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Measurement of competitiveness in smallholder livestock systems and emerging policy advocacy: An application to Botswana

Sirak Bahta [a],*, Patrick Malope [b]

[a] International Livestock Research Institute (ILRI), Private Bag 0033, Gaborone, Botswana
[b] Botswana Institute for Development Policy Analysis, Private Bag BR-29, Gaborone, Botswana

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ABSTRACT

Farm level cross sectional data of 556 randomly selected livestock producers were used to investigate the competitiveness of smallholder beef farmers in Botswana. The results show the presence of inefficiency, with about 74% of the variation in actual profit from maximum profit (profit frontier) between farms mainly arising from differences in farmers' practices rather than random variability. Further the mean profit efficiency level of 0.58 suggests that there is a substantial scope to improve beef profitability in Botswana. Significant profit efficiency drivers include, among others, education, distance to market, herd size, access to information and access to income from crop production. Considering the importance of livestock sector for wealth creation and poverty eradication in the rural areas where poverty is more pronounced, there is a need for appropriate development strategies and policies directed towards addressing these factors. In particular there is need to invest in market infrastructure in order to improve market access, hence profit efficiency of smallholder livestock farmers.

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Introduction

As a consequence of harsh climate and relatively poor soils, Botswana's agriculture is dominated by livestock production, which accounts for over 80% of the agricultural sector's output. Crop production is both risky and unprofitable. Beef dominates the livestock sector, as it is one of the country's major foreign exchange earners and contributes about 57% of agricultural value added (Food and Agriculture Organisation (FAO) and Ministry of Agriculture (MoA), 2013). In addition, the beef sector is one in which many indigenous Botswana participate in, and so it is important for wealth creation and poverty reduction especially in the rural areas. For this reason livestock policy has tended to favour the beef sector at the expense of others such as small stock.

Botswana's livestock production is dualistic in structure in that it includes both commercial and traditional/communal systems of production. The division between the two is based on land tenure, and not so much on herd sizes or any other criteria. The communal system of production is found in the communal/tribal land areas where animals graze in open rangelands with no defined property rights to grazing resources, and few fences. Conversely, the commercial system of keeping livestock is found in the freehold and leasehold land, and is characterised by fenced farms and owners' exclusive rights to grazing resources. The majority of livestock (cattle and small stock) are found in the communal system, holding 88% of cattle and 98% of small stock (sheep and goats) in 2011. In terms of productivity, the commercial sector performs slightly better than the communal sector. For example, in 2011 the mortality rate was 1.6% in the commercial sector, but 6.6% in the communal sector. The off-take rate in the commercial sector was 13.5% in that year, while it was 6.9% in the communal sector. Similar comparisons can be made for livestock birth rates: 54.4% for the commercial sector and 38.9% for the communal sector, however this is compromised by the high mortality mentioned above (Statistics Botswana, 2013).

Past studies of Botswana's beef competitiveness or profitability have investigated performance under various projected price regimes and trade agreements (Botswana Institute for Development Policy Analysis (BIDPA), 2006, Jefferis, 2007; ODI, 2007), enterprise budgeting (BIDPA, 2006; FAO and MoA, 2013; Panin and Mahabile, 1997), estimating multifactor productivity and technical inefficiency (Irz and Thirtle, 2004;Thirtle et al., 2000) and exploring the beef value chain (Bahta et al., 2013; FAO and MoA, 2013).

Limitations of these studies include that they either failed to account for farmers' management-related adjustments to farm budgets in the presence of broader economic change, and/or that

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* Corresponding author.
E-mail addresses: s.bahta@cgiar.org (S. Bahta), pmalope@bidpa.bw (P. Malope).

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with very limited household data there was an assumption of technical efficiency in terms of input use and the production technology employed. Hence, efficiency has not been estimated, nor examined for its actual and potential influence on competitiveness and the factors affecting it. A further limitation of past work is the common treatment of the co-existing production systems: FAO and MoA (2013) demonstrate substantial differences in profitability across different technological models, but the analysis was based on a deterministic treatment of constructed household types rather than estimated from representative data.

The study that most comprehensively measured Botswana's livestock sector's competitiveness is the 2006 BIDPA study. It measured competitiveness at the macro level using trade-related data and aggregate production. Its trade-related indices fail to take into account productivity or efficiency at the farm level, a gap the present study attempts to fill. A second limitation of the BIDPA study is that it used a Computable General Equilibrium (CGE) model to measure the impacts of various economic shocks such as changes in export prices and import tariffs on the whole economy, and in particular the beef sector. Such a model does not illuminate what should happen at the farm level in order to improve productivity or efficiency. According to Van Wijk (2014) farm households differ in many respects and recognising this variability is key to designing policies to help poor farmers mon one hand, and contribute to sector competitiveness on the other. Macroeconomic models fail to address these issues at farm level and hence may not provide for appropriate policy recommendations for help poor farmers. Microeconomic models such as the one presented in Section 'methodological approach' offer additional insight because they try to disentangle the causes of low competitiveness which macroeconomic models cannot, but which are important as they contribute to overall aggregate competitiveness.

The livestock production system, especially in the communal sector, operates within a complex system. It is characterised by multiple activities such as off-farm employment, crop production and other activities as a strategy to reduce risk (droughts and diseases) associated with livestock farming. This can have significant implications in terms of efficiency and hence productivity as farmers do not devote sufficient time to their livestock enterprises. In addition, in some areas, especially in the western sand veldt zone of the country, crop production areas are remote from livestock grazing areas and this makes it difficult for farmers to use complementary inputs such as labour. Livestock production areas are usually also located far from areas where there are opportunities of formal employment or other off farm economic activities. As a result the majority of farmers are able to visit their farms only at weekends, and hence the term "weekend farmers" is often applied to beef producers in Botswana. Such risk mitigation issues are difficult to deal with at macroeconomic level and this is a further contribution of the current study.

Attempts have been made to improve macroeconomic models, such as the CGE model used by BIDPA, largely through the incorporation of microeconomic-behaviour into macroeconomic analysis. These improvements entail the use of real households/producers instead of representative households/producers groups (Bourguignon et al., 2003; Briones, 2014). Such improvements make it possible to capture within-group differences in a manner not possible with macroeconomic models. An Ethiopian example is provided by Little et al. (2014) in that despite recent growth in exports, macroeconomic assessments fail to appreciate the constraints to increasing market off-take rates and the microeconomic incentives faced by pastoralist households. Microeconomic models based on household level data attempt to deliver a deeper understanding of individual farm circumstances than do representative farms, and hence take into account differences in individual farms and production systems.

To fill the gaps identified above, the current study employs the relative profit efficiency approach (Delgado et al., 2008a,b) using farm level cross sectional survey data from the ILRI/ACIAR/MOA project.[1] The data was collected in three districts (Southeast, Chobe and Central) of Botswana. The survey assembled detailed information on costs and returns of livestock production encompassing different farm sizes across the selected districts. The information collected enabled the researchers to identify determinants of profitability, or profit efficiency (Delgado et al., 2008a,b). The identification of the determinants of profitability/profit efficiency will assist in determining policy options needed to enhance profitability of beef production and hence competitiveness at farm level.

While it is recognised that competitiveness has many definitions and hence different measures, the present study uses profitability analysis to measure competitiveness at farm level. The appropriateness of this approach rests on the fact that the present study measures efficiency at farm level, and other measures of competitiveness are related to profitability. The general objective of this study is therefore to measure competitiveness of beef production in Botswana using profitability as a yardstick. Its specific objectives are to identify the determinants of profitability, efficiency drivers and the overall profit efficiency of beef production in Botswana.

The paper is organised as follows: Section 'literature review'; Section 'methodological approach' presents methodological approach used in the study, followed by the description of the study area, data and estimation procedure; Section 'results and discussion' provides the results and Section 'conclusions and policy implications' concludes with major findings and their policy implications.

Literature review

Definition of competitiveness

Competitiveness is an ambiguous concept so can be defined in several ways and addressed from different perspectives (Agriculture Canada, 1991; Kennedy et al., 1998; Latruffe, 2010). As noted by Latruffe (2010) competitiveness can be measured at three levels. These are the microeconomic level, where competitiveness is measured at a single firm/farm level; meso-economic level where it is measured at commodity or sector level and finally at macroeconomic level where it is measured at aggregate or country level.

According to Banse et al. (1999) there is no simple measure or definition of competitiveness that has gained universal acceptance. Several definitions of competitiveness relate in one way or another to profitability. Agriculture Canada (1991) defines competitiveness as the sustained ability to profitably gain and maintain market share. Latruffe (2010) defines competitiveness as the ability to sell products that meet demand requirements in terms of price, quality and quantity and at the same time ensure profits over time that enable the firm to thrive. Kennedy et al. (1998) define competitiveness as the ability of a business profitably to create and deliver value at prices equal to or lower than those offered by other sellers in a given market. In agribusiness, a competitive firm/farm is one that has the ability to produce and sell quality products in a given market at a profit. Thus, to be competitive requires that the farm not only sells, or attains a given market share, but it must also do this at a profit for its continued existence. This calls for

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[1] The Smallholder Livestock Competitiveness Project is an ACIAR-funded project implemented by the International Livestock Research Institute in partnership with the Botswana Ministry of Agriculture's Department of Agricultural Research.

efficiency in the use of resources employed and hence productivity is an important aspect of competitiveness.

Measures of competitiveness

According to Latruffe (2010) competitiveness is a relative measure and has several measurement methods. The author divides these methods into two categories: one based on neoclassical economics; and the other on the strategic management school. Neoclassical economics measures of competitiveness focus on trade issues and measure competitiveness using the real exchange rate, comparative advantage indices, export and import indices and other trade-related metrics. These measures are normally used to measure competitiveness at meso-economic or macroeconomic levels, rather than at firm level. Some of the studies which used trade measures of competitiveness in agri-food sector, among others, include Mulder et al. (2004) in the Mercosur countries, Ball et al. (2006) and Carraresi and Banterle (2008) in EU countries, Drescher and Maurer (1999) in Germany, Venturini and Boccaletti (1998) in Italy and Bavorova (2003) in the Czech Republic.

In contrast, the strategic management school places emphasis on the firm's structure and strategy, and define competitiveness as cost leadership and/or non-price supremacy. Competitiveness measures that fall under this category include cost, profitability and productivity and efficiency. Most measures of competitiveness at firm level use profitability as a yardstick. Several studies have been undertaken to determine profitability of different agricultural enterprises, including livestock in both emerging and developing countries (Banse et al., 1999; Delgado et al., 2008a,b; Emam and Salih, 2011; Longwe-Ngwira et al., 2012; Staal, 2002; Thorne et al., 2002).

Productivity and efficiency are also often cited as indicators or measures of competitiveness. Measuring efficiency means measuring the potential input reduction or potential output increase relative to a reference, which can be technically defined by non-parametric and parametric methods (Latruffe, 2010). The parametric approach, such as data envelope analysis, which uses linear programming to construct the efficiency frontier with the best performing farms of the sample. It relies on specifying a production function and econometrically estimating it assuming that all deviations from the frontier are the result of technical inefficiency and without taking into account the effect of possible noise on the frontier. The current study uses the parametric approach, stochastic frontier model, which assumes a double random error by adding to the deterministic model an additional random error, as specified in Section 'methodological approach'.

Some reviews of measurement of competitiveness (e.g. Latruffe, 2010) advocate all-inclusive measurement of competitiveness as a single firm's is insufficient for advocacy on aggregate matters. Conversely, some researchers (Harrison and Kennedy, 1997; Krugman, 1994) argue that measuring a nation's or a sector's (macro or mesolevel) competitiveness lacks intuitive interpretation, and so favour individual (firms' or farms') assessment of competitiveness. Further, according to several authors (Banterle and Carraresi, 2007; Fischer and Schornberg, 2007), trade measures (export market shares, revealed comparative advantage, relative import advantage and relative trade advantage) do not account for a country's or sector's size, and so constrain usefulness for purposes of comparison. Moreover, macro-level measurements of competitiveness are exposed to vagaries of specification of exchange rate, and to distortion associated with government intervention. As one example, Gorton and Davidova (2001) in their comparative analysis of Central and Eastern European Countries (CEECs) and the European Union (EU) found that the competitiveness of the CEECs had been underestimated as a result of direct payments received by EU farmers. An additional consideration was that the analysis failed to capture the dynamic nature of firms and farms with regard to adjustment to incentives such as price. CGE models and partial equilibrium models offer some relief for this later problem, but as they are based on aggregate data they ignore variations across firms and farms.

In general, using microeconomic data allows for variations across firms and farms that would not be captured with the use of aggregated data. In this study we used microeconomic data to inform policy makers with regard to avenues for enhancing profitability of beef production in Botswana.

Determinants of competitiveness

Farm level competitiveness is determined by many factors, some external to the firm/farm, while others are internal and hence the firm has control over. Several researchers have identified an inverse relationship between farm size and productivity (Buckwell and Davidova, 1993; Cornia, 1985; and Staal, 2002), with supporting arguments favouring small farms as they do not require labour supervision and other organisational delegation, and otherwise, exploit the clear profit motivation of family labour. Lapar et al. (2005) focused on cost structures to find that small dairy farms were more cost efficient than large ones, and hence more profit efficient. However, a counter argument in the developing country context draws on large farms' available economies of scale and preferential access to both output and input markets, such that positive correlation between farm size and profitability and/or efficiency has been demonstrated (Delgado et al., 2008a,b; Hall and LeVeen, 1978; Kolawole, 2006; Nganga et al., 2010).

Social capital has been used to explain farm performance as a proxy for farmer's management capacities which are not directly observable (Latruffe, 2010). The effect of farm manager's age on technical efficiency or productivity is ambiguous. It may be negative due to older farmers' resistance to change and unwillingness or inability to adopt technological innovations (Brummer and Loy, 2000). Further, older farmers are at or near their exit stage and hence may reduce their commitment to business and profit maximisation as other priorities appear (Rakipova et al., 2003; Nganga et al., 2010). On the other hand, age may influence positively farm performance as older farmers are more experienced, and notably, can apply accumulated knowledge to the efficient use of inputs (Kolawole, 2006; Lapar et al., 2005; Mathijs and Vranken, 2001; Otieno et al., 2012).

The farmer's education level is expected to positively influence farm performance. Kolawole (2006), Nganga et al. (2010), Mathijs and Vranken (2001), and Otieno et al. (2012) found a positive relationship between education and technical efficiency. However, Sotnikov (1998) found the opposite and explains this counter-intuitive relationship on the specificity of agricultural education in Russia at that time, which being concerned more with technical than management practices, had supposedly promoted inefficiency and poor farm performance.

Chavas et al. (2005) found that gender cannot explain differences in farm technical efficiency. However, Timothy and Adeoti (2006) found that female cassava farmers in Nigeria showed superior technical efficiency than did their male counterparts, but lower allocative efficiency. These latter authors attribute differences in efficiency between female and male farmers to differential access to inputs.

Off-farm work is likely to influence the efficiency of a farm, but the sign of the relationship may be disputed: farmers' time allocated to off-farm work reduces time spent on efficiency-improving managerial and productive activities. Conversely, spending time off the farm might improve farmer's ability through the acquisition of information and knowledge and hence farm performance. Further, off-farm work can assist in accumulating capital which when invested on the farm can increase efficiency. Otieno et al. (2012) found a positive relationship between off farm income and profit efficiency and argue that this is evidence of re-investment of off-farm earnings into farm production. Rakipova et al. (2003) argue that this is consistent with the hypothesis that producers with off-farm work must compensate for the time they spend off-farm, making more efficient use of their own labour and management. Thus, they become better managers and more efficient in the use of resources.

Methodological approach

Conceptual model

This study employs efficiency as a measure appropriate for assessment of smallholder farms' competitiveness. Following the definitions employed above, smallholder farmers are most able to stay in business, and perhaps to advance and maintain market offtake (as an analogue of market share), if they are efficient users of farm resources both in the technical (being on the production possibility frontier given existing technology) and allocative (being on the right place on the production frontier, given prevailing prices) senses (Delgado et al., 2008a,b). Thus, farmers who are more efficient users of farm resources in securing profits per unit of output are more likely to be able to maintain profits and market share and be in a position to invest more into the farm enterprise for future growth.

According to Delgado et al. (2008)a,b, the standard way of assessing farm-specific profit efficiency is to estimate a "profit frontier" across a sample of farms, and then measure how far each farm in the sample lies below the frontier. Fig. 1 shows a profit frontier for a sample of farms, each dot corresponds to the actual outcome in terms of profit per unit for a specific farm. Delgado further noted that an ordinary least squares (OLS) regression on data from a sample of farms of different sizes and profits per unit of output against input and output prices and fixed factors of production (land, labour, etc.) will always lie below the theoretical frontier (as shown in Fig. 1). Identification of the "most efficient" farm can be undertaken by estimating a stochastic profit frontier, which allows for measurement error in the econometric estimation of the frontier itself. The stochastic profit frontier also allows for the fact that observations for some farms will lie above the estimated "best" frontier. Points on the stochastic frontier curve (estimated by maximum likelihood methods and labelled MLE) represent fully efficient farms (on the frontier), and all points below the frontier represent inefficient farms in terms of their specific resources at prevailing input prices.

The ratio of actual profit per unit (Y_i in Fig. 1 for farm *i*, estimated by OLS) to ideal profit (Y^*) is then farm-specific profit efficiency: a measure bounded by 0 (worst; zero profit) and 1 (best; on the frontier). Farm-specific inefficiency is then a distance "below" or within the frontier (Y^*- Y_i). This approach allows investigation of the elements that contribute most to explaining relative profit efficiency across farms. Individual farmers may lie well below the profit frontier due to farm-specific characteristics, transaction costs, barriers to inputs or markets, or policy distortions that influence their position relative to the frontier.

There are two approaches to modelling production: the direct (primal) and dual (Mohammed et al., 2013). The direct approach specifies production function to derive input demand and product supply functions with *a priori* specification of the production function, while the dual approach requires no *a priori* specification of the production function to derive input demand and output supply functions. The current study applied the theory of duality using a profit approach rather than cost function because of the limitations of the latter as it assumes that output levels are not affected by factor price changes (Lopez, 1982). In addition, the dependent variable of the cost function does not allow consideration of revenues (Mester, 2003). However, as indicated in many studies (Delgado et al., 2008a,b; Mohammed et al., 2013), problems are also often encountered with both independent and dependent variables when estimating the profit frontier.

The dependent variable employed here is defined as profit normalised by the price of beef output. One problem observed from the data is that few farms had zero or negative profit in the survey period. This required the addition of a scalar *n* (following Delgado et al., 2008a,b) to the observed profit in order to meet the requirement of (most commonly-used translog or Cobb–Douglas) profit frontiers, as they employ logarithms in their dependent variables. This approach was favoured over dropping observations with zero or negative profit because there were few such cases, and their negative values were observed to be proportionately small relative to average farm unit profit: hence, the scalar *n* is small relative to the mean unit profit). The resulting bias from a non-linear transformation of the data is judged to be of minor importance compared to the bias that would arise from using a less appropriate functional form or from arbitrarily dropping the least efficient sample members.

The foregoing discussion leads us to an estimation approach of the stochastic profit frontier which has two stages. The first explains each farm's unit profit performance in terms of technical and allocative efficiency, and the second explains differences in efficiency in terms of farm-specific variation, as well as due to policy-induced distortions.

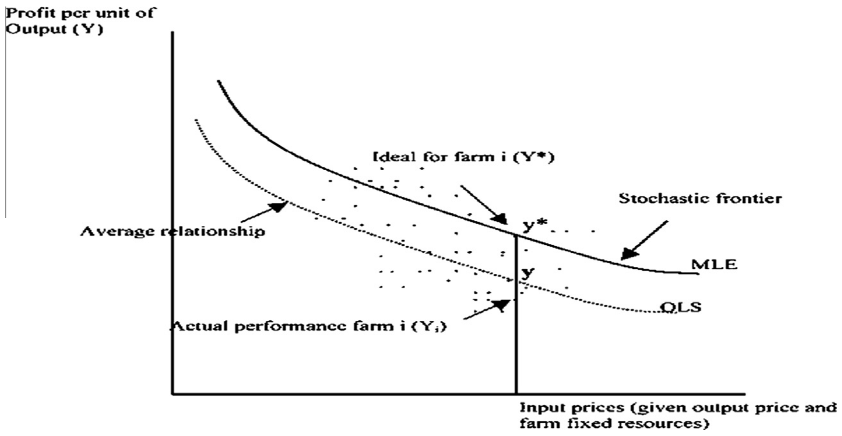

Fig. 1. Frontier (MLE) stochastic profit function for a sample of farms (source: Delgado et al., 2008a,b).

Farm profit is measured in terms of gross margin (GM) which equals the difference between the total revenue (TR) and total variable cost (TVC) and is given by:

$$GM(\pi) = \sum(TR - TVC) = \sum(PQ - WX_i) \tag{1}$$

To normalise the profit function, gross margin (π)[2] is divided throughout by P_i (the market price of beef output) to obtain:

$$\frac{\pi}{P_i}(P_i, Z_i) = \frac{\sum(P_iQ_i - WX_i)}{P_i} = Q_i - \frac{WX_i}{P_i} = f(X_i, Z_i) - \sum p_iX_i \tag{2}$$

where *TR* is the total revenue from cattle activity, *TVC* is the total variable costs (feeds, fodder, hired labour, electricity, medicines and vaccines, water, transport, etc.), of securing revenue, excluding family labour per farm *i*; P_i represents price of beef output (Q_i); X_i represents the quantity of optimised input used, Z_i represents fixed inputs used, $p_i = W/P_i$ which represents normalised price of input X_i while $f(X_i, Z_i)$ represents the production function.

Empirical model

Due to its flexibility in estimation, a translog profit frontier function was first considered as an appropriate model for this study (Delgado et al., 2008a,b). However, useful results with a translog production function require limiting the number of production factors (and hence interactions) to those with explanatory power, in order to minimise the cumulative effect of collinearity. Hence, the initial test for introduction of a specific production factor into the translog production function is to estimate, by the OLS method, the translog production function related only to the analysed factor (Pavelescu, 2011). If the results obtained from OLS estimation are considered feasible, the respective production factor may then be introduced into an extended translog production function. Pursuant to this, our initial tests revealed high multicollinearity[3] due to the high correlation between input levels and factor price variables on one hand, and interaction variables on the other. Eliminating the interaction variables lead to the adoption of the Cobb–Douglas profit function.

The Cobb–Douglas profit function in its implicit form specifies production efficiency of the farmers and is expressed as follows:

$$\pi_i = f(p_i, Z_i)\exp(V_i - U_i) \quad \forall i = 1, 2, \ldots n \tag{3}$$

where π_i, p_i, and Z_i are as defined as earlier. V_i is assumed to be an independent and identically distributed random error, having normal $N(0, \sigma^2)$ distribution, independent of the U_i. U_i is the profit inefficiency effect, which is assumed to be non-negative truncation of the half-normal distribution, $^{+}N(\mu, \sigma^2)$.

In estimation we seek to capture, or assign to individual farms, farm-specific effects on inefficiency, following Battesse and Coelli (1995). The procedure allows for systematic differences across farms in the distribution of U_i and, thus, estimation of the expected value of the farm-specific inefficiency as a function of farm characteristics in a single step maximum likelihood estimation.

The explicit Cobb–Douglas functional form for the beef farmers in the study area is therefore specified as follows:

$$\begin{aligned}\ln \pi_i = {} & \ln \beta_0 + \beta_1 \ln p_{1i} + \beta_1 \ln p_{2i} + \beta_1 \ln p_{3i} + \beta_1 \ln Z_{1i} + \beta_1 \ln Z_{2i} \\ & + \beta_1 \ln xZ_{3i} + (v_i - u_i)\end{aligned} \tag{4}$$

where (with *i* subscripts dropped) π represents normalised profit computed as total revenue less total variable costs divided by the output price, *p* represents output price, P_1 represents feed prices, P_2 veterinary services' prices, P_3 wage prices, Z_1 total fixed capital, Z_2 total family labour hours, Z_3 crop land area; and the β's are the unknown coefficients to be estimated.

As stated above, the non-negative random variable (U_i) is independently normally distributed with truncations at zero, i.e. $\mu_i \sim^{+} N(\mu_i, \sigma_u^2)$ with mean μ_i, and where $\mu_i = M_{ik}\delta_k$ and the technical inefficiency effects (μ_i) in Eq. (4), can then be specified as:

$$u_i = \delta_0 + \sum_{k=0}^{l} M_{ik}\delta_k + v_i \tag{5}$$

where v_i is the inefficiency error term as defined earlier and the M_{ik} are *k* socio-economic explanatory variables (age and education of household head, annual household non-farm income, average distance to market, herd size measured in beef equivalent[4] and dummy variables for gender, information access, FMD[5] location in FMD disease zone, access to income from crop activities, and access to credit) observed for farm *i*. δ is a vector of unknown coefficients to be estimated simultaneously with Eq. (4).

The variance of the random errors, σ_v^2 and that of the profit inefficiency effect σ_u^2, and the overall variance of the model σ^2 are related as: $\sigma^2 = \sigma_v^2 + \sigma_u^2$, which measures the total variation of profit from the frontier and can be attributed to profit inefficiency (Battese and Corra, 1977).

Given the likelihood ratio of the errors in Eq. (4), Battese and Coelli (1995) provides a log likelihood function after replacing σ_v^2 and σ_u^2 with $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and estimating:

$$\gamma = \sigma_u^2/(\sigma_v^2 + \sigma_u^2) \tag{6}$$

where γ represents the share of inefficiency in the overall residual variance with values on the interval [0, 1]. A gamma lying between 0 and 1 indicates the presence of inefficiency. A γ value of 1 or close to 1 suggests the existence of a deterministic frontier and, that inefficiency effects are important explainers of profit across farms. Lastly, a γ value close to 0 can be seen as evidence of absence of inefficiency – which favours OLS estimation.

The profit frontier and inefficiency functions specified in Eqs. (4) and (5) were jointly estimated using FRONTIER 4.1 (Coelli, 1996). The program combines the two-stage procedure into one: the maximum likelihood method estimates the profit function parameters; and those of the inefficiency model, the profit frontier function. As mentioned above, two estimation procedures (OLS and ML) were used to establish whether or not profit efficiency is affected by farmer-specific characteristics. The first (OLS) model is the traditional response function in which the efficiency effects are not present (i.e. $U_i = 0$). This is a special case of the stochastic frontier production function model in which the total variation of output due to technical inefficiency is zero: that is $\gamma = 0$. The

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[2] Considering the inclusion of fixed costs as independent variable in the equation, Y_i is gross margin which is used as a proxy for profit. However, for the sake of consistency with the literature we refer subsequently to Y_i as profit.

[3] Prior test of multicollinearity in STATA 11 show the presence of high multicollinearity between interaction and individual variables. Thus, interaction variables were dropped which improved the presence of multicollinearity to acceptable levels (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).

[4] Following (Otieno et al., 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 and 500 kg. 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 $\geqslant$1 year have not calved), male calves (between 8 weeks and <1 year), female calves (between 8 weeks and <1 year), pre weaning males (<8 weeks), pre weaning females (<8 weeks) are 400 kg, 350 kg, 390 kg, 300 kg, 250 kg, 220 kg, 95 kg 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.

[5] Foot and Mouth Disease.

Table 1
Cattle holdings and population per district and region in 2011.

District/region	Cattle holdings	Cattle population	Proportion in total traditional cattle holdings (%)	Proportion in total traditional cattle population (%)
South east	1499	18,378	2.0	0.81
Serowe	2590	159,800	3.5	7.07
Letlhakane	2627	191,535	3.5	8.47
Selebi-Phikwe	1316	78,181	1.8	3.46
Nata	6697	224,542	9.0	9.93
Central region[a]	13,230	654,058	17.7	28.94
Chobe	148	2,616	0.2	0.12
Total in sampled area	14,877	675,052	19.9	29.9
Botswana total	74,664	2,260,262	100.0	100

[a] This figure for Central District includes the in the figures in Nata, which falls under Tutume Agricultural Region. Source: Statistics Botswana (2013).

Table 2
Sample characteristics of the survey.

Variables	Mean
Value of beef cattle output (Pula per year)	5955.04
Average beef cattle price (Pula)	1993.04
Feed cost (Pula per year)	605.57
Veterinary cost (Pula per year)	650.89
Paid labour cost (Pula per year)	2853.32
Cost of other inputs (Pula per year)	704.86
Value of fixed capital (Pula)	13,1779.50
Total crop land area (hectares)	6.19
Family labour (hours per month)	210.34
Age of household head (years)	59.79
Gender (% female farmers)	22.1%
Education of household head (years)	4.95
Household off farm income (Pula per year)	54815.57
Distance to market (km)	39.65
Herd size (beef cattle equivalent)	23.86
Information access (yes = 1, no = 0)	76.8%
FMD disease zone (yes = 1, no = 0)	42.8%
Crop income (yes = 1, no = 0)	48.4%
Credit access (yes = 1, no = 0)	2.3%

Pula abbreviated by P is the currency Botswana with the exchange rate to USD at 1P = 0.1159USD (FNB, 2013).

second (ML) model is the general model where there is no such restriction.

The two models were compared for the presence of profit inefficiency effects using the generalised likelihood ratio test which is defined by the chi-squared (χ^2) test statistic, defined as $\chi^2 = -2\ln\{H_o/H_a\}$ where the mixed distribution is set at α% level of significance and $k + 1$ degrees of freedom, where k is equal to the number of parameters (as in M_k) used in the inefficiency model (Ngwenya et al., 1997). H_o denotes the null hypothesis that $\gamma = 0$ which offers a value of the likelihood function for the frontier model, and H_a is the alternative hypothesis that $\gamma = 0$ for the general frontier model.

Data and descriptive analysis

Description of the study area

A cross-sectional farm level survey was used to generate data for this study. This was carried out as a partnership between ILRI, Botswana's Ministry of Agriculture, and local authorities under the auspices of the Competitive Smallholder Livestock in Botswana research project. The survey was carried out among livestock farmers in three districts (South East, Chobe and Central districts) of Botswana as described above.

According to Statistics Botswana (2013), the South East administrative district is adjacent to Gaborone, the capital of Botswana and the district headquarters (Ramotswa) is about 40 km from the capital city. The agricultural district is known as Bamelete/Tlokweng and is one of the five districts forming the Gaborone Agricultural Region. The district held 18,378 cattle which represented 0.81% of the Botswana's total cattle herd, while the number of cattle holdings represented 2% of the total cattle holdings (Table 1). The Chobe district lies on the north western part of Botswana and is predominately a tourist area with rich wildlife resources. The district forms the Maun Agricultural Region, together with Ngamiland East and Ngamiland West. Table 1 shows that in 2011 the proportion of cattle held in the district was 0.12% of the total. The reasons for this low proportion of cattle in Chobe area are first, the large national parks and forest conservation areas limit the amount of land available for livestock grazing. Second, the area is infested by Tsetse fly which causes disease in cattle and hence historical cattle numbers have been low. Lastly, the area is the home to buffalos, which carry FMD. The area is considered a red zone or "FMD area" by World Organisation of Animal Health (OIE) and Botswana's Department of Veterinary Services. Farmers in the area are not allowed to trade with other regions, nor with BMC without a 21-day quarantine period. The ILRI/ACIAR/MOA project included this area as part of the survey to explore the differences in competitiveness of farmers in FMD and non-FMD areas.

The Central Agricultural Region is the largest geographical agricultural region in Botswana and consists of seven agricultural districts. The data for the study was collected from three districts in the agricultural region; Serowe, Selebi-Phikwe, Letlhakane and Nata in Central Administrative District, but falling under Tutume Agricultural District in Francistown Agricultural Region. The Central Agricultural Region had a total of 654,058 cattle of which 78,181 were in Selibi-Phikwe, 159,800 in Serowe, 191,535 in Letlhakane and 224,542 in Nata (Table 1). The agricultural district as a whole kept 28.94% of the national cattle herd in the traditional sector, as a consequence of its vast areas suitable for cattle farming. Some parts of the region, around Nata and Selebi-Phikwe, are however categorised as FMD zones.

A multi-stage cluster (area) sampling approach (Horppila and Peltonen, 1992) was used to select a sample from the population. First, the central district (Botswana's largest district), was divided into four sub-districts (to account for the differences in farming systems, ecology and soil type), to form six clusters. Within a cluster, extension areas[6] were randomly selected from lists of all extension areas, taking into account the general distribution of cattle in the study area. Subsequent stages involved a random selection of crushes[7] or sample of locations, from which a number of farmers were randomly selected.

A structured questionnaire was used to collect data. The main variables captured in the data included detailed information on

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[6] Extension areas are areas within districts that are classified based on delivery of agricultural extension services.

[7] Normally the veterinary district offices keep list of farmers by crushes. Thus, list of farmers was provided by crushes for each extension area in respective district/sub district.

Table 3
Stochastic profit frontier estimates.

Variables	OLS		MLU	
	Coefficient	*t*-values	Coefficient	*t*-values
Constant	−0.035	−0.253	2.613	0.128
Ln (feed)	-0.200^{***}	−2.360	-0.255^{***}	−2.971
Ln (veterinary)	-0.322^{***}	−3.555	-0.442^{***}	−5.187
Ln (labour)	0.010	1.122	−0.004	−0.480
Ln (fixed capital)	0.042^{***}	3.600	0.007	0.567
Ln (family labour hours)	0.008	0.459	−0.003	−0.188
Ln (crop land area)	0.105^{***}	3.142	0.051^{***}	3.125
σ^2			0.442^{***}	17.066
γ			0.742^{***}	7.143
Log likelihood function	−597.103		−561.978	
LR test of the one-sided error	70.25			

Note: statistical significance levels: ***1%; **5%; *10%.

costs of production inputs such as feeds, veterinary supplies and advisory services, labour and fixed inputs and returns to beef farming. In addition to the cost and revenue information necessary to calculate profits, the questionnaire elicited information on cattle breeding method, disease prevalence, access to extension and market services, and households' social and demographic characteristics.

Descriptive analysis

The characteristics of the sampled farms are summarised in Table 2. On average farmers produce about 5955 Pula worth of beef cattle output annually and receive an average price of about 1993 Pula per head. An average household/farm annually spends 605.57 Pula for feed, 650.89 Pula for veterinary requisites and 2853.32 Pula for paid labour. The amount spend on paid labour equates to about 238 Pula/month, which was lower than the legal minimum wage for agricultural labour of 445 Pula in 2011. Other rewards for labour (housing, payment in kind) are known to be in use, and in addition there is widespread use of family labour (each farm reports using 210 h monthly on average) which may be unpaid.

About 48% of the respondents in the study area reported that they have received income from crop farming, and on average a farm household owns about 6.19 ha of land for crop production. In terms of demographic characteristics, the table shows that the average age of the household head is 59.79 years. The respondents reported on average 4.95 years of schooling suggesting that the majority did not attend school or they attended only up to primary, as primary schooling occupies 7 years.

The overwhelming majority of farmers are male (77.9%), suggesting that livestock farming is predominately a male activity. This figure is however, higher than the figure reported by the 2011 Preliminary Annual Agricultural Statistics (Statistics Botswana, 2013) survey which reported the national average of 65% cattle holdings being owned by males.

When asked whether they had access to information on livestock marketing, the majority (76.8%) indicated that they have access to information. The average distance to the most commonly used market is 42.8 km. A sizeable proportion (43%) of farms were located in FMD areas (Chobe, Selibi-Phikwe, and Nata). On average a farm household receives an annual non-farm income of 54,815.57 Pula. Generally, farmers appear to have limited access to credit with just 2.3% indicating that they had accessed credit during the study period.[8]

Results and discussion

Profit frontier estimates

Table 3 shows that the estimated value of γ is significantly different from zero, suggesting that the profit variations occur both as a result of farmer inefficiency and exogenous factors outside the farmers' control. This strongly dominates measurement error and other random disturbances. About 74.2% of the variation amongst farms of actual profit from maximum profit (i.e. on the profit frontier) arose from differences in farmers' practices, rather than from random variability.

The table also shows the log likelihood function for the full stochastic profit frontier model (−561.978), and the value of the OLS fit of the profit function (−597.103), indicating that the OLS fit of the profit function is less than that for the full frontier model. The generalised likelihood-ratio test statistic for testing the absence of the profit inefficiency effects from the frontier is given by: $\text{LR} = -2\{-597.103 - (-561.978)\} = 70.25$. This value is significant at the 1% level of test because it exceeds 22.25, the critical value obtained from Table 1 of Kodde and Palm (1986) for the degree of freedom equals to 11 ($k = \delta_i + 1$). Thus, the null hypothesis is strongly rejected, leading to the acceptance of the full model, which incorporates profit inefficiency effects.

The value of σ^2 is also significant, implying that the technical efficiency equation can explain the differences between farms' profit, and profit positions on the frontier function. Table 3 further shows that all the first order explanatory variables, except for family labour, have the expected signs. The input prices (except paid labour) are statistically significant and have negative signs suggesting that profits could be increased when the prices of feed and veterinary products are reduced. The estimated coefficients for fixed capital and paid labour have a positive sign, while family labour has an unexpected negative sign. However none of these are statistically significant.

The estimate on the coefficient for crop land area is positive and statistically significant. This implies that an increase in crop land area increases farm profit significantly. A plausible explanation for this is that farmers who have more crop land are likely to have more crop residues which they use to feed their animals and hence can abate feed costs.

Determinants of profit inefficiency

Table 4 shows the estimates of the coefficients for the efficiency drivers. To aid interpretation, 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

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[8] The field survey is conducted from June to end of July 2013 and the information collected is based on the past 12 months (June–July 2012 – June–July 2013).

Table 4
Determinants of profit inefficiency among beef farmers.

Variables	Coefficients	*t*-Values
Constant	2.798	0.137
Age of household head	0.020	0.191
Education of household head	-0.037^{*}	−1.806
Annual household non-farm income	−0.004	−0.541
Distance market (commonly used)	-0.030^{**}	−2.128
Herd size	-0.233^{***}	−6.756
Gender (% female farmers)	0.104	1.442
Information access (yes = 1, no = 0)	0.107^{*}	1.903
FMD disease zone (yes = 1, no = 0)	0.036	0.570
Crop income (yes = 1, no = 0)	-0.175^{***}	−2.965
Credit access (yes = 1, no = 0)	−0.173	−0.918

Note: statistical significance levels: ***1%; **5%; *10%.

effects component of the model. This means that a positive sign on the coefficient is interpreted as a negative influence on efficiency because the value of u would be higher when the farm is further away below the profit frontier. On the contrary, a negative sign of the coefficient is interpreted as having a positive influence on efficiency (Brummer and Loy, 2000; Coelli et al., 2005; Delgado et al., 2008a,b; Otieno et al., 2012).

Results in Table 4 displays a coefficient estimate for education of the household head that is negative and statistically significant. This suggests that profit inefficiency declines with an increase in years of schooling. Education, therefore, reduces profit inefficiency in beef production, and thus more educated farmers are more efficient than are less efficient ones. The estimate on the coefficient for distance to the most commonly used market is also negative and significant, which indicates that farmers travelling long distances to sell their animals are more efficient. A plausible explanation for this is that despite high transport costs, farmers prefer to access distant markets in search of better sales prices. The differentials between local prices and those at distant markets apparently more than offset the transport cost and hence farmers who sell to these markets are more profit efficient than those who sell in local markets. Bahta et al. (2013) have shown that when farmers in rural Botswana sell their animals in the area around their village, they prefer to sell to individuals (other farmers, or directly to consumers) as price is established by mutual negotiation and payment is made without delay. However, the number of animals that individuals can buy is limited and so farmers who want to access profitable market channels and/or have larger numbers to sell, must travel to distant towns, where BMC[9] collection points and other potential buyers, such as butcheries, are located.

Farmers who own a large cattle herd are seen to be more efficient than those owning small herds. This suggests economies of scale in beef cattle production. However, the relation between herd size and gross margin in Botswana is not straightforward and varies with livestock herd size groups (Bahta et al., 2013; BIDPA, 2006). In those studies, farmers who own more than 200 cattle have the highest gross margin while farmers with less than 20 TLU (Bahta et al., 2013) and with 150–200 TLU cattle herd size (BIDPA, 2006) achieved a negative gross margin.

The results in Table 4 further shows that the coefficient for access to market information is positive and significant. This is unexpected as it implies that farmers with less access to market information are more efficient. A possible reason for this finding could be associated with the quality of information disseminated to farmers.

Table 4 also shows that the coefficient for crop income is negative and statistically significant. This implies that farmers who earn income from crop production are more efficient than those who earn none. This suggests that income from crop farming is being reinvested into livestock farming, and/or that there are other synergies between the two farm activities including use of crop residues as feed resources.

The estimates on coefficients for age of household head, household non-farm income, gender, FMD disease zone, and credit access all have the expected signs, but none are statistically significant.

Profit efficiency estimates

Table 5 shows the profit efficiency estimates of individual beef cattle farmers in Botswana. These vary from a minimum of 0.282 to a maximum of 1.0, with a mean inefficiency score of 0.58. This is interpreted as meaning that a substantial reduction (42%) in profitability is occurring due to inefficiency. This in turn suggests that current profits could be increased by 42% on average, without requiring changes in the current technological and management package.

Conclusions and policy implications

This study identifies widespread profit inefficiency in beef production in Botswana, and an average mean profit efficiency score of 0.58. This means that there is considerable scope to improve beef production profitability under the prevailing production and input mix, and technology and management. The presence of inefficiency in the study lends support to the argument that production models that assume absolute efficiency could lead to misleading conclusions. This was supported by the log likelihood ratio test result in all models which rejected the model without inefficiency in favour of the one that incorporates inefficiency.

Inefficiency varies substantially between farms. Although characterising producer heterogeneity is possible up to a point, and useful in improving understanding of supply response as represented in higher level models such as IMPACT (Msangi et al., 2014), much remains unknown about such heterogeneity. This is a subject for future research, particularly in Botswana where cattle production has traditionally been subdivided into just two arbitrary types (communal, unfenced; and privately-held, fenced).

The profit model suggests that the profit of smallholder beef producers can be increased through increased cropland area and reduced input prices. Thus, policies to improve farm profits could be directed at reduction of input prices and encouraging beef farmers to engage in crop farming, in particular employing fodder production. Consideration of input prices needs to be tempered by findings such as those of Little et al. (2014) which identified

Table 5
Profit efficiency estimates for beef cattle farmers.

Efficiency estimates	Frequency	Percentage	Minimum	Maximum
<.20	0	0	0	0
0.2–0.3	5	1	0.282	0.299
0.3–0.4	71	13	0.302	0.399
0.4–0.5	152	27	0.400	0.499
0.5–0.6	118	21	0.500	0.598
0.6–0.7	89	16	0.600	0.698
0.7–0.8	47	8	0.701	0.792
0.8–0.9	32	6	0.803	0.899
0.9–1	42	8	0.906	1
Total	556	100		
Mean	58%			

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[9] The BMC agents (including feedlot operators) regularly visit cattle posts and villages to buy only young animals (weaners) and purchase older animals only if farmers delivered the animals to local BMC collection points (Bahta et al., 2013).

numerous non-price drivers of livestock sales decisions: similar effects may surround input purchase decisions which would offset price changes. Turning to cropped areas, the study illustrates at microeconomic level the crop-livestock interactions which although somewhat simple in their exposition here, remain difficult to incorporate into higher level models even at landscape level where resource endowments (such as water and climate) are represented (Van Wijk (2014)). Policy options for enhanced land access include allowing livestock farmers to have arable lands nearer to or within vicinity of their livestock farms: at present some Land Boards (land allocating authorities) do not allow crop production activities to take place in areas designated for livestock grazing.

This study identified efficiency drivers as: education of the household head; distance to commonly used market; information access; herd size, and access to income from crop production. The first three of these drivers would normally be considered supply curve shifters in a partial equilibrium modelling sense. However, this study has shown that they are in fact means of moving producers onto the relevant supply curves rather than moving the curves themselves. In Botswana, government invested heavily items other than soft and hard infrastructure such as farmer training and marketing. Effects of access to distant markets implies that spatial price differentials are large enough to offset transport costs: this result brings into question certain precepts of price formation, but more practically it argues for bringing markets nearer to cattle production areas. This relates to the lack of awareness and information about the quality requirements of markets detected in earlier work by Bahta et al. (2013).

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