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Assessing the Economic Efficiency of Dairy Production Systems in Uasin Gishu County, Kenya

Michael B. Kibiego,[1*] Job K. Lagat[1] and Bockline O. Bebe[2]

[1]Department of Agricultural Economics and Agribusiness Management, Egerton University, P. O. Box 536-20115, Egerton, Kenya.

[2]Department of Animal Sciences, Egerton University, P. O. Box 536-20115, Egerton, Kenya.

* E-mail of the corresponding author: kibiegomb@gmail.com

Abstract

The objective of this paper is to estimate economic efficiency in the dairy production sector in Uasin Gishu County of Kenya. Zero grazing, semi-zero grazing and open grazing production systems are analyzed separately using the Cobb-Douglas stochastic frontier cost function. In a second stage we examine the degree to which the calculated efficiency correlates with a set of explanatory variables using a censored regression model. The results indicate that each of the three milk production systems is relatively inefficient, with potential in all cases for reducing input costs or increasing output. Economic efficiency increased with the level of intensification of milk production, with open grazing, semi-zero grazing and zero grazing attaining 0.43, 0.51 and 0.69 respectively. The maximum likelihood estimates of milk production were an increasing function of cost of feeds and equipment in the three production systems with statistical significance of 5%. The estimated determinants of economic efficiency were positively related with education and social capital, and negatively related with gender, land size and market access.

Keywords: Dairy production; Economic efficiency; Frontier cost function and Intensification

Introduction

Smallholder dairy farming is considered one of the most important in the agricultural sector in Kenya (Murage *et al.*, 2011). Although Uasin Gishu County is leading nationally in terms of milk production, it is experiencing structural changes towards intensification due to declining household land sizes. Analysis of intensification of smallholder milk production in Kenya suggest that an evolution process of intensification pathways occurs, mainly involving feeding and breeding strategies (Bebe *et al.*, 2008). It would appear that intensification pathways in smallholder milk production are diverse and involve investment in external input use. Further analysis of intensification of milk production by Baltenweck *et al.* (2000) concluded that there was no clear-cut relationship between the intensification level and the level of competitiveness at the farm level. The per farm and per cow, of more intensified systems showed higher levels of net cash flows and returns to family labour, while per quantity of milk produced in less intensive systems appeared to be more competitive. A similar analysis of intensification in Uganda by Nanyeenya *et al.* (2008) concluded that all smallholder milk production systems were profitable and remunerated labour above the opportunity cost.

The contrasting results on competitiveness of smallholder milk production suggest the need for further analysis of intensification pathways because optimal resource use differs between the pathways. Competitive enterprises attain positive returns to investment including land, labour and capital, and represent a rewarding investment. Researchers have suggested that improvement in efficiency is one of the key factors for the survival of dairy farms (Alvarez et al., 2008; Tauer and Belbase, 1987). Consequently, the aim of this study was to gain insight into the economic efficiency of dairy production systems in Uasin Gishu County of Kenya, which is the leading milk producing county. In addition, the determinants of economic efficiency are considered. On the basis of literature, number of cows in the herd, major inputs in dairy cattle (feed, labour and capital), land size, contact with the extension, the membership in cooperatives and organization and education of employees and experience of farmers can be included into the most evaluated determinants of the efficiency in dairy farms Michalickova *et al.* (2013). The determinants will shed light on the options that dairy farmers have in enhancing their economic efficiency.

Literature review

According to Coelli (1996) modern efficiency measurement begins with the work of Farrell (1957) who drew upon the work of Debreu (1951) and Koopmans (1951). Farrell (1957) defined a simple measure of firm efficiency that considers multiple inputs and proposed that efficiency of a firm consists of: (i) technical efficiency, which reflect the firm's ability to obtain maximum output from a given set of inputs, and; (ii) allocative efficiency, which reflects the ability of a firm to use the inputs in optimal proportions, given their respective prices. Combining the two measures produces economic efficiency that is consistent with the principles of profit maximization. According to Kumbhaker and Lovell (2000), profit maximization requires a firm to have both technical and allocative efficiency. Previous relevant literature has focused on estimating the level of economic efficiency among samples of dairy farms. To do so, these studies have used either a non-parametric method such as Data Envelopment Analysis (for instance Alemdar *et al.,* 2010) or an econometric approach such as stochastic (production, cost or profit) frontier models (Bravo-Ureta *et al*., 2008; among others). These two methodologies have also been used to analyze the potential sources of inefficiencies (Tauer and Mishra, 2006; Murova and Chidmi, 2009). Technical and economic efficiencies for a sample of swine producers in Hawaii were measured (Sharma *et al.,* 1998) and the results revealed considerable inefficiencies in swine production. The study found that farms producing market hogs were more efficient than those producing feeder hogs. Based on the results, the study concluded that the swine producers can reduce their production costs by 38-46% (Sharma *et al.,* 1998) depending upon the production method and returns to scale considered. This study relates to the current one with respect to the method of analysis. Estimating a stochastic frontier model, Nehring *et al.* (2012) revealed that size was the major determinant of competitiveness of U.S. organic dairy farms.

Kumbhakar and Lovell (2000) argue that stochastic frontier models have the advantage of dealing with stochastic noise and allowing for a single step estimation of the inefficiency effects. But these models have the disadvantage of making assumptions about underlying data generating process for instance Ordinary Least Squares (OLS), Three Stage Least Squares (3SLS) and Generalized Method of Moments (GMM). The advantage of GMM over the other estimators, like 3SLS, is that GMM does not require strong assumptions about the underlying data generating process and has the ability to generate standard errors that are robust with respect to heteroscedasticity and autocorrelation (Ooms, 2007).This paper used a stochastic frontier model and chose the Cobb-Douglas stochastic frontier cost function. An advantage of frontier models is that they can provide useful information to the policy maker for the design of productivity-enhancing policies (Del Gatto *et al*., 2011). Once the production function is known, the first-order conditions for profit maximization are derived. From these first-order conditions, functions for output supply, variable input demands and shadow prices of quasi-fixed inputs are derived, assuming price-taking behavior in input and output markets. Thus, the farm is assumed to be in static equilibrium with respect to outputs and variable inputs.

Methodology

The study area and data collection

Uasin Gishu County was chosen for this study because it was leading in milk production, had both the highest population of dairy cows in Kenya and the three dairy production pathways. First, the population was stratified according to a poverty level of at least 46% and milk production potential of 60,000 – 90,000 liters/Km^2/year. Second, a probability proportional to size technique was used to obtain the number of farmers per stratum. Finally, random sampling was used within the strata to select 246 individual households. Collection of data involved administration of pre-tested structured questionnaires. The study combined primary and secondary data. The data included the quantities and prices of all inputs and output of milk production. Output was milk while inputs were feeds, breeding costs, herd health management costs, investment in housing and equipments and labour costs.

Data Analysis

The Cobb-Douglas stochastic frontier production function was used to estimate the economic efficiency of smallholder milk production. Following Coelli (1996) the model is expressed as:

$$Y_i = x_i\beta + (V_i - U_i) \quad , i = 1,\ldots, N \qquad (1)$$

Where

Y_i = logarithm of the milk production of the i-th farm;

X_i = a *kx1* vector of the logarithm of the input quantities of the i-th farm;

β = a vector of unknown parameters;

V_i = random variables which are assumed to be $N(0,\sigma_V^2)$, and independent of the U_i;

U_i = non-negative random variables which are assumed to account for technical inefficiency in production, and are assumed to be $|N(0, \sigma_U^2)|$.

The computer program FRONTIER version 4.1 was used to estimate the model and obtain maximum likelihood estimates of the stochastic frontier production function. The production function has farm effects which are assumed to be distributed as truncated normal random variables. Calculation of the maximum likelihood estimates (Coelli, 1996) requires that:

$$\sigma^2 = \sigma_V^2 + \sigma_U^2 \qquad (2)$$

and $$\gamma = \frac{\sigma_U^2}{\sigma_V^2 + \sigma_U^2} \qquad (3)$$

The parameter, γ, must lie between 0 and 1 and thus this range was searched to provide a good starting value for use in an iterative maximization process of Davidson-Fletcher-Powell (DFP) algorithm. A model selection procedure was conducted by testing the significance of the γ parameter. If the null hypothesis that $\gamma = 0$ is accepted, this would indicate that σ_U^2 is zero and hence the U_i term should be removed from the model, leaving a specification with parameters that can be consistently estimated using ordinary least squares. To estimate economic efficiency, the dual cost frontier was derived from the primal Cobb-Douglas production function in equation (1) utilizing the assumption of duality. The dual cost frontier is given as (Xu, *et al.,* 1998):

$$C_i = h\,(p_i, Y_i^*, \Phi) \qquad (4)$$

Where
C_i = minimum cost of the *i-th* farm due to Y_i^*,
p_i = input price vector.
Y_i^* = output adjusted for stochastic disturbances.
Φ = vector of parameters estimated.
The economically efficient input vector for the *i-th* farm, x_{ie}, was derived by applying Shephard's Lemma, then substituting the firm's input price and the adjusted output levels into the derived system of input demand equations given by (Xu, *et al.,* 1998):

$$\frac{\delta C_i}{\delta p_k} = x_{ie}(P, Y_i^* \Phi) \qquad (5)$$

Given that the observed costs of production of the *i*-th firm are calculated by $\sum X_i P_i$, and the economically efficient costs as $\sum X_{ie} P_i$, the economic efficiency indices (EE) are thus computed by determining the ratio of the two, thus:

$$EE = \frac{\sum X_{ie} P_i}{\sum X_i P_i} \qquad (6)$$

Results and Discussion

The maximum likelihood estimates (MLE) for economic efficiency of the stochastic frontier cost function is shown in Table 1. Overall significance of the model, given by the estimated sigma squared (δ^2) was 0.48 for zero grazing, 0.97 for semi zero grazing and 0.97 for open grazing. The δ^2 were significantly different from zero at 5% level for the three dairy production systems, meaning that there was a good fit and correctness of the specified distributional assumption of the composite error term. Gamma (γ) showed that 100%, 95 % and 95% of the variation in milk output was due to inefficiency under zero grazing, semi-zero grazing and open grazing systems respectively (Table 1).

These results show that the economic inefficiency effects are significant at 5% level in the stochastic frontier cost function. They are consistent with the findings of Manohara *et al.* (2004) and Sajjad, *et al*, (2010). The returns to scale (RTS) were 1.95, 1.30 and 1.12 for zero grazing, semi-zero grazing and open grazing respectively. These results indicate increasing returns to scale and that milk production was in stage I of the production surface. This shows that efforts should be made to expand the present scope of production to actualize the potential in it, that is, more of the variable inputs could be employed to achieve more output. The amount of milk production increases by the value of each positive coefficient as the cost of each variable is increased by one unit. Similarly, the amount of milk production declines by the value of each negative coefficient as the cost of the respective variable is increased by one unit. Feeds constitute the largest component of the cost of milk production in the zero grazing system and a unit increase in the cost of feeds will increase milk production by 0.45 units. A large proportion of the feeds used in zero grazing systems are purchased relative to the costs incurred for feeds in open and semi zero grazing systems. Semi zero grazing and open grazing systems had negative feed cost coefficients of -0.26 and -0.25 respectively, with open grazing coefficient being significant. Sajjad, *et al*, (2010) reported a coefficient of 0.38 for the cost of feed that was significant at 5% level. The feeds include pastures, fodder, hay, silage, concentrates, minerals, other supplements and water. Further work needs to be carried out on the quality of the feeds used in milk production in Uasin Gishu County as it appears variable.

Table 1: The maximum likelihood estimates (MLE) for economic efficiency of the stochastic frontier cost function

Parameter		Zero grazing MLE estimates coefficient (t-ratio)	Semi-zero grazing MLE estimates coefficient (t-ratio)	Open grazing MLE estimates coefficient (t-ratio)
Constant	β_0	-0.19	7.30	7.29
		(-0.20)	(5.45)	(7.45)
Feeds	β_1	0.45	-0.26	-0.25**
		(1.42)	(-1.81)	(-2.60)
Herd replacement	β_2	1.27**	0.33**	0.28
		(2.26)	(2.75)	(1.09)
Health management	β_3	0.09**	-0.03	0.01
		(2.28)	(-0.20)	(0.17)
Housing	β_4	-0.03	0.457**	0.32**
		(-0.73)	(2.99)	(2.86)
Equipment	β_5	0.10	0.06	0.13**
		(1.82)	(0.70)	(2.01)
Labour	β_6	-0.01	0.16**	0.13**
		(-0.21)	(2.35)	(2.64)
Sigma-Squared	δ^2	0.48	0.97	0.97
		(5.28)	(5.08)	(5.08)
Gamma	γ	1.00**	0.95**	0.95**
		(90.05)	(30.76)	(30.76)
Log (likelihood)	θ	-12.65	-77.05	-114.03
LR test statistic		98.41	58.71	159.14
Mean efficiency		0.69	0.51	0.43

Herd replacement costs comprise of artificial insemination (AI) charges, payment of bull services and purchase of heifers. Most of the small scale farmers used either AI or bull schemes as they cannot easily afford to buy a heifer. In the zero grazing and semi zero grazing systems, herd replacement costs influenced milk output positively and significantly with coefficients of 1.27 and 0.33 respectively. Also in open grazing system, the coefficient for herd replacement was positive. Small scale dairy farmers are known to keep zebu cross breeds that have low milk production levels.AI is recommended for use by the dairy farmers so as to improve the genetic traits for milk production and animal performance aspects such as longevity in the herd, number of calvings and resilience to certain diseases. Health management costs had a positive and significant coefficient in the zero grazing system, a positive coefficients in the open grazing and a negative but insignificant coefficient in semi zero grazing. Disease control and management is critical in livestock production. The small scale farmers are faced with tick borne diseases that include East Cost Fever, heart water and red water among others. In addition, there are notifiable diseases like foot and mouth disease, lumpy skin disease and anthrax. There are also management diseases like mastitis and management conditions like hypocalcaemia and hypomagnesia. Prevention and control of diseases and conditions is important for a productive dairy herd.

Housing costs had significant and positive coefficients in semi-zero-grazing (0.457) and open grazing (0.320). Investment in housing will thus increase the amount of milk produced. Housing reduces the loss of feeds during supplementary feeding. It is also needed for storage of feeds such as hay for use during the dry season. Housing costs had a negative coefficient (-0.03) in zero grazing system as the cows are already under an enclosure. Equipment costs are critical in dairy production as they can substitute for labour in the case of motorized chuff cutters. These equipment also help to reduce milk loses through spillage and spoilage (e.g. milk cans). There is a need for credit provision for smallholder dairy farmers to access dairy equipment and increase milk production.

The labour costs had significant coefficients in semi zero grazing and open grazing systems while it had a negative but insignificant coefficient in the zero grazing system. Labour is needed for grazing and collecting feed, processing feed and feeding, planting, weeding and manuring fodder and milking. Other labour needs are marketing milk, spraying/dipping, cleaning the shed and fetching water for the animals. Considering that milk production is a labour intensive enterprise, there is a need to increase the capital so as to substitute for labour and reduce the labour costs. However, where the opportunity cost of labour is very low, the labour costs are cheap especially when it is unskilled labour. There is a need to increase the amount of investment in dairy production so as to benefit from the increasing returns to scale across the three dairy production systems in Uasin Gishu County. These results are consistent with that of Sajjad, *et al*, (2010) whose coefficients for equipment and labour use in milk production was 0.10 and 0.20 respectively. Increased investment in these inputs is expected to increase milk production.

As shown in Table 2, the economic efficiency for the zero grazing production system ranges from 17 % to 99 % with a mean of 69%. The presence of economic inefficiency indicates that there is potential to increase output gains without increasing input use. This implies that if farm households were to be fully efficient they will achieve a cost savings of 31%. On the other hand, if the average farm household in the sample was to achieve the economic efficiency level of its most efficient counterpart, then the average farm household could realize a 30% cost savings. A similar calculation for the most economically inefficient household reveals a cost saving of 82%.Economic efficiency for semi-zero grazing production systems ranges from 11 % to 92 % with a mean of 51%. These farmers have an opportunity of saving costs by 49 percent so as to achieve full efficiency. On the other hand, if the average farm household was to achieve the economic efficiency level of its most efficient counterpart, then they could realize a 44.46% cost savings (that is, 1–[51 /92]). A similar calculation for the most economically inefficient household practicing semi zero grazing reveals cost saving of 88% (that is, 1– [11.37 /92.40]).

Table 2: Economic efficiency scores of the stochastic frontier cost function

	zero grazing		semi-zero grazing		open grazing	
frequency	Sample size	efficiency scores	Sample size	efficiency scores	Sample size	efficiency scores
1st Quartile	8	0.30	22	0.21	31	0.21
2nd Quartile	8	0.62	22	0.41	31	0.36
3rd Quartile	8	0.85	22	0.63	32	0.48
4th Quartile	7	0.97	23	0.80	32	0.67
Total	31		89		126	
Min		0.17		0.11	0.09	0.09
Max		0.99		0.92	0.87	0.87
Mean		0.69		0.51	0.43	0.43
Std. Dev		0.26		0.22	0.17	0.17

Economic efficiency for open grazing production systems ranged from 9.63% to 87.73% with a mean of 43% (Table 2). This implies that if farm households using this production system were to be fully efficient they will achieve a cost savings of 56%. On the other hand, if the average farm household in the sample was to achieve the economic efficiency level of its most efficient counterpart, then the average farm household could realize a 50% cost savings (that is, 1–[43.11 /87]). A similar calculation for the most economically inefficient farm household reveals cost saving of 89% (that is, 1– [9/87]). Sajjad, *et al*, (2010) confirmed the presence of economic inefficiency effects in milk production by using the generalized likelihood ratio test with the estimated gamma parameter (γ) of the cost function being 0.781 indicating that 78.1% of the variation in the total cost of production among the farmers was due to the presence of economic inefficiency. The zero grazing system had a minimum and maximum economic efficiency of 0.17 and 0.99 respectively, with a mean of 0.69.The other two milk production systems had lower values. Semi-zero grazing system recorded a minimum and maximum economic efficiency of 0.11 and 0.92 respectively and a mean of 0.51. Open grazing system had the lowest economic efficiency scores with a mean of 0.4311, a minimum score of 0.09 and a maximum value of 0.87.Therefore zero grazing is more superior than semi zero grazing and open grazing with respect to economic efficiency. These results imply that not all producers are able to minimize necessary costs for the intended production of outputs. Alvarez *et al.* (2008) estimated independent stochastic cost frontiers for various groups of farms in Spain to calculate their levels of efficiency. The empirical results showed that intensive farms were closer to their cost frontier than extensive ones, suggesting a positive relationship between intensification and efficiency. The current study has given similar conclusions because zero grazing units have greater mean economic efficiency compared to both semi-zero grazing and open grazing. Constantin *et al,* (2009) observed that producers do not always optimize their production functions. The production frontier characterizes the minimum number of necessary combinations of inputs for the production of diverse products, or the maximum output with various input combinations and a given technology. Producers operating above the production frontier are considered technically efficient, while those who operate under the production frontier are denoted technically inefficient (Constantin *et al.,* 2009). Milk producers can be supported to acquire knowledge and/or resources necessary to shift from inefficient to efficient production.

Determinants of economic efficiency

Table 3 shows the coefficients and the corresponding standard errors of the determinants of economic efficiency for the three milk production systems. In the zero grazing system, gender, education, land size, social capital and distance to the market are statistically significant. Gender is the only statistically significant variable influencing economic efficiency in semi zero grazing. None of the variables is statistically significant for open grazing system. Gender had a coefficient of -0.21 for zero grazing system. (Table 3).This suggests that being in a male-headed household has a positive effect on economic efficiency (Lovo, 2013).This situation is due to the fact that most of the productive resources in Uasin Gishu County, including land, equipment, livestock and housing are owned by men. The results in Table 3 show that age has a negative coefficient with economic efficiency. But this was not statistically significant. Education coefficient of 0.18 was strongly significant at 99% level for zero grazing system. Both semi-zero grazing and open grazing had positive coefficients for education. These results show that more educated farmers can make sound farm management decisions that lead to greater economic efficiency**.** The policy advice from these results is the need to provide both formal and informal training for dairy farmers so as to enhance their efficiency in milk production. Considering that most of the farmers are adults, tours to more efficient dairy farms will be beneficial. Nganga *et al*. (2010) observed that “the level of education, experience, and the size of the farm influenced profit efficiency positively while profit efficiency decreased with age”.

Household size showed a mixed effect on economic efficiency in the milk production systems. Although it was not significant, it had a negative coefficient in zero grazing system (-0.02) and a positive sign in the other two systems. Alemdar *et al.* (2010) found that use of family labor may have positive and negative effects on efficiencies depending on the situation. The importance of a large household size is its contribution to labour. However, a large family size may consume the capital needed for investment in milk production. Distance to market in the zero grazing system was statistically significant with the expected negative sign. It is considered as proxy for transaction costs. The farther away a household is from the market, the more difficult and costly it would be to get involved in input and output markets.

Table 3: Coefficients and corresponding standard errors of the determinants of economic efficiency for the estimated censored regression model

	zero grazing			semi-zero grazing			open grazing		
economic efficiency	coefficient	t	P>|t|	coefficient	t	P>|t|	coefficient	t	P>|t|
Gender	-0.21	-2.05	0.053*	-0.333	-2.57	0.012**	-0.011	-0.21	0.835
	-0.1			-0.129			-0.054		
Age	0	-0.18	0.861	-0.002	-0.4	0.689	0	-0.07	0.947
	0			-0.005			-0.002		
Education	0.18	3	0.007***	0.034	0.89	0.378	0.012	0.95	0.347
	-0.06			-0.039			-0.012		
Household size	-0.02	-1.1	0.286	0.012	0.71	0.478	0.01	1.1	0.275
	-0.01			-0.017			-0.009		
Experience	0.02	1.34	0.196	0.001	0.15	0.878	0.001	0.36	0.717
	-0.01			-0.005			-0.002		
Land size	-0.05	-2.12	0.046**	-0.006	-0.33	0.74	0.003	0.58	0.565
	-0.02			-0.019			-0.005		
Social capital	0.08	3.33	0.003***	-0.144	-1.26	0.211	-0.023	-0.6	0.552
	-0.02			-0.114			-0.039		
Distance to market	-0.21	-2.57	0.018**	0.008	0.74	0.462	0.001	0.1	0.922
	-0.08			-0.011			-0.009		
Credit access	0.046	0.5	0.624	-0.041	-0.49	0.627	0.028	0.75	0.454
	-0.093			-0.083			-0.037		
No. of cattle	-0.133	-0.74	0.466	0.01	0.68	0.498	-0.003	-0.54	0.588
	-0.18			-0.016			(0.003)		

Social capital was significant and positive in the zero grazing system with a coefficient of 0.08 (Table 3). This result shows that collective action strengthens farmers' bargaining and lobbying power and facilitates obtaining institutional solutions to constraints and coordination. In addition, collective action has an additional advantage of spreading fixed transaction costs. Empirical evidence support the ability of farmers' co-operatives to bring about rural development in general and improved input use in particular. A study in the lake region of Kenya identified several challenges facing agriculture that can be solved by the co-operatives. The challenges included lack of access to inputs, marketing problems and absence of farmers' organizations (Ochola *et al.*, 2003). Therefore, social capital can solve the problem of failures of deliveries of inputs and timeliness failures that cause erratic availability even when overall supply is unconstrained.

Conclusion

The results of the analysis indicate that presence of economic inefficiencies affected milk production. Economic efficiency increased with the level of intensification of milk production. The elasticity of milk production was an increasing function of costs of herd replacement, housing and labour in the three production systems with statistical significance of 5%. There is need to increase the level of intensification in milk production to enhance economic efficiency. Gender, education, land size, social capital and market access are important determinants of economic efficiency of milk production.

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