Analysis of Economic Efficiency and Farm Size: A Case Study of Wheat Farmers in Nakuru District, Kenya

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Abstract

The primary objective of this study is to examine the effect of farm size on economic efficiency among wheat producers and to suggest ways to improve wheat production in the country. Specifically, the study attempts to estimate the levels of technical, allocative and economic efficiencies among the sampled 130 large and small scale wheat producers in Nakuru District. The social-economic factors that influence economic efficiency in wheat production have also been determined.

Results indicate that the mean technical, allocative and economic efficiency indices of small-scale wheat farmers are 85%, 96% and 84%, respectively. The corresponding figures for the large-scale farmers are 91%, 94% and 88%, respectively. The number of years of school a farmer has had in formal education, distance to extension advice and the size of the farm have strong influence on the efficiency levels. The relatively high levels of technical efficiency among the small scale farmers defy the notion that wheat can only be efficiently produced by the large scale farmers.

Keywords: allocative efficiency, economic efficiency, Kenya, stochastic frontier production function, technical efficiency, wheat production

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1.0 Introduction

The relationship between farm size and land productivity has been widely debated in literature for decades and several reasons and explanations for the inverse relationship between farm size and land productivity have been put forward and tested.

A first reason is imperfect factor markets including failures in the land market, credit market Assuncão and Ghatak (2003), insurance market, Dercon and Krishnan (1996) and labour market (Barrett (1996); Assunç̃o and Braido (2007). Malfunctioning or absence of these markets will lead to suboptimal resource allocation at the farm level implying inefficiencies. An important cause of labour market imperfections in developing countries is labour supervision cost; as hired labour is assumed to be less motivated and effective, it takes more productive family labour to supervise hired labour which decreases overall labour productivity at farm level Lipton (2010). This would explain why labour and farm productivity are lower on large farms, which require more hired labour. Studies by Assuncão and Braido (2007) and Barrett *et al.,* (2010) argue that the imperfect market hypotheses imply the presence of unobservable variation between households that leads to differences in the input intensity levels which are correlated with farm area. Therefore, they add a set of household-specific characteristics such as household size, dependency ratio, and gender of the household head in testing the inverse relation between farm size and productivity. However, no previous study has shown that household characteristics completely explain land productivity.
A second important explanation questions whether the land productivity between farm size and productivity emerges (or not) from omitted variables. Importantly, differences in soil quality lead to differences in soil productivity which clearly affect output with small farmers being more productive because of having plots of better quality. In addition, farming practices and production methods might vary according to farm size, leading to differences in yields and productivity Byiringiro and Reardon (1996) and Assuncão and Braido (2007). All these studies show a decrease in the severity of land productivity when controlling for soil quality (Lamb (2003) and Barrett *et al.,* (2010), but none has found that the land productivity declines. Lipton (2010) used differentiation in farm management skills as an explanatory variable of farm productivity using panel data which allows for household-specific fixed effects. However, the evidence does not suggest that managerial skills explain land productivity.
A third explanation of the land productivity is related to methodological issues. As one of the unsettled issues, Lipton (2010) mentions that large farms cannot be considered linear replicas of small ones. Incentives to use inputs vary with production scale, that is, larger farms use different technologies than small farms. Most empirical studies on the land productivity are based on cross-sectional data and econometric models can fail to capture nonlinearities and often impose a common specification (parameters) for the whole sample. Moreover, the scale ranges that are allowed in the models may be too small to measure scale effects Collier and Dercon (2009).

1.1 Background of the Study

Wheat is the second most important crop after maize in Kenya with regard to both production and consumption. Until the early 1970's Kenya was a net exporter of wheat but currently the country imports about 60% of the total domestic demand. Wheat is grown in the cooler and medium-rainfall regions covering the Nakuru, Uasin Gishu, Trans-Nzoia and Narok districts and is mostly rain-fed. Production is carried out by small, medium and large scale farmers numbering about 9,000. The industry, supported by about 20 millers, contributes 1.4% and 30% to overall and cereal GDP, respectively. The small scale farmers are the majority of the producers but their production accounts for only one quarter of the total wheat produced. The domestic demand for wheat is growing at the rate of 7% per year even though production is increasing marginally. Wheat and its by-products have gained importance in the households' consumption patterns in the last decade. In 2005 wheat and its by-products accounted for 44% of total expenditure of main staples in urban areas, up from 35% in 1999 (Nyoro *et al*, 2005). Kenya is a high cost wheat producer and for this reason, the country requested the Common Market for Eastern and Southern Africa (COMESA) for safeguard measures to allow the country to address weaknesses in competitiveness of the sub-sector.

The increasing domestic demand for wheat is driven largely by the rapidly growing population, increased urbanization, rising incomes and a change in food preferences from traditional cereals towards wheat and wheat products. Though the country has the potential of increasing the production of wheat, the sector is faced by several challenges, notably: expensive inputs (chemicals, seeds and fertilizers); insufficient farm machineries; high fuel prices; unstable producer prices; and, sub-division of large scale farms into smaller units. The small scale farmers are the majority of the producers but they differ significantly in the use of inputs, agronomic practices and productivity from the large scale farmers (Nyoro *et al.*, 2005). The actual levels of efficiency and sources of inefficiencies among the different size categories are, however, unknown. Measuring economic efficiency in wheat production is important for a number of reasons: the significance of the sub-sector in terms of farm incomes to the rural economy; regional integration (more open borders, especially under COMESA and the East African Cooperation) is spawning higher levels of competition that require increased production and distribution efficiency; and, the importance of the sub-sector to the country's strategies relating to achievement of broad food self-sufficiency, rural employment creation and poverty reduction.

Following the experiences of the 2007/08 global food crisis when many food net-importing countries, especially those in Sub-Sahara Africa) were unable to secure supplies from the international market, the country has embarked on an aggressive plan to boost its domestic food production under the auspices of the Agriculture Sector Development Strategy (ASDS). This is essentially an import substitution strategy that requires increased investments to the agriculture sector, reformation the agricultural research and information dissemination systems, and improving access to credit in order to increase technological innovation particularly among the growers of the major cereal grains (maize, wheat and rice).

1.2 Objectives of the Study

The analysis of the link between economic efficiency and farm size in Kenya is partly motivated by the increasing pressure on agricultural land that arises from increasing population and the persistence of high rural populations despite increasing urbanization. Agricultural land is also under pressure from other sources: climate change that aggravates the already diminished fallow periods due to fragmentation in the more populous and high rainfall potential regions; declining soil fertility; and, the need for equity in land ownership that brings the large wheat farms into high prominence. The study therefore addresses an important question of whether or not there are significant economic efficiency differences between large scale farms and smallholder units that are the most likely to predominate in the future as the different pressures mount on the land resource.

The general objective of this study is to examine the effect of farm size on economic efficiency among wheat producers in Nakuru District and to suggest ways to improve wheat production in the country. The specific objectives are to estimate the levels of technical, allocative and economic efficiencies among the large and small scale wheat producers; to assess the effect of farm size on technical, allocative and economic efficiency; and to determine socio-economic factors influencing efficiency among small and large scale wheat producers. The following null hypotheses will be tested: H_0: farm size has no effect on economic efficiency; H_0: none of the identified socio-economic factors influences efficiency

2.0 Farm Size and Efficiency

Several studies have investigated the levels of technical and allocative efficiencies on various farm enterprises with different findings. Obare *et al.*, (2010) applied a dual stochastic efficiency technique and a two-limit Tobit model to analyze resource allocative efficiency in Irish potato production in Kenya. The authors established that Irish potato production in Nyandarua North District is characterized by decreasing returns to scale with a mean allocative efficiency of 0.57. The paper further established that farming experience, access to extension and credit and membership in a farmers' association positively and significantly influenced allocative efficiency.

Mulwa *et al*., (2009) used a two-step estimation technique (DEA meta-frontier and Tobit Regression) to highlight the inefficiencies in maize cultivation and their causes in Western Kenya. The study found that farmers could reduce their input use by about 20-30% and still achieve their current production level. The costs could be reduced by over 50% without affecting production thereby indirectly increasing the farmers' incomes. A study by Abate *et al* (2002) applying a stochastic frontier model in Ethiopia found that tenure status significantly influences technical efficiency. The authors report that more than half of the farmers cultivating wheat on their own plots operated above the average efficiency level compared to less than one quarter for those cultivating on borrowed plots. Beside land tenure systems, several other social economic and resource factors were identified to have an influence on technical efficiency. Technical efficiency was higher for older farmers due to experience gained over time. Male headed households were found to be more efficient than female headed households and households with more educated heads were found to be more efficient. This study however had its emphasis on wheat production and the results would not be generalized to other enterprises.

Ogundari and Ojo (2007) estimated technical and allocative efficiency of smallholder crop farmers in Nigeria using Cobb Douglas production and cost functions. The finding of the study was that farmers operated under increasing returns to scale and therefore had the potential of improving their efficiency. The educational level of the head of farmer (schooling years), farm size, quantity of fertilizer, age of farmer, credit availability and farming experience of the farmer were found to influence technical efficiency significantly.

The evidence on the farm-size efficiency relationship is mixed. It is important to clearly define the terms and methodologies adopted in investigating the relationship between farm size and the efficiency of farms based on the particular region. Most frontier studies have focused only on technical efficiency even though it is by improving overall economic efficiency that major gains in output could be achieved. The few studies reviewed above suggest there is still a gap in our understanding of the relationship between farm size and economic efficiency. This paper attempts to fill the gap by examining overall efficiency on wheat production.

2.1 Theoretical Framework

This study uses the parametric stochastic efficiency technique that follows the Kopp and Diewert (1982) cost decomposition procedure to estimate technical, allocative and economic efficiencies. Its advantage lies in the application of a stochastic frontier model with a disturbance term specification that captures noise, measurement error and exogenous shocks beyond the farm. The two-step regression model has been used to analyze the effects of the social-economic factors on economic efficiency using a censored Tobit model.

Over fifty years ago, Farrell (1957) introduced a methodology to measure economic efficiency *(EE)*, technical efficiency *(TE)*, and allocative efficiency *(AE;* by definition, *EE* is equal to the product of *TE* and *AE*. According to Farrell, *TE* is associated with the ability to produce on the frontier isoquant, while *AE* refers to the ability to produce at a given level of output using the cost-minimizing input ratios (Figure 1). Alternatively, technical inefficiency is related to deviations from the frontier isoquant, and allocative inefficiency reflects deviations from the minimum cost input ratios. Thus, *EE* is defined as the capacity of a firm to produce a predetermined quantity of output at minimum cost for a given level of technology (Farrell 1957; Kopp and Diewert 1982). Productive units can be inefficient either by obtaining less than the maximum output available from a determined set of inputs (technical inefficiency) or by not purchasing the lowest priced package of inputs given their respective prices and marginal productivities (allocative efficiency). Efficiency measurement can be categorized as either input or output oriented: input-oriented technical efficiency evaluates how much input quantities can be reduced without changing the quantities produced while output-oriented measures of efficiency estimate the extent to which output quantities can be expanded without altering the input quantities used (Coelli, 1994). Efficiency estimation can best be demonstrated by relating both allocative and technical efficiency and for ease of conceptualization, Farrell’s methodology has been applied widely while undergoing many refinements.

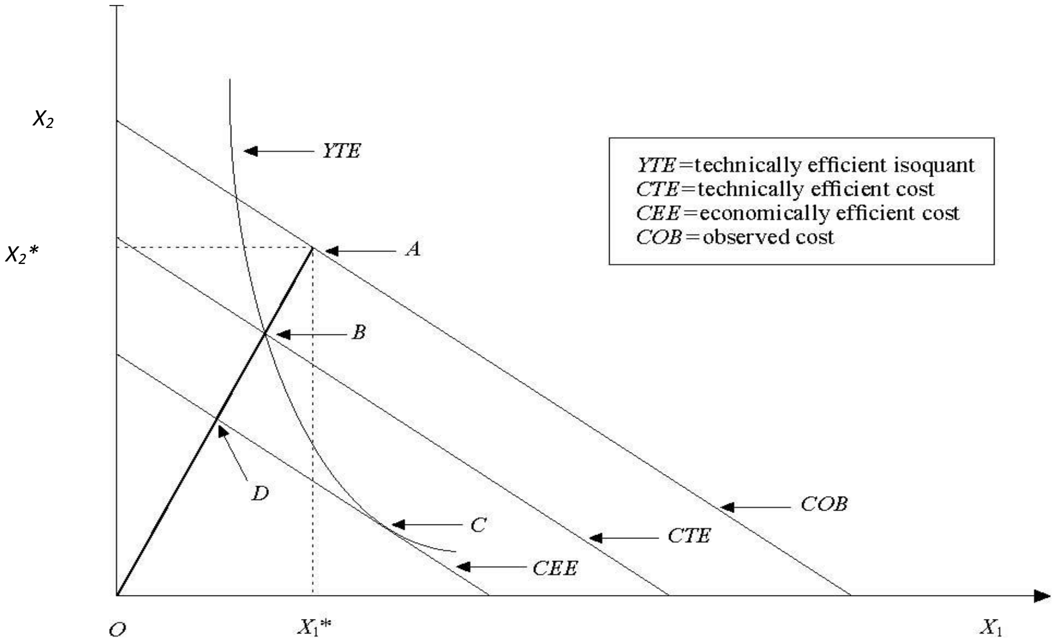

Figure 1: Graphical Representation of Observed, Technically, and Economically Efficient Cost Measures

Technical Efficiency (TE), *Allocative efficiency* (*AE)* and *Economic Efficiency* (*EE)* are equal to:
TE=OB/OA=CTE/COB,
AE=OD/OB=CEE/CTE, and
*EE=TE*AE= OD/OA=CEE/COB.*

3.0 Empirical framework: stochastic frontier production and cost functions

As in Bravo-Ureta and Evenson (1994) and Bravo-Ureta and Rieger (1997), the parametric technique used in this study follows the Kopp and Diewert (1982) cost decomposition procedure to estimate technical, allocative and economic efficiencies. The firm's technology is represented by the stochastic frontier production function as follows;

$$Y_i = f(X_i;\beta) + e_i \qquad \textit{(Equation 1.1)}$$

where:
Y_i = the output of the ith farmer

X_i = a vector of input quantities of the ith farmer

β = a vector of unknown parameters to be estimated

$e_i = (V_i - U_i)$ *(Equation 1.2)*

The V_i are assumed to be independent and identically distributed *N (0,* $\sigma^2{}_v$*)* random errors independent of the U_i.The U_i are non-negative technical inefficiency effects representing management factors and are assumed to be independently distributed with mean u_i and variance σ^2.The *i*th farm exploits the full technological production potential when the value of U_i comes out to be equal to zero, and the farmer is then producing at the production frontier beyond which he cannot produce. The greater the magnitude of U_i from the production frontier the higher the level of inefficiency of the farmer (Drysdale *et al.*, 1995).The maximum likelihood estimation of Equation 1.1 provides estimators for the *beta* coefficients. The variances of the random errors σ^2v and that of the technical and allocative inefficiency effects $\sigma^2{}_u$ and overall variance of the model σ^2 are related thus:

$$\boldsymbol{\sigma^2 = \sigma^2{}_v + \sigma^2{}_u} \qquad \textit{(Equation 1.3)}$$

The ratio $\gamma = \sigma^2{}_u / \sigma^2$, measures the total variation of output from the frontier which can be attributed to technical or allocative inefficiency (Battese and Corra, 1977).

Subtracting v_i from both sides of Equation 1.1 yields:

$$Y^*{}_i = y_i - v_i = f(X_i;\beta) - U_i) \qquad \textit{(Equation 1.4)}$$

Where $Y^*{}_i$ is the observed output of the ith firm, adjusted for the stochastic noise captured by v_i

Equation 1.4 is the basis for deriving the technically efficient input vectors and for analytically deriving the dual cost frontier of the production function represented by Equation 1.1. For a given level of output $\boldsymbol{Y^*{}_i}$ **,** the technically efficient input vector for the ith firm, $X^t{}_i$ is derived by simultaneously solving Equation 1.4 and the ratios $X_1/X_i = k_i$ (i>1) where k_i is the ratio of observed inputs X_1 and X_i. Assuming that the production function in Equation 1.1 is self-dual, the dual cost frontier can be derived algebraically and written in a general form as;

$$C_i = f(P_i;\ \alpha, Y_i^*; \alpha) \qquad \textit{(Equation 1.5)}$$

Where $\boldsymbol{C_i}$ is the minimum cost of the ith firm associated with output $\boldsymbol{Y^*{}_i}$**,** P_i is a vector of input prices for the ith firm and $\boldsymbol{\alpha}$ is a vector of parameters.

The economically efficient input vector for the ith firm, X_i^e is derived by applying Shephard's Lemma and substituting the firm's input prices and output level into the resulting system of input demand equations;

$$\partial C_i / \partial P_i = X_i^e\ (P_i\, Y_i^*\ ; \beta) \text{i=1, 2…., m inputs} \qquad \textit{(Equation 1.6)}$$

where β is a vector of estimated parameters

The observed, technically efficient and economically efficient costs of production of the ith firm are equal to $P_i`X_i$, $P_i`X^t_i$, and $P_i`X^e_i$, respectively. These cost measures are used to compute technical (TE) and economic (EE) efficiency indices for the ith firm as follows;

$$TE_i = P_i`X_i^t / P_i`X_i \qquad \textit{(Equation 1.7a)}$$

$$EE_i = P_i`X_i^t / P_i`X_i \qquad \textit{(Equation1.7b)}$$

Following Farell (1957), the allocative efficiency (AE) index can be derived from equations (1.7a) and (1.7b) as follows;

$$AE_i = P_i`X_i^e / P_i`X_i^t \qquad \textit{(Equation 1.8)}$$

Thus the total cost or economic efficiency of the ith firm $\boldsymbol{(P_i`X_i - P_i`X_i^e)}$can be decomposed into its technical $\boldsymbol{(P_i`X_i - P_i`X_i^t)}$ and allocative $\boldsymbol{(P_i`X_i^t - P_i`X_i^e)}$ components.

3.1 The Production Function

A production function can be expressed generally as $Y = f(X_i)$ where, Y is output level per unit of time, and X_i denote quantities of different inputs. Using only labor (L) and capital (K) and other factors of production held constant (in the short run), we have $Y = f(L, K)$. Generally, labor units can be changed at a short notice but it takes more time to install machinery or equipment represented here by K. Production functions can be expressed in different forms depending on the technological relationship between Y and X; indeed, the functional relationship between output and inputs is referred to as the firm's technology. Due to duality, knowledge of a firm's technology automatically reveals a firm's cost function (the relationship between Y and total cost of all inputs (including fixed costs). One of the most commonly used production function specifications for agricultural production relationships is the Cobb-Douglas function generally expressed as follows in the case of two inputs:

$$\boldsymbol{Y = (L, K) = AL^aK^b}$$

where A is a scale parameter (constant) and *a* and *b* are elasticity of output response due to changes in L and K, respectively; the coefficients a and b are generally restricted to ensure the technology exhibits decreasing returns to scale, thus allowing for a profit maximum

A variation of the Cobb-Douglas[1] function applied in this study is the stochastic frontier model defined in Equation 1.9 it is simply a linearization of the above general form using logs:

[1]*The Cobb-Douglas production form is chosen because its practicality and ease in the interpretation of its estimated coefficients. Despite its limitations of constant elasticity of substitution, the Cobb-Douglas is found to be an adequate representation of our data.*

$$\ln Y_i = \beta_0 + \beta_1 \ln fert_1 + \beta_2 \ln seed_2 + \beta_3 \ln chem_3 + \beta_4 \ln foliar_4 + \beta_5 \ln hlab_5 + \beta_6 \ln flab_6 + V_i - U_i$$

(Equation 1.9)

where:

ln	=	natural logarithm
Y_1	=	wheat output (in kg) of the i^{th} farmer per acre
$fert_2$	=	quantity of fertilizer used in kg per acre
$seed_2$	=	quantity of seeds used in kg per acre
$chem_3$	=	quantity chemicals used in kg per acre
$foliar_4$	=	quantity of foliar used in liters per acre
$hlab_5$	=	cost of hired labor per acre
$flab_6$	=	imputed cost of family labor per acre
v_i	=	random error
u_i	=	inefficiency measure.
β_i	=	parameters to be estimated

The u_i is the non-negative truncation (at zero) of the normal distribution with mean, μ_i and variance σ^2. The variables specified in the model were subjected to a correlation test that showed that all the variables were not highly correlated.

3.2 The Cost Function

The economic cost of an input is the minimum payment required to keep the input in its present employment. It is the payment the input would receive in its best alternative employment. The corresponding dual stochastic frontier cost function which is the basis of estimating the allocative efficiencies of the farmers is specified as follows:

$$C_i = f(P_i;\ \alpha, Y_i^* + U_i) \quad \text{i=1, 2, 3… N} \qquad \textit{(Equation 1.10)}$$

where;

C_i = minimum cost of the i^{th} firm associated with output, Y_i
f = Cobb-Douglas functional form
P = input prices employed by i^{th} farm in wheat production
α = parameter to be estimated
Y^*_i = the observed wheat output per acre of the i^{th} firm adjusted for the statistical noise captured by V_i
U_i provides information on the levels of allocative efficiency of the i^{th} farm

The Cobb-Douglas cost frontier function for the wheat farmers is specified as follows:

$$\ln C_i = \alpha_0 + \alpha_1 \ln y^*_1 + \alpha_2 \ln pfert_2 + \alpha_3 \ln pseed_3 + \alpha_4 \ln pchem_4 +$$
$$\alpha_5 \ln pfoliar_5 + \alpha_6 \ln phlab_6 + \alpha_7\, pflab_7 + U_i$$

(Equation 1.11)

where:
C_i = total cost of production of i^th farm per acre
Y^*_1 = observed wheat output per acre adjusted for statistical noise
$pfert_2$ = price of fertilizer per kg
$pseed_3$ = price of seeds per kg
$pchem_4$ = price per liter of chemical
$pfoliar_5$ = price per liter of chemical
$phlab_6$ = wage rate per day
$pflab_7$ =imputed family labor per day.

3.3 Determining factors influencing efficiency

Several authors have investigated the relationship between efficiency and various socio-economic variables using two alternative approaches[2]. One approach is to compute correlation coefficients to conduct other simple non-parametric analysis. The second way, usually referred to as a two-step procedure, is to first measure farm level efficiency and then to estimate a regression model where efficiency is expressed as a function of socio-economic attributes. Kalirajan (1991) observed that socio-economic attributes have roundabout effects on production and hence should be incorporated into the analysis directly while Ray (1988) argued that the two-step procedure is justifiable if one assumes that production function is multiplicatively separable in what he calls discretionary (included in production function) and non-discretionary (used to explain variations in efficiency) inputs. Analysis of the effects of firm-specific factors on economic efficiency has generated considerable debate in frontier studies. In this study, the two-step procedure has been adopted to analyze the effects of socio-economic factors in the economic efficiency of the wheat producers. The economic efficiency estimates obtained are regressed on some socio-economic factors using the Tobit model. This use of a second stage regression model of determining the socio-economic attributes in explaining inefficiency has been suggested in a number of studies (for example: Sharma *et al*., 1999; Dunghana et at., 2004)

The Tobit model

Assume the theoretical Tobit model, which takes the form:

$$\boldsymbol{Y}_k^* = \boldsymbol{X}_k\boldsymbol{\beta} + \boldsymbol{U}_k \qquad \textit{(Equation 1.12)}$$

[2] For a review of several of these papers, see Bravo-Ureta *et al* (1991)

Where Y_k is the latent (hidden) independent variable for the k[th] farm; X_k is the vector of independent variables which have been postulated to affect efficiency.

The vector $\boldsymbol{\beta}$ comprises the unknown parameters associated with the independent variables for the k[th] farm, and $\boldsymbol{U_k}$ is an independently distributed error term assumed to be normally distributed with zero mean and constant variance. Dummy variables were added to represents the various socio-economic factors such as age, gender and level of education of the head of household among others. Because the dependent variable in Equation 1.12 is a measure of efficiency, the variables with a negative (positive) coefficient will have a positive (negative) effect on efficiency levels.

3.4 Data and Sampling Procedure

The study was carried out in Rongai and Ngata divisions in the new Nakuru district where a representative sample of 138 wheat farmers was randomly selected. The District covers an area of 1484.1 km^2 where 796.23km^2 is arable land, 45km^2 is water mass, forests 7 km^2 and national parks cover 188 km^2. The district is located in the high potential (over 1,800 meters above sea level) and low potential (less than1, 800 meters above sea level) agro ecological zones. The high potential zone generally receives more rainfall over a longer period of time than the low potential zone. The average farm size for small scale is 2.5 acres while for large scale is 200 acres. The district has three districts Agro-ecological zones; Lower Highland (LH3-LH4) mainly the wheat/maize/barley zone, the Lower Midland (LM3) zone and the Upper Midland (UM2-5) which is the upper sisal zone. According to the Ministry of Agriculture, these two divisions produce 75% and 25% of the total wheat produced in the district respectively. A list of farmers in the district was provided by the Ministry of Agriculture at the divisional offices that was used to select the sampled farmers.

The sampling procedure used was stratified proportional sampling method since the population of the wheat farmers was not homogeneous. The sampling frame comprised all wheat farmers (in the 2008 season) in Ngata and Rongai divisions. Two separate lists from the sampling frame were developed. One list consisted of all the farmers who grew wheat on more than twenty (>20) acres to form the first strata while the second list comprised of farmers growing wheat on twenty acres and less (20 and less) of land. The sample size was determined using a formula developed by Krejcie and Morgan (1970) which is shown below.

$$S = \frac{x^2NP(1-P)}{d^2\,(N-1)} + x^2P(1-P) \qquad \textit{(Equation 1.13)}$$

where:
S = required sample size
X^2 = table value of chi-square for 1 degree of freedom at the desired confidence level which is 3.841 for 95% confidence level
P = population proportion assumed to be 0.5 since this would provide the maximum sample size
D = degree of accuracy expressed as a proportion (0.05)
N = population of wheat farmers in the division

Using the above formula, the sample size computed for a population of 150 small scale farmers was 108 farmers while the sample size for the 30 large-scale farmers was 28 farmers. Ngata division had more large-scale and small-scale farmers that Rongai division. Therefore, to determine the sample size for each division for the small scale farmers the sampling was proportional to size at 60% for Ngata division and 40% for Rongai Division. For the large scale farmers the proportion was 57% in Ngata division and 43 % in Rongai division. The farmers were then randomly selected from each stratum using the proportionate random sampling to form the study sample. A total number of 138 farmers were sampled.

The household data was collected using a structured questionnaire by trained enumerators. The survey sought information on wheat acreages, quantity of inputs and their prices, quantity harvested, credit, extension, demographic characteristics of household members as well as the quality of life indicators.

The data was compiled and cleaned using SPSS data entry builder and SPSS data editor. The analysis was done using Frontier 4.0 and STATA statistical packages.

4.0 Key results and discussion

This section highlights the key results on the production systems, productivity and efficiency levels.

4.1 Production systems and farmers' profile

Majority of the farmers (both small scale and large scale) were growing wheat on rented land. The high cost of renting land had implications on the area that farmers were able to put under production.

Wheat production was highly mechanized with most of the farm activities being carried out by use of tractors. The large scale farmers reported high use of inputs such as certified seeds and fertilizers while most small scale farmers used recycled seeds during planting. The main reason for the use of recycled seeds was that they were cheaper than the purchased hybrid seeds. As a result, the productivity among the small scale farmers was lower than the large scale farmers. Wheat productivity in the district was below the normal yields mainly due to inadequate rainfall during the 2007 cropping season. The use of inputs such as certified seeds was quite low and farmers relied on recycled seeds. Fertilizer use was also low especially among the small scale farmers. The main cost components were cost of chemicals, land preparation costs and fertilizer and seed costs.

Majority of the farmers had achieved the primary level of education. The literacy level determines the rate and extent of technology adoption and with such level of education, the uptake of technology can be enhanced. Most farmers were self-employed in agriculture implying that they were available on their farms most of the times. The results indicate that most farmers were not accessing extension services mainly due to unavailability of extension workers and farmers had to travel long distances to access extension advice. Similarly, few farmers accessed credit facilities mainly due to lack of collateral and very strict conditions of accessing credit.On average, the gross margins were Kenya shilling 9,787 and Kenya shilling 7,260 per acre for large scale and small scale farmers respectively. All other costs held constant, the gross margins looks attractive for both categories of farmers. This indicates that wheat production can be a profitable enterprise among the small-scale farmers. With the supply of labor in the rural areas, the small scale farmers would manage to produce wheat in a cost-effective manner. This argument is supported by maize sector Kenya where majority of the farmers are small-scale farmers practicing labor-intensive farming techniques and they supply the bulk of maize produced in the country.

4.2 Technical, Allocative and Economic Efficiencies.

The maximum-likelihood (ML) estimates of the parameters of the stochastic production frontier were obtained using the program, FRONTIER 4.1 (Coelli, 1994). These results are presented in Table 1 which also presents the OLS results of the average production function for comparison. The signs of the of the slope coefficients of both OLS and ML estimates are positive except for family labor that has a negative coefficient implying increasing the family labor affects wheat production negatively. ML estimated coefficients such as seeds, fertilizers and chemicals are significant while for OLS only chemicals coefficient is statistically significant. The estimate of the variance parameter gamma (γ) is also significantly different from zero, which implies that the inefficiency effects are significant in determining the levels of wheat output of the sampled farmers. The estimated production function is given as;

$$LnY_i=4.5 \; +0.48lnseed_i + 0.11lnfert_i +0.11lnchem_i + 0.09lnfoliar_i +0.04lnhiredlab_i - 0.027Lnfamlabor_i. \qquad \textit{(Equation 1.14)}$$

where:

Y_i = wheat output per acre in kilograms

$seed_i$ = quantity of seeds per acre in kilograms

$fert_i$ = the quantity of fertilizer per acre in kilograms

$foliar_i$ = the quantity of foliar used per acre in kilograms

$chem_i$ = the quantity of chemicals used per acre in liters

$hiredlab_i$ = the cost of hired labor per acre

$famlabor_i$ = the imputed cost of family labor per acre

Table 1: Ordinary least squares (OLS) estimates of the average production function and ML estimates of the stochastic production frontier for the sampled wheat producers

	OLS estimates			ML estimates		
Variable	Coefficient	Standard error	t-ratio	Coefficient	Standard error	t-ratio
Intercept	4.59	1.003	4.57	4.46	0.882	5.06
lnseed	0.28	0.228	1.24	0.48	0.205	2.35*
lnfertilizer	0.08	0.054	1.49	0.11	0.043	2.63*
lnfoliar	0.1	0.114	0.89	0.09	0.083	1.13
lnchemical	0.19	0.066	3.02*	0.11	0.042	2.64*
lnhiredlabor	0.04	0.029	1.52	0.04	0.025	1.76
lnfamilylabor	-0.04	0.034	-1.34	-0.027	0.031	-0.85
sigma squared	0.54			1.26	0.216	5.82
gamma(γ)	-			0.93	0.036	2.59*
Log likelihood	-140.54			-131.2		

*significant at the 5% level

The dual cost frontier derived from the stochastic production frontier shown in Table 1, is as follows:

Table 2: The OLS estimates of the stochastic cost function

Cost per acre	Coefficient	Standard error	t	P>t
lnpseed	0.267	0.15	1.76	0.08
lnpfertilizer	0.010	0.03	0.34	0.731
lnpfoliar	0.012	0.01	0.89	0.378
lnpchemical	0.223	0.05	4.35	0.000
lnplabor	0.147	0.27	0.54	0.589
lnobserved Y*	1.042	0.13	7.78	0.000
Constant	-1.507	1.82	-0.83	0.410

$$Ln\, C_i = -1.507 + 0.267(pseed_i) + 0.010(pfert_i) + 0.012(pfoliar_i) + 0.223\,(pchem_i) + 0.147\,(lnpwage_i) + 1.042\,(ln\, \mathbf{Y^*}_i). \quad \text{(Equation 1.15)}$$

where:

C_i = the cost of production per acre of i^{th} farm
$pseed_i$ = the price of seed per kg
$pfert_i$ = the price of fertilizer per kg
$pfoliar_i$ = the price of foliar per kg
$pchem_i$ = the price of chemical per liter

$pwage_i$ = the wage rate per day
Y^*_i = the wheat output in kg per acre adjusted for statistical noise

4.3 Distribution of technical (TE), allocative (AE) and economic (EE) efficiency measures

Results as indicated in Table 3 show that the mean technical, allocative and economic efficiency indices of small-scale wheat farmers are 85%, 96% and 84% respectively while for the large-scale farmers the mean technical, allocative and economic efficiency indices are 91%, 94% and 88%. Thus the results from both small and large scale farmers reveal some considerable levels of inefficiencies in wheat production in Nakuru District. However, the large scale farms have relatively higher technical and economic efficiencies compared to small-scale farmers.

Table 3: Mean TE, AE and EE scores by farm size

Farmsize	TE	AE	EE
Small scale	0.85	0.96	0.84
Large scale	0.91	0.94	0.88
Overall	0.88	0.95	0.86

The mean technical efficiency scores were quite high for both small and large scale farmers but were higher among large farms than for the small farms. However, the results show that there is still some considerable level of inefficiencies in the use of inputs for the corresponding output levels. The allocative efficiency was higher among small-scale farmers than for large-scale farmers implying that small-scale farmers were quite price-sensitive to the input prices than the large scale farmers. The overall economic efficiency was quite high for both farm categories though was higher among large scale than small-scale farmers. The mean technical, allocative and economic efficiency estimates between large and small scale farmers was statistically significant.

The relatively high levels of technical efficiencies among the small scale farmers defies the notion that wheat production in the country can only be efficiently produced by the large scale farmers. This study shows that it is possible for small-scale farmers to produce wheat efficiently. In many parts of Africa including Kenya small farms remain at the center of agriculture and rural development. However, one of the main causes for the low agricultural productivity is the lack of appropriate machineries that cater to and suit the requirements of small-scale farms. For this reason, many small farms are deemed as unproductive and inefficient. To raise the productivity of wheat among small scale farmers in the country basic farm mechanization requirements to cater to small-farm needs must be met, such as: suitability to small farms; simple design and technology; versatility for use in different farm operations; affordability in terms of cost to farmers; and most importantly, the provision of support services from the government and the private sectors/manufacturers.

4.4 Farm size and Efficiency

Statistical tests were carried out on the relationship between the size of the farm and technical efficiency. The test results shows that the mean differences in technical scores are significantly different from zero at 1% and 5% levels of significance. The null hypothesis that the mean difference equal zero is rejected thus, accepting the alternative that the mean difference for between small scale and large scale is less than zero. These results indicate that large scale farms have a higher technical efficiency than small scale farms. Results on the statistical tests on the association between farm size and allocative efficiency show that the mean difference in allocative efficiency scores is statistically different from zero at 1% and 5% level of significance. The null hypothesis that there is no mean difference between small scale and large scale is rejected. This implies that there is statistical difference in allocative efficiencies between small-scale and large-scale wheat farms. A similar test was done on the association between farm size and economic efficiency. The results show that the mean difference in economic efficiency scores between small-scale and large-scale farmers is statistically different from zero at 1% and 5% levels of significance. The null hypothesis is rejected and this implies that the large-scale farmers have higher economic efficiency than small-scale farmers.

4.5 Findings on factors influencing efficiency

For this purpose, the parameters technical efficiency (TE), allocative efficiency(AE) and economic efficiency(EE) indices were estimated censured Tobit procedure for the following socio-economic characteristics:

1) Farm size, equal to zero for small scale and one for large scale
2) Age, given by age of the household head
3) Gender, equal to zero for female head and one for male head
4) Marital status, equal zero for single, one for married and two for widowed
5) Level of education of head, equal to zero for no education, one for primary education and two for post-primary education
6) Main occupation of household head, equal to zero for salaried and one for self-employed
7) Belong to a farmer group, equal to zero for No and one for Yes
8) Distance to the nearest certified seed seller (km)
9) Distance to nearest extension services (km)
10) Land tenure, equals zero for owned land and one for rented land
11) Source of seed, equal to zero for recycled seed and one for purchased seed

The Tobit results presented in Table 4 show there is the lack of consistent pattern of association between efficiency and some socio-economic characteristics such as farm size, age of the head and years of experience in growing wheat. The clearest pattern that emerges is that most of these social-economic characteristics were positively related to efficiency. The positive sign of farm size implies that technical efficiency increases with the size of the farm. The size of the farm is also significant with allocative efficiency. The negative sign for the age of the head implies that efficiency of production declined with the age of the head. The significant influence of education on farm efficiency is critical indicating that households headed by more educated heads were more educated compared with households headed by less educated heads. The interpretation is that farmers who had a higher level of training were more technically and economically efficient that those with low level of training.

Table 4:Tobit model estimates for different efficiency measures

Variable	*Technical Efficiency*		*Allocative Efficiency*		*Economic Efficiency*	
	Coefficient	*t-ratio*	*Coefficient*	*t-ratio*	*Coefficient*	*t-ratio*
|Farm size	0.00	(0.06)	0.02*	(1.90)	0.01	(1.37)
Age of head	-0.00	(0.10)	0.00	(0.84)	0.00	(0.16)
Gender	0.01	(0.13)	-0.00	(0.20)	-0.00	(0.20)
Marital status	-0.05	(1.25)	0.03	(1.59)	0.00	(0.03)
Education	0.04**	(2.36)	-0.01	(1.51)	0.01***	(2.62)
Main occupation	0.00	(0.10)	-0.00*	(1.21)	0.01	(1.39)
Belong to group	-0.01	(0.62)	0.01	(1.37)	0.00	(0.38)
Distance to extension service	-0.00*	(1.77)	-0.00	(1.46)	-0.00**	(2.26)
Distance to certified seed seller	-0.00	(0.95)	-0.00	(0.06)	0.00	(0.95)
Tenure	-0.00	(0.20)	-0.00	(0.31)	0.00	(0.05)
Seed source	-0.01	(0.81)	-0.00	(0.25)	-0.00	(0.16)
Constant	0.90***	(11.45)	0.95***	(26.38)	0.87***	(36.90)
Observations	129		129		129	

Absolute value of t statistics in parentheses * significant at 10%; ** significant at 5%; *** significant at 1%

The positive relationship between the education level of household head and economic efficiency can be supported by similar results reported in studies which have focused on the association between formal education and technical efficiency (Uaiene and Arndt, 2009; Bozoglu and Ceyhan, 2007; Bravo-Ureta and Pinheiro, 1994). In general, more educated farmers are able to perceive, interpret and respond to new information and adopt improved technologies such as fertilizers, pesticides and planting materials much faster than their counterparts. This result is consistent with the findings by Abdulai and Eberlin (2001) which established that an increase in human capital will augment the productivity of farmers since they will be better able to allocate family-supplied and purchased inputs, select and utilize the appropriate quantities of purchased inputs while applying available and acceptable techniques to achieve the portfolio of household pursuits such as income. The result that shorter distances to extension providers influenced farm efficiency is also consistent with findings by Seyoum et al. (1998) who found a 14% difference in technical efficiency between farmers who had access to extension services and those who did not in a study on farmers within and outside the Sasakawa- Global 2000 project. Extension workers play a central role in informing, motivating and educating farmers about available technology.

5.0 Conclusions

The relationship between farm size and efficiency is one of the more persistent puzzles in development economics, even more so as many potential determinants have been put forward and tested without being able to provide a fully satisfying explanation. The findings from this study suggest that gains from improving technical efficiency exist in all farm categories but they appear to be much higher on large than on small farms. While small farms tend to use land more intensively in an attempt to alleviate land constraints, the study suggests that the relatively higher level of technical efficiency observed on small farms is largely attributable to the adoption of traditional land saving techniques rather than the use of modern land saving technologies. Small-scale farms are found to be more allocatively efficient than the larger farms. Nevertheless, gains from improving allocative efficiency exist in more than 90% of the sample households. Accordingly, measures aimed at reducing labor congestion on the farms, relaxing liquidity constraints, and improving the functioning of land rental markets can significantly improve productive efficiency. While self-sufficiency in wheat remains a stated goal of the government, it has remained elusive over the years. With current yields, self-sufficiency will be accomplished only if area under wheat is increased substantially or through intensification leading to higher yields.

Efforts should also be made to improve extension services, access to high yielding seed varieties and proper crop husbandry methods. Opening up more areas in the potential wheat areas in the country, mostly in the marginal areas through irrigation, could assist in increasing output substantially faster than simply targeting policy interventions towards increased input use. The existing small scale wheat farmers should be supported in lowering their costs of production to ensure that they remain in production since their production will remain critical to the government's strategies on food security, poverty reduction and increased rural employment.

Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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REFERENCES:

Abate, B., F. Machel and A. Gezahegn (2006). Effect of Farm Size on Technical Efficiency of Teff Production: A case Study of the Moretina Jiru District, Central Ethiopia.

Assuncão, J. and L. Braido (2007). Testing household-specific explanations for the inverse productivity relationship, *American Journal of Agricultural Economics,* vol. 89, pp 980-990.

Assuncão, J. and M. Ghatak (2003). Can unobserved heterogeneity in farmer ability explain the inverse relationship between farm size and productivity, *Economics Letters*, vol 80, pp 189-194.

Barrett, C (1996). On price risk and the inverse farm size–productivity relationship, *Journal of Development Economics,* vol. 51, pp 193–215.

Barrett, C., M. Bellemare and J. Hou (2010). Reconsidering conventional explanations of the inverse productivity–size relationship, World Development, vol. 38, pp 88–97.

Byiringiro, F., E. Becquey, Y. Martin-Prevel, P. Traissac and T. F Reardon (1996). Farm productivity in Rwanda: Effects of farm size, erosion, and soil conservation investments, *Journal of Agricultural Economics*, Vol. 15, pp 127–136.

Bozoglu, M. and V. Ceyhan (2007). Measuring the Technical Efficiency and Exploring the Inefficiency Determinants of Vegetable Farms in Samsung Province, Turkey, *Journal of Agricultural Systems* vol 94, pp 649-656.

Bravo-Ureta, B.E. and R.E Evenson (1994). Efficiency in agricultural production: the case of peasant farmers in eastern Paragua*y, Journal of Agricultural Economics,* vol 10, pp 27-53.

Bravo-Ureta, B.E. and L. Rieger (1997). Dairy farm efficiency measurement using stochastic frontiers and neoclassical duality, *American Journal of Agricultural Economic, vol.*73, pp 421-428.

Coelli, T.J (1994). A guide to FRONTIER version 4.1: a computer program for stochastic frontier production and cost function estimation, Department of econometrics, University of New England, Armidale, Australia.

Collier, P. and S. Dercon (2009). African Agriculture in 50 years: Smallholders in a Rapidly Changing World, Paper presented at the 2009 Food and Agriculture Organization Expert Meeting on How to Feed the World in 2050.

Dercon, S. and P. Krishnan (1996). Income portfolios in rural Ethiopia and Tanzania: Choices and constraints, *Journal of Development Studies*, vol. 32, pp 850–875.

Dunghana, B.R., P.L Nuthall and G.V Nartea (2004). Measuring the Economic Efficiency of Nepalese Rice Farms Using Data Envelopment Analysis, *The Australian Journal of Agricultural and Resource Economics,* vol 48**,** pp 347-369.

Drysdale, P., K.P Kalirajan and S. Zahao (1995). The Impact of Economic Reform on Production Growth in Chinese Agriculture, *American Journal of Agricultural Economics,* vol 73, no2, pp 266-275.

Eberlin, R. and A. Abdulai (2001). Technical Efficiency during Economic Reform in Nicaragua: Evidence from Farm Household Survey Data, *Journal of Economic Systems,* no.2, vol 25, pp 113-125.

Farrell, M.J (1957). The Measurement of Productive Efficiency, *Journal of the Royal Statistical Society*, series A, vol 120, pp 253-290.

Kalirajan, K (1991). The importance of efficient use in the adoption of technology: a micro panel data analysis, *Journal of Production Analysis,* vol 2, pp 113-126.

Kopp, R.J. and W.E Diewert (1982). The decomposition of frontier cost function deviations into measures of technical and allocative efficiency, *Journal of Economics,* vol 19, pp 319-331.

Krejcie, R.V. and D.W Morgan (1970). Determining Sample Size for Research Activities, *Education and Psychological Measurement,* vol 30, pp 607-610.

Lamb, R (2003). Inverse productivity: Land quality, labor markets, and measurement error, *Journal of Development Economics*, vol. 71, pp 71-95.

Lipton, M (2010). From policy aims and small-farm characteristics to farm science needs, *World Development*, vol. 10, pp 1399-1412.

Mulwa, R., A. Emrouznejad and L. Muhammad (2009). Economic Efficiency of Smallholder maize Producers in Western Kenya: a DEA meta-frontier analysis, *International Journal of Operation Research,* vol 4, no.3, pp 250-267.

Nyoro, J., M. Muyanga and I. Komo (2005). Wheat and wheat products trade in Kenya, Report prepared for cereals growers association and cereal millers association, Tegemeo Institute.

Obare, G.A, D.O Nyagaka, W. Nguyo and S.M Mwakubo (2010). Are Kenyan smallholders allocatively efficient? Evidence from Irish potato producers in Nyandarua North district, *Journal of Development and Agricultural Economics,* vol 2, no.3, pp 078-085.

Ogundari, K. and S. Ojo (2007). Economic Efficiency of small scale food crop production in Nigeria: A stochastic frontier approach, *Journal of Social Sciences,* vol 14, no.2, pp 123-130.

Ray, S (1988). Data envelopment analysis, nondiscretionary inputs and efficiency: an alternative interpretation, *Journal of Socio-Economic Planning Science*, vol 22, pp 167-176.

Seyoum, M.J., G.E Battese and E.M Fleming (1998). Technical Efficiency and Productivity of Maize Producers in Eastern Ethiopia: A Study of Farmers within and Outside the Sasakawa-Global 2000 Project, *Journal of Agricultural Economics,* vol 19, pp 341-348.

Sharma, K.R., P. Leung and H.M Zaleski (1999). Technical, Allocative and Economic Efficiencies in Swine Production in Hawaii: A Comparison of Parametric and Nonparametric Approaches, *Journal of Agricultural Economics,* vol 20**,** pp 23-35,.

Uaiene, R.W. and C. Arndt (2009). Farm Household Technical Efficiency in Mozambique, contributed paper for presentation at the IAAE Conference, Beijing, China 16-22 August 2009.