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A metafrontier analysis of determinants of technical efficiency in beef farm types: an application to Botswana.

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Abstract

The study used a stochastic metafrontier model followed by a Tobit regression model to estimate technical efficiency and meta-technology ratios and assess factors influencing efficiency of a suite of beef farm types in Botswana. Results show that the average technical efficiency level is 0.496 for the whole sample and 0.355, 0.463 and 0.571 for beef farms who engage in cattle only, cattle and crop, and cattle, crop and small stock farming, respectively. Considerable scope is identified for improving beef production in Botswana, and targeting is enabled by the differential results across the farm types. Policy analysis using models that assume different beef farm types operate under similar technology are therefore presenting a misleading picture. Considering the importance of livestock sector in poverty reduction, there is a need for appropriate policies directed towards enhancing efficiency. Especially, such policies should be targeted on provision of technology-related services such as controlled breeding methods.

Key words: Beef production; metafrontier, technical efficiency determinants; Botswana

JEL codes: Q12, Q18, C5



1. Introduction

Measurement of technical efficiency (TE) assesses the performance of firms' use of resources to produce goods and services (Pascoe, et al, 2003). Further, it can provide useful information for potential efficiency gains and enhanced competitiveness, at existing levels of resources and technology (Abdulai and Tietje, 2007). Aside from investigating factors that influence TE, the analysis offers insight into key variables to policy making for optimal resource utilization and this in turn has implications for productivity and livelihood improvement. TE analysis has been applied extensively in arable, dairy and integrated farming but with limited focus on livestock in general and beef in particular (Otieno et al, 2014).

In Botswana, livestock, particularly beef is one of the country's major foreign exchange earners and contributes about 57 percent of agricultural value added (Food and Agriculture Organization (FAO) and Ministry of Agriculture (MoA), 2013). In addition, the beef sector is the main source of livelihood for many indigenous Batswana (Bahta and Malope, 2014). However, with the exception of Bahta and Malope (2014) who investigated profit efficiency of beef farmers, past studies have never investigated TE of beef cattle production, nor of any other agricultural sub sector in Botswana.

Despite a recent decline in relative importance alongside mining, agriculture remains an important sector of Botswana's economy (FAO and MoA, 2013). In particular, it accounts for 30 percent of national employment. More than 80 percent of the agricultural GDP is from livestock production; crop production contributes slightly less than 20 percent. Livestock provides raw materials for the manufacturing sector and serves as the country's major agricultural source of foreign exchange (Ministry of Finance and Development Planning (MFDP), 2009).

Recent trends, however, indicate declining beef productivity. Causal factors are likely to include many supply-side constraints, apparent as low off-take rates and high stock losses (Bahta and Malope, 2014). Climatic constraints on arable crop production serve both to reinforce livestock's dominance of the agricultural sector and to limit the options available for animal feeding. Beyond the farm gate, there is significant overcapacity in beef processing, with consequent low profitability in processing operations (FAO and MoA, 2013, BIDPA, 2006). Throughout the value chain, high costs of sanitary and phyto-sanitary (SPS) compliance are

apparent, and on the demand side, reductions in EU beef support prices have adversely affected competitiveness.

Although agricultural policy has tended to favor the beef sub-sector (Bahta and Malope, 2014), most of the public funds and human resources allocated to the sub-sector are employed in monitoring disease outbreaks, vaccination campaigns for trans-boundary diseases such as Foot and Mouth Disease (FMD) and implementing the livestock traceability system (LITS). Both LITS and disease control programs are requirements for export markets' access, particularly that of the European Union (EU). Limited resources have been allocated to ensure that farmers have better access to technologies, use market services, and upgrade their skills in order to improve their technical efficiency.

Further, weak linkages between research-extension service providers and farmers are reckoned to contribute to low and/or inappropriate use of inputs by farmers. It is very common for district-level extension officers to be preoccupied with issuance of livestock movement permits (part of LITS). This leaves extension officers with limited time for extension work such as assisting farmers in identifying diseases and curing/attending to sick animals, uptake of new technologies or organizational models for feed production and utilization. Limited human resources, and physical plant such as vehicles, are exacerbated during FMD vaccination campaigns during which extension officers are required to rotate between regions leaving the extension offices unmanned. As a result, livestock productivity and growth are relatively low (Statistics Botswana, 2014); however the livestock sector is still expected to play an important role in Botswana's national development plan (Ministry of Finance and Development Planning (MFDP), 2009).

Building on previous work in Botswana, the present study investigates technical efficiency of beef with the main focus on traditional or smallholder beef farms that, according to Statistics Botswana (2013), own 88 and 98 percent of the nation's cattle and small stock herd, respectively, and operate mainly under communal or open access rangelands. Botswana's cattle production systems are traditionally categorized on the basis of land tenure type irrespective of the herd size. The current study investigates determinants of TE in different beef cattle production farm types in Botswana, in particular by departing from conventional classification of farm systems. Smallholder beef farms are accordingly categorized into three farm types, namely beef only farmers, beef and crop farmers and farms that incorporate beef, and crop and small stock production. Such classification is intended to examine the impact on technology gaps and

technical efficiency of apparent differences in technology and organizational structure, asset ownership and human capital, both within and between these farm types. It is hypothesized that there is significant technological gap differences, and hence factors that affect TE. These differences could originate from the apparent differences in access to and utilization of agricultural inputs among these three farm types, among other things. Such subdivisions could provide a much-needed counterpoint to past policy commentary on Botswana's beef production system which has focused only on labels such as "traditional" and "commercial"¹.

Investigation of the determinants of TE in beef cattle production provides analytical insights to enhance beef supply in domestic as well as export markets (EU markets), where Botswana is currently unable to fully utilize its preferential access quota (Hachigonta et al, 2013).

The current study employs the stochastic metafrontier-Tobit method. This involves, first estimating TE through a metafrontier approach as suggested by Battese and Rao (2002), and subsequently using a Tobit model (Tobin, 1958) to investigate determinants of the TE. The stochastic metafrontier-Tobit method is preferred to using a one-step stochastic frontier approach (SFA) because it accounts for technology gaps and allows comparison of TEs across heterogeneous groups (Battese and Rao, 2002; Villano et al., 2010) such as production systems. Normally the Tobit model can also be applied with Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) to investigate determinants of efficiency. However, DEA has a limitation in hypothesis tests regarding the TE component and entails computational complexity in incorporating the random term (Coelli et al., 2005). Similarly, SFA fails to account for technology differences amongst sample sub-groups, and can accommodate few explanatory variables, without loss of parsimony (Battese and Rao, 2002).

The remaining part of the paper is organized as follows: section 2 provides the analytical framework; section 3 explains the data used and empirical estimation followed in the study; section 4 discusses the results, and section 5 offers key conclusions from the results and their policy implications.

¹ Traditional (smallholder) farming is characterized by uncontrolled grazing due to open access to rangeland resources while the commercial system involves production in either freehold or leasehold ranches (Statistics Botswana, 2008).

2. Analytical framework

As noted above, the estimation procedure involves applying first SFA to investigate TEs across the different production systems. As the SFA allows comparison only of farms operating with similar technologies, its use entails an assumption of similar technologies across farms which actually differ: this can result in erroneous measurement of efficiency by mixing technological differences with technology-specific inefficiency (Tsionas, 2002). The next step involves estimation of a metafrontier, an approach proposed by Battese and Rao (2002), to adjust the TE scores from SFA in order to account for differences in technology. Finally, a Tobit model is used to assess variations in the TE scores obtained from the metafrontier estimation.

Suppose that there are j groups or production systems in the cattle industry. The stochastic production frontier is specified as:

$$Q_i = f(X_i, \beta) \exp(v - u) \quad (1)$$

Where Q_i is the output of the i^{th} farm

x_i is the vector of inputs used by the i^{th} farm

β is a vector of production input parameters to be estimated

v is assumed to be independent and identically distributed random error, representing the effects of statistical noise, having a normal distribution with zero mean and variance given by σ^2 ,

i.e. $v \sim N(0, \sigma_v^2)$.

u represents the farm-specific technical inefficiency in production and is assumed to be independent of v and non-negative truncation of the half-normal distribution, i.e. $u \sim |N(0, \sigma_u^2)|$ (Battese and Coelli, 1995) and it follows that (Aigner et al., 1977):

$$\sigma^2 = \sigma_v^2 + \sigma_u^2 \quad (2)$$

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 departure of output from the frontier due to technical inefficiency is defined by a parameter (γ) given by:

$$\gamma = \frac{\sigma_u^2}{\sigma^2}, \text{ such that } 0 < \gamma < 1 \quad (3)$$

To obtain asymptotically efficient estimators, equation 1 can be estimated using maximum likelihood approach (Coelli, 1995); which applies a one-step or a two-stage estimation process. The one-step approach includes simultaneous estimation of TE parameters and factors that might explain inefficiency (i.e., inefficiency effects) in one stochastic frontier equation. On the other hand, the two-step estimation process involves determination of TE levels in a stochastic frontier, followed by a separate regression of variables associated with the estimated efficiency levels. The latter procedure is not preferred since the use of TE estimates from stage-one as the dependent variable in the second step introduces bias that emanates from the violation of the assumed i.i.d. property of u and leads to inconsistent estimates of the inefficiency effects (Kumbhakar et al., 1991; Battese and Coelli, 1995).

The following discussion in this section considers a stochastic frontier in which inefficiency effects are included. Suppose that $u = M\delta$ where M is a vector of the various factors that influence the technical inefficiency of farms, while δ is a vector of inefficiency parameters to be estimated. Thus, the stochastic frontier production function (equation 1) for j production systems can be re written as (Battese and Rao, 2002):

$$Q_{ij} = f(X_{ij}, \beta_j) \exp(v_{ij} - M_{ij}\delta) \quad (4)$$

where Q_{ij} is the output for the i^{th} farm in the j^{th} production system; $f(\cdot)$ is the functional form used; β_j is a vector of input parameters to be estimated for the j^{th} production system; M is a matrix of factors that influence the technical inefficiency of farms; and δ is a vector of inefficiency parameters to be estimated.

Assuming that any deviation is pure statistical noise (such as measurement errors and other unobserved factors or those outside a farmer's control e.g., animal disease outbreak and weather), the TE can be expressed as the ratio of actual output observed to the expected maximum level from the use of available inputs (Boshraadi et al., 2008):

$$TE_{ij} = \frac{f(X_{ij}, \beta_j) \exp(v_{ij} - M_{ij}\delta)}{f(X_{ij}, \beta_j) \exp(v_{ij})} = -M_{ij}\delta \quad (5)$$

A frontier measures individual farmers' performance, relative to the dominant technology in a particular production system. As noted above, all farms do not necessarily operate using the same technology and assuming similar technology might result in measurement errors.

Therefore, the stochastic frontier model in (4), which only allows comparison of farms operating with similar technologies is inappropriate for comparing the performance of farms across different groups of farms which are basically not identical in terms of technology access and usage (O'Donnell et al., 2008). To accommodate such differences in technology, various alternatives have been proposed in the literature.

FIGURE 1 HERE

One such alternatives is use of the stochastic metafrontier production function which uses both panel and cross sectional data to measure efficiency and technology gaps where firms produce in different technological environments (Battese and Rao, 2002; Battese et al., 2004). The stochastic metafrontier production function is designed to be a smooth function that envelops the explained (deterministic) components of the group stochastic frontier functions (e.g., for different production systems) (Battese et al. 2004)². It captures the highest possible output level (y) attainable, given the input (x) and common technology in the industry as shown in Figure 1. It is constructed deterministically by solving a linear programming problem, which minimizes the distance between a group's frontier and the metafrontier (Barnes et al, 2011). Thus, a farm in farm group *b* can be both measured relative to its own frontier and to the metafrontier and output levels for producers who are efficient both in respective group frontiers and in the entire industry lie on the metafrontier.

According to Battese et al. (2004), the estimation of metafrontier involves an optimization problem which comprises first fitting individual stochastic frontiers for separate groups and then optimizing them jointly through an LP or QP approach.

Following O'Donnell et al. (2008), the stochastic metafrontier equation can be expressed as:

$$Q^* = f(X_i, \beta^*) \quad i=1, 2 \dots N \quad (6)$$

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

² Normally, the stochastic meta-frontier includes two distinct data-generating mechanisms (one that explains deviations between observed outputs and group frontiers, and another that explains deviations between observed outputs and the metafrontier). This method is limited in such a way that some points on the estimated metafrontier may lie below points on the estimated group frontiers, thus, to avoid such limitation, Battese et al. (2004) designed the stochastic metafrontier to be a smooth function.

$$f(X_i, \beta^*) > f(X_i, \beta_j) \text{ for all } j = 1, 2 \dots j \quad (7)$$

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

$$\min \sum_{i=1}^n |\ln f(X_i, \beta^*) - \ln f(X_i, \beta_j)| \quad (8)$$

$$s.t. f(X_i, \beta^*) \geq \ln f(X_i, \beta_j)$$

The standard errors of the estimated metafrontier parameters can be obtained through bootstrapping or simulation methods.

In terms of the metafrontier, the observed output for the i^{th} farm in the j^{th} production system (measured by the stochastic frontier in equation 4) can be expressed as:

$$Q_{ij}^* = \exp(-M_{ij}\delta) \cdot \frac{f(X_i, \beta_j)}{f(X_i, \beta^*)} \cdot f(X_i, \beta^*) \exp(v_{ij}) \quad (9)$$

where (recall from (5) that, $-M_{ij}\delta = TE_{ij}$) the middle term represents the technology gap ratio (TGR) that can be expressed:

$$TGR_i = \frac{f(X_i, \beta_j)}{f(X_i, \beta^*)} \quad (10)$$

Given the observed inputs, according to Battese and Rao (2002), the TGR measures the ratio of the output for the frontier production function for the j^{th} group or production system relative to the potential output defined by the metafrontier. TGR values approaching 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.

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 TGR is, hereafter, referred to as meta-technology ratio (MTR).

The TE of the i^{th} farmer relative to the metafrontier (TE_i^*) is the ratio of the observed output for the i^{th} farm relative to the metafrontier output, adjusted for the corresponding random error such that:

$$TE_i^* = \frac{Q_{ij}}{f(X_i, \beta^*) \exp(v_{ij})} \quad (11)$$

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

$$TE_i^* = TE_{ij} \cdot MTR_i \quad (12)$$

Finally, the determinants of technical efficiency are investigated using a two-limit Tobit (Wooldridge, 2002), specified as:

$$\theta^{k*} = M\delta + e$$

$$\theta^{k*} = \{(0 \text{ if } \theta^{k*} < 0); (\theta^{k*} \text{ if } 0 < \theta^{k*} < 1); (1 \text{ if } \theta^{k*} > 1)\} \quad (13)$$

where θ^{i*} and θ^j are the latent and observed values of the metafrontier TE scores, respectively; M denotes the vector of socio-demographic and other independent variables assumed to influence efficiency; and e is the random term.

3. Data and estimation

3.1 Data and descriptive analysis

This paper uses farm-level cross sectional survey data collected under the auspices of a development research project³. The project assembled detailed information on costs of and returns to livestock production, along with selected technical, physical and demographic variables for farm household operations across groups representing different farm types. Coverage of the survey was basically restricted to livestock farmers in three major livestock production districts of Botswana, (South East, Chobe and Central). Notwithstanding cattle production's dominance in terms of output in Botswana's agriculture, many livestock farmers also engage in crop and small stock production. Goat rearing, for example, is the most popular livestock activity among smallholder farmers, with 82,176 goat holdings, followed by 72,925 cattle holdings (Statistics Botswana, 2014). Beef farmers who additionally have crop farms could also possibly use the farm crop residues to feed their animals, thereby reducing feed costs. Bahta and Malope (2014) found that farmers who have crop land area and earn income from crop production are more profit efficient due to the benefit of growing feeds and the possible

³ The Smallholder Livestock Competitiveness Project is funded by the Australian Centre for International Agricultural Research (ACIAR) and implemented by the International Livestock Research Institute (ILRI) in partnership with the Botswana Ministry of Agriculture's Department of Agricultural Research (DAR).

reinvestment of income from crop farming into livestock farming, respectively. This is supported by Statistics Botswana (2014), whose results indicate that most (some 78 percent of) cattle farmers rely on their own crop residues to feed their cattle. Similarly, beef farmers who additionally engage in both crop and small stock production (mixed farm type) have the opportunity to raise quick cash from the sales of their goats or sheep, and this cash can be mobilized to cover feed, veterinary and transport costs.

Therefore, for the purposes of the present study, beef farmers are grouped into three farm types, cattle, cattle and crop (beef farms additionally engage in crop production) and mixed farming (beef farms who additionally engage in both crop and small stock production). Such analysis at the level of beef farm type is proposed as desirable because it is likely that these farms are operating with different technologies. It is also expected that differences in technology and organization, as well as asset ownership and human capital both within and between these beef farm types could cause or underlie significant differences in the technologies used by the farms. From the policy point of view, it is of interest for the study to distinguish the beef farm type differences in their mean efficiency levels, technology gaps and identify common determinants of technical efficiency. These assertions require statistical testing, as there would be no good reason for estimating separately the efficiency levels of beef farm types relative to a metafrontier production function if these farmers are found to operate under the same technology (Battese et al, 2004). A likelihood-ratio (LR)⁴ test of the null hypothesis, that the beef farm type stochastic frontier models are the same for all farms in Botswana, was calculated after estimating the stochastic frontier for pooled data from all beef farm types. The value of the associated LR statistic was 76.2 which is highly significant (Kodde and Palm, 1986) and so this null hypothesis is rejected.

Selected farm characteristics from the survey, subdivided by beef farm types, are shown in Table 1. About half of the beef farm households in the survey engage additionally in crop and small stock production. Similarly about 31 percent of the beef farm households produce crops alongside cattle production. Farm households in this cattle production group represent about 19 percent of the total survey sample.

⁴ Following Battese et al (2004), the likelihood ratio (LR) statistic calculated as : $-2\{\ln[L(H_0)] - \ln[L(H_1)]\}$ where $\ln[L(H_0)]$ is the values of the log likelihood function for the stochastic frontier estimated by pooling the data for all beef farm types and $\ln[L(H_1)]$ is the sum of the values of the log likelihood functions for the three beef farm type production frontiers. The degrees of freedom for the Chi-square distribution involved are 30, the difference between the number of parameters estimated under H1 and H0.

On average, mixed farm types have larger herd size than do the cattle, and the cattle and crop farms. Both cattle and cattle and crop farms tend to keep indigenous (local) cattle breeds such as *Tswana*, which are relatively more adapted to hot and dry conditions. In contrast, the mixed farm types have a majority of crossbred and pure exotic breeds.

At least 50 percent of farmers in the three farm types depend on non-farm income, which includes household income from formal salary and other business activities. Farms engaged only in cattle production have significantly higher dependence on non-farm income. This could represent mostly the so-called absentee⁵ farmers, which are primarily engaged in cattle production. Level of education is also higher for this group than for the others (Table 1), and enables high-earning jobs in the civil service and other formal employment. Similarly, about 50 percent of cattle and crop farms and 75 percent of mixed farmers derive additional income from crop and crop and small stock, respectively. The mixed farms have significantly higher average income from other agricultural output, which is obvious since such beef farm types may have additional income from sales of both crop and small stock animals.

Beef farms engaged only in cattle production do not have access to land for crop production purposes, and their principal agricultural income is from selling their cattle. Beef farm types that additionally engage in crop and both crop and small stock activities have on average 6.5 hectares of land for crop production purposes. As outlined by Bahta and Malope (2014), some land boards (land allocating authorities in tribal/communal land) do not allow crop production activities to take place in areas designated for livestock grazing. This has cost and productivity implications for livestock farmers, which are expected to be revealed in the current analysis which takes account of farm type.

Households' average distance from the commonly-used market is 51.1 kilometers, but farmers who engage in cattle and crop production report accessing markets as far as 58.2 kilometers away, while farmers who engage only in cattle production and mixed farms report somewhat shorter distances to markets: as far away as about 48.5 kilometers. On one hand this implies that, small scale livestock farmers do not use distant markets when they engage only in cattle production, but may also suggest that distance to an attractive market is a constraint to farms who engage only in cattle production.

⁵ Absentee farmers denotes to farmers who work somewhere outside of their village/town and manage their farms by hiring herdsmen.

Table 1 further show that beef farming is dominated by male and relatively older farmers. More than 70 percent of farmers in all the production types are male, although both cattle and cattle and crop farmers feature on average more than a quarter of female operators. There is no significant difference in the average age of cattle and crop and mixed farms, but generally farmers in both categories are slightly more aged, as well as more experienced in cattle production than the cattle farmers.

Across the three farm types, the level of formal education averages 4.85 years and there is no significant difference in education among these farm types. This level corresponds to some years of primary schooling.

When asked about access to market information in the past year, more than 60 percent of the respondents in all farm types indicated that they had such access and on average about 80 percent of all the beef farm households reported having access to veterinary advisory services. This result contradicts MFDP (2009), which reports that veterinary extension officers at the district extension offices are preoccupied with other services rather than assisting farmers in animal husbandry and disease control.

TABLE 1 HERE

This result suggests the need for further investigation of veterinary services and the quality of the services farmers get from such institutions. Results further indicate that only about 12 percent of households use controlled cattle breeding method which, in turn, further questions the quality of the services extension services provide.

On average, 10 percent of all farmers sold more than 50 percent of their cattle to the Botswana Meat Commission (BMC)⁶ during the study period (2012/2013). Normally, BMC do not use contract sales, however, farmers who managed to sell to BMC can benefit from its services. The Botswana Meat Commission (BMC) is the principal market channel for the country's finished cattle and weaners (Bahta et al. 2013).

⁶ Botswana Meat Commission (BMC), a government parastatal enterprise that has monopsony rights over the purchase of cattle for export and the sale of exported beef.

3.2 Empirical estimation

Due to measurement difficulties, this study follows the revenue approach recently applied in the literature (Hadley, 2006; Abdulai and Tietje, 2007; Gaspar *et al.*, 2009) and defines output as:

$$Q_{i(j)} = \frac{\sum_r^R yP}{t} \quad (14)$$

where $Q_{i(j)}$ is the annual value of beef cattle output of the i^{th} farm in the j^{th} production system (measured in Botswana Pula⁷); r denotes any of the three forms of cattle output considered, i.e., current stock, sales or uses for other purposes in the past twelve-month period; y is the number of beef cattle equivalents⁸; p is the current price of existing stock or average price for cattle sold/used during the past twelve months; and t is the average maturity period for beef cattle in Botswana, which based on expert consultation is assumed to be four years.

Similarly, to ensure that the study captures the approximate share of feeds from different sources in each beef production system, the quantities of purchased and non-purchased (on-farm) feeds were first adjusted in accordance with the average annual number of dry and wet months⁹, respectively, in the country.

Average feed prices were computed using the survey's price information collected for purchased feed with further validation by animal nutrition experts in the Department of Agricultural Research (DAR). 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 shadow prices) to the average per unit price of improved fodder.

Thus, following Otieno (2011), the total annual improved feed equivalent was computed as:

$$\{\varphi(p_f * d) + S(n_p * w)\} \quad (15)$$

⁷ One Botswana Pula is on average 0.1261 USD (Yahoo Finance (2013)).

⁸ Following (Otieno, 2012; Hayami and Ruttan., 1970; O'Donnell et al., 2008), Beef cattle equivalents were computed by multiplying the number of cattle of various types by conversion factors. Following insights from discussions with BMC (Botswana Meat Commission), 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 Botswana, is between 452-500kg. according to BMC, the average slaughter weights for castrated adult males (oxen>3 years), Immature males (< 3 years), Cows (calved at least once), Heifers(female ≥1yr, have not calved), Male calves (between 8 weeks&<1year),Female calves (between 8 weeks&<1year), , Pre weaning males (<8 weeks), Pre weaning females (<8 weeks) are 400kg, 350kg, 390kg,300kg,250kg, 220kg,95kg and 95 kg, respectively. The calculated average slaughter conversion factors were then: 1.0, 0.86, 0.76, 0.84, 0.65, 0.48, 0.54,0.21 and 0.21, for Bulls, castrated adult males, Immature males , Cows, heifers, Male calves, Female calves, Pre weaning males and Pre weaning females, respectively

⁹Botswana is an arid country and according experts information the length of the wet season when farmers mostly use on-farm or non-purchased feeds do not exceed 5 months. Consequently, the study uses 5 wet and 7 dry months, respectively.

Where; ϕ and S denote, respectively, the ratio of prices of purchased and non-purchased feed to that of improved fodder; p_f and n_p represent the average quantities of purchased and non-purchased feeds, respectively, in kilograms per month; d is the approximate number of dry months (when purchased feeds are mainly used), while w is the length of the wet season (when farmers mostly use on-farm or non-purchased feeds) in a particular area.

The provision of animal health services (AHS) in Botswana is dominated by government through the Department of Veterinary Services (DVS), in particular through the Livestock Advisory Centre (LAC). The LACs¹⁰ supply veterinary drugs to farmers at a subsidized rate. Bahta et al (2013) found that smallholder farmers in general incur relatively low costs for vaccines and drugs, as most of the farms benefit from subsidized inputs sold by LACs and/or free vaccination programs. The same study further found that the bulk of existing customers for private input suppliers are commercial farmers, and smallholder farmers mostly buy from private input suppliers when they either could not source the desired drugs from LACs or had exceeded their limits on purchases from LACs.

The differential effect of the subsidy among these farms is expected to be limited since all the beef farm households included in this study are small holder farmers who are entitled to the LAC subsidized services. Thus, it is assumed that lower disease incidence in a given production system is partly due to greater investment in veterinary management.

Depreciation costs on fixed inputs were based on the straight line method, using useful economic life of farm equipment provided by each farm household. Labor costs comprise both paid and unpaid labor; the latter valued using the average minimum farm wage in a particular district. The labor 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.

Table 2 summarizes the aforementioned production variables that are used in the model to estimate the SFA. On average, mixed farms use more inputs and produce the highest output.

Mixed farms spend significantly more on veterinary services¹¹ and there is no significant difference between cattle and cattle-crop farm types with respect to veterinary costs.

TABLE 2 HERE

¹⁰ LAC is a division under the Department of Veterinary Services (DVS) in the Ministry of Agriculture. LAC serves as an outlet for the sales of subsidized livestock inputs to the farming community such as veterinary drugs etc. According to FAO (2013), LAC has a network of about 36 centers throughout the country.

¹¹ Veterinary costs for small stock animals are not included.

There is no significant difference on the costs of labor between cattle-crop and mixed farms and both farm types have significantly higher costs of labor than do farms who only engage in cattle production. This is an expected result as such farms use additional labor for their crop and small stock production activities. Apparently, most of the smallholder farmers hire labor to engage in various farm activities and, hence, it is difficult to break down the costs of labor by activities and isolate the labor costs associated only with cattle production.

Cattle farms have significantly higher costs of purchased feeds since such types of farms rely only on cattle production and don't have access to any cropping land that can be used for feed production.

Although Table 1 reveals no significant difference in the size of cropping land between cattle-crop and mixed farms, the mixed farms use significantly more on-farm produced feeds than do cattle-crop farm types (Table 2). Similarly mixed farm types have significantly higher costs of depreciation and other inputs. This could be due to most of mixed farms' possessing farm assets such as tractors, dip sprayers, and irrigation equipment that have to be used for both livestock and crop activities and consequently incur higher running costs.

To ensure consistent estimates of inefficiency effects in the SFA, a one-stage model is used, as proposed by Battese and Coelli (1995). In estimating the SFA both Cobb-Douglas and Translog production models were tested to test the model's fit to the survey data.

A likelihood ratio test showed that the Cobb-Douglas functional form provided a better fit to the survey data than a translog model¹².

All the parameters in the proposed stochastic frontier and technical inefficiency effects model were estimated simultaneously in the equation:

$$\ln Q_{i(j)} = \beta_{0(j)} + \sum_{r=1}^4 \beta_{r(j)} \ln X_{ir(j)} - M_i \delta_j + v_{i(j)} \quad (16)$$

Where $Q_{i(j)}$ is the annual value of beef cattle output of the i^{th} farm in the j^{th} production system and measured as indicated in (16). X_{ir} represents a vector of inputs where X_{i1} is total feed

¹² Following Battese et al (2004), the likelihood ratio (LR) statistic calculated as : $-2\{\ln[L(H_0)] - \ln[L(H_1)]\}$ where $\ln[L(H_0)]$ and $\ln[L(H_1)]$ are values of the log likelihood function for the Cobb-Douglas and translog models, respectively. The test fails to reject the null hypothesis that Cobb-Douglas model is a better specification of sample data, with a LR statistic of 11.98 compared to the chi-square critical value of 14.2 at 10% and 10 degrees of freedom. Degrees of freedom equal the difference in the number of parameters estimated in the two models.

equivalents, X_{i2} denotes the cost of veterinary services, X_{i3} is the cost of labor, and X_{i4} is a Divisia index calculated as (Boshirabadi et al., 2008)¹³:

$$X_{i4} = \prod_{r=1}^2 C_{ir(j)}^{\alpha_{ir}} \quad (17)$$

Where $\alpha_{ir(j)}$ represents the share of the n^{th} input in the total cost for the i^{th} farm in the j^{th} production system; $C_{i1(j)}$ is the depreciation; insurance and taxes on farm buildings, machinery and equipment (Pula); $C_{i2(j)}$ represents other overhead costs including fuel, electricity, market services, maintenance costs, branding etc., in Pula terms.

Intuitively, a positive sign of the coefficient of efficiency driver variable (δ) implies inefficiency because the value of u ($u=M\delta$) would be higher when the farm is farther away below the frontier. On the contrary, a negative sign of the coefficient is interpreted as potentially having a positive influence on efficiency (Brummer and Loy, 2000; Coelli et al., 2005; Delgado, et al. 2008; Otieno et al. 2012).

The parameters of the stochastic frontiers were obtained by using FRONTIER 4.1 software (Coelli, 1996). The linear programming, to estimate metafrontier (Equation 8), and bootstrapping of standard errors were undertaken in SHAZAM version 10 (Whistler *et al.*, 2007), while STATA version 11 (StataCorp, 2009) was used for the Tobit analysis (Equation 13).

4. Result and discussion

Table 3 shows that for technical efficiency relative to metafrontier, cattle farms have a mean TE of 0.355, cattle and crop farms a mean of 0.463 and mixed farms a mean of 0.571. The mean TE of mixed farms is significantly higher than that of the other farm types. The average pooled sample TE with respect to metafrontier is 0.496. This indicates first, that there is considerable scope for improving smallholder beef production in Botswana - by up to 50 percent of the total potential. Secondly, the stark differences between farm types point to where efficiency is at its lowest and hence suggests that policy responses must be targeted. The mean meta-technology ratio (MTR) in the whole sample is 0.76; with about 96 percent of farmers across the three beef production systems having MTR estimates below 1. This implies that, on average, beef farmers in Botswana produce 76 percent of the maximum potential output achievable from the available

¹³ The Divisia index is a proxy variable used to consolidate inputs such as depreciation and other costs so that to improve the model fit. All input costs are adjusted with the share of cattle income in household income.

technology. Moreover most of farmers, about 96 percent, have MTR estimates below 1, which indicates that they use the available technology, such as use of cross breeds, sub-optimally. This could be due to low rates of adoption or poor utilization of adopted technologies influenced by, as described above, the quality of extension services they receive.

The average MTR is high in beef farmers who are also engaged in other agricultural activities (crop and small stock farming). This is somehow consistent with the differences in relative levels of investments in the cattle enterprise by farmers in the three production systems (indicated in Table 2).

It is interesting to note that in all but cattle only farms, the value of the maximum meta-technology gap ratio obtained is 1 (Max MTR=1) which indicates that their group frontiers are tangent to the metafrontier (Battese et al., 2004).

Therefore, more access to better technology (e.g. cattle breeds or feed planning techniques) is necessary in order that those farmers who use technology sub-optimally achieve further productivity gains.

TABLE 3 HERE

The study showed that 96 percent 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 could be due to, as noted by Diagne (2010), lack of awareness of the technologies and/or how to use them, which leads to low rates of adoption or poor use of agricultural technologies in sub-Saharan Africa. Consistent with relative levels of investments in the three beef production systems (Table 2), the average MTR is higher in beef farms who additionally engage in either crop (0.84) or both crop and small stock production (0.81).

As noted above, the main objective of this study is to identify and explain sources of inefficiency, which are widely referred to as inefficiency effects (Coelli et al., 2005). To investigate possible determinants of inefficiency, the study used several socio-economic and technology related explanatory variables. A test of multicollinearity using variance inflation factors (VIF)¹⁴ was conducted to select or drop explanatory variables for the inefficiency model.

¹⁴ Prior test of multicollinearity in STATA 11 was conducted to select variables for the inefficiency model. As a rule of thumb, a variable whose VIF values are greater than 10 may merit further investigation. Tolerance, defined as 1/VIF, is used by many researchers to check on the degree of collinearity (Chen et al, 2003).

Subsequently, a pooled stochastic frontier was estimated using all the descriptive variables as possible determinants of inefficiency.

Table 4 presents the results of the pooled stochastic frontier and metafrontier estimation. The metafrontier results show that an increase in the use of any of the four inputs used in the model would lead to significant improvement in output.

It should be noted that in stochastic frontier estimation, the parameter for inefficiency level usually enters the model as the dependent variable in the inefficiency effects component of the model. This, therefore, means that a positive sign of the coefficient of efficiency driver variable (in the M -vector) implies inefficiency. On the contrary, a negative sign of the coefficient is interpreted as potentially having a positive influence on efficiency (Brummer and Loy, 2000; Coelli et al., 2005).

As indicated in Chen and Song (2008), a straightforward interpretation of regression parameters is available from the two-stage Tobit estimation since the dependent variable used in the subsequent Tobit model is the technical efficiency score obtained from optimization in the metafrontier estimation. Therefore, a positive value on a coefficient in the metafrontier-Tobit model infers that increases in the associated variable would increase efficiency (Wooldridge, 2002).

Table 4 further shows that, the value of σ^2 is significant, which implies that the frontier model is stochastic (rather than deterministic). Moreover the estimated value of γ is significantly different from zero, implying that 99 percent of the discrepancies between the observed value of beef output and the frontier output can be attributed to factors within the farmers' control. The estimated inefficiency effects from both models show that herd size, controlled breeding method and age of the farmer significantly increase efficiency while having more than 50 percent of indigenous breeds would reduce inefficiency. Using BMC as a main market channel, earning additional agricultural income and distance to commonly used market were also found to be positively influence efficiency and statistically significant in the metafrontier-Tobit model.

The observed significant statistical differences amongst the three types of beef farm systems suggests, as indicated in Battese et al. (2004), that the pooled stochastic frontier is inappropriate for policy application. Therefore, subsequent discussion focuses on the variables that are significant in the metafrontier-Tobit model.

The coefficient on herd size is positive and statistically significant. This implies that farmers who own large cattle herds are more efficient, possibly due to economies of scale. This finding is supported by Bahta and Malope (2014) who found that farmers with large cattle herds are more efficient in terms of profit. However, that study also acknowledges that the relationship between herd size and gross margin in Botswana is a complex one, and possibly governed by differences in technology and associated management systems and labor configuration (Bahta et al., 2013; BIDPA, 2006). The coefficient of indigenous breed is negative and statistically significant which implies, apart from the herd size, the importance of the genetic composition of cattle herd. That is, having less indigenous animals would increase efficiency. This is also supported by the significance of the use of controlled breeding technology (Table 4) which is consistent with the view of Wollny (2003) that controlled cattle breeding might be expected to increase efficiency by improving genetic quality, enhancing adaptation of cattle to environmental conditions and ensuring a better fit of stocking rate to feed supply and markets within and between years.

The results also show that more sales of cattle to BMC increases efficiency. Although there is no formal contract for selling cattle to BMC, farmers who are able to meet requirements and access BMC markets can benefit from BMC's year-round demand and on farm collection services.

However, Bahta et al, (2013) report that some farmers are reluctant to sell to BMC due to their lack of understanding on the quality requirement and inclined choice towards selling old animals. Normally BMC offers on farm collection service through its agents to farmers who sell young animals or weaners.

This is in line with the opinion 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. Therefore, based on BMC's above-mentioned continuous demand and service delivery, it is expected that farmers who meet the requirements and are able to sell more cattle to BMC, are relatively efficient.

This finding should be interpreted within the current Botswana cattle trade regime since a study by Hamza, et al (2014) found that farmers benefit more if the current export monopoly of BMC is abolished.

TABLE 4 HERE

The significance of age suggests that, as noted by several authors (Lapar, et al. 2005; Mathijs and Vranken, 2001) there might be efficient use of inputs by older farmers that emanates from application of their knowledge accumulated from experience. However, Bahta and Malope (2014) found no influence of age in the profit efficiency of beef farmers in Botswana. Results further show the use of distant markets could significantly reduce TE. This contradicts the view of Bahta and Malope (2014) who founds that farmers who travel long distances to sell their animals are more efficient in terms of profit. A plausible explanation is that farmers prefer to access distant markets in search of better prices since the price differentials between the local prices and the distant market outlets could offset the transportation cost. Contrary to this, Bahta et al., (2013) have shown that, although in limited number, farmers in rural Botswana prefer to sell their animals to individuals around their village as price is set on mutual negotiation without any delay of payment. Given that on average only 10 percent of the farmers sell more than half of their animals (Table 1) to BMC, which offers on farm collection service, and the mean distance traveled is about 50 km; the current finding is not surprising. This means distant markets might increase profit efficiency due to better prices they might offer (Bahta and Malope, 2014), but not necessarily technical efficiency which is the ability of a firm to achieve a certain output threshold using a minimum quantity of inputs, under a give technology (Farrell, 1957).

Three income variables were included in the metafrontier-Tobit model to test its effect on TE. The significance of income from other agricultural activities implies that, as noted by Bahta and Malope (2014), there might be a considerable re-investment of such earnings in several farm activities by beef farmers in Botswana due to the synergies between cattle, small stock and crop activities. However, this is not the case for non-farm earnings as it is not significant in the model. This could be due to, as noted by Rakipova et al. (2003), the time spent doing off-farm which work reduces time spent on efficiency-improving managerial activities. In fact there is a tendency amongst Botswana's farmers who engage in other businesses and earn higher income from non-farm activities, to use livestock farming as a supplemental activity. This may include the many so-called absentee farmers in Botswana who are relatively educated (see section 3.1) as the interaction between income and education¹⁵ shows a negative impact on technical efficiency.

¹⁵ Inclusion of formal education did not individually improve the model fit, but including the interaction between formal education and income in the metafrontier-Tobit model offers an improvement in the ability to explain TE.

5. Conclusions

With the main objective of estimating efficiency levels and technology gaps across different technologies used by beef farms and identifying the determinants of technical efficiency of beef farms, a metafrontier-tobit production function model is applied to beef-producing households in Botswana.

Results show that the majority of farmers use available technology sub-optimally and produce less than the potential beef output. The average MTR (Meta Technology Ratio) and TE (Technical Efficiency) estimated for the whole sample are 75.6 and 49.6, respectively. Further it was found that herd size, farmers' age, cattle sales to BMC, controlled cattle breeding method and having additional agricultural income all contribute positively to efficiency. Conversely, having more indigenous cattle, distance to market, income and formal education did not have a favorable impact on efficiency. These findings have important implications on policies directed towards improving beef production in Botswana: in part because indicators of households' strength and weakness are identified and in part because shortcomings of implementation or delivery of services (rather than their absence) are identified as problematic.

Predictably, the results pointed out the importance of providing livestock farmers with 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. Possible essential interventions would include improving farmers' access to appropriate knowledge on animal husbandry such as cattle feeding methods, disease monitoring and breeding. Additionally, acquainting farmers to relatively better and affordable technology, such as locally adaptable breeds and breeding programs, would enable relatively efficient farmers to achieve further productivity gains. A key contribution of this study is however to signal the key roles played by different technologies in the different farm type groups, and this indicates both the need for further research and for the identification and promotion of technologies which suit certain production and marketing models.

Beef farmers should be encouraged to undertake arable farming, especially fodder production, and keep small stock so as to improve their resilience to droughts and increase livelihood opportunities. This could be facilitated by allowing farmers to own arable lands in their vicinity of their livestock farms and organizing formal small stock markets, which at present are almost

nonexistent. The current study has identified the variety of relationships which may exist between access to arable land and the farm type.

Further, efforts should be made to bring markets nearer to cattle production areas. Farmers should be provided with reliable market information, which could possibly help farmers to make good informed decisions before they travel to distant markets in search of better prices (Bahta and Malope, 2014). This helps farmers to understand the market quality requirements and benefits from the on farm collection services that the BMC offers through its agents.

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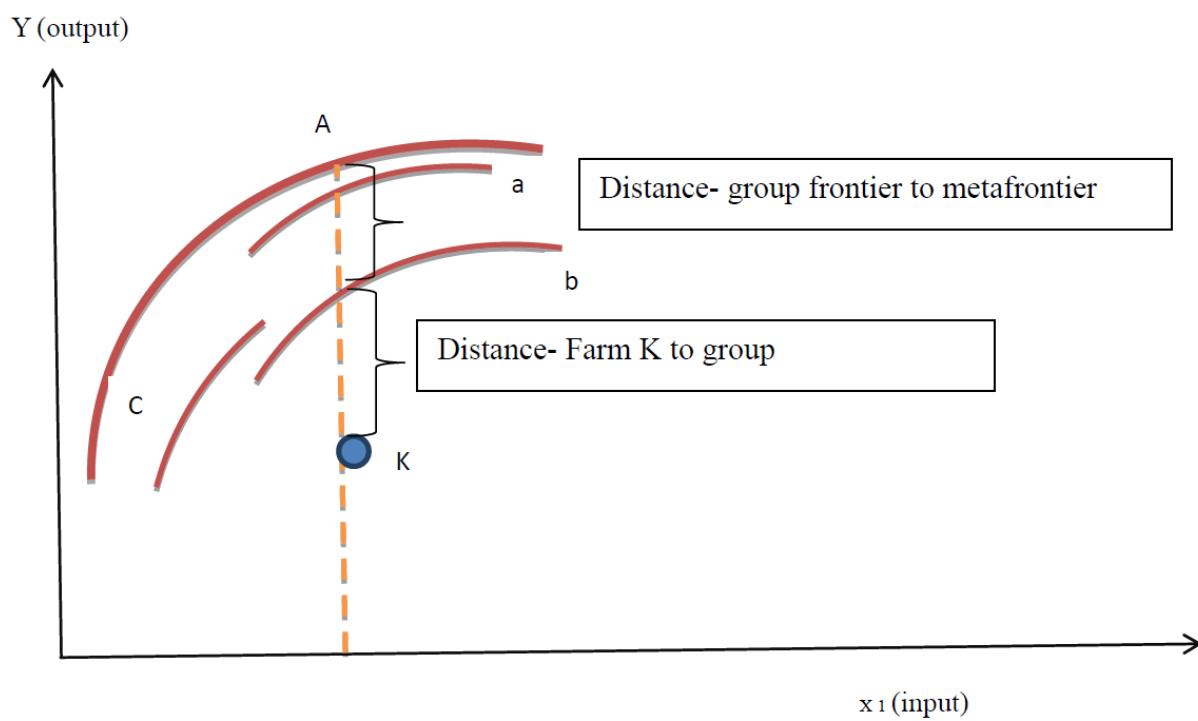


Figure 1: Graphical description of metafrontier (Source: Adapted from Battese et al. (2004)).

Table1: Descriptive statistics of sample characteristics

	Cattle farms (N=107)	Cattle and crop (N=177)	Mixed farms (N=284)	Pooled sample (N=568)
Farm type (% of farmers)	19.0	31.0	50.0	100
Herd size	16.28 ^b	16.80 ^b	30.43 ^a	23.5
Main cattle breed is indigenous (% of farmers)	73.8 ^a	74.0 ^a	65.8 ^b	69.9
Dependence on non-farm income (% of farmers)	61.7 ^a	50.3 ^b	49.3 ^b	51.9
Education of Household head (years)	5.50 ^a	4.35 ^a	4.92 ^a	4.85
Farms with income from other agricultural sales (% of farmers)	0 ^c	53.1 ^a	75.4 ^b	54.22
Crop land area (Ha)	0 ^b	6.60 ^a	6.46 ^a	5.29
Distance to commonly used market (Kms)	46.4 ^b	58.2 ^a	48.5 ^b	51.1
Average age of household head (years)	54 ^b	60 ^a	58 ^a	57
Experience in cattle production (years)	17.1 ^b	25.9 ^a	26.0 ^a	24.3
Gender (% of female farmers)	29.0 ^a	26.0 ^a	16.2 ^b	21.7
Access to prior market information in the past year (% of farmers)	63.6 ^a	58.2 ^b	63.7 ^a	61.9
Access to veterinary services (% of farmers)	79.4 ^b	76.2 ^c	83.8 ^a	80.63
Use of controlled cattle breeding method (% of farmers)	13.0 ^a	11.0 ^a	13.0 ^a	12.6
More than 50% cattle sales to BMC (% of farmers)	2.8 ^c	5.0 ^b	15.0 ^a	10.0

Note: ^{a,b,c} differences in the superscripts represent significant differences (at 10% level or better) across the production systems.

Table 2: Average annual output and inputs

Variables	Cattle farms (N=107)	Cattle and crop (N=177)	Mixed farms (N=284)	Pooled sample (N=568)
Value of beef cattle output (Pula)	21,670 ^a	23,011 ^a	39,590 ^b	31,048
Veterinary costs (Pula)	476 ^a	374 ^a	634 ^b	524
Paid labor costs (Pula)	5725 ^a	7928 ^b	8609 ^b	7854
Purchased feed equivalents (Kg)	535 ^c	234 ^a	390 ^b	370
On-farm feed equivalents (Kg)	0 ^a	463 ^b	694 ^c	492
Depreciation costs (Pula)	3482 ^a	2761 ^a	5302 ^b	4168
Cost of other inputs (Pula)	2812 ^a	3519 ^a	5012 ^b	4134

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

Table 3: Technical efficiencies and Meta technologies of different beef farm types

Model	Cattle farms	Cattle and crop farms	Mixed farms	Total
TE w.r.t. the metafrontier				
Mean	0.353 ^c	0.463 ^b	0.571 ^a	0.496
Min	0.162	0.064	0.333	0.064
Max	0.747	0.765	0.836	0.836
SD	0.117	0.146	0.083	0.140
Meta-technology ratio				
Mean	0.461 ^b	0.843 ^a	0.814 ^a	0.756
Min	0.204	0.663	0.742	0.204
Max	0.951	1.000	1.000	1.000
SD	0.151	0.076	0.074	0.171

Note: ^{a,b,c} differences in the superscripts represent significant differences (at 10% level or better) across the production systems.

Table 4: Production function estimates and determinants of technical efficiency

Variable	Pooled Stochastic frontier		Metafrontier-Tobit	
	Coefficient	Standard error	Coefficient	Standard error
Constant (β_0)	10.6	0.1409	7.46	0.00001
Improved feed equivalents (β_1)	0.10**	0.0578	0.20***	0.00001
Veterinary cost (β_2)	0.40***	0.1229	0.21***	0.00001
Labor (β_3)	0.10	0.0977	0.10***	0.0001
Divisia index for other costs (β_4)	0.30**	0.1005	0.50***	0.00029
Inefficiency effects				
Constant (β_0)	3.71***	0.1490	0.41***	0.0201
Beef herd size (δ_1)	-0.03***	0.0013	0.001***	0.0001
Indigenous breed (δ_2)	0.21***	0.0811	-0.03***	0.0120
Non-farm income (δ_3)	-0.005	0.004	0.001	0.0001
Age of farmer (δ_4)	-0.01**	0.0018	0.001**	0.0003
Gender (% female farmers)(δ_5)	0.12	0.0772	0.01	0.0113
Sales to BMC (δ_6)	-0.16	0.1245	0.04***	0.0168
Controlled breeding method (δ_7)	-0.35**	0.1245	0.13***	0.0159
Distance to common market (Kms) (δ_8)	0.015	0.625	0.002***	0.0001
Other agricultural income (% of farmers) (δ_9)	-0.10	0.0671	0.09***	0.0095
Income-education (δ_{10})			-0.001*	0.00064
sigma-squared	0.45***	0.030		
gamma	0.99***	0.015		
N	568		568	
log likelihood function	-518.63		456.66	

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).