APPLICATION OF STOCHASTIC FRONTIER APPROACH MODEL TO ASSESS TECHNICAL EFFICIENCY IN KENYA'S MAIZE PRODUCTION

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Abstract

Kenya realised tremendous growth in maize production between 1964 and 1997, fueled by the introduction of high yielding hybrid maize. However, from 1997, there has been a decline in yield from 1.85 to 1.57 metric tones per hectare with observed supply shortages occasionally. Maize shortages result in famine among the poor urban and rural households. Since almost all the arable land is under cultivation, future increase in maize production will heavily depend on technical efficiency and yield improvement rather than expansion in area under production. The main objective of this study was to determine the technical efficiency of smallholder maize production in Kenya. The stochastic frontier model was used as the method of analysis to estimate several production function forms using cross-sectional household data for the 2003/2004 main cropping season. Variations in technical efficiency index across smallholder farm units were explained through a number of socio-economic, farm characteristic and Agro-Ecological Zone variables. The results of the translog functional form revealed that the technical efficiency index across smallholder farm units ranged from 8 to 98 percent. Purchased hybrid seeds, use of tractors for land preparation, number of school years of household head, male headed households, age of household head, access to credit and high potential zone dummy variables had a negative sign, and therefore decreased technical inefficiency (increased technical efficiency). Calculations of marginal effects showed that purchased inputs and primary education had the highest improvement of technical efficiency i.e. hybrid seed (36%), tractor services (26%) and an extra year of household head primary schooling (0.84%). It is therefore concluded that improvement of maize input markets together with an emphasis on primary school education would enhance maize productivity. Thus, if hybrid seeds, tractor services and agricultural credit are made available and affordable to farmers technical efficiency would increase.

Key words*:* Socio-economic factors, farm characteristics, maize

1.0 Introduction

Most of the studies into the estimation and explanation of variation in technical efficiency in agriculture have mainly focused on Asian countries particularly Pakistan (Parikh and Shah,1994; Batese *et al*., 1996), India (Battese and Coelli, 1995) and China (Wang *et al*., 1996). However, with the notable exceptions of Seyoum *et al*., (1998) and Mochebelele and Winter-Nelson (2002), measurements of technical efficiency in Sub-Saharan region and especially East African agriculture has received less attention. Empirical investigation of efficiency of Kenyan farmers has been limited to studies of a sample of farms mostly in the high potential zones and mainly to dairy farmers. These studies have used average production function (Kilungo, 1999; Murithi, 1990; Mwangi, 1981) to evaluate the efficiency of resource use in agriculture. However, the use of average production function implicitly assumes that all producers face the same set of prices and therefore run the risk of confusing the effects of allocative inefficiency with those of technical inefficiency. Further, average production function models do not provide a numerical measure of farm-specific efficiency (Aigner *et al*., 1977). Additionally, no Kenyan study was particularly concerned with evaluating those factors which might be associated with the inability of producers to attain the technically efficient frontier in the cereals sub-sector. This study therefore sought to estimate the levels of technical efficiency/inefficiency of maize production across the Agro-Ecological zones in Kenya using a stochastic frontier production function model, following Battese and Coelli (1995). It differs from previous work on efficiency of Kenyan agriculture (Kilungo, 1999; Murithi, 1990; Mwangi, 1981) in that it utilized survey data which was maize enterprise specific and hence allowed the model to be formulated, for the most part, using variables which represent farm specific input quantities. It further differed by using the approach developed by Battese and Coelli (1995) in which the inefficiency effects were modeled explicitly to identify the cross-sectional socio-economic characteristics, management practices and agro-ecological zones that impact the technical efficiency of maize production.

Maize is an important staple food in Kenya, grown in almost all agro-ecological zones and accounts for about 40 percent of daily calories (Kibaara, 2005). It has a per capita consumption of 98 kilograms which translates to between 30 and 34 million bags of annual maize consumption in Kenya. The country produces an average of 28 million bags annually (each bag weighing 90 kilograms). The deficit is usually bridged by imports from neighboring countries. There was a steady growth in maize production between 1964 and 1997, fueled by the introduction of high yielding hybrids. For example, between 1979 and 1986, production increased from 1.75 million tons (19 million bags) to 2.9 million tons (32 million bags) (Nyoro, 2002).

The national average maize yields are estimated at 1.8 tons per hectare (20 bags of 90kilogram bags). These yields are about one twentieth of those attained internationally in countries such as Argentina. In the early 80s, the maize yields started to increase following adoption of hybrid maize varieties and the accompanying high fertilizer use to the extent that by 1986, the average national yields were over 2 tons per hectare (Nyoro, 2002). However, this growth was not sustained. Yields started to fall gradually and stagnated at 1.85 metric tones per hectare by the end of 1989 (Karanja *et al*., 1998).

Maize yields differ by agro-ecological zones. Some of the farmers in the high potential maize zones in the Riff Valley have been able to achieve between 4 and 6 tons per hectare (i.e. 45 and 65 bags per hectare). This implies that there is potential to increase maize productivity in the country. However, since 1997 there has been a continuous decline in national average yield to as low as 1.57 metric tones per hectare (i.e. 17 bags /ha). Since almost all the arable land is under cultivation in Kenya, future increase in maize production will heavily depend on technical efficiency and yield improvement rather than expansion in areas under production (Karanja and Oketch, 1992)**.** The government policy on the maize sub-sector is to increase production so that self-sufficiency and food security can be achieved. One way of realizing this goal is to increase farm output by improving technical efficiency. It was therefore necessary to determine the level of technical efficiency and the various socio-economic and management characteristics attributed to inefficiencies in maize production.

2.0 Methodology

2.1 Data and Variables

The data used in this study were taken from cross-sectional household survey carried out by Tegemeo Institute of Agricultural Policy and Development, Nairobi-Kenya in 2003/2004 short rain cropping season. It was collected under the Tegemeo Agricultural Monitoring and Policy Analysis Project (TAMPA), a collaborative effort between the Institute, Michigan State University and United States Agency for International Development. The project was mandated to provide baseline information and subsequent monitoring of smallholder agricultural production patterns to assess the impacts of changes in the agricultural policy environment on selected socio-economic and regional groups in Kenya. The study used 2003/2004 main harvest cropping year cross-sectional household data. Stratified random sampling was used to select 2017 agricultural households covering all the eight (8) provinces of Kenya in the rural areas. The sample was a national representation of all maize growing farmers in high potential areas in the rift valley; medium potential areas in central province and western province; marginal zones in Eastern province and South Nyanza; arid areas of North Eastern and the coastal lowlands of Kenya. Then a survey of all the respondents was undertaken for the study. The sample was categorized in to high, medium and low potential zones. Trained graduates with a degree in an agricultural related field gathered data via person-to-person interview under the supervision of experienced researchers from Tegemeo Institute. The descriptive statistics are as presented in Table 1.

The average yield per acre was 8.27 bags (20 bags/ha). This yield was relatively low compared to maize yields in the maize basket zone of the Rift Valley province because it is a national average yield of the whole country. This yield was obtained by using: 42 kilograms of fertilizer, 9.11 kilograms of seed and 61 person-days of labor. In addition, 42 percent of the households used manure. The statistics revealed that 59 percent of the farmers purchased hybrid seed while the rest used retained hybrid or local seeds recycled for a number of years. Only 23 percent of the

Table 1: Descriptive statistics for the variables

Variable	**Description**	**Units**	**Mean**	**Std. Deviation**	**Min**	**Max**
Yield	Yield in bags per acre	Bag/acre	8.27	6.46	0.95	34
Fert	Fertilizer per acre	Kilograms/acre	42.06	52.45	0	420
Seed	Seed per acre	Kilograms/acre	9.11	5.06	0.63	48
Labor	Person-days per acre	Person-days/acre	61.29	45.67	2	372
Manure	Used manure on the maize field	1=yes, 0=no	0.42	0.49	0	
Purchybr	Purchased hybrid maize seed	1=yes, 0=no	0.59	0.49	0	1
Tractor	Used tractor for land preparation	1=yes, 0=no	0.23	0.42	0	1
Schyrs	Number of school years	Years	7.18	4.71	0	19
Malehead	Head if household	1=male, 0=else	0.84	0.36	0	1
Headill	Head of household ill	1=yes, 0=no	0.08	0.26	0	1
Agedummy	Age of household	1=<50, 0=>50 years	0.4	0.49	0	1
Offinc	Off-farm income	1=yes, 0=no	0.68	0.47	0	1
Credit	Obtained credit	1=yes, 0=no	0.24	0.43	0	1
Low	Low potential	1=yes, 0=no	0.27	0.45	0	1
Medium	Medium potential	1=yes, 0=no	0.43	0.5	0	1
High	High potential	1=yes, 0=no	0.29	0.46	0	1

Source: Tegemeo Institute, Kenya, 2004, rural household survey

Households used tractors and this low usage could be related to the high cost of leasing or owning a tractor. In addition, the land terrain may hamper use of tractors. It was also observed that 84 percent of the households were male headed. Only 8 percent of the households reported illness of the head of the household within three months prior to the date of the interview. The household heads with less than 50 years of age constituted 40 percent of the sample. The proportion that received agricultural credit was only 24 percent. Finally, 27 percent of the respondents were in the low potential region, 43 percent in the medium and 29 percent in the high potential region. In addition, 68 percent of the households engaged in an off-farm income earning activity.

2.2 The Technical Inefficiency Effects Model

The Battese and Coelli (1995) technical inefficiency effects model is an extension of the more usual stochastic error component frontier function which allows for identification of factors which may explain differences in efficiency levels between observed decision-making units. The conventional stochastic frontier approach involves estimation of a function with a composite error term, including a symmetric and a one-sided component (following Aigner *et al*. (1977) and Meeusen and van den Broeck (1977)). In the case of the frontier production function, the symmetric component, v_i, represents random variations in production due to factors outside the control of the farmer (such as climate and measurement error) and is assumed to be independently and identically distributed as *N(0,* σ_v^2).The one-sided component, μ, is associated with technical inefficiency of production and measures the extent to which observed output deviates from potential output given a certain level of inputs and technology. Commonly, it has been assumed that this component has an identical and independent half-normal distribution, although a variety of other distributional specifications are possible (Greene, 2002). The one sided component reflects technical inefficiency relative to the stochastic frontier and as such $\mu_i = 0$ for any production unit whose output lies on the frontier and $\mu_i > 0$ for any output lying below the frontier.

A number of studies have explored the determinants of technical efficiency using a two-step procedure (Parikh and Shah, 1994; Karanja, 2002). However, Battese and Coelli (1995) developed a one-step procedure of estimating the parameters of the stochastic production frontier and the inefficiency model simultaneously given that the technical inefficiency effects are stochastic. In this case the μ_i, are assumed to be non-negative random variables, independently distributed and arising from the truncation at zero of the normal distribution with variance σ^2 and mean $z_i\delta_i$ where z_i is a vector of variables which are assumed to explain technical inefficiency and δ is a vector of coefficients to be estimated.

2.3 Empirical Model Specification

A number of previous studies specified a Cobb-Douglas production function to represent the frontier function; however, the Cobb-Douglas function imposes a severe prior restriction on the farm's technology by restricting the production elasticities to be constant and the elasticities of input substitution to unity (Wilson, *et al*., 1998). This study specifies the stochastic frontier production function using the flexible translog specification. The model is specified as follows.

$$\ln y_i = \alpha_0 + \sum_{k=1}^{3} \alpha_k \ln x_{ki} + \frac{1}{2} \sum_{k=1}^{3} \sum_{j=1}^{3} \alpha_{kj} \ln x_{ki} \ln x_{ji} + \varepsilon_i$$

$$\varepsilon_i = v_i - u_i \quad \text{……(1)}$$

Where, In denotes natural logarithms, y and x variables are defined in Table 1, α's are parameters to be estimated. The inefficiency model is estimated from the equation given below.

$$u_i = \delta_0 + \sum_{m=1}^{12} \delta_m z_i \quad \text{……(2)}$$

The variables z_i are the variables in the inefficiency model. Equation 3 below shows a joint estimation of a stochastic frontier production function in Limdep (Greene, 2002).

$$lnyield = \alpha_0 + \alpha_1 lnfert + \alpha_2 lnseed + \alpha_3 lnlabor + \alpha_4 lnfert^2 + \alpha_5 lnseed^2 + \alpha_6 lnlabor^2 + \alpha_7 lnfert^* \alpha_8 lnseed + \alpha_9 lnfert^* lnlabor + \alpha_{10} lnseed^* lnlabor + \alpha_{12} lnmanure + \delta_0 + \delta_1 purchybr + \delta_2 tractor + \delta_3 schyrs + \delta_4 schsqd + \delta_5 malehead + \delta_6 headill + \delta_7 agedummy + \delta_8 offinc + \delta_9 offinc^* schyrs + \delta_{10} purchybr^* credit + \delta_{11} high + \delta_{12} low + v \quad \text{……(3)}$$

The first section is the stochastic frontier production function while the second part captures the inefficiency model variables. The model generates variance parameters, (i.e.) Lambda, $\lambda = (\sigma_u/\sigma_V)$; variance of the model (Sigma σ), variance of the stochastic model (σ_v^2) and variance of the inefficiency model (σ_u^2).

3.0 Model Estimation and Results

Equation 3 was estimated after correcting the data for heteroscedasticity and the orthogonality condition which were found to be present. Data were also analyzed using different functional forms, i.e. the translog, quadratic, transcendental and Cobb-Douglas production functions. Table 2 shows results of the stochastic frontier model from the different functional forms.

Table 2: Technical efficiency from different production functional forms

Variable	Parameters	Translog	Cobb Douglas	Quadratic	Transcendental
Stochastic Frontier					
Intercept		0.0844	0.7464***	0.0089	0.7284***
LNFERT		0.0399	0.1433***	-0.0217	0.0335***
LNSEED		0.6929***	0.4706***	0.9239***	0.7726***
LNLABOR		0.4255***	0.1476***	0.4019***	0.1719***
LNFERTSQ		0.0348***		0.0346***	
LLNLABORSQ		-0.0360**		-0.0349*	
LNSEEDSQ		-0.1631***		-0.1308***	
LNFERT*LNLABOR		-0.0414***			
LNFERT*LNSEED		0.0470***			
LNLABOR*LNSEED		0.0575*			
MANUREH		0.0808***	0.0344	0.0712***	0.4820***
FERT					0.0036***
SEED					-0.0653***
LABOR					-0.0013*
FSERT*SEED					0.000044
FERT*LABOR					0.000014***
SEED*LABOR					0.0002***
Inefficiency model					
Constant		0.3413***	0.3168***	0.0712***	0.4820***
Purchased hybrid		-0.5238***	-0.4909***	0.3474***	-0.2624***
Tractor use		-0.3628***	-0.3744***	-0.5245***	-0.3429***
School years		-0.0109*	-0.0064*	-0.3615***	0.0005*
School years squared		0.0022***	0.0023***	-0.0108*	0.0021***
Male headed		-0.1206	-0.0982	0.0022***	-0.0306***
Ill head of household		0.1056	0.0975	-0.1227	0.0594
Age dummy		-0.0006	-0.0007	0.1010	-0.0004
Off-farm income dummy		0.0184	0.0151	-0.0007	-0.0214
Off-income*education		-0.0271***	-0.0292***	0.0166**	-0.0217***
Purchase*credit		-0.3161***	-0.3485***	-0.0271***	-0.3470***
High potential		-0.5972***	-0.4886***	-0.3658***	-0.2372***
Low potential		0.2362***	0.2272***	-0.5978***	0.1348
Variance parameters					

Lambda (σ_u/σ_v)	λ	1.9336***	1.9689***	1.933***	2.0155***
Sigma	Σ	0.9351***	0.9682***	0.9424***	0.8692***
Sigma-squared(u)	σ_u^2	0.6899***	0.7451	0.7011	0.6063***
Sigma-squared(v)	σ_v^2	0.1845	0.1922	0.1871	0.1492***
Ln (likelihood)		-2121.0	-2166.00	-2131.00	-2078.00
Gamma, $\sigma_u^2/(\sigma_u^2+\sigma_v^2)$	γ	0.789	0.795	0.789	0.803
Mean technical efficiency		49%	49%	49%	48%

Source: Authors' analytical estimates. ***, ** and * represent significance level at 1%, 5% and 10% consecutively

The mean technical efficiency was computed for each model. The estimated mean TE is 49 percent, however, the estimate from the transcendental function was lower by one percent. Because the four functions generate similar results, this study focused on the result of the translog production function because of its flexibility as compared to the restrictive Cobb-Douglas function in the production function and the inclusive capability to capture the interactive term of inputs as quadratic functional form. Although the transcendental production function captures the three stages of production, it is not considered in this case because of lower technical efficiency. The translog production function has been used in stochastic production frontier studies by Wilson *et al*., (2001); Liu and Zhuang, (2000); Awudu and Eberkin, (2001); Awudu and Huffman, (2000), and Wilson *et al*., (1998).

Elasticities of output with respect to input were calculated at the mean of the data from the parameter estimates shown in Table 2 and had the following values (t-statistics follow in the paratheses): fertilizer 0.17 (5.7656), seed rate 0.63 (3.0335) and labor 0.46 (2.0724). The semi-elasticity for manure was 8.4 implying that for the households that used manure, the median yield is higher by 8.4 percent as compared to their counterparts who did not use manure, *ceteris paribus*.

Elasticity of output with respect to labor was positive as expected unlike in other studies in Europe (Wilson *et al*., 1998; Dawson, 1987; and Hallam and Machado, 1996) who also specified the production frontier function in translog form. As observed in the above results, all the input elasticities were inelastic; a one percent increase in each input resulted in a less than one percent increase in yield.

The Marginal Value Products (MVPs) were computed as: fertilizer Kshs. 39.86, seed rate Kshs. 665.23 and labor Kshs. 72.42. The unit factor prices of fertilizers, seeds and labor were given as Kshs 30.00, Kshs. 130.00 and Kshs. 70.00 respectively. Profit maximizing conditions require the MVP to equal the respective unit factor prices. This necessary condition was only satisfied for labor because MVP was approximately equal to the price of labor (wage rate). Therefore, use of labor will be irrational and will lead to losses. The output price in Kenya Shilling (Ksh) is 1170.

However, for fertilizer and seed the MVP is greater than the factor price, which indicates that maize production has not reached the optimal use of inputs, and could probably benefit the farmers by increasing the quantity of seed and fertilizer used in maize production.

Likelihood ratio tests were performed to test various hypotheses in Table 3. The first test determined if the Cobb-Douglas functional form was an adequate representation of the frontier production against the alternative translog specification. The null hypothesis, H_0 = $ß_{ik}$ = 0 is rejected in favor of the translog production function. The second null hypothesis explored the test that specifies each farm was operating on the technically efficient frontier and that the systematic and random technical efficiency in the inefficiency effects were zero. This was rejected in favor of the presence of inefficiency effects. The final null hypothesis determined whether the variables included in the inefficiency effects model had no effect on the level of technical inefficiency. $H_0; \lambda = \delta_0 = \delta_2 = \dots \delta_p = 0$, the null hypothesis was rejected confirming that the joint effect of these variables on technical inefficiency was statistically significant.

Table 3: Llikelihood ratio tests

Null hypothesis	Calculated value	Df	Pvalue	Decision
$H_0 = ß_{ik} = 0$	95.73	6	0.0000	Reject Ho
$H_0;u = 0$	480.15	1	0.0000	Reject Ho
$H_0; \lambda = \delta_0 = \delta_2 = \dots \delta_p = 0$	175.14	13	0.0000	Reject Ho

Source: Authors' Analytical Tests, 2005

The TE of the ith farm is calculated from the following:

*TE_i=exp (-u_i) *100 (TE is converted into a percent by multiplying this equation by 100).* (4)

Technical efficiency was calculated using the conditional expectation of the above equation, conditioned on the composed error ($e_i = v_i - u_i$), and evaluated using the estimated parameters presented in Table 2 from the translog production function.

TE is computed for each farm with the households later disaggregated into three regions, i.e. the high, medium and low potential. Figure 1 shows a histogram of predicted technical efficiencies. The minimum estimated efficiency was 8.04 percent, the maximum 98.30 percent and the mean was 49 percent with a standard deviation of 19.71 percent. The results imply that in the short run, there is a scope for increasing maize production by 51 percent by adopting technologies and techniques used by the best practice maize farms. This suggests that, on average; about 51.30 percent of maize yield is lost because of inefficiency. However, each region has a different estimated mean technical efficiency.

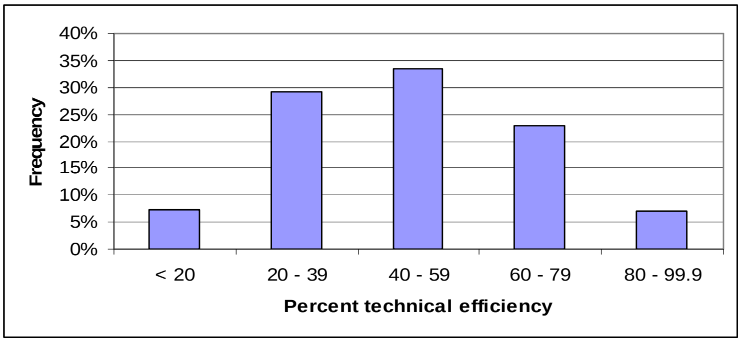

Figure 1: Frequency Distribution of Predicted Technical Efficiency
Source: Tegemeo Institute, Kenya, 2004 rural household survey

Most of the variables determining inefficiencies were also statistically significant. The estimate of λ was 1.9258 and σ is 0.9300 were large and significantly different from zero, indicating a good fit and correctness of the specified distribution assumption. (λ) is the ratio of variance of u (σ_u) over variance of v (σ_v) and is an indication that the one sided error term u dominates the symmetric error v, so variation in actual maize yield comes from differences in farmer's practice rather than random variability.

4.0 Technical Inefficiency and Socio-Economic Characteristics

Given the difference in efficiency levels among farm units, it was appropriate to determine why some producers can achieve relatively high efficiency whilst others were technically less efficient. Variation in the TE of producers may arise from socio-economic, managerial decisions and farm characteristics that affect the ability of the farmers to adequately use the existing technology. The parameter estimates for the inefficiency model presented in Table 2 suggest a number of factors which may explain part of the variation in observed efficiency levels.

The results reveal that hybrid seeds, use of tractors for land preparation, number of school years for head of household, off-farm income, access to credit, and high potential zone have the most important effects in determining levels of technical inefficiency for this sample. A negative sign on the dummy variable for purchasing hybrid seeds indicates that use of certified maize seed decreases technical inefficiency. However, despite the gains in technical efficiency, only 59 percent of the farmers used certified purchased hybrid seeds. This was probably because of high prices for hybrid seeds, making them unaffordable to most subsistence maize producers. The other maize producers used recycled seeds. Use of tractors in land preparation reduces technical inefficiency. Compared to use of manual labor, use of tractors allows deep tillage of the soil that enhances yield. In addition, tractor use ensures timely land preparation, planting and weeding. Years of school variable indicated that an increase in the number of school years decreases technical inefficiency. In addition, the coefficient on the interactive dummy on years of school and credit was negative and significant at one percent suggesting that educated farmers without a credit constraint were more efficient than their counterparts who face credit constraints. Awudu and Huffman (2000) made a similar conclusion on the efficiency of rice farmers in Northern Ghana. The positive impact of the off-farm income variable indicated that farmers engaged in off-farm income earning activities tend to exhibit higher levels of inefficiency. This suggests that involvement in non-farm work is accompanied by reallocation of time away from farm related activities, such as adoption of new technologies and gathering of technical information that is essential for enhancing production efficiency. However, for the Kenyan maize farmers an interaction between off-farm income and education variables was negative, an indication that educated farmers that generate off-farm income tend to exhibit higher technical efficiency levels in maize production. Such farmers were not financially constrained and can therefore purchase the required inputs for maize production. In addition, they have sufficient education to enable them to make timely decisions on the allocation of farm inputs and general farm management. Educated farmers are better managers meaning that they produce closer to their production frontier.

Finally, the coefficient on the dummy variable for the high potential maize zone suggests that producers in this region are less inefficient and closer to their production frontier than their counterparts in medium and low maize potential region. Probably, this could be explained by the favorable climate for maize production in the high potential maize zones. On the other hand, the dummy variable for the low potential region was positive, indicating that maize producers in the low potential regions were inefficient. In order to avoid the dummy variable trap, the medium potential region was captured by the intercept (constant) variable; in this case the intercept was positive and therefore shows that, technically producers in the medium potential regions are less efficient than those in the high potential.

The estimated parameters on the inefficiency model presented in Table 2 only indicate the direction of the effects that the variables have on inefficiency levels. Quantification of the marginal effects of these variables on technical efficiency is possible by partial differentiation of the technical efficiency predictor with respect to each variable in the inefficiency function. In their article, Battese and Coelli (1995) show that for the *i*-th firm in the *t*-th time period, technical efficiency is predicted using the conditional expectation:

$$TE_{it} = E[\exp(-\mu_i)\mathrm{I}E_i = e_i]$$

$$= \exp(-\mu_* + \frac{1}{2}\sigma_*^2)\left(\frac{\Phi[(\mu_*/\sigma_*) - \sigma_*]}{\Phi(\mu_*/\sigma_*}\right) \quad (5)$$

Where

$$\mu_* = (1-\gamma)z_{it}\partial - \gamma\varepsilon_{it}$$

$$\sigma^2{}_* = \gamma(1-\gamma)\sigma_s^2$$

$$\gamma = \frac{\sigma_u^2}{\sigma_s^2}, \ \sigma_s^2 = \sigma_u^2 + \sigma_v^2$$

$\varepsilon_i = v_i - \mu_i$ and Φ represents the distribution of the standard normal random variable. Table 4 presents results of partial differentiation of equation (5) with respect to each of the inefficiency variables, evaluated at their mean values or with a value of one for dummy variables and where the residuals e_t are calculated at the mean values of the dependent and independent variables in the stochastic frontier function (Wilson, *et al*., 2001).

Table 4 shows the marginal effects of the efficiency measuring variables (this table is interpreted differently, a positive sign indicate an increase in TE). If the variables are constructed as dummy variables, the respective coefficients estimated represent a one-off shift in efficiency rather than a true marginal effect. Producers who use hybrid maize seed are 36 percent more efficient than those that do not, *ceteris paribus*. This is equivalent to an increased yield of 6 bags. As seen earlier from the descriptive statistics, most maize producers use a seed rate close to the recommended 10-kilogram.

Table 4: Marginal effects of the efficiency measuring variables

Variable	**Change in TE**	**Change in TE in %**	**Change in bags per acre**
PURCHASE OF HYBREED MAIZE***	0.3632	36.32	6.14
TRACTOR***	0.2612	26.12	4.41
SCHOOL YEARS*	0.0084	0.84	0.14
SCHOOL YEARS SQUARED***	-0.0017	-0.17	-0.03
MALEHEAD	0.0918	9.18	1.55
HEADILL	-0.0847	-8.47	-1.43
AGEDUM	0.0005	0.05	0.01

Source: Tegemeo Institute, Kenya, 2004 Rural Household Survey

Therefore, in order to increase the yield, they probably need to improve the quality of maize seeds rather than the quantity of seed. Mechanizing farming operations is a very important step toward increasing production efficiency, in this case, producers that use tractors increase the level of technical efficiency by 26 percent, and this can be converted to approximately 4 bags of maize per acre. The marginal change (gain in TE) for an additional year of school is 0.84 percent. This translates to 0.14 bags (or 13 kilograms). However, this change in TE increases at a decreasing rate of 0.17 percent.

Male-headed households have a marginal effect of 9.18 percent TE and are relatively more efficient than the female headed households. However, its coefficient (i.e. -0.1206) was not statistically significant. A plausible explanation for these results is that women generally have less access to agricultural resources (e.g. land ownership, extension services, credit etc.) which results in inefficiency in their operations. For example in the current study, 16 percent of the households who received agricultural credit in the eight (8) agro-ecological zones (AEZ) were female headed. Western Highlands had 30 percent followed by Coastal Lowlands with 25 percent. All the other six (6) AEZs had less than 20 percent of agricultural credit going to female headed households. Though illness of the household head was not statistically significant; the marginal effect was 8.47 percent. Younger maize producers (less than 50 years old) are 0.05 percent technically more efficient than the older producers. Finally, participation in off-farm income earning activity reduces technical efficiency by 1.45 percent.

5.0 Summary and Recommendations

This study set out to provide estimates of technical efficiency in Kenyan maize production and to explain variations in technical efficiency among farms due to managerial and socio-economic characteristics. Farm specific technical efficiencies were computed using 2003/2004 maize production cross sectional data from the Tegemeo Institute of Agricultural Policy and Development. The results show that the overall mean technical efficiency is estimated at 49 percent and that there is scope for increasing maize production by using the current technology. However, technical efficiency ranges between 8 to 98 percent among the maize producers in Kenya. Use of certified hybrid seed, use of tractors for land preparation, level of education, an interaction of off-farm income and education, purchase of hybrid seed on credit, younger age of the household heads and households in the high potential areas are associated with a higher technical efficiency. Further, calculations of marginal effects have shown that use of hybrid seed increase technical efficiency by 36 percent from the current 49 percent. In addition, mechanizing maize farms increase technical efficiency by 26 percent. In addition, an extra year of school is projected to increase the level of technical efficiency by 0.84 percent.

This study has shown that use of agricultural credit to purchase hybrid seed reduces technical inefficiency. Credit is necessary to encourage technical innovations, such as use of yield-enhancing inputs, which cost slightly more, but transforms the entire input-output relationship. Currently agricultural lending by commercial banks is relatively low and stands at 5.35 percent of the total lending portfolio (Kodhek, 2004). The main deterrent to obtaining credit is high interest rates as the annual percent rate ranges between 12 to 65 percent for commercial banks and village banks (i.e. rural community owned Financial Services Associations which are mainly promoted by K-Rep development agency since 1997), respectively (Kodhek, 2004). Thus, the financial markets for rural agriculture are quite limited, and results in low access to credit.

Financial markets in Kenya operate under market forces of supply and demand. However, liberalized lending rates do not seem to have achieved the social desired outcome in agriculture. The government should probably influence lending rates on credit and loans for farmers by developing rural oriented financial institutions with borrowing terms geared towards agricultural development. Another government intervention is to streamline the operation of mushrooming microfinance institutions (MFIs) and village banks. Another conclusion is that an effort to emphasize primary schooling will have a positive impact on the technical efficiency in maize production. However, since the benefits of education are not instantaneous, the government should consider focusing on educating current farmers in best production practices. Non-formal agricultural education, often provided by both public and private extension services, is needed for human capital capacity building in a wide range of rural organizations and groups. The study has also shown that male-headed households are more efficient than female-headed households. FAO argues that, in Sub-Saharan Africa as a whole, 31 percent of rural households are headed by women, mainly because of the tendency of men to migrate to cities in search of wage labor. Despite this substantial role, women have less access to agricultural resources which results in inefficiency in their operations. For example, only 5 percent of the resources provided through extension services in Africa are available to women, although in some cases, particularly in food production, African women handled 80 percent of the work. Also in this study only 16 percent of agricultural credit was received by female headed households. The Kenyan government should address the concerns and needs of women, with focal points in the ministries of agriculture and other key institutions. Among other things, the government should set a law that stresses the equality of men and women in obtaining land titles, access to extension services for women, access to credit and in general access to agricultural resources which seem to limit the effectiveness of their activities.

Future studies could probably include variables that address the decision maker in maize production rather than the assumption that the household head is the decision maker in farm decisions. In addition, a quantification of number of visits by an agricultural extension agent and field level soil type could improve the precision of measurement of technical efficiency.

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