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Assessment of technical efficiency and its determinants in beef cattle production in Kenya

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The stochastic metafrontier method is applied to estimate technical efficiency levels in beef cattle production in Kenya. Subsequently, a Tobit model is used to assess factors that might influence efficiency. Results show that the average efficiency level is 0.69, suggesting that there is considerable scope to improve beef production in Kenya. Considering the importance of the livestock enterprise to rural livelihoods and its potential role in poverty reduction, there is need for appropriate development strategies for enhanced efficiency. In particular, livestock development policies should focus on provision of technology-related services. For instance, promoting use of controlled cattle crossbreeding methods would enhance productivity gains. Effective institutional support is also necessary in order to improve efficiency, including improved access to market contracts, better farm management skills and off-farm income opportunities.

Key words: Beef production, technical efficiency determinants, metafrontier, Kenya.

INTRODUCTION

Measurement of technical efficiency (TE) provides useful information on competitiveness of farms and potential to improve productivity, with the existing resources and level of technology (Abdulai and Tietje, 2007). Moreover, investigating factors that influence TE offers important insights on key variables that might be worthy of consideration in policy-making, in order to ensure optimal resource utilisation. There is extensive literature on TE of crops, dairy and mixed crop-livestock farms, but that on beef cattle enterprises is limited (Barnes, 2008; Ceyhan and Hazneci, 2010; Featherstone et al., 1997; Fleming et al., 2010; Hadley, 2006; Iraizoz et al., 2005; Rakipova et

al., 2003 are exceptions). In Kenya, 70% of all households are engaged in crop and livestock farming; about 84% of them depend on livestock for livelihoods in rural areas (KIPPRA, 2009). However, past studies on efficiency mainly focus on crops (Nyagaka et al., 2010) and dairy (Kavoi et al., 2010); no study has analysed the TE of beef cattle farms in Kenya.

The present study investigates TE and its determinants in beef cattle production in Kenya. There are three main beef cattle production systems in Kenya: nomadic pastoralism, agro-pastoralism and ranches. Nomadic pastoralism and agro-pastoralism contribute about 65%

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of total beef output in Kenya, while the rest is obtained from ranches and a small proportion from culled dairy cattle (Omiti and Irungu, 2002). Further, it is estimated that over 60% of livestock in Kenya is kept by pastoralists in the arid and semi-arid lands (which constitute about 80% of Kenya's landmass) providing employment to about 90% of the population in those areas and contributing nearly 95% of their income (KIPPRA, 2009). However, more than 50% of pastoralists in Kenya live below the poverty line, that is, they survive on less than USD\$1 per day (Thornton et al., 2007). As noted by Larsen et al. (2009), improving the efficiency and productivity of crop and livestock enterprises is important for enhancing economic growth and reducing poverty in agriculture-dependent developing countries such as Kenya.

Livestock contribute about 42% of agricultural output in Kenya; 35% of this is derived from beef cattle. Generally, beef production is considerably less than estimated consumption (FAO, 2005; MoA and KIPPRA, 2009). However, development of the livestock sub-sector is relatively neglected by policy. For instance, public funds allocated to livestock development are low (less than 10% of the annual national development expenditure) (Mugunieri et al., 2011; Otieno, 2008). Consequently, most farmers have limited access to better farm technologies, requisite skills and market services. Further, weak linkages between research-extension service providers and farmers are considered to contribute to low and/or inappropriate use of inputs by farmers. As a result, agricultural productivity and growth are relatively low; yet the agricultural sector is expected to play an important role as the engine of national economic development (Mugunieri and Omiti, 2007; Oluoch-Kosura, 2010).

Investigating the determinants of TE in beef cattle, production should provide analytical insights to enhance beef supply in the domestic market, and possibly enable Kenya to export, for example, to the European Union (EU) where it has preferential access. Moreover, as land becomes scarce and enterprise competitiveness change in developing countries such as Kenya, it is important to streamline development policy to prioritize resource allocation on cattle production systems that offer commensurate returns to investments. The analysis of determinants of TE would provide insights to address this information need. For example, in Uganda, similar analytical insights have been used to advocate for policies that encourage sedentarization of nomads by promoting investment on requisite inputs such as water and pasture development, and provision of basic infrastructure (Wurzinger et al., 2009).

In this study, we use the stochastic metafrontier-Tobit (henceforth referred to as SM-Tobit) method. This involves first, estimating TE through a metafrontier approach (O'Donnell et al., 2008), and subsequently using a Tobit model (Tobin, 1958) to investigate determinants of the TE. The SM-Tobit method is preferred to a one-step

stochastic frontier approach (SFA) (Aigner et al., 1977; Meeusen and van den Broeck, 1977) because although a one-step SFA reduces bias in estimation, the metafrontier framework improves analysis by accounting for technology gaps and allows comparison of TEs across heterogeneous groups (O'Donnell et al., 2008; Villano et al., 2010) such as production systems. For completeness of analysis of efficiency determinants, a one-step SFA (Battese and Coelli, 1995) is applied alongside the SM-tobit model. The use of ordinary least squares (OLS) regression to estimate determinants of TE (see for example, Dadzie and Dasmani, 2010) is considered unsuitable because it might lead to biased estimates, given that TE scores are bounded between 0 and 1. Further, use of SFA with dummies for study sites or production systems is not recommended in capturing technology differences. Specifically, such dummy variables were found to be highly correlated with farm characteristics and did not improve the model fit; their inclusion led to statistical insignificance of most parameters.

Generally, the Tobit model can be applied to investigate determinants of efficiency in any of the following two formats:

- (a) Stochastic frontier-Tobit, for example in Nyagaka et al. (2010). However, this approach does not account for technology differences and cannot accommodate many explanatory variables, without loss of parsimony;
- (b) SM-Tobit, which allows hypothesis tests on the nature of inefficiency, and accounts for technology differences.

In addition, this approach is suitable for modelling a continuous censored dependent variable (such as TE, which is bounded between 0 and 1) (Bravo-Ureta and Pinheiro, 1997; Wooldridge, 2002). However, there is a dearth of empirical literature on application of the SM-Tobit method, Chen and Song (2008) being an exception. The present study contributes to the literature by applying this approach to investigate TE and its determinants in beef cattle production in Kenya.

ANALYTICAL FRAMEWORK

Estimation of the SM-Tobit involves three stages. First, the SFA (Aigner et al., 1977; Meeusen and van den Broeck, 1977) is used to investigate TEs across the production systems. In the second stage, a metafrontier (O'Donnell et al., 2008) is estimated to adjust the TE scores from SFA, taking into account any technology differences. Finally, a Tobit model is applied to assess variations in the TE scores obtained from the metafrontier estimation. Assume there are k groups or production systems in the cattle industry. The stochastic production frontier is specified as:

$$Q_i = f(X, \beta) + \varepsilon^* \quad (1)$$

where Q_i is the output of the n^{th} farm; X is the vector of inputs used by the n^{th} farm; β is a vector of production parameters to be estimated; ε^* is the composite disturbance term given by:

$$\mathcal{E}^* = v - u \tag{2}$$

where v represents statistical noise assumed to be independently and identically distributed (IID) as a normal random variable with zero mean and variance given by σ_v^2 , that is, $v \sim N(0, \sigma_v^2)$ (Aigner et al., 1977). Farm-specific technical inefficiency in production is typically assumed to be captured by u , which is a non-negative random variable.

The u is assumed to be IID half-normal, that is, $u \sim |N(0, \sigma_u^2)|$.

Although u can also assume exponential or other distributions, the half-normal distribution is preferred for parsimony because it entails less computational complexity (Coelli et al., 2005). The u is independent of the v -term and it measures the TE relative to the stochastic frontier. When data are in logarithm terms, u is a measure of the percentage by which a particular observation or farm fails to achieve the frontier, ideal production rate (Greene, 2003). Following Battese and Corra (1977), the variation of output from the frontier due to technical inefficiency is defined by a parameter (γ) given by:

$$\gamma = \frac{\sigma_u^2}{\sigma^2} \text{ such that } 0 \leq \gamma \leq 1 \tag{3}$$

where $\sigma^2 = \sigma_u^2 + \sigma_v^2$.

Taking account of various determinants of TE, we can specify the stochastic frontier production function in (1), for each production system as (O'Donnell et al., 2008):

$$Q_{nk} = f(X_{nk}, \beta_k) \exp(v_{nk} - Z_{nk} \delta) \tag{4}$$

where Q_{nk} denotes the output for the n^{th} farm in the k^{th} production system; $f(\cdot)$ is the functional form used, for example the Cobb-Douglas or translog specification; β_k is a vector of input parameters to be estimated for the k^{th} production system; Z is a vector of factors that influence the technical inefficiency of farms, while δ is a vector of inefficiency parameters to be estimated.

The TE can be measured as the ratio of actual output observed (Equation 4) to that expected maximum level from the use of available inputs (assuming any deviation is pure noise) (Boshrabadi et al., 2008):

$$TE_{nk} = \frac{f(X_{nk}, \beta_k) \exp(v_{nk} - Z_{nk} \delta)}{f(X_{nk}, \beta_k) \exp(v_{nk})} = -Z_{nk} \delta \tag{5}$$

Each frontier measures individual farmers' performance relative to the dominant technology in a particular production system. However, the model in (5) is inappropriate for comparing the performance of farms across different groups of farms that are not identical technology-wise (O'Donnell et al., 2008). In order to capture variations in technology within and between production systems, Battese et al. (2004) suggest the use of a meta-frontier production function to measure efficiency and technology gaps of firms producing in different technological environments. The meta-frontier is considered as a smooth function that envelops the explained (deterministic) components of the group stochastic frontier functions (e.g., for different production systems). It explains deviations between observed outputs and the maximum possible explained output levels in the group frontiers. The meta-frontier equation can be expressed as:

$$Q^* = f(X_n, \beta^*) \quad n = 1, 2, \dots, N \tag{6}$$

where $f(\cdot)$ is a specified functional form; Q^* is the meta-frontier output; and β^* denotes the vector of meta-frontier parameters satisfying the constraints:

$$f(X_n, \beta^*) \geq f(X_n, \beta_k), \text{ for all } k = 1, 2, \dots, K \tag{7}$$

In order to satisfy the condition in (7), an optimization problem is solved where the sum of absolute deviations (or squared deviations) of the meta-frontier values from the values of the group frontiers are minimized:

$$\begin{aligned} \min \sum_{n=1}^N |\ln f(X_n, \beta^*) - \ln f(X_n, \beta_k)| \\ \text{s.t. } \ln f(X_n, \beta^*) \geq \ln f(X_n, \beta_k) \end{aligned} \tag{8}$$

In terms of the meta-frontier, the observed output for the n^{th} farm in the k^{th} production system (measured by the stochastic frontier in (4)) can be expressed as:

$$Q^*_{nk} = \exp(-Z_{nk} \delta) * \frac{f(X_n, \beta_k)}{f(X_n, \beta^*)} * f(X_n, \beta^*) \exp(v_{nk}) \tag{9}$$

where (recall from (5) that, $-Z_{nk} \delta = TE_{nk}$) the middle term in Equation (9) represents the technology gap ratio (TGR):

$$TGR_n = \frac{f(X_n, \beta_k)}{f(X_n, \beta^*)} \tag{10}$$

The TGR measures the ratio of the output for the frontier production function for the k^{th} group or production system relative to the potential output defined by the metafrontier, given the observed inputs (Battese et al., 2004). Values of TGR closer to 1 imply that a farm in a given production system is producing nearer to the maximum potential output given the technology available for the whole industry. The TGR is subsequently referred to as meta-technology ratio (MTR) to account for the wider environment in which production takes place and other factors that might influence the potential productivity gains from a given technology. The TE of the n^{th} farmer relative to the meta-frontier (TE^*_n) is the ratio of the observed output for the n^{th} farm relative to the meta-frontier output:

$$TE^*_n = \frac{Q_{nk}}{f(X_n, \beta^*) \exp(v_{nk})} \tag{11}$$

Following (5), (9), and (10), TE^*_n can be expressed as the product of the TE relative to the stochastic frontier of a given production system and the MTR:

$$TE^*_n = TE_{nk} \cdot MTR_n \tag{12}$$

After estimating the metafrontier TE scores, determinants of efficiency are investigated using a two-limit Tobit model, given that efficiency scores are bounded between 0 and 1 (Bravo-Ureta and Pinheiro, 1997; Wooldridge, 2002). The two-limit Tobit model is specified as:

$$\begin{aligned} \theta^{k*} &= Z\delta + e \\ \theta^{k*} &= \left\{ \begin{aligned} &0 \text{ if } \theta^{k*} < 0; \\ &\theta^{k*} \text{ if } 0 < \theta^{k*} < 1; \\ &1 \text{ if } \theta^{k*} > 1 \end{aligned} \right\} \tag{13} \end{aligned}$$

where θ^{k*} and θ^k are the latent and observed values of the metafrontier TE scores, respectively; Z denotes the vector of

socio-demographic and other independent variables assumed to influence efficiency; and e is the random term.

Data and estimation

Sampling and data collection

The study was conducted in four districts (Kajiado, Kilifi, Makueni and Taita Taveta), which are representative of the main beef cattle production systems in Kenya: nomadic pastoralism, agro-pastoralism and ranches. Nomads are usually found in climatically marginalised environments; they are less sedentary and migrate seasonally with cattle and other livestock in search of pasture and water (Fratkin, 2001). They are less commercialised, but derive a relatively large share of their livelihood from cattle and other livestock. Generally, nomads are considered to maintain cattle principally as a capital and cultural asset, and sell only when absolutely necessary (Thornton et al., 2007). In contrast, the agro-pastoralists are sedentary; they keep cattle and other livestock, besides cultivating various crops, and are fairly commercialised. Finally, ranches are purely commercial livestock enterprises, but may also grow a few crops for use as on-farm fodder or for sale. The ranches mainly use controlled grazing on their private land, and purchased supplementary feeds. However, both the nomads and agro-pastoralists generally depend on open grazing, with limited use of purchased feeds (except during dry periods).

The areas sampled in the study are contiguous, hence logistically more accessible. A multi-stage cluster (area) sampling approach (Horppila and Peltonen, 1992) was used. Within the four districts, smaller administrative units (divisions) were randomly selected from lists of all divisions in these districts, taking into account the general distribution of cattle in the study area. Subsequent stages involved a random selection of a sample of locations, from which a number of smaller units (sub-locations) were selected. The primary sampling units for the survey were 40 sub-locations. Systematic random sampling was used to select individual respondents for interview during the survey.

A structured questionnaire was applied for data collection. The main variables captured in the data included: relative importance of cattle and other enterprises to household income; cattle inventory in the past twelve months; production inputs such as feeds, labour, veterinary supplies and advisory services, and fixed inputs; cattle breeding method; access to extension and market services; and household socio-demographic characteristics. With the assistance of local experienced interviewers who were adequately trained prior to the surveys, the questionnaire was pre-tested, edited and then administered through face-to-face interviews of farmers between July and December 2009. A random route procedure (for example first left, next right, and so on) was followed by the interviewers to select every fifth or tenth farmer, in sparsely or densely populated sub-locations, respectively (Lohr, 2007). In total, 313 farmers including 66 ranchers, 110 nomads and 137 agro-pastoralists were interviewed.

Some of the farm characteristics from the survey are shown in Table 1. On average, ranchers have larger herds and farms than the nomads and agro-pastoralists. Both nomads and ranchers tend to keep indigenous (local) cattle breeds such as the east African *Zebu* and *Boran*, which are relatively more adapted to dry and hot areas (e.g., Kajiado and Kilifi) where most farmers in both systems live. In contrast, the agro-pastoralists have a majority of crossbreeds and pure exotic breeds. The ranchers have significantly higher average monthly household incomes than nomads and agro-pastoralists. In common with the nomads, they depend more heavily on cattle as the main source of income. Only a quarter of farmers in the three systems depend on off-farm income. This is consistent with the observation that a few pastoralists near Peri-urban areas are gradually diversifying their

activities into wage labour or small businesses, due to rapid population growth and the concomitant pressure on resources, such as water and grazing land (Thornton et al., 2007). Further, one-third of the farmers (although a smaller proportion of ranchers) depend on both crops and other livestock such as sheep and goats (sheeps), besides cattle enterprises.

The ranchers use most of their land to grow fodder. Most agro-pastoralists and nomads have individual land ownership with relatively secure tenure (possess either a title deed or allotment letter). About 40% of ranchers however, have group-owned land without secure tenure. Most of these farms were previously large-scale government or private landholdings that have only been subdivided recently, either to address group ranch management problems or to provide long-term access to younger members (Thornton et al., 2007). However, as noted by Lengoiboni et al. (2010), the existing land laws and property rights in land administration in Kenya tend to focus on ownership and control of land, but are inadequate in serving pastoralists' temporal and spatial access rights. Generally, improved land tenure and access rights (e.g., through land registration) are considered as important prerequisites for long-term and ecologically beneficial land-related investments, technology adoption and productivity enhancement (Deininger, 2010; Kabubo-Mariara et al., 2010; Oluoch-Kosura, 2010).

Over 60% of all farmers, including more than three-quarters of the nomads are found in rural areas. More than half of farmers in all the production types are male, with ranchers having less than a quarter of females. There is no significant difference in the average age of agro-pastoralists and ranchers, but generally farmers in both categories are slightly older than the nomads. Across the three production systems, the level of formal education (secondary and above) is consistently lower than 40%.

Currently, ranchers benefit from relatively better access to livestock extension and veterinary advisory services, and most of them have farm managers. A higher proportion of agro-pastoralists use controlled cattle breeding. This is consistent with the observation that the more commercially-oriented farmers (that is, ranchers and agro-pastoralists) prefer cattle breeding strategies that target market and/or profitability requirements, e.g., faster growth and higher gains in live weight, while the relatively less-commercialised nomads mainly focus on cattle survival traits such as drought resistance, hardiness and disease tolerance (Gamba, 2006). Generally, more than half of farmers sell cattle to abattoirs, e.g., the Kenya Meat Commission (KMC), while the rest sell to other outlets such as open-air markets. Only one third of farmers (mostly ranchers) have access to prior market information and sell on contract. As noted by Omiti et al. (2009) and Shilpi and Umali-Deininger (2008), improving market infrastructure (e.g., provision of appropriate market information and contract opportunities) and enabling farmers to access the markets are important for enhanced commercialisation, and would possibly improve their incomes and livelihoods.

Empirical estimation

The main production variables for the beef cattle enterprise are summarised in Table 2. On average, ranchers use more inputs and produce the highest output. Nomads and agro-pastoralists use significantly lower amount of feeds and invest less in professional veterinary services. Farmers (especially the nomads) in remote areas of Kenya with limited access to professional veterinary services prefer community-based and /or self-administered herbal animal health services (Irungu et al., 2006). The agro-pastoralists have the highest unpaid labour component, perhaps to reduce costs due to greater enterprise diversification compared to the other farm types. Consistent with their less-sedentary nature, the nomads use the least amount of on-farm feeds (which might be from

Table 1. Sample characteristics from the survey, 2008 to 2009.

Variable	Nomads (n = 110)	Agro-pastoralists (n = 137)	Ranchers (n = 66)	Pooled sample (n = 313)
Average cattle herd size	53.1 ^b	11.4 ^c	150.9 ^a	55.5
Main cattle breed is indigenous (% of farmers)	68.2 ^a	27.0 ^c	54.5 ^b	47.3
Monthly income above Kshs 20,000 (% of farmers)*	22.7 ^b	15.3 ^b	84.8 ^a	32.6
Percentage of farmers who derive more than half of income from cattle (specialisation)**	78.2 ^b	36.5 ^c	93.9 ^a	63.3
Dependence on both crops and other livestock (% of farmers)	31.8 ^a	38.7 ^a	7.6 ^b	29.7
Dependence on off-farm income (% of farmers)	25.5 ^a	24.8 ^a	24.2 ^a	24.9
Average farm size (acres)	84.1 ^b	9.5 ^b	426.5 ^a	123.6
Land ownership with title deed/allotment letter (% of farmers)	78.2 ^a	77.4 ^a	54.5 ^b	72.8
Individual land ownership and not communal (% of farmers)	96.4 ^a	96.4 ^a	65.2 ^b	89.8
Rural location (% of farmers)	83.6 ^a	65.7 ^b	72.7 ^b	73.5
Gender (% of male farmers)	66.4 ^b	67.2 ^b	87.9 ^a	71.2
Average age of respondent (years)	38.6 ^b	42.4 ^a	42.1 ^a	41.0
Secondary education and above (% of farmers)	30.0 ^a	38.7 ^a	34.8 ^a	34.8
Access to livestock extension services in the past year (% of farmers)	49.1 ^b	35.8 ^c	77.3 ^a	49.2
Access to veterinary advisory services in the past year (% of farmers)	50.0 ^b	51.8 ^b	87.9 ^a	58.8
Percentage of farms with manager	8.2 ^b	7.3 ^b	75.8 ^a	22.0
Use of controlled cattle breeding method (% of farmers)	58.2 ^b	79.6 ^a	68.2 ^b	69.6
Main market is abattoir e.g., KMC (% of farmers)	49.1 ^c	64.2 ^b	77.3 ^a	61.7
Access to prior market information in the past year (% of farmers)	26.4 ^b	19.7 ^b	68.2 ^a	32.3
Sale of cattle on contract (% of farmers)	16.4 ^b	24.8 ^b	53.0 ^a	27.8
Experience in cattle production (years)	15.5 ^a	13.2 ^a	13.7 ^a	14.1

^{a,b,c} differences in the subscripts denote significant differences (10% level or better) across the production systems. * 75 Kenyan shillings (Kshs) were equivalent to USD\$1 at the time of the survey. ** Other studies e.g., Hadley (2006) also defined specialisation as the proportion of household income derived from a particular enterprise. Further, based on the distribution of income in the present study, the 50% criterion is used in order to maintain a reasonable sample in each category.

naturally-growing pasture in their temporary abodes or possibly donations from sedentary farmers; there is no evidence to indicate that nomads invest in fodder cultivation). Generally, both nomads and agro-pastoralists use poor livestock feeding regimes (Oluoch-Kosura, 2010); this might entail infrequent feeding schedules and inadequate and/or low quality feeds. However, nomads have higher depreciation costs than agro-pastoralists, because almost all of them possess portable cattle equipment such as dip sprayer, chaff cutter, dehorning and castration equipment (Table 2).

In order to ensure consistent estimates of inefficiency

effects in the SFA, the one-stage model proposed by Battese and Coelli (1995) was preferred over the alternative two-stage analytical process. A likelihood ratio (LR) test showed that the Cobb-Douglas functional form provided a better fit to the pooled and individual-group survey data than a translog model. The LR test failed to reject the null hypothesis that Cobb-Douglas model was a better specification of sample data, with for example LR statistic of 3.58 compared to the chi-square critical value of 18.31 at 5% and 10 degrees of freedom in the case of the pooled sample. All parameters in the stochastic frontier and model for technical inefficiency effects were

simultaneously estimated in one equation as:

$$\ln Q_{n(k)} = \beta_{0(k)} + \sum_{i=1}^4 \beta_{i(k)} \ln X_{m(k)} - Z_n \delta_{(k)} + v_{n(k)} \quad (14)$$

where $Q_{n(k)}$ is the annual value of beef cattle output (measured following the approach in Hadley, 2006, assuming one price in each site); X_{ni} represents a vector of inputs where X_{n1} is beef herd size, X_{n2} denotes total feed equivalents, and X_{n3} is the cost of veterinary services, while X_{n4} is a *Divisia* index calculated as (Boshrabadi et al., 2008):

Table 2. Average annual output and inputs, 2008 to 2009.

Variable	Nomads (n = 110)	Agro-pastoralists (n = 137)	Ranchers (n = 66)	Pooled sample (n = 313)
Value of beef cattle output (Kshs)	135,961 ^b	37,807 ^c	579,155 ^a	186,452
Beef cattle equivalents (herd size)	36 ^b	8 ^c	112 ^a	40
Depreciation costs (Kshs)	7,278 ^b	2,535 ^c	228,042 ^a	51,753
Veterinary costs (Kshs)	17,256 ^b	14,911 ^b	145,036 ^a	43,174
Paid labour costs (Kshs)	33,547 ^b	10,648 ^c	128,512 ^a	43,549
Opportunity cost of unpaid labour (Kshs)	37,219 ^b	47,752 ^a	35,286 ^b	41,422
Purchased feed equivalents (Kg)	5,848 ^b	3,331 ^c	14,162 ^a	6,500
On-farm feed equivalents (Kg)	219 ^c	4,005 ^b	18,442 ^a	5,718
Cost of other inputs, e.g., market services, branding etc. (Kshs)	17,943 ^b	5,339 ^c	189,863 ^a	48,678

^{a,b,c} differences in the superscripts denote significant differences (at 10% level or better) across the production systems. Total labour costs and feed equivalents comprise both paid and unpaid labour, and purchased and on-farm feeds, respectively.

$$X_{n4(k)} = \prod_{i=1}^p C_{ni(k)}^{\alpha_{ni}} \quad (15)$$

Where $\alpha_{ni(k)}$ represents the share of the i^{th} input in the total cost for the n^{th} farm in the k^{th} production system; $C_{n1(k)}$ = depreciation, insurance and taxes on farm buildings, machinery and equipment (Kshs); $C_{n2(k)}$ = total cost of labour (Kshs); $C_{n3(k)}$ = other costs, e.g. fuel, electricity, market services, hire/maintenance of machinery, purchase of ropes, branding etc. (Kshs).

Inputs were measured as follows. The beef cattle herd size was computed as the average number of cattle kept in the past twelve months, adjusted with the relevant conversion factors. Following insights from focused group discussions with key informants in the livestock sector in Kenya, the conversion factors were calculated as the ratio of average slaughter weight of different cattle types to the average slaughter weight of a mature beef bull. The average slaughter weight of mature bull, considered to be suitable for beef in Kenya, is 159 kg (FAO, 2005). The estimated conversion factors were: 0.2, 0.6, 0.75, 0.8 and 1, for calves, heifers, cows, steers and bulls, respectively.

In order to capture the approximate share of feeds from different sources in each production system, the quantities of purchased and non-purchased (or on-farm) feeds were first adjusted with the average annual number of dry and wet months, respectively, in each district. Assuming one price in a given locality (Chavas and Aliber, 1993), average feed prices were computed using prices from district annual reports and recent surveys (Lukuyu et al., 2009), after validation with research staff at the Kenya Agricultural Research Institute (KARI). Both purchased and non-purchased feeds were then converted to improved feed equivalents by multiplying the respective feed quantities by the ratio of their prices (or opportunity costs) to the average per unit price of improved fodder. Depreciation costs on fixed inputs were based on the straight line method, assuming a 10% salvage value. The depreciable value of an asset was based on the proportion of time that it was used in the cattle enterprise. Labour costs comprise both paid and unpaid labour; the latter valued using the average minimum farm wage in a particular district. The labour costs were adjusted with the share of cattle income in household income. Similar adjustments were applied to other incidental variable costs, such as fuel and electricity bills.

Intuitively, a negative sign of an element of the δ vector in Equation (14)

implies that the variable has a positive influence on TE or decreases inefficiency (Brummer and Loy, 2000). The log likelihood for the half-normal model can be expressed following Greene (2003). The parameters of the stochastic frontiers were obtained by maximising the likelihood function using FRONTIER version 4.1c software (Coelli, 1996). The metafrontier in (5) was estimated through linear programming (LP) and standard errors obtained using the bootstrapping technique in SHAZAM version 10 software (Whistler et al., 2007). Finally, the Tobit model (13) was estimated using LIMDEP version 9.0/NLOGIT version 4.0 software (Greene, 2007), to investigate determinants of TE. The log-likelihood function for the two-limit Tobit model is expressed following Wooldridge (2002).

RESULTS AND DISCUSSION

The results reported in Table 3 show that relative to the metafrontier, nomads have a mean TE of 0.65, agro-pastoralists a mean of 0.70 and ranchers a mean of 0.76. The average pooled sample TE with respect to the metafrontier is 0.69, implying that there is scope to improve beef production in Kenya by up to 31% of the total potential (Table 3). The mean meta-technology ratio (MTR) in the pooled sample is 0.93, implying that, on average, beef farmers in Kenya produce 93% of the maximum potential output achievable from the available technology.

In addition, the study showed that 98% of farmers across the three production systems have MTR estimates below 1, indicating that they use the available technology (e.g., crossbreed cattle) sub-optimally. Perhaps this can be explained by the view of Diagne (2010) that low rates of adoption or poor use of agricultural technologies in sub-Saharan Africa is largely due to lack of awareness on the technologies and/or how to use them. The average MTR is highest in ranches (0.96) and lowest in the agro-pastoralist system (0.91). This is consistent with the differences in relative levels of investments in the cattle enterprise by farmers in the three production systems

Table 3. Technical efficiency and meta-technology ratios.

Model		Nomads	Agro-pastoralists	Ranchers	Total
TE w.r.t. the pooled frontier*					
	Mean	0.711 ^b	0.749 ^a	0.774 ^a	0.741
	Min	0.328	0.275	0.442	0.275
	Max	0.972	0.945	0.954	0.972
	SD	0.141	0.133	0.121	0.135
TE w.r.t. production system frontiers*					
	Mean	0.681 ^b	0.767 ^a	0.792 ^a	0.738
	Min	0.302	0.313	0.499	0.302
	Max	0.998	0.936	0.938	0.998
	SD	0.172	0.119	0.101	0.143
TE w.r.t. the metafrontier					
	Mean	0.647 ^c	0.696 ^b	0.763 ^a	0.693
	Min	0.278	0.267	0.481	0.267
	Max	0.943	0.909	0.944	0.944
	SD	0.162	0.112	0.099	0.136
Meta-technology ratio					
	Mean	0.942 ^b	0.907 ^c	0.963 ^a	0.931
	Min	0.905	0.806	0.892	0.806
	Max	1.000	1.000	1.000	1.000
	SD	0.020	0.044	0.025	0.040

Notes: * these TE scores are only shown for completeness of analysis. However, comparisons are based on metafrontier and meta-technology ratios due to differences in technology across the production systems. ^{a,b,c} Differences in the superscripts denote significant differences (at 10% level or better) across the production systems.

(for instance, see higher depreciation costs for ranchers in Table 2). Further, that the MTR is higher for nomads than for agro-pastoralists can perhaps be explained by the notion of 'catching-up or convergence to best practice' (Rao and Coelli, 1998). This stipulates that, on average, farmers who conventionally operate below the technology frontier might be expected to adopt technologies at a relatively faster rate than those who produce near the frontier.

Ranchers and nomads have relatively low variation in MTRs (SD is 0.020 and 0.025), perhaps because both groups keep indigenous breeds or their crosses, while the agro-pastoralists have more crossbreeds of indigenous and exotic cattle. Compared to the exotic breeds, indigenous breeds generally adapt well to drier conditions where most beef cattle are reared in Kenya. The maximum estimated MTR is 1 in all three production systems, which means that the group frontiers are tangent to the metafrontier (Battese et al., 2004); it was found that 2% of farmers in the sample (at least one farm from each production system) produce on the metafrontier. This suggests that in order to achieve further productivity gains (for the small proportion of technology-optimal farmers) it is important to provide a

relatively better technology (cattle breed). When MTRs are higher than meta-technical efficiency scores, it implies that individuals are better at using available technologies, but their efficiency measures remain relatively low due to other non-technology factors.

Besides estimating TE scores, another key objective of TE analysis is to explain possible sources of inefficiency, commonly referred to in the literature as inefficiency effects (Coelli et al., 2005). In this study, possible determinants of TE were investigated by inclusion of various socio-economic and technology-related variables in the estimation. The selection of variables for the inefficiency model started with a review of literature on relevant policy variables followed by a test of multicollinearity through computation of variance inflation factors (VIF) for each of the descriptive variables (Table 1). This involved estimation of 'artificial' OLS regressions between each of the farm characteristics as the 'dependent' variable with the rest as independent variables:

VIF for each regression is calculated as:

$$VIF_i = \frac{1}{1 - R_i^2} \quad (16)$$

Table 4. Production function estimates and determinants of technical efficiency.

Variable	Pooled Stochastic frontier (n = 313)	Metafrontier-Tobit (n = 313)
Production input parameters		
Constant (β_0)	7.62***(0.146)	8.28***(0.0016)
Beef herd size (β_1)	0.89***(0.016)	0.90***(0.0001)
Improved feed equivalents (β_2)	0.04***(0.013)	0.03***(0.0001)
Veterinary cost (β_3)	0.08***(0.015)	0.06***(0.00004)
<i>Divisia</i> index for other costs (β_4)	0.02***(0.007)	0.02(0.0133)
Inefficiency effects		
Constant (δ_0)	-0.30(0.407)	0.62***(0.031)
Indigenous breed (δ_1)	-0.26(0.178)	0.01(0.016)
Controlled breeding method (δ_2)	-0.65***(0.256)	0.06***(0.018)
Access to market contract (δ_3)	-0.62***(0.240)	0.04**(0.017)
Farm size (δ_4)	0.0006**(0.0003)	-0.00002(0.00002)
Specialisation (δ_5)	0.84***(0.281)	-0.04**(0.016)
Peri-urban location (δ_6)	0.84***(0.284)	-0.01(0.017)
Presence of farm manager (δ_7)	-1.27**(0.527)	0.05**(0.022)
Age of farmer (δ_8)	-0.01*(0.007)	0.0007(0.001)
Off-farm income (δ_9)	-0.92***(0.367)	0.03*(0.017)
Beef herd size (δ_{10})	-	0.003***(0.0001)
Income-education (δ_{11})	-	-0.04**(0.018)
σ^2	0.30***(0.093)	-
γ	0.86***(0.050)	-
Log likelihood function	-32.36	206.06

Notes: statistical significance levels: ***1%; **5%; *10%. Corresponding standard errors are shown in parentheses. The log likelihood of a Tobit model with continuous dependent variable (censored between 0 and 1, in this case) can be positive or negative because it represents the log likelihood of a density or cumulative density function, unlike in discrete distributions where the log likelihood is of a probability and always negative or zero (Greene, 1990).

where R_i^2 is the R^2 of the artificial regression with the i^{th} independent variable as a 'dependent' variable.

Since all the independent variables exhibited $VIF_i < 5$, it was concluded that there was no multicollinearity and therefore all these variables were eligible for inclusion in the model estimation (Maddala, 2000). The next stage involved estimation of a pooled stochastic frontier where all the descriptive variables were included as possible determinants of inefficiency. From this, variables that were insignificant and did not improve the overall model fit were dropped. Subsequent re-estimations were undertaken to obtain better results in terms of significance.

Results from the pooled stochastic frontier and metafrontier are shown in Table 4. Positive input parameters imply that increased usage of these inputs would yield more output as postulated by theory, assuming that producers are rational (Coelli et al., 2005). The metafrontier results show that an increase in the use of any of the three inputs (beef herd size, improved feed equivalents, veterinary expenditure) would lead to significant improvement in output. The sum of elasticities generally equals one, indicating that on average the

constant returns to scale property of the Cobb-Douglas specification fits the data. The sum of input elasticities were slightly below one, for nomads (0.98) and agropastoralists' frontiers (0.97), and marginally exceeded one (1.02) for ranchers. Necessary regularity conditions are fulfilled. All marginal physical products were found to be positive at the sample mean and for all observations (that is, there is monotonicity). Further, concavity test is fulfilled as the second order derivatives of production parameters were negative in all production systems. Perhaps, the only violation occurs for second derivative of herd size, which though negative is insignificant.

In a one-step stochastic frontier estimation, the parameter for inefficiency level usually enters the model as the dependent variable in the inefficiency effects component of the model; therefore a negative sign of a variable in the *Z-vector* implies that the corresponding variable would reduce inefficiency (or increase efficiency). On the contrary, a positive *Z-variable* is interpreted as potentially having a negative influence on efficiency (Brummer and Loy, 2000; Coelli et al., 2005). In the two-stage Tobit estimation however, conventional interpretation of regression parameters is applicable

because the TE measure obtained from the optimisation process in the metafrontier estimation is used as the dependent variable in the subsequent Tobit model (Chen and Song, 2008). Thus, positive signs of variables in the metafrontier-Tobit model imply that such variables would increase efficiency.

The significance of σ^2 confirms that the frontier model is stochastic (rather than deterministic). Moreover, the value of γ implies that 86% of the discrepancies between the observed value of beef output and the frontier output can be attributed to failures within the farmers' control. Results on the estimated inefficiency effects from both the stochastic frontier and the metafrontier-Tobit models show that use of controlled breeding method, access to market contract, presence of farm manager and off-farm income would significantly improve efficiency, while specialisation (higher dependence on beef cattle for income) would reduce efficiency (see lower part of Table 4). Farm size, farmer's age and Peri-urban location were found to be significant in the pooled stochastic frontier, but not in the metafrontier-Tobit model. The finding on farm size contradicts that of Sharma et al. (1999) who showed that large farms in the relatively industrialized state Hawaii (compared to less industrialized Kenya) were more efficient than small ones, due to relatively lower labour use and feed cost, per unit of output, in the large farms.

Perhaps the unexpected influence of farm size on efficiency might be attributed to lack of long-term investments on land by most Kenyan pastoralists. Moreover, although some farmers have relatively secure land tenure, as noted earlier (Table 1), Fenske (2011) observed that social and cultural constraints often prevent Kenyan pastoralists from using land as collateral in order to acquire other requisite farm inputs; hence most of the land is fallow. As a consequence, the fallow land acts as an indirect cost, for example in the form of high opportunity cost of feeds and labour to oversee grazing elsewhere. Results show that older farmers are likely to be more efficient, perhaps because they are likely to have more experience (Rakipova et al., 2003). Further, Peri-urban location was shown to contribute significantly to inefficiency. This does not support the observation of Stifel and Minten (2008), that remoteness increases inefficiency in rice production in Madagascar through limited access to technology and infrastructure. In the present study, however, it is worthwhile to note that main grazing areas and water sources for most cattle farmers are located away from the urban centres.

Given the statistical differences in the production systems, the pooled stochastic frontier might be considered inappropriate for policy application and are only presented for completeness of the analysis (Battese et al., 2004). Hence, the subsequent discussion focuses on variables that are significant in the metafrontier-Tobit estimation. Controlled cattle breeding might be expected to increase efficiency by improving genetic quality,

enhancing adaptation of cattle to environmental conditions and ensuring optimal stocking (Wollny, 2003). Further, Kavoi et al. (2010) note that, given proper management, planned crossbreeding of exotic and indigenous cattle can improve potential for higher output in relatively dry areas of Kenya. Results show that use of market contracts also significantly improves TE. This is consistent with the view of MacDonald et al. (2004) that sales contracts are important in enabling farmers to obtain steady and increased income through an assured market, and reduced input and output price risks. Well-functioning contractual arrangements might also provide improved access to better inputs and more efficient production methods (Oluoch-Kosura, 2010). In addition, provision of better contracts and improving other market infrastructure (e.g., information services) are deemed important for increased agricultural commercialisation and possibly better incomes and livelihoods to farmers (Omiti et al., 2009; Shilpi and Umali-Deininger, 2008).

Moreover, availability of a manager with appropriate managerial capacity is considered to be a useful asset in the organisation of inputs and overall decision-making in the farm (Nuthall, 2009). Therefore, availability of a professional farm manager might be expected, as shown in this study, to enhance co-ordination of farm operations and ensure better utilisation of resources. On the contrary, lack of proper management might lead to accumulation of less productive resources and their less intensive use, consequently resulting in lower efficiency (Meon and Weill, 2005).

The significance of off-farm income suggests that, as noted by Alene et al. (2008), there might be considerable re-investment of such earnings in various farm operations by some cattle keepers in Kenya. The finding on specialisation seems to contradict the suggestion by Rakipova et al. (2003) that farmers who depend heavily on cattle production for their livelihoods might be more efficient. However, this result supports Featherstone et al. (1997), Hadley (2006), Hallam and Machado (1996) and Iraizoz et al. (2005), that specialised farmers are relatively less efficient due to lack of flexibility to adapt to changes in market and policy environments.

Compared to the stochastic frontier, the metafrontier-Tobit model offers an improvement in the ability to explain TE; two additional variables, that is, beef herd size and an interaction term (for education and income), are found to be significant. These two variables were dropped from the pooled stochastic frontier results in Table 4 because their inclusive led to wrong signs and statistical insignificance of other parameters due to correlation with input parameters in the one-step SFA estimation. The metafrontier-Tobit approach eliminates the correlation and yields more parsimonious results with these two variables included. Beef herd size is shown to have a positive effect on efficiency, which implies that economies of scale are important in improving efficiency (Featherstone et al., 1997). There is a general expectation

in the literature that education of a household head or main decision maker in the farm should contribute to improved efficiency. More so, the returns to formal education are considered to be higher in modernised agricultural systems, where most operations are knowledge-based (Phillips, 1994).

In the present study, income and formal education did not individually improve the model fit, but inclusion of the interaction variable shows that farmers with formal education and higher income are relatively less efficient. Perhaps this suggests that such farmers (especially the agro-pastoralists) are likely to invest more in, and/or pay greater attention to, enterprises that are more profitable than beef cattle. Indeed, cross tabulations show that 52% of cattle farmers with formal education and higher income also keep shoats (sheep and goats). Shoats might be considered as substitutes to cattle; this suggests that some farmers could be shifting resources away from, and possibly lowering efficiency in, beef cattle enterprises. Generally, shoats are often regarded as an important alternative to cattle in pastoral areas, because they are more resilient to droughts, have faster reproduction rates (allowing quick herd replacement) and can be easily sold to reduce losses in severe droughts (Lebbie, 2004; Huho et al., 2011).

Moreover, weak linkage between formal training systems and local farmers' information needs is often considered to contribute to inappropriate and/or low use of inputs and technologies in sub-Saharan Africa (Diagne, 2010; Oluoch-Kosura, 2010); hence lower efficiency. Generally, this appears consistent with the 'traditional vs. modernised system' hypothesis suggested by Phillips (1994); inability to adapt formal skills to local conditions in traditional systems results in less than optimal returns from education. This is consistent with Allam et al. (2011) who also found a negative significant influence of formal education on TE due to the tendency by highly educated people to practice less professional farming because they consider agriculture to be relatively less rewarding than other economic sectors.

Conclusions

This study applied the stochastic metafrontier-Tobit model to investigate TE and factors that might influence efficiency in beef cattle production systems in Kenya. Results show that the majority of farmers use available technology sub-optimally and produce less than the potential output; average MTR is 0.93 and TE is 0.69. Further, it was found that controlled cattle breeding method, access to market contract, availability of a professional farm manager, off-farm income, herd size and farmers' age all contribute positively to efficiency. On the contrary, farm size, income and formal education did not have a favourable influence on efficiency. These findings may have important implications on policies

aimed at improving beef production efficiency in Kenya.

It appears reasonable to provide relevant livestock extension and other support services that would facilitate better use of available technology by the majority of farmers who currently produce sub-optimally. Necessary interventions, for instance, would include improving farmers' access to appropriate knowledge on cattle feeding methods and disease monitoring. Moreover, provision of relatively better technology (e.g., locally adaptable and affordable cattle breeds and breeding programmes) would enable relatively efficient farmers to achieve further productivity gains.

In order to improve resilience to droughts and to enhance livelihood opportunities, farmers should be encouraged to keep optimal herds of cattle and shoats (sheep and goats), and promote synergies between both enterprises (e.g., through balanced re-investments), rather than shifting resources away from cattle enterprises. Further, it is necessary to improve farmers' access to requisite market services, including contract opportunities. In addition, it is important to provide appropriate training services that enhance farmers' management practices, and/or encourage them to employ skilled farm managers. Policies that promote diversification of enterprises, including creation of off-farm income opportunities would also contribute to improving efficiency among Kenyan beef farmers. Future research could offer more insights by investigating requisite institutional arrangements, market infrastructure, regulations and farm investment incentives that would promote better use of farm technology and efficient production in cattle enterprises.

Conflict of Interests

The authors have not declared any conflict of interests.

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