. From this analysis, Farrel (1957) defined the firm's technical efficiency as *OQ/OP*, which naturally is true because this ratio has the properties that a measure of technical efficiency obviously needs. It takes the value unit for a perfectly efficient firm and would become indefinitely large. Moreover, so long as the isoquant *SS'* has a negative slope, an increase in the resource per unit output of one factor would imply lower efficiency, when other factors would be held fixed. However, Farrel (1957) postulated that one also needs to know the extent to which the firm uses the various resources in best proportions in view of their prices.

Therefore, following the same model of Farrel (1957), if the isocost line *AA'* has a slope equal to the ratio of prices of two resources, *Q'* and not *Q* is the optimal method of production. In as much as both points represent 100 percent technical efficiency, the costs of production at *Q'* would only be a fraction *OR/OQ* of those at point *Q*. It is therefore natural to define this ratio as the price efficiency of *Q*. Furthermore, Farrel (1957) explained that if the observed firms were to change the proportions of their inputs until they were the same as those represented by *Q'* while keeping technical efficiency constant, their costs would be reduced by an amount *OR/OQ* as long as resource prices did not change. It would be therefore reasonable to let this ratio measure the price efficiency of the observed firm too.

The argument drawn from this model seems not to be entirely conclusive as it would be impossible to say what would happen to the firms' technical efficiency if they changed the proportions of their inputs. However, with this qualification, the model seems to be the best measure of technical efficiency available (Farrel, 1957). Furthermore, the model also has the desirable property of giving the same price efficiency to the firms using resources in the same proportions. If the observed firms were perfectly efficient, both technically and in respect of prices, their costs would be a fraction *OR/OP* of what they are in fact are. According to Farrel (1957), it is convenient to call this ratio the overall efficiency of the firm and one may note that it is equal to the product of technical and price efficiencies.

1.2 The Stochastic Frontier Analysis

The previously discussed model by Farrel (1957) motivated several authors to improve the theory of measurement of technical efficiency and two methods have since been widely used to measure efficiency. The two methods are data envelopment analysis (DEA) and stochastic frontier method or analysis. The former is a nonparametric approach that developed out of mathematical programming techniques while the latter is a parametric approach that estimates technical efficiency within a stochastic production function model (Chakraborty et al., 2001). In this study, the stochastic frontier analysis was used in preference to the DEA framework because it posseses the following attractive features that make it worthy to be used as an alternative to the DEA framework (Greene, 2008).

Firstly, the stochastic frontier analysis posseses the 'stochastic' aspect unlike the DEA framework that allows it to handle appropriately measurement problems and other stochastic influences that would otherwise show up as causes of inefficiency for smallholder maize farmers. Secondly, the stochastic frontier analysis is suitable for such kind of data as were used in this study that possess unmeasured but surely substantial cross country heterogeneity. It provides a means to accommodating such heterogeneity which the DEA framework does not (Greene, 2008). Thirdly, the programming procedures under DEA framework are not based explicitly on an assumed statistical model and thus the properties of the estimators are therefore ambiguous (Greene, 2008). In short, the DEA framework's estimators from mathematical programming have the notable disadvantage that they do not naturally produce standard errors for the coefficients, which the stochastic frontier analysis is able to, so inference is excluded in the former, something that is not preferred in this study.

The main pioneers of the stochastic frontier analysis were Aigner et al. (1977) and Meeusen and van den Broeck (1977) with the motivation that the unconventionality from the frontier of the production activity could not be under total control by the economic agent in this case the smallholder maize farmer under study. Their work was an extension of the study by Farrel (1957) from which they formulated the stochastic production frontier so as to bridge the gap between theory and empirical work. Aigner et al. (1977), Meeseen and Van den Broeck (1977) and Battese and Corra (1977) postulated that the error term of the stochastic frontier production function is composed of two independent components of which the stochastic noise term would allow statistical tests of hypotheses related to the production structure and level of efficiency. The two error component stochastic frontier production function suggested to represent technical inefficiency was employed as shown below:

$$Q_i = f(X_i;\beta)\exp(v_i - u_i) \tag{1}$$

where Q_i is the scalar output of the i^{th} smallholder farm, $\mathbf{X_i}$ is the vector of resources and β is a vector of parameters. v_i is the disturbance term assumed to be independently and asymmetrically distributed $(-\infty \le v_i \le \infty)$ and it captures the effects of random shocks outside the smallholder farmers' control. Such random shocks include unfavourable external effects, unpredictable events such as bad weather, equipment failure and injuries among others. u_i captures the factors that are under the control of the smallholder maize farmers. In this paper, u_i is assumed to be independently and asymmetrically distributed as normal-half-normal and normal-exponential (Aigner et al., 1977; Meeusen & van den Broeck, 1977). Other possible specifications of the distribution of u_i were suggested by Greene (1980a) and Lee (1983) and are still being used in most empirical work. This study assumed the two distributions because the normal-half-normal distribution is unduly narrow and therefore need for more robust results (Greene, 2008).

Empirically, technical efficiency of a smallholder maize farmer of the i^{th} household is defined as the ratio of the observed amount of output (Q_i) to the corresponding potential or frontier amount of output (Q_i*) conditioned on the amount of resources used by that farmer. This definition is represented by Equation (2) below.

$$Technical\ Efficiency_i = \frac{Q_i}{Q_i^*} \tag{2}$$

Substituting Equation (1) into Equation (2) yields the following;

$$Technical\ Efficiency_i = \frac{f(X_i, \beta)\exp(v_i - u_i)}{f(X_i, \beta)\exp(v_i)} = \exp(-u_i) \quad (3)$$

The main thrust of this analysis is from Jondrow et al. (1982). From their work, the density function of u_i is as follows;

$$f(u_i) = \frac{1}{\sqrt{2\Pi}}(\frac{1}{\sigma_n})\exp(\frac{-u^2}{2\sigma_n^2});\ \mathrm{u_i} \geq 0 \quad (4)$$

For v_i, the density function is as follows;

$$f(v_i) = \frac{1}{\sqrt{2\Pi}}(\frac{1}{\sigma_v})\exp(\frac{-v^2}{2\sigma_v^2});\ \mathrm{u_i}\ \ (-\infty \leq \mathrm{v} \leq \infty) \quad (5)$$

And the density function of Q_i which is the joint density of (u_i and v_i) is given by;

$$f(Q_i) = 1 \Big/ \{\sigma\sqrt{\frac{\Pi}{2}}\} \exp(\frac{\varepsilon^2}{2\sigma^2})[1 - F(\frac{\varepsilon}{\sigma})(\frac{\gamma}{1-\gamma}) \quad -\infty \leq \mathrm{u_i} \leq \infty \quad (6)$$

where *F(.)* is the cummulative distribution of the standard normal random variable while ε_i, σ^2, and γ are defined as follows;

$$\varepsilon_i = v_i - u_i$$
$$\sigma^2 = \sigma_v^2 + \sigma_u^2$$
$$\gamma = \sigma_u^2 \big/ \sigma^2 \quad (7)$$

where γ lies between 0 and 1. Its values that are near 1 mean that the random component of the inefficiency effects significantly contributes to analysis of production systems. The loglikelihood of the sample is given below;

$$L(Q_i : \theta) = \Pi[\frac{1}{\sigma\sqrt{(\frac{\Pi}{2})}}\exp(\frac{\varepsilon^2}{2\sigma^2})(1-F)\{(\frac{\varepsilon}{\sigma})(\frac{\gamma}{1-\gamma})] \quad (8)$$

where θ is the parameter to be estimated and it is equivalent to the production parameters σ^2 and γ (Jondrow et al., 1982). Jondrow et al. (1982) observed that measurement of u_i for individual observations is derived from the conditional distribution of u_i and ε_i. If the normal and half-normal distributions of v_i and u_i, are respectively given, the conditional mean of u_i on ε_i and can be derived as follows following Jondrow et al. (1982).

$$E(u_i \mid \varepsilon_i) = \int u_i f(u_i \mid \varepsilon).du_i \quad (9)$$

where $f(u_i|\varepsilon_i) = f(u_i; \varepsilon_i)/\mathrm{f}(\varepsilon_i)$

The density function of u_i given ε_i and using Equations (4) and (5) is equivalent to the following after re-parameterization.

$$f(u_i;\varepsilon_i) = \frac{1}{\sqrt{2\Pi}}\frac{\sigma}{\sigma_v\sigma_u}\exp[\frac{-\sigma_u^2}{2\sigma_u^2\sigma_v^2}(u_i + \sigma_u^2/\sigma^2)^2]\ 1 \Big/ 1 - F(.) \quad (10)$$

where *F(.)* is the cummulative normal density function. Therefore, Jondrow et al. (1982) concluded this with the expected value of u_i as follows:

$$E(u_i;\varepsilon_i) = (-\sigma_u\sigma_v/\sigma)[f(.)/(1-F(.)) - (\varepsilon)/\sigma\sqrt{\gamma/(1-\sigma}} \quad (11)$$

Where *f(.)* represents the values of the standard normal density function. The estimates of $E(u_i \mid \varepsilon_i)$ can be obtained by the method of Maximum Likelihood Estimation (MLE) which is used to obtain estimates of γ, σ_v and σ_v by evaluating Equation (10). As a result, the technical efficiency of an individual smallholder farmer can be calculated as follows:

$$Technical\ Efficiency_i = \exp(u_i; \varepsilon_i) \tag{12}$$

For the exponential case, u_i is assumed to follow one-parameter exponential with the following density function: $f(u_i) = \exp(\frac{-u_i}{\sigma_v}) / \sigma_u$. The following results were obtained by Jondrow et al. (1982) as the resulting expected value of u_i,

$$E(u_i \mid \varepsilon_i) = \sigma_v \left[\frac{f(\frac{\varepsilon_i}{\sigma_v} + \frac{\sigma_v}{\sigma_u})}{1 - F(\frac{\varepsilon_i}{\sigma_v} + \frac{\sigma_v}{\sigma_u})} - \frac{\varepsilon_i}{\sigma_v} + \frac{\sigma_v}{\sigma_u} \right] \tag{13}$$

Where the *F(.), f(.)* and the parameters σ_u σ_v and ε_i are as previously defined. The results of the expected value of u_i are obtained as in Equation (12).

2. Data and Methods

2.1 Data Types and Sources

This study used data from a survey of households in Zambia conducted in 2008 by the Central Statistical Office (CSO) with financial and technical support from the Food Security Research Project (FSRP) and the Ministry of Agriculture and Co-operatives (MACO). The data were nationally representative and collected as part of the Rural Incomes and Livelihood Survey (RILS) and were the third Supplemental Survey to the 1999/2000 Post Harvest Survey (PHS) that was conducted in August/September 2000. The objectives of the survey were several. But this study mainly used the data as they contained necessary information about farmer adoption of CF practices and general perceptions. A total sample of 7,825 smallholder farm households was selected using a stratified three-stage sampling procedure. However, only 160 households were relevant for this study as these were the only smallholder maize farm households that adopted MT practices in Zambia. An adopter of MT in this study was considered as a farm household that planted a maize crop on any of their pieces of farm land and practiced MT in the 2006/2007 farming season.

2.2 The Empirical Model

To estimate Equations (12) and (13), this study follows the approach similar to the work by Battese and Coelli (1995) on panel data in which they estimated technical inefficiency from the stochastic frontier. In their study, technical inefficiency was simultaneously explained by a set of variables that were representative of the firm specific characteristics and time. The method dodges away from the inconsistency problems that come with the two-stage approach used in previous empirical works (for example; Kalirajan, 1981; Pitt & Lee, 1981; Kumbhakar & Hjalmarsson, 1995; Kabede, 2001). This method is a one step approach in which the inefficiency term is explicitly expressed as a function of the farmer or firm characteristics and the random error term (Kumbhakar et al., 1991; Reifschneider & Stevenson, 1991). Since the major interest of the study was technical efficiency measurement, the Cobb-Douglas production function was employed because of its capacity to provide an adequate representation of the production technology (Binam et al., 2004). It was specified as follows:

$$\ln Q_i = \beta_0 + \beta_1 \ln X_{1i} + \beta_2 \ln X_{2i} + \beta_3 \ln X_{3i} + \beta_4 \ln X_{4i} + v_i + u_i \tag{14}$$

where Q_i = total maize output in kilograms per hectare, β_i = the k×1 vector of parameters to be estimated and *X*'s are resources used to produce total maize output which include capital, land, labour, and seeds. They are also defined in Table 1. *ln* is the natural logarithm. v_i is the statistical noise term while u_i represents farm specific characteristics that are related to the inefficiency term and is estimated as shown in Equation (15).

$$u_i = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 ... + \delta_k Z_k \tag{15}$$

δ_i 's are the parameters to be estimated while Z_i's are the characteristics that are hypothesized to affect technical inefficiency. These are also defined in Table 1. Estimation of both Equations (14) and (15) was simultaneously done using MLE in Stata 13.

3. Results and Discussions

3.1 Descriptive Statistics

The variables used in this study are presented in Table 1. Column (1) shows the symbols representing the variables as indicated in Equations (14) and (15). Column 2 shows the definitions of the same variables. Columns (3), (4), (5) and (6) respectively indicate the variable means, standard deviation, minimum and maximum values. For the stochastic production function variables, the average total maize output was about 2 metric tons per hectare (ha) while the lowest was 11 kilograms per ha. The highest total maize output recorded was 48.432 metric tons per ha. The average amount of farm land cultivated was 1.61 ha with the lowest land cultivated being 0.2 ha while the largest area was 8 ha. This confirms that the farmers involved were smallholder farm households. The average capital owned by the smallholder farm household was ZMW625 while the highest amount owned was ZMW16, 700. Average man-days recorded in the season were about 31 days while average amount of seeds used were about 108 kilograms (kg) per ha.

Table 1. Summary statistics for variables used in the study

(1)	(2)	(3)	(4)	(5)	(6)
Variable	**Variable description**	**Mean**	**Std. Dev**	**Minimum**	**Maximum**
Output and input variables					
Q	Total maize productivity (kg/ha)	2032.55	4020.31	11.0.	48432.15
X_{1i}	Land in hactares	1.61	1.55	0.20	8
X_{2i}	Capital in ZMK	625.51	1821.39	0	16700
X_{3i}	Labour (mandays)	31.64	14.77	5.18	73.57
X_{4i}	Seeds in kg	107.99	36.89	3	214
Farm specific Variables					
Z_{1i}	Age in years	50.68	15.58	23	90
Z_{2i}	Gender of head (=1 if male, 0 otherwise)	0.72	0.45	0	1
Z_{3i}	Marital status (=1 if single, 0 otherwise)	0.17	0.38	0	1
Z_{4i}	Primary education (=1 if yes, 0 otherwise)	0.77	0.42	0	1
Z_{5i}	Basic education (=1 if yes, 0 otherwise)	0.23	0.42	0	1
Z_{6i}	Secondary education (=1 if yes, 0 otherwise)	0.07	0.25	0	1
Z_{7i}	Tertiary education (=1 if yes, 0 otherwise)	0.03	0.16	0	1
Z_{8i}	Household size	5.41	2.54	1	13.00
Z_{9i}	Off farm income per adult equivalent (ZMW)	1971.44	11200	6.207.06	138000
Z_{10i}	Agro-ecological region 1 (=1 if yes, 0 otherwise)	0.25	0.45	0	1
Z_{11i}	Agro-ecological region 2 (=1 if yes, 0 otherwise)	0.57	0.50	0	1
Z_{12i}	Agro-ecological region 3 (=1 if yes, 0 otherwise)	0.18	0.39	0	1
Z_{13i}	Extension service (=1 if received, 0 otherwise)	0.20	0.40	0	1
Z_{14i}	Livestock holding in total livestock units (TLU)	2.79	5.93	0.02	53.74
Z_{15i}	Distance to vehicular road in kilometres	6.33	11.78	0	80
Z_{16i}	Distance to input market in kilometres	33.85	36.10	0	150
Z_{17i}	Distance to product market in kilometres	16.77	23.54	0	126
Z_{18i}	Fertilizer (=1 if had access, 0 otherwise)	0.30	0.46	0	1
Z_{19i}	Belong to farmer association (=1 if yes, 0 otherwise)	0.07	0.23	0	1
Z_{20i}	Access to loans (=1 if yes, 0 otherwise)	0.26	0.44	0	1
Sample size					**160**

For farm specific characteristics, Table 1 indicates that the smallholder farm household heads had an average age of about 50 years old. The youngest farm household head was 23 years old while the oldest was 90 years old. About 72 percent of household heads were males while only about 17 percent of the household heads were single by marital status. The rest were considered to be married or have been married before. Table 1 further indicates that about 77 percent of the household heads had attended primary education while about 23 percent and 7 percent had attended basic and secondary education, respectively. Furthermore, the summary statistics indicate that about 3 percent of the household heads had attended tertiary level of education. Average household size was about 5 while the maximum number of household members recorded was 13, the lowest being 1. Table 1 further indicates that the average off farm income per adult equivalent was ZMW1, 971, the highest amount recorded as ZMW138, 000.

In terms of location by AER, 25 percent of smallholder maize farmers that practiced MT were located in AER I while 57 percent and 18 percent were located in AER II and AER III, respectively. AER I and II are low rainfall and drought prone areas while AER III are high rainfall areas in Zambia (Haggblade & Tembo, 2003). The average distances to vehicular road, input and output markets were about 6, 34 and 17 kilometers, respectively. Furthermore, the longest distances smallholder maize farmers would travel to access vehicular road network, input and output markets were 80, 150 and 126 kilometres, respectively. For access to fertilizer, about 30 percent of the smallholder maize farmers had access to it. Some of the farm households in the data belonged to farmer associations and Table 1 indicates that about 7 percent of farmers in the sample had such a previledge. Furthermore, Table 1 shows that about 26 percent of smallholder maize farm households that practiced MT had access to loans, while the rest did not. The last row shows that the sample size used in this study was 160.

3.2 Empirical Results

The MLE estimates of the stochastic frontier analysis are reported in Table 2. Column (1) presents the variables for both the stochastic production frontier and the technical inefficiency functions while Columns (2) and (4) present their estimates of the coefficients under half-normal and exponential model distributions, respectively. Standard errors under half-normal and exponential model distributions are respectively reported in Columns (3) and (5). Variance parameters are presented after variables in the technical inefficiency function while the log-likelihood values are presented in the last row for both model distributions.

The log-likelihood functional values and parameter estimates for both the stochastic production and technical inefficiency functions are relatively the same for both distributions. However, the variance parameters are not similar in their magnitudes though they are all statistically significant at 1 percent. As Kabede (2001) rightly suggested, the reason for the differences in their magnitudes could be due to the different specification of distributions of the inefficiency term which should be suitable for the data setting under study. The generalized likelihood ratio test defined by the chi-square χ^2 for presence of technical inefficiency indicates that the null hypothesis of absence of technical inefficiency (γ =0**)** is strongly rejected at 5 percent significance.

$$[\chi^2, (5\%, 4) = 10.4].$$

As shown in Table 2, estimates of λ are large for both half-normal and exponential model distributions (1.746 and 0.817, respectively) and statistically significant at 1 percent indicating that both models were of good fit. σ's (0.873 and 0.623) were statistically significant at 1 percent implying that the conventional production function would not be a satisfactory representation of the data used. γ represents the ratio of variance of farm specific technical efficiency to the variance of total maize output. The estimates of γ for half-normal and exponential model distributions were 0.753 and 0.400 respectively. These results mean that under the half-normal model distribution, more than 75.3 percent of the variation in total maize output was due to differences in their technical efficiency.

Table 2. Maximum likelihood estimates of stochastic production frontier and technical inefficiency models

(1)	(2)	(3)	(4)	(5)
Model	Half-normal		Exponential	
	Coefficient	Std. Error	Coefficient	Std. Error
Dependent variable	Ln(total maize output/hectare)		Ln(total maize output/hectare)	
Stochastic production frontier function				
Constant	1.949	1.182	1.838*	1.104
Ln(land in hactares)	-1.85***	0.16	-1.85***	0.140
Ln(capital in ZMW)	0.008	0.010	0.010	0.010
Ln(labour in mandays)	2.612***	0.830	2.621***	0.800
Ln(seed in kg)	0.306***	0.089	0.291***	0.085
Technical inefficiency function				
Age in years	-0.004	0.004	-0.003	0.004
Gender (=1 if male, 0 otherwise)	0.007	0.131	0.019	0.126
Marital status (=1 if single, 0 otherwise)	0.292*	0.154	0.288*	0.152
Primary education (=1 if yes, 0 otherwise)	-0.202	0.186	-0.160	0.171
Basic education (=1 if yes,0 otherwise)	-0.230*	0.136	-0.199	0.132
Secondary education (=1 if yes, 0 otherwise)	-0.152	0.265	-0.168	0.259
Tertiary education (=1 if yes, 0 otherwise)	-0.767*	0.441	-0.727*	0.386
Household size	0.0334	0.075	0.033	0.074
Square of household size	-0.925***	0.359	-0.920***	0.347
Off farm income (ZMW)	35.3***	0.654	35.0***	0.581
AER I (=1 if yes, 0 otherwise)	0.0572	0.240	-0.0329	0.238
AER II (=1 if yes, 0 otherwise)	0.167	0.230	0.102	0.219
AER III (=1 if yes, 0 otherwise)	0.546**	0.264	0.499**	0.241
Extension service (=1 if yes, 0 otherwise)	-0.185	0.143	-0.158	0.139
Livestock holding in tlu	-0.026	0.034	-0.020	0.034
Distance to vehicular road (km)	0.010**	0.005	0.010**	0.005
Distance to input market (km)	-0.003	0.002	-0.003	0.002
Distance to product market (km)	-0.002	0.002	-0.001	0.002
Fertilizer access (=1 if yes, 0 otherwise)	0.171	0.140	0.157	0.137
Belong to farmer association (=1,0 o/w)	0.103	0.243	0.084	0.229
Access to loans (=1 if yes, 0 otherwise)	-0.126***	0.036	-0.128***	0.038
Constant	-0.554	0.623	-1.847	0.494
Variance parameters				
Lambda (λ)	1.746***	0.359	0.817***	0.148
Sigma square (σ^2)	0.763***	0.258	0.394***	0.054
Sigma_u (σ_u)	0.758***	0.236	0.397***	0.098
Sigma_v (σ_v)	0.434***	0.129	0.486***	0.060
Gamma (γ)	0.753		0.400	
Log likelihood	-151.10		-149.71	

***Significant at 1 percent; **Significant at the 5 percent level *Significant at the 10 percent level.

However, the exponential model results suggest that at least 40 percent of variation in their farm output is due to differences in their technical efficiency. This result should not raise eyebrows as results from the two models still indicate closely related levels of the average technical efficiency (60 and 71.7 percent) of the same sample (see Table 3).

The coefficients of the stochastic production frontier functions represent output elasticity values. They are similar in their magnitudes and signs for both model distributions. For instance, the output elasticity values for land, labour and seeds are statistically significant at 1 percent significance level in both cases. The output elasticity value of land means that if the smallholder maize farmers that practiced MT increased land allocation by 10 percent, this would result in 18.5 percent fall in the total maize output holding other factors fixed. The positive output elasticity value for labour means that if the smallholder maize farmers were to increase their man-days by 10 percent, this would be associated with about 26 percent rise in total maize output holding other factors constant. The farming season in Zambia is long enough to accommodate this observation.

In Table 1, it was indicated that the lowest number of days smallholder maize farmers that practice MT would work on their farm lands were about 5 man-days. This was perhaps due to illness or other factors the farm household members were exposed to. The positive output elasticity value for seeds means that if smallholder maize farmers increased their amount of seeds by 10 percent, this would be associated with about 3 percent increase in total maize output, *ceteris paribus*. Notice that the types of seeds considered in this study were improved varieties and the result is not surprising as improved varieties are meant to improve output (Kabede, 2001).

The results on labour and seeds are consistent with the results by Gouse et al. (2006) and Langemeier (2010). Results on seeds and and labour corroborate with those obtained by Chiona et al. (2014). The output elasticity value for capital was so low in magnitude that it was statistically insignificant. This was surprising as capital is expected to be a statistically significant input in production. The reason might be because only a few smallholder maize farmers had enough capital for farm investments. As seen from Table 1, the farm household with lowest capital recorded nothing and the average amount was ZMW635 only.

Among the results reported, the result for labour is the highest (2.610). This is not startling as the labour input has the most influence on any farm output. This result is consistent with Kabede (2001) who observed that farming activity is traditonal and labour intensive and thus availability of labour determines what can be produced at a farm. Studies on CA practices in Zambia have pointed out that CA practices include MT and that they duly require labour input for positive results (Haggblade & Tembo, 2003; Nyanga, 2012; Ng'ombe et al., 2014). Thus production functions of smallholder maize farm households that practice MT in Zambia are dorminated by the labour input.

Moreover, the sum of the output elasticity values in Table 2 represents returns to scale (RTS) of 1.074. This entails that maize production by smallholder farmers in Zambia was in stage I of the neoclassical production function. This implies that there is need for the farmers to continue increasing their production as they were still short of their production frontiers. This was confirmed by the generalized loglikelihood ratio test discussed above. The result further implies that if the smallholder maize farmers who practiced MT were to increase their resources by one percent, their total maize output would rise more than proportionally.

3.3 Factors That Affect Technical Efficiency

Sources of technical efficiency are the variables that appear in the inefficiency function of Table 2. Marital status is statistically significant at 10 percent under both model distributions. Its positive coefficient means that smallholder maize farm household heads that are single would more likely reduce technical efficiency at the farm, holding other factors fixed. This implies that married household heads would on the other hand increase the farm's technical efficiency. The reason could be because the household heads and their spouses would be in a better position to advise each other on what agricultural technologies to adopt and share information about how best they can apply them at their farm. Besides, smallholder farm households whose heads are married might have more labour available than those headed by single heads, an input that was observed to have most contribution in the stochastic frontier production function.

The dummy variable basic education is statistically significant at 10 percent under the half-normal model distribution only. But the sign is negative in both cases. The result means that smallholder maize farmers that have received education at basic level would be more technically efficient than those that have not. This result is consistent with Belbase and Gravowski (1985), Kalirajan and Shand (1985), Bravo-Ureta and Pinheiro (1997) and Kabede (2001). However, they contrast those results by Musaba (2014) who observed an opposite relation between education and technical efficiency. Furthermore, similar results are obtained as indicated by the dummy variable tertiary education. The negative coefficient also means that smallholder maize farmers that practice MT would be more technically efficient if they received tertiary education than otherwise, holding other factors constant. The reason might be that such farmers would more likely follow and apply the recommended principles underlying MT at their farms and result in efficient resource use. These results are analogous to those under the exponential model distribution case.

Household size is not statistically significant at affecting technical inefficiency. However, the variable square of household size is statistically significant at 1 percent under both model distributions. This result means that as the size of the smallholder maize farm household increases, it does not affect technical efficiency until a certain number when it positively affects it, *ceteris paribus*. This result shares the opposite version of the law of diminishing returns in production but it corroborates with the findings by Ajewole and Folayan (2008).

Off farm income is statistically significant at 1 percent under both model distributions. Its positive coefficient means that holding other factors constant, increase in off farm income of a smallholder maize farm household that practices MT would reduce its technical efficiency. A more plausible explanation is that smallholder maize farmers that are involved in off farm income generating activities would allocate less time on MT practices such as dry season land preparation but concentrate more on the latter. In other words, such households would trade off their managerial input from MT to off farm income generating activities. In such cases, attention to MT practices is reduced and hence negatively affecting their technical efficiency at a farm. This finding is consistent with the results by Abdulai and Eberlin (2001), Ajewole and Folayan (2008) and Chiona (2014).

Biophysical conditions were also considered to affect technical efficiency of smallholder maize farm households that practice MT in Zambia. For example, the coefficient of AER III was positive and statistically significant under both model distributions. This finding means that when other factors are held constant, smallholder maize farm households that practice MT and are located in AER III would be technically less efficient than those located in Zambia's other AERs. The coefficients for AER I and AER II were both positive but statistically insignificant. Zambia's AER III is the highest rainfall area and previous studies contend that such an area is unsuitable for MT practices (Pieri et al., 2002; Haggblade & Tembo, 2003; Nyanga et al., 2011; Ng'ombe et al., 2014).

Distance to a vehicular road is statistically significant at 5 percent under both model distributions. Distance to a vehicular road in this study refers to the amount of distance smallholder maize farmers that practice MT have to travel to reach a road that is passable by vehicles. The longer the distance is, the more remote the area would be considered. Thus the variable distance to vehicular road was used in this study as a proxy for remoteness. The positive coefficient implies that keeping other factors constant, if smallholder maize farm households that practice MT are located in remote areas, they would be more technically inefficient than those in non-remote areas. This could be because access to agricultural services such as field days, field visits by MT advocates, smooth communication and extension services among others would be limited. This would in one way cut them off from access to valuable information on MT and thereby negatively affecting their technical efficiency.

Furthermore, a smallholder farm household's access to loans was statistically significant for both model distributions. This means that when other factors are held constant, smallholder maize farmers that have access to loans or credit would be more technically efficient than those who do not. This result is consistent with the findings by Nwagbo (1989), Desai and Mellor (1993), Obwona (2006), Ajewole and Folayan (2008). A more suitable explanation for this could be as suggested by Desai and Mellor (1993) that if farm level credit is properly extended and managed, it enhances diversified systems of agriculture which stabilize and perhaps increase agricultural productivity.

3.4 Distribution of Technical Efficiency of MT Smallholder Farm Households in Zambia

Results of the distribution of technical efficiency scores of smallholder maize farm households that practiced MT are reported in Table 3. Column (1) shows the interval of technical efficiency scores in which households lie. Column (2) shows the number of households under each interval while column (3) shows their respective percentages. Column (4) shows their cummulative percentages. Column (1) through to column (4) fall under the half-normal model distribution case while the other columns in Table 3 fall under the exponential model distribution case. Columns (5), (6) and (7) respectively show the number of households, their percentages and cummulative percentages under each interval.

Table 3. Distribution of technical efficiency of smallholder maize farmers that practice MT in Zambia

Model	Half-normal case			Exponential case		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Model	Half-normal			Exponential		
Technical efficiency	Number of household s	Percent	Cummulative percent	Number of households	Percent	Cummulative percent
< 20%	1	0.63	0.63	1	0.63	0.63
20.01- 30%	6	3.75	4.38	4	2.5	3.13
30.01- 40%	11	6.88	11.25	1	0.63	3.75
40.01- 50%	20	12.5	23.75	3	1.88	5.63
50.01- 60%	32	20	43.75	16	10	15.63
60.01- 70%	38	23.75	67.5	28	17.5	33.13
70.01 - 80%	43	26.88	94.38	57	35.63	68.75
80.01 - 90%	9	5.63	100	49	30.63	99.38
90 -100%	0	0		1	0.63	100
Total	160	100		160	100	
Mean	0.600			0.717		
Std. Dev	0.158			0.134		
Minimum	0.093			0.085		
Maximum	0.893			0.909		

Results indicate that under the half-normal case, 43 smallholder maize farm households that practiced MT in Zambia were between 70 and 80 percent technically efficient. For the exponential model distribution, 57 households were in that interval. For the exponential case, only 1 smallholder maize farm household was between 90 and 100 percent technically efficient while under the half-normal, there was none with such a level. Both cases indicate that there was only 1 smallholder maize farm household with technical efficiency less than 20 percent. The distributions of the technical efficiency scores are fairly normal for both cases. The half-normal model results shows that on average, at least 60 percent of the smallholder maize farm households were technically efficient in Zambia while the exponential model shows an average score of 71.7 percent.

The estimated range of technical efficiency scores for the half-normal model distribution is 80 percent (0.093 to 0.893 percent) while for the exponential case, it is 82.4 percent (0.085 to 0.909 percent). Values from both model distributions are seemingly comparable though their distributions are different. However, both results are fairly and normally distributed as observed before. They are similar to results obtained by Chiona et al. (2014).

4. Conclusions and Policy Implications

This study used the stochastic frontier analysis to estimate the levels of technical efficiency of smallholder maize farmers that practice MT in Zambia. The Cobb-Douglas production function was the main type of production function used with the inefficiency term assumed to be half-normally distributed in one analysis and exponentially distributed in another. Data used were 2008 nationally representative with 160 smallholder maize farm households that adopted MT in the 2006/2007 farming season in Zambia.

Results showed that among the four main factors of production (land, labour, capital and seeds) used, labour was the most used input and that capital was not statistically significant though its effect on total maize output was positive. Returns to scale were increasing implying that if the smallholder maize farmers increased their inputs by one percent, total maize output would increase more than proportionally. Efficiency results indicated that individual differences in their technical efficiency levels at their farms partly contributed to variation in their total maize output.

The half-normal model distribution results of the stochastic frontier production function showed that more than 60 percent of the smallholder maize farmers that practiced MT were technically efficient while the exponential model distribution results indicated closely related results of 71.7 percent. The most technically inefficient farmer under the half-normal model recorded an efficiency score of 9.3 percent while the most technically efficient farmer was about 89.3 percent technically efficient. For the exponential model, the most technically inefficient farmer had an efficiency score of 8.5 percent while the most technically efficient farmer was 90.9 percent technically efficient. These results show that smallholder maize farm households that practice MT in Zambia still do not operate from their frontier levels. Despite the average levels of their technical efficiency scores being higher 60 percent, they have about 30 to 40 percent levels of efficiency to exhaust.

From the potential factors that were sought to affect technical efficiency of smallholder maize farmers that adopted MT in Zambia, marital status, level of education, square of household size, off farm income, AER III, distance to vehicular road and access to loans were statistically significant. Results showed that married household heads were more technically efficient than single ones. This indicated that marriage is an important institution in Zambia that enhances technical efficiency of smallholder maize farmers that practice MT. Levels of education at basic and tertiary level positively contributed to technical efficiency of smallholder maize farmers. This implies that smallholder maize farmers that practice MT should be encouraged to receive at least basic level of education and as much as college education where they would perhaps be exposed to relevant knowledge or acquire skills that would improve their efficiency levels when executing MT practices. But that would be necessary if basic schools and colleges filled with skilled staff are present in remote areas where it is generally expected that illiteracy levels are high.

The statistical significance of the square of household size means that as household size increases, there is a certain number that it reaches that is pivotal to improving levels of technical efficiency. This result encourages the need for smallholder maize farmers that practice MT to work together in numbers; something that would increase amount of labour available during their practice of of MT farming activities. A large household with members in their productive ages might increase supply of labour for agricultural activities, an input which was considered the most contributing factor to total maize output in the production function in this study. Off farm income positively affected technical inefficiency among MT smallholder farmers. This implies that MT competes for labour used for off farm income generating activities and therefore this study calls for decreased divided attention by smallholder maize farmers who adopt MT in order for them to be more technically efficient.

Furthermore, smallholder maize farmers that adopted MT and were located in AER III were more technically inefficient than those located in other AERs in Zambia. This calls for need for promotion of MT in AER I and II, areas with erratic rainfall patterns in Zambia as previously mentioned. Large distance to vehicular road positively affected technical inefficiency implying that there is need for more infrastructural development in the transport sector so that smallholder maize farmers that practice MT in remote areas are not disadvantaged from access to agricultural information and other agricultural services by MT promoting agencies such as Conservation Farming Unit and others in Zambia. The significance of access to loans implies that access to such forms of credit was necessary for smallholder maize farmers as this would probably encourage them to invest in MT modern equipment such as the Magoye ripper or be able to purchase improved seeds and fertilizer to improve their efficiency. This revelation opens up the ground to call for financial institutions and government to increase access to loans to smallholder maize farmers that practice MT in Zambia.

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References

Abdulai, A., & Eberlin, R. (2001). Technical efficiency during economic reform in Nicaragua: evidence from farm household survey data. *Economic Systems, 25*, 113-125. http://dx.doi.org/10.1016/s0939-3625(01)00010-3

Aigner, D. J., Lovell, C. A. K., & Schmidt, P. (1977). Formulation and estimation of stochastic frontier production models. *J. Econ., 6*, 21-37. http://dx.doi.org/10.1016/0304-4076(77)90052-5

Ajewole, O. C., & Folayan, J. A. (2008). Stochastic Frontier Analysis of Technical Efficiency in Dry Season Leaf Vegetable Production among Smallholders in Ekiti State, Nigeria. *Nigeria. Agricultural Journal, 3*(4), 252-257. http://medwelljournals.com/abstract/?doi=aj.2008.252.257

Battese, G. E., & Coelli, T. J. (1995). A model for technical inefficiency effect in stochastic frontier production for panel data. *Empirical Economics, 20*, 325-332. http://dx.doi.org/10.1007/bf01205442

Battese, G. E., & Corra, G. S. (1977). Estimation of a production frontier model: with application to the pastoral zone of Eastern Australia. *Australian Journal of Agricultural and Resource Economics, 21*(3), 169-179. http://dx.doi.org/10.1111/j.1467-8489.1977.tb00204.x

Belbase, K., & Grabowski, R. (1985). Technical efficiency in Nepalese agriculture. *The Journal of Developing Areas*, 515-526.

Binam, J. N., Tonyè, J., Nyambi, G., & Akoa, M. (2004). Factors affecting the technical efficiency among smallholder farmers in the slash and burn agriculture zone of Cameroon. *Food Policy, 29*(5), 531-545. http://dx.doi.org/10.1016/j.foodpol.2004.07.013

Bravo‐Ureta, B. E., & Pinheiro, A. E. (1997). Technical, economic, and allocative efficiency in peasant farming: evidence from the Dominican Republic. *The Developing Economies, 35*(1), 48-67. http://dx.doi.org/10.1111/j.1746-1049.1997.tb01186.x

Bravo-Ureta, B. E & Riegler, L (1991). Dairy Farm Efficiency Measurement Using Stochastic Frontier and Neoclassical Duality. *American Journal of Agricultural Economics, 73*, 421-428. http://dx.doi.org/10.2307/1242726

Chakraborty, K., Biswas, B., & Lewis, W. C. (2001). Measurement of technical efficiency in public education: A stochastic and nonstochastic production function approach. *Southern Economic Journal*, 889-905. http://dx.doi.org/10.2307/1061576

Chiona, S. (2011). Technical and Allocative Efficiency of Smallholder Maize Farmers in Zambia. Master of Science Thesis. University of Zambia, Lusaka. Retrieved from http://dspace.unza.zm:8080/xmlui/handle/123456789/1813?show=full

Chiona, S., Kalinda, T., & Tembo, G. (2014). Stochastic Frontier Analysis of the Technical Efficiency of Smallholder Maize Farmers in Central Province, Zambia. *Journal of Agricultural Science, 6*(10), 108-118. http://dx.doi.org/10.5539/jas.v6n10p108

Desai, B. M., & Mellor, J. W. (1993). *Institutional Finance for Agricultural Development: An Analytical Survey of Critical Issues* (Food Policy Review 1). Washington: International Food Policy Research Institute.

Effiong, E. O., & Onyenweaku, C. E. (2006). Profit efficiency in broiler production in Akwa Ibom State, Nigeria. *International Journal of Agriculture and Rural Development, 7*(1), 72-79. http://dx.doi.org/10.4314/ijard.v6i1.2588

Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society. Series A (General)*, 253-290. http://dx.doi.org/10.2307/234310

Food and Agriculture Organization (FAO). (2011). *FAO Stat*. Retrieved on January 12, 2014, from http://faostat.fao.org/site/291/default.aspx

Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: the heretics' view. *Field crops research, 114*(1), 23-34. http://dx.doi.org/10.1016/j.fcr.2009.06.017

Gouse, M., Piesse, J., & Thirtle, C. (2006). Output and labour effects of GM maize and minimum tillage in a communal area of KwaZulu Natal. *Journal of Development Perspective, 2*, 35-48.

Greene, W. H. (2008). The Econometric Approach to Efficiency Analysis. *The Measurement of Productive Efficiency and Productivity Chang*e, 92-250. http://dx.doi.org/10.1093/acprof:oso/9780195183528.003.0002

Greene, W. (1980a). Maximum Likelihood Estimation of Econometric Frontier Functions. *Journal of Econometrics, 13*, 27-56. http://dx.doi:10.1016/0304-4076 (80)90041-x

Henderson, B. B., & Kingwell, R. S. (2001). An Investigation of the Technical and Allocative Efficiency of Broadacre Farmers. In *2002 Conference (46th), February 13-15, 2002, Canberra* (No. 125109). Australian Agricultural and Resource Economics Society.

Haggblade, S., Kabwe, S., & Plerhoples, C. (2011). Productivity impact of conservation farming on smallholder cotton farmers in Zambia.

Haggblade, S., Tembo, G., Kaboré, D., Reij, C., Ajayi, O. C., Franzel, S., … Place, F. (2010). Sustainable Soil Fertility Management Systems. In S. Haggblade & P. Hazell (Eds.), *Successes in African Agriculture: Lessons for the Future*. Baltimore: Johns Hopkins University Press.

Haggblade, S., & Tembo, G. (2003). *Development, Diffusion, and Impact of Conservation Farming in Zambia*. Food Security Research Project.

Jondrow, J., Knox Lovell, C. A., Materov, I. S., & Schmidt, P. (1982). On the estimation of technical inefficiency in the stochastic frontier production function model. *Journal of econometrics, 19*(2), 233-238. http://dx.doi.org/10.1016/0304-4076 (82)90004-5

Kabwe, M. (2012). Assessing Technical, Allocative and Economic Efficiency of Smallholder Maize Producers Using the Stochastic Frontier Approach in Chongwe District, Zambia. Master of Science Dissertation, University of Pretoria, Pretoria, South Africa.

Kabwe, S., & Donovan, C. (2005). *Sustained use of Conservation Farming practices among small scale farmers in Zambia.* Michigan State University, USA.

Kabwe, S. (2012). *Factors Affecting Efficiency of smallholder cotton producers in Zambia* (M.Sc dissertation, University of Zambia).

Kalirajan, K. (1981). An econometric analysis of yield variability in paddy production. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie, 29*(3), 283-294. http://dx.doi.org/10.1111/j.1744-7976.1981.tb02083.x

Kalirajan, K. P., & Shand, R. T. (1985). Types of education and agricultural productivity: a quantitative analysis of Tamil Nadu rice farming. *The Journal of Development Studies, 21*(2), 232-243. http://dx.doi.org/10.1111/j.1744-7976.1981.tb02083.x

Kalirajan & Shand (1985). Types of education and agricultural productivity: A quantitative analysis of Tamil Nadu Rice farming. *Journal of Development Studies, 21*(2), 232-243. http://dx.doi.org/10.1080/00220388508421940

Kebede, T. A. (2001). Farm household technical efficiency: A stochastic frontier analysis. *A Study of Rice Producers in Mardi Watershed In the Western Development Region of Nepal. Departemen of Economics and Social Sciences, Agricultural University of Norway*.

Kassie, M., Zikhali, P., Pender, J., & Köhlin, G. (2010). The economics of sustainable land management practices in the Ethiopian Highlands. *Journal of agricultural economics, 61*(3), 605-627. http://dx.doi.org/10.1111/j.1477-9552.2010.00263.x

Kassie, M., Pender, J., Yesuf, M., Kohlin, G., Bluffstone, R., & Mulugeta, E. (2008). Estimating returns to soil conservation adoption in the northern Ethiopian highlands. *Agricultural Economics, 38*(2), 213-232. http://dx.doi.org/10.1111/j.1574-0862.2007.00295.x

Kumbhakar, S. C., & Hjalmarsson, L. (1995). Labour - use efficiency in Swedish social insurance offices. *Journal of Applied Econometrics, 10*(1), 33-47. http://dx.doi.org/10.1002/jae.3950100104

Kumbhakar, S. C. (1991). Estimation of technical inefficiency in panel data models with firm-and time-specific effects. *Economics Letters, 36*(1), 43-48. http://dx.doi.org/10.1016/0165-1765(91)90053-N

Kumbhakar, S., Ghosh, S., & McGuckin, J. (1991). A Generalized Production Frontier Approach for Estimating Determinants of Inefficiency in U.S. Dairy Farms. *Journal of Business and Economic Statistics, 9*, 279-286. http://dx.doi.org/10.1080/07350015.1991.10509853

Kuntashula, E., Chabala, L. M., & Mulenga, B. P. (2014). Impact of Minimum Tillage and Crop Rotation as Climate Change Adaptation Strategies on Farmer Welfare in Smallholder Farming Systems of Zambia. *Journal of Sustainable Development, 7*(4), 95-110. http://dx.doi.org/10.5539/jsd.v7n4p95

Langemeier, M. (2010). Relative technical and cost efficiency of no-till farms. *Journal of International Farm Management, 5*(2), 1-11. www.ifmaonline.org

Lee, L. (1983). A Test for Distributional Assumptions for the Stochastic Frontier Function. *Journal of Econometrics, 22*, 245-267. http://dx.doi:10.1016/0304-4076 (83)90102-1

Meeusen, W., & Van den Broeck, J. (1977). Efficiency Estimation from Cobb – Douglas Production Functions with Composed Error. *International Economic Review, 18*, 435-444. http://dx.doi.org/10.2307/2525757

Musaba, E., & Bwacha, I. (2014). Technical Efficiency of Small Scale Maize Production in Masaiti District, Zambia: A Stochastic Frontier Approach. *Journal of Economics and Sustainable Development, 5*(4), 104-111.

Mwape, F. (1988). *Relative Economic and Allocative Efficiency of Emergent and Commercial Maize Farms in Zambia*. Ph.D Thesis, University of Manitoba, Winnipeg, Canada. Retrieved from http://mspace.lib.unmanitoba.ca/jspui/handle/1993/16767

Namonje, T. S. (2014). Does Late Delivery of Subsidized Fertilizer Affect Smallholder Maize Productivity and Production? *"Employment Strategies in the Developing World - How to create sufficient, productive and decent jobs"* Lusaka 18th September 2014.

Ngoma, H., Mulenga, B. P., & Jayne, T. S. (2013). Determinants and Extent of Use of Minimum Tillage Practices among Zambian Smallholder Crop Farmers from 2008 to 2012.

Ngombe, J., Kalinda, T., Tembo, G., & Kuntashula, E. (2014). Econometric analysis of the factors that affect adoption of conservation farming practices by smallholder farmers in Zambia. *Journal of Sustainable Development, 7*(4), 124-138. http://dx.doi.org/10.5539/jsd.v7n4p124

Nyanga, P. H., Johnsen, F. H., Aune, F. H., & Kalinda, T. H. (2011). Smallholder Farmers' Perceptions of Climate Change and Conservation Agriculture: Evidence from Zambia. *Journal of Sustainable Development, 4*(4), 73-85. http://dx.doi.org/10.5539/jsd.v4n4p73

Nyanga, P. H. (2012). Factors influencing adoption and area under conservation agriculture: a mixed metthods approach. *Sustainable Agriculture Research, 1*(2), 27. http://dx.doi.org/10.5539/sar.v1n2p27

Nwagbo, E. C. (1989). Impact of Institutional Credit on Agriculture in Funtua Local Government area of Katsina State, Nigeria. *Samaru J. Agric. Res., 6*, 75-86.

Obwona, M. (2006). *Determinants of technical efficiency differentials amongst small and medium scale farmers in Uganda: A case of tobacco growers* (Vol. 152). African Economic Research Consortium.

Onyenweaku, C. E., & Effiong, E. O. (2006). Technical efficiency in pig production in Akwa Ibom State, Nigeria. *International Journal of Agriculture and Rural Development, 6*(1), 51-57. http://dx.doi.org/10.4314/ijard.v6i1.2588

Pieri. C., Evers, Landers, G., Connell, P., & Terry, E. (2002). *No-Till Farming for Sustainable Rural Development.* Agriculture & Rural Development Working Paper. Washington, DC 20433. Retrieved from http://www.betuco.be/CA/Notillage%20Farming%20for%20 Sustainable%20 Development.pdf

Pitt, M. M., & Lee, L. F. (1981). The measurement and sources of technical inefficiency in the Indonesian weaving industry. *Journal of development economics, 9*(1), 43-64. http://dx.doi:10.1016/0304-3878 (81)90004-3

Reifschneider, D., & Stevenson, R. (1991). Systematic departures from the frontier: a framework for the analysis of firm inefficiency. *International Economic Review*, 715-723. http://dx.doi.org/10.2307/2527115

Schmidt, P., & Knox Lovell, C. A. (1979). Estimating technical and allocative inefficiency relative to stochastic production and cost frontiers. *Journal of econometrics*, *9*(3), 343-366. http://dx.doi:10.1016/0304-4076 (79)90078-2

Siziba, S. (2008). Assessing the adoption of conservation agriculture in Zimbabwe's smallholder sector. PhD Thesis. University of Hohenheim, Germany.