SMALLHOLDER DAIRYING IN KENYA: THE ASSESSMENT OF THE TECHNICAL EFFICIENCY USING THE STOCHASTIC PRODUCTION FRONTIER MODEL

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Abstract
Dairying in Kenya remains a multi-purpose cattle system providing milk, manure and capital assets to the farmer. Dairy activities in Kenya are predominantly run by smallholders and are concentrated in the high and medium potential areas. Smallholders operating 1-3 dairy cows on small farms are predominant in Kenya. They produce 56% of the total milk in the country and supply 80% of Kenya's marketed milk. Estimated growth in the consumption of milk and dairy products in developing countries is 3.3%, which is in line with Kenya's 3% per year. National statistics show that milk production continues to decline. For example, since 2000 milk annual growth rate has been 1.4% compared to 9.2% experienced between 1980 and 1990. The main challenge of Kenya's dairy industry is how to confront growing milk demand and a highly competitive export environment when yields are as low as 195 litres per lactation. One of the key options is to develop a vibrant competitive dairy sector in Kenya by increasing the efficiency of production. Thus, this study examined the technical efficiency of smallholder dairy farms of rural Kenya. Data from a 2005 survey of smallholder farms in five provinces was utilized to examine the technical efficiency of smallholder farms. The Cobb-Douglas stochastic production frontier model was used to identify the determinants of technical inefficiency. The findings revealed that the mean efficiency was 79 percent, which suggested that 21 percent of production was lost due to technical inefficiency. The technical efficiency also varied across regions ranging from a mean of 83.9% in Central region and 72.5% in Nyanza region. Land size, access to extension service, infrastructure and the level of schooling were found to reduce inefficiency.

Key words*:* Smallholder dairy, technical efficiency, stochastic production frontier

1.0 Introduction

Kenya is a developing country and the agricultural sector is particularly important for its large contribution to national income and employment. Kenya's economy is still heavily dependent on agriculture. The National statistics show that the agricultural sector currently contributes about 26% of Kenya's gross domestic product (GDP) and is a major source of livelihood for the majority of households, especially in the rural areas. The dairy industry is the single largest agricultural sub-sector contributing about 14% of agricultural GDP and 3.5% of total GDP respectively. Omore (1999) has shown that, milk production sustains about 800,000 small-scale farmers who account for 80 per cent of the country's total milk production and offers employment of about 350,000 jobs along the milk marketing chain. Milk sales are beneficial to farmers. Annual net earnings from milk cash income averages $370 (Ngigi et. al, 2003). The stated Government policy in the National Food Policy and the Kenya Dairy Development Policy is to maintain a position of broad self-sufficiency in food crops, milk and meat production. The policy also seeks to establish reserve stocks that will ensure both the security of food supply and an equitable distribution of foodstuffs to each section of the community.

Currently, the demand for milk is growing because milk is an important part of the diet of both rural and urban Kenyans, with per capita milk consumption of 80-100 litres per year. It has been estimated that annual consumption of milk and dairy products in developing countries will more than double (i.e. from approximately 168 to 391 million tonnes) between 1993 and 2020 (Thorpe et al., 2000). Population growth, urbanization and increased purchasing power are expected to drive this increase in consumption. Estimated growth in the consumption of milk and dairy products in developing countries is 3.3%. This projection is closely in line with Kenya's annual population growth rate of 3%. However, Food and Agriculture Organization (FAO) statistics (2005a) show that the annual milk growth rate in Kenya continues to lag behind the projected consumption and population growth rates. For example since the year 2000 milk annual growth rate has been 1.4% as compared to 9.2% experienced between 1980 and 1990. The productivity per animal remains as low as 195 litres per lactation despite the availability of advanced dairy production technologies when compared with other developing countries like India whose productivity per cow is more than 2000 litres per lactation (Karanja, 2003).

Kenya was a net exporter of dairy products but since 1997, imports have grown and exports declined. The Common Market for Eastern and Southern Africa (COMESA) statistics indicate that currently the milk production in this region is estimated to be 12 million tonnes per year against a demand of 14 million tonnes. The demand for milk and milk products in this region is expected to rise to about 400 million metric tonnes of milk in the year 2020. Thus, given the massive increases in the demand for food of animal origin that has been predicted for developing countries in the coming years, will the expected large increase in population and demand for milk be met by the current level production? To answer the above question, there was need to know the current efficiency of production of the smallholder dairy farms in rural Kenya since they are the majority of the producers of milk in East Africa as well as in the Sub Saharan region.

The main purpose of this paper was, therefore, to investigate the technical efficiency of smallholder dairy farms in rural Kenya. It also determined the socio economic factors influencing milk yields for small holders.

2.0 Methodology

2.1 Data sources and variables

Cross sectional data was used in this study. The data came from the REPEAT Research on Poverty and Environment and Agricultural Technology survey carried out in 2005 by Temegeo Institute of Agricultural Policy and Development, Kenya and the Foundation of Advanced Studies in International Development (FASID), Japan. Stratified random sampling was used to select 900 agricultural households covering five (5) main agricultural provinces of Kenya i.e. Central, Rift Valley, Western, Nyanza and Eastern Provinces. The sample was a national representation of all crop and dairy keeping farmers in the main agricultural provinces. Then a survey of all the respondents was undertaken for the study. A structured questionnaire instrument was used to collect data on physical quantities of inputs, their costs and production of crops and livestock for the period. Household socio-economic variables were also collected during the survey, e.g. assets owned, education level, type of household head i.e. whether female headed or male headed and distance to the nearest urban centre. In the analysis of technical efficiency the regions were classified into the high potential areas (i.e. Central Province) and the medium potential areas (i.e. Rift Valley, Nyanza, Western and Eastern Province). Afterwards the dairy keeping households were selected from the sample. Then data cleaning ensued, removal of outliers was done and observations with missing values were discarded. Ultimately, 474 household cases were used for the stochastic frontier analysis.

Technical efficiency (TE) was estimated simultaneously along with its determinants. The level of efficiency was measured using Cobb Douglas production function; the output and input variables included in the production frontier are described below and summarized in Table 1. Output refers to the total quantity of milk produced measured in litres. The inputs included labor (sum of family and hired labor), number of milking cows, total costs for commercial feeds and veterinary services and the breed type of the cows. The variables for inefficiency model were mainly farm specific factors, farmers specific factors and organizational factors. These variables included land size; education level of household male and female; off farm income; use of extension services and infrastructure. Land size was measured in acres, education level was measured by the number of years of schooling, off farm income was measured by the total revenue earned outside the farm in Kenyan shillings, infrastructure was captured by the amount of time in hours it took to get to the nearest urban Centre, a dummy variable was used to capture water infrastructure (i.e. 1 if there is water on the farm, 0 otherwise); a dummy variable was used to captures extension service provision using Artificial Insemination service (i.e. 1 if the farmer is served with A.I, 0 otherwise). Finally, a dummy variable was used to differentiate the potential in provinces (i.e. 1 for central province as a high potential area, 0 otherwise). The descriptive statistics are as presented in Table 1.

Table 1: Descriptive statistics for the variables

Variable	Units	Mean	Std. Dev	Min	Max
Milk Yield	Yield in litres	4077.66	4005.03	195	38635.82
Labor	Man hours	4.29	2037.07	553.20	13463
Milking cows	Number	4	2	1	18
Cost of feeds	Kenya Shilings	8175.97	6176.80	10	22550
Breed	Type (Improved or local)	0.467	0.423	0	1
Health costs	Kenya Shilings	2004.88	2327.10	0	26600
Land size	Hectares	4.57	4.37	0.2	38
Offincome	Kenya Shilings	19037.95	47795.35	0	440000
Travel time	Hours	0.52	0.23	0.15	1.62
Educ Male	Number of years of schooling	10.16	3.81	0	20
Educ Female	Number of years of schooling	9.14	4.16	0	19
Water	Dummy for yes=1, No =0	0.33	0.63	0	1
A.I Service	Dummy for yes=1, No=0	0.42	0.56	0	1

Source: Tegemeo Institute, Kenya, REPEAT Survey, 2007

The average yield of milk per cow per lactation of the sampled farms was 4077.66 litres while the minimum was 195 litres per lactation. This yield was relatively low compared to other milk producers who realize a minimum of 6000 litres of per cow per lactation such as Israel and South Africa. This yield was obtained by milking 4 cows on average which used: 4.29 Man-hours, expenditures of Kshs. 8175.97 on purchased feeds and Kshs 2004.88 veterinary services and 4.57 Hectares. In addition, farmers spent 30 (0.52*60) minutes of travelling to the nearest shopping centre. Dairy farmers engaged in off-farm activities realized Kshs. 19037.95. About 47% of the farmers had improved breeds while about 42% had local breeds. Only 33% of the sampled farms had water on farm. About 42% of the farmers used Artificial Insemination service while 56% used bulls.

2.2 Technical inefficiency effects model

The technical efficiency of an individual is defined in terms of the ratio of the observed output of the corresponding frontier output conditioned on the level of inputs used by the farm. Technical inefficiency is therefore defined as the ratio of the amount by which the level of production for the farm is less to the frontier output. The use of stochastic frontier production approach is the most popular approach to measure technical efficiency. The stochastic production Frontier function that was first proposed by Aigner, and his colleagues (1977) and Meeuseen and Van den Broecl (1977) is defined as follows:

$$Y_i = f(x_i;\beta) + e_i \quad \text{(1)}$$

where i = 1, 2,……N,

$e_i = v_i - u_i$,

Where Yi represents the output level of the ^{i}th sample farm; f(x; β) is a suitable function such as Cobb Douglas or translog production functions of vector X_i of inputs for the ^{i}th farm and vector β_i of unknown parameters; e_i is an error term made up of two components, vi which is a random error having zero mean N(0; σ^2) associated with for example measurement errors in production and weather conditions which farmers do not have control over and μ_i which is a non negative truncated half normal N(0; σ^2) random variable associated with farm specific factors which leads to the *i* th farm not attaining maximum efficiency of production. It is associated with technical efficiency and ranges between zero and one. Thus,

$$\hat{TE}_i = Y_i / Y_i^* \quad \text{(2)}$$

where, $Y_i^* = f(x_i;\beta)$, highest predicted output for the i th farm

$$\hat{TE}_i = Exp(-u_i) = Y_i / Y_i^* \,(Actual output / Frontier output) \quad \text{(3)}$$

Technical Inefficiency = $1 - \hat{TE}_i$ …… (4)

2.3 Empirical model specification

The Cobb Douglas production Frontier was used to specify the stochastic production frontier hence forming the basis for deriving the technical efficiency and its related efficiency measures. The stochastic Cobb Douglas production function was chosen because this functional form has been widely used in farm efficiency analyses for both developing and developed countries. The first application of the stochastic frontier model to farm-level agricultural data was presented by Battese and Corra (1977). Data from the 1973/74 Australian Grazing Industry Survey were used to estimate deterministic and stochastic Cobb-Douglas production frontiers for the three states included in the Pastoral Zone of Eastern Australia. The variance of the farm effects were found to be a highly significant proportion of the total variability of the logarithm of the value of sheep production in all states. The parameter estimates exceeded 0.95 in all cases, hence the stochastic frontier production functions were significantly different from their corresponding deterministic frontiers. Kalirajan (1981) estimated a stochastic frontier Cobb-Douglas production function using data from 70 rice farmers for the rabi season in a district in India. The variance of farm effects was found to be a highly significant component in describing the variability of rice yields. Bagi (1982a) used the stochastic frontier Cobb-Douglas production function model to determine whether there were any significant differences in the technical efficiencies of small and large crop and mixed-enterprise farms in West Tennessee. The variability of farm effects were found to be highly significant and the mean technical efficiency of mixed-enterprise farms was smaller than that for crop farms (about 0.76 versus 0.85, respectively). However, there did not appear to be significant differences in mean technical efficiency for small and large farms, irrespective of whether the farms were classified according to acreage or value of farm sales. Dawson and Lingard (1989) used a Cobb-Douglas stochastic frontier production function to estimate technical efficiencies of Philippine rice farmers using four years of data.

The individual technical efficiencies ranged between 0.10 and 0.99, with the means between 0.60 and 0.70 for the four years involved. In developing countries, studies on technical efficiency include that of Nega *et al.* (2006) who analyzed the inefficiency of smallholder dairy producers in the central Ethiopian highlands using the stochastic production frontier technique and confirmed the existence of systematic inefficiency in milk production. The average efficiency level of the farmers was only 79% implying that milk output would be attained on average by 21% with the existing technology by training dairy farmers on better production techniques. The study recommended training of farmers on proper feeding, calving, milking, cleaning of cows, storing milk, marketing as well as other management skills to improve efficiency in milk production. Kibaara (2005) analyzed the technical efficiency in Kenya's maize production using a translog production function. The results indicated that maize farmers were 49% efficient with a range of 8 to 98%. The number of years of formal schooling, age of household head, health of the household head, gender of the household head, use or non use of tractors and off-farm income were found to have an impact on technical efficiency.

In this study, the Frontier (4.1) software program was used to estimate the Stochastic Frontier Model. This program used the maximum likelihood technique for estimation (Coelli 1996). The general non-log form model is specified as follows:

$$y = f(x_1, x_2) \qquad (5)$$

The general log form model is specified as follows:

$$y_i = \alpha_0 + \sum_{k=1}^{5} \alpha_k \ln x_{ki} + v_i - u_i \qquad (6)$$

Where, ln 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.

$$u_i = \delta_0 + \sum_{m=1}^{8} \delta_m z_i \qquad (7)$$

The variables z_i are the variables in the inefficiency model. Equation 7 above shows a joint estimation of the stochastic frontier production function in Frontier 4.1.

$$\begin{aligned} \ln y = {} & \beta_0 + \beta_1 \text{lnlabour} + \beta_2 \text{lnlabour}^{\wedge}2 + \beta_3 \text{lncows} + \beta_4 \text{lnfeeds} + \beta_5 \text{lnothercosts} \\ & + \beta_6 \text{Breed} + \delta_0 + \delta_1 \text{land} + \delta_2 \text{offincome} + \delta_3 \text{traveltime} + \delta_4 \text{schyrsmale} + \delta_5 \text{schyrsfemale} \\ & + \delta_6 \text{watersource} + \delta_7 \text{AIservice} + \delta_8 \text{regionaldummy} + v_i - u_i \end{aligned} \qquad 8$$

Where :
Y= milk yield in litres;
Feeds = cost of feeds;
Other costs = Veterinary costs;
Cows = number of cows;
Breed = Type of breed (improved or local)
Labor = labor in man hrs;
Land size= number of acres of land;
Offinc = dummy for off farm income Yes =1 No = 0;
Travel time= time in hrs to the nearest urban centre;
Educmale = number of years of schooling for males;
Educfemale = number of years of schooling for females;
Water= dummy for source of water, has water on the farm: Yes = 1 No =0;
AI = dummy for AI services, Uses AI: Yes = 1 No =0;
Regional dummy = dummy for high potential region;
$v_i - u_i$ = error terms, and the former refers to normal statistical error while the latter concerns technical efficiency of farms.

3.0 Model estimation results

The estimated coefficients of the production frontier for smallholder dairy farms are presented in Table 2. Most of the estimates were found to be significant at the five percent significance level. The summary statistics on the technical efficiency of individual farms for the 474 smallholder farms are presented in Table 3, which presents the range of technical efficiency scores of the farms and the number of farms within each range.

The mean efficiency of the small dairy farms was 79%, with the highest efficiency value of 94% and the lowest farm efficiency value of 46%. These results clearly rejected the null hypothesis that there was no gap between potential and actual milk production of smallholders' dairy farming in rural Kenya meaning that most farmers had not yet attained full efficiency and there was still potential to increase milk production by 21% on average.

Table 2: Results of the maximum likelihood estimates of stochastic production function

Parameter	Coefficient	Standard Error	t-ratio
Beta0	10.359	1.399	7.395***
Labor	-1.109	0.353	-3.139***
labour^2	0.066	0.023	2.935***
Milking cows	0.964	0.044	21.721***
Cost of feeds	0.163	0.015	10.800***
Breed	0.815	0.033	8.213***
Health costs	-0.002	0.015	-0.158
Delta0	1.420	0.907	-1.565
Land size	-0.008	0.079	-0.099
Off farm income	0.017	0.019	0.899
Travel time	0.419	0.195	2.149**
Educ Male	0.385	0.194	1.994**
Educ Female	-0.006	0.095	-0.067
Water	-0.416	0.173	-2.398**
AI service	3.243	1.296	-2.617***
Regional	0.590	0.191	-3.097***
sigma^2	0.692	0.142	4.890***
gamma	0.812	0.049	16.297***

Log likelihood function=-0.27913653E+03
Source: Authors' Analytical Estimates, 2007.
Asterisk indicates: *significant at 10%, ** significant at 5% and ***significant at 1%.

Table 3: Results of summary statistics on technical efficiency of individual farms

Technical Efficiency	Frequency	Percentage
<50	7	1.480
50-59	28	5.91
60-69	60	12.66
70-79	115	24.26
80-89	183	38.61
90-99	81	17.09
Total	474	100

Source: Authors' Analytical Estimates, 2007.

The summary statistics of technical efficiency for the smallholder farms in the five regions presented in Table 4 indicated the diversity of scores of efficiency among regions, which suggests that the diversity in socio economic factors can have different impacts on efficiency in milk production in different regions.

Table 4: Results of scores of technical efficiency among regions

Region	Observation	Mean	Std. Dev	Min	Max
Nyanza	73	0.725781	0.109076	0.456	0.906
Western	43	0.750442	0.085484	0.544	0.891
Rift Valley	140	0.768786	0.120632	0.464	0.94
Central	200	0.83924	0.090964	0.479	0.938
Eastern	18	0.7805	0.099433	0.577	0.913

Source: Authors' Analytical Estimates, 2007.

4.0 Technical inefficiency and socio-economic characteristics

Considering the detailed results, the coefficient of labor was significant at 1% though it had a negative sign, while when labor was squared; the coefficient became positive and statistically significant at 1%. This shows that when labor increased from the present level, milk production declined, but after some time milk production increases. The plausible explanation for this observation being that dairying requires some experience especially on management practices like feeding and not all the laborers may possess this experience. In the absence of such experience in the majority of employed labor, the coefficient tends to be negative. With an increase in experienced labor force, milk production tends to increase as shown by the squared labor term. Another possible explanation is that in most cases, family labor may be used which may not be restricted to only dairying and hence it may be difficult to correctly quantify the amount of time strictly spent on dairying activities.

The coefficient of feeds was positive and statistically significant at 1% as was expected meaning that feeds are critical in milk production and thus an increase in feeding increased milk production. The coefficient of cows was significant at 1% and had a positive sign as was expected, meaning that milk production increased with the increase in the number of milking cows. The number of cows was a good proxy for farm size. Thus, the higher the number of cows a farmer owns, the higher the milk production.

The coefficient of breed was significant at 1% and had a positive sign as was expected, meaning that milk production increased with the type of breed, improved cows would give more milk than the local breeds. The coefficient of health costs was negative though it was not significant. Normally a high expenditure in health is a proxy for unhealthy animals or poor management and this reduces milk production.

Considering the estimates of the determinants of technical efficiency, the coefficient of land was negative, meaning that land size may reduce inefficiency due to economies of scale, though the coefficient was not statistically significant. The explanation is that in smallholder dairy farms, there is a tendency of integrating dairy and the growing of food or cash crops on the same piece of land; hence, economies of scale may not be realized. Furthermore, intensification of dairy, such as zero grazing, is enabling farmers to keep cows without necessarily having land as long as they have a source of feeds. Thus, land may not have an impact on efficiency.

The coefficient of off farm income was positive, meaning that an increase in off farm income may increase inefficiency, but this coefficient was not statistically significant. This may indicate that the surveyed farmers may solely be depending on farming and therefore the off farm activities do not affect their farm activities. The coefficient of years of schooling for males was positive and statistically significant at 5%, which clearly indicates that more years of schooling for males increases their inefficiency in milk production, while the coefficient of that of females was negative but was not statistically significant. The major argument is that with more years of schooling, males tend to get off farm employment and income activities, which may result in dairying inefficiency.

The coefficient of travel time to the nearest urban centre which was a proxy for infrastructure was positive and statistically significant at 1%, meaning that inefficiency increased when more time was taken in traveling to the nearest urban centre. Bad roads are evident in most rural areas of Kenya and thus it takes a lot of time to get milk to the market and to get the inputs to the farms especially the feeds. Bad roads also deter extension services from being effective, thus increasing inefficiency. Milk production requires speedy transportation to the market and requires easy access to commercial feeds and artificial insemination services which are obtainable from the nearest urban centres.

The dummy for source of water at the farm was negative and statistically significant at 1%, meaning that having water on the farm reduced inefficiency. Dairying requires water throughout and access to water on the farm cannot be overemphasized.

The dummy for artificial insemination was negative and statistically significant at 1%, meaning that it reduced inefficiency to use artificial insemination. Artificial insemination was a good proxy for extension service. Artificial insemination allows farmers to upgrade their animals and reduces fertility diseases such as brucellosis, which reduce milk production. Thus, Artificial Insemination helps in reducing inefficiency. The government provided this service to the farmers up to 1992 when the dairy industry was liberalized and the private agents started to offer this service.

The regional dummy that represented the high potential areas (i.e. Central Province) was negative and statistically significant at 1%. This means that being in a high potential region reduces technical inefficiency. This region is noticeable for its good infrastructure, high quality breeds and its close proximity to the capital city of Nairobi, where most of the milk is sold and inputs especially the commercial feeds are processed.

5.0 Policy implications and recommendations

One of the important policy implications concerns technology. Feeds were found to reduce inefficiency. Technologies that will enable the farmers to produce feeds cheaply should be introduced as several farmers depend on manufactured feeds besides grazing land to feed milking cows, it is thus imperative to facilitate easy access to manufactured feeds at affordable prices. The government needs to encourage production of manufactured feeds by promoting industrial activities.

Another policy implication is to make the artificial insemination services affordable to farmers since it reduces inefficiency. This will help the farmers to upgrade their dairy cows without using the traditional bulls that may have low quality genetic potential and are capable of transmitting breeding diseases.

Importantly, the government needs to improve infrastructure especially rural roads, which in most cases are in a deplorable condition. This will enable the farmers to access the inputs and to market their produce with ease. This is not only beneficial to the milk producers but also to the other agricultural activities. Water is an important input in dairy production and its supply on farms cannot be overemphasized. The supply can be piped water or borehole water and this will greatly reduce the inconvenience and the time that the farmers have to take to fetch water for their animals. This will also save useful labor time that can be used in other farming activities.

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