Agricultural Systems 149 (2016) 30–39

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Evaluating the productivity gap between commercial and traditional beef production systems in Botswana

Omphile Temoso PhD Candidate *, Renato Villano Associate Professor, David Hadley Dr. Senior Lecturer

UNE Business School, University of New England, Armidale, NSW, 2351, Australia

ARTICLE INFO

Article history:
Received 11 November 2015
Received in revised form 29 April 2016
Accepted 24 July 2016
Available online xxxx

Keywords:
Beef production
Productivity
Technical efficiency
Stochastic metafrontier
Botswana

ABSTRACT

The beef cattle production system in Botswana is dualistic in structure in that it includes both traditional and commercial production systems, which are distinct from one another in terms of objectives, land tenure, technology, and management practices. The purpose of this paper is to measure the key performance indicators of beef cattle production systems in Botswana and explore the drivers of change in those indicators. We examine differences in productivity and production technologies between the two beef production systems. The results show that traditional farms are technically inefficient and that their technology lags behind that of commercial farms. The use of improved breeds, off-take rates and selling to the Botswana Meat Commission (which control the only exporting abattoirs in Botswana) were found to improve technical efficiency in the commercial production system, but only off-take rates had a positive effect on efficiency in the traditional production system. Both farming systems have the potential to overcome technology constraints and achieve the highest attainable productivity level through improvements in; beef cattle technologies, farmer capacity in production and marketing, and the effectiveness of the technology transfer process.

1. Introduction

Beef cattle production plays a significant role in the economy of Botswana; it contributes 57% to agricultural GDP and remains the main source of food, income, employment and investment opportunities for the rural population (van Engelen et al., 2013). Despite its importance to the economy and rural livelihoods, the beef sector is currently facing serious challenges; both cattle sales for slaughter and beef exports have declined significantly since the 1990s leading to commentators having doubts about the sustainability of the industry (Bahta and Malope, 2014; van Engelen et al., 2013; Jefferis, 2005). Generally, this has been attributed to low productivity caused by low efficiency and the small scale of farms, and slow adoption of improved breeding and feeding technologies. This is worsened by the semi-arid production environment in Botswana (i.e., poor soils, low and unreliable rainfall and high temperatures) and frequent outbreaks of diseases such as foot and mouth (FMD).

The purpose of this study is to measure and compare production technologies and productivity of traditional and commercial beef production systems in Botswana and to explore some of their performance drivers. The two production systems are distinct from one another in terms of objectives, land tenure, technology and management practices. They face varying constraints; have different resource endowments and a variety of opportunities for growth. Observed differences in productivity and efficiency may be influenced by differences in technology, herd sizes and biological factors (e.g., birth rates, breeds), environmental factors (e.g., climate, vegetation and soils) and economic factors (e.g., access to markets and infrastructure). Therefore, it is imperative to investigate how these factors affect each production system and their productivity. Improving productivity among these systems may help to overcome, or to ameliorate, the constraints that the beef industry currently faces.

Our study contributes to previous studies which have attempted to understand the performance of different beef production systems and what drives them (e.g., Barnes et al., 2008; Behnke, 1985, 1987; Mahabile et al., 2005; Malope and Batisani, 2008; Rennie et al., 1977; Otieno et al., 2014). Due to unavailability of data on external inputs (biological and environmental factors) our study focusses only on economic aspects of the production systems and hence we have not explored how stocking rate, forage allowance, production intake and forage utilisation efficiency influence livestock productivity. We estimate technical efficiency (TE) which provides useful information on the competitiveness of farms and their potential to improve productivity with existing resources and levels of technology (Abdulai and Tietje, 2007). Some of the previous studies which have measured the performance of different livestock systems in Botswana have been carried out using data from experimental ranches run for scientific purposes with uneconomic levels of management and which are not subject to commercial constraints (e.g., Rennie et al., 1977; Behnke, 1985). Hence, it was not clear how the knowledge gained from the results of these studies

* Corresponding author.
E-mail addresses: otemoso@myune.edu.au (O. Temoso), rvillan2@une.edu.au (R. Villano), dhadley@une.edu.au (D. Hadley).

http://dx.doi.org/10.1016/j.agsy.2016.07.014
0308-521X/

could be applied on the ground. The few other studies that have analysed farm (household) level data (e.g., Mahabile et al., 2002; Barnes et al., 2008) have calculated partial measures of productivity such as per head/hectare measures. It is well established that these types of studies may lead to misleading policy implications because they fail to explain what portion of output difference is due to inefficient use of a given input and/or the existence of scale economies (Coelli et al., 2005; Temoso et al., 2015a). Recent studies such as Bahta and Malope (2014) and Temoso et al. (2015b) have also analysed the performance of beef production in Botswana, however, they only focussed on the traditional beef production system.

This study aims to advance the understanding of productivity differences in beef production systems in Botswana using a stochastic production frontier that can simultaneously model for factors that may be associated with the inability of producers to reach their production potential and thus is useful in identifying those aspects of the production process or environment which farmers and/or policy makers might target in order to improve beef production. To make comparisons across the two production systems a metafrontier approach is employed that enables us to measure the extent of technology gaps between the two production systems. This will help us answer the question of whether it is indeed the case that traditional beef farms really lag behind their commercial counterparts in terms of productive performance and production technology; as previous literature has shown. A comparison of the two production systems is of particular relevance to policy makers in Botswana given the ongoing policy efforts that attempt to develop a more dynamic agricultural sector; where both commercial and traditional farms play a role in agricultural development. The results allow us to identify the differences in productive performance between the two beef production systems in Botswana and the drivers of those differences, and hence where policies to improve production technologies could be focused.

Differentiation by farming system may give insights into the effects of different land tenure systems upon resource use and productivity. In 1975 the government of Botswana introduced a land tenure policy (the Tribal Grazing Lands Policy, TGLP) which attempted to address rangeland degradation by encouraging ranching and improving livestock productivity through the allocation of exclusive rights to groups and individuals on newly designated commercial land (Ministry of Agriculture, Botswana, MoA, 1991; Cullis and Watson, 2005). Policy makers viewed this policy as a way to encourage modernisation (commercialisation) of the livestock industry as well as encouraging more widespread participation of farmers in the modernised industry. This policy was followed by the fencing component of the 1991 National Agricultural Development Policy (NADP) (Ministry of Agriculture, Botswana, MoA, 1991), which stated that '*fencing the rangeland will increase productivity*' (Cullis and Watson, 2005, p. 19). As has been the case in other developing countries, the major argument put forward to justify implementation of these policy instruments was that farms held under exclusive and secure rights are more productive than farms held under customary land tenure (Maxwell and Wiebe, 1999; Place, 2009). However, the empirical evidence on the relationship between land tenure and agricultural productivity remains mixed (Place, 2009) and some researchers have argued that land tenure policy in Botswana has completely failed to attain its objectives (e.g., Maxwell and Wiebe, 1999). We hope to contribute to this discussion.

The rest of the paper is organised as follows. Section 2 provides a description of the differences between traditional and commercial production systems in Botswana. The empirical method and data variables are discussed in Section 3. Results are reported and interpreted in Section 4. Finally, conclusions and policy implications are drawn in Section 5.

2. Traditional versus commercial beef production systems in Botswana

The majority of the beef cattle (approximately 80% of the cattle herd) in Botswana are found within the traditional, communal grazing system. The communal livestock grazing system is largely undeveloped; characterised by extensive grazing on tribal grazing areas with no defined property rights and uncontrolled grazing (Bahta and Malope, 2014; van Engelen et al., 2013). Although communal traditional farmers lack tenure security (which prevents them from using their assets as security to access finance for purchasing inputs) they have unrestricted rights to resources such as water and grassland. In some areas small groups of farmers have drilled their own boreholes and acquired an individual right to the use of that water (van Engelen et al., 2013; Rennie et al., 1977).

In the past the Ministry of Agriculture has recommended maximum stocking rates; however, these restrictions were never enforced by the land authorities nor observed by farmers (Mahabile et al., 2002; Malope and Batisani, 2008). The literature on land tenure and agriculture in Africa (Migot-Adholla et al., 1991; Place, 2009) argues that lack of individual grazing rights may encourage high stocking rates that reduce herd productivity and leads to low calving and high mortality rates and discourages investment in improvements such as better breeds. On average farmers within the traditional production system can be characterised as smallholders with a few animals per household operating in an environment within which infrastructure and market organisation are usually poor. Livestock management within this system is primitive and it is difficult to introduce modern livestock farming practices such as the use of improved breeds and supplementary feeding.

In contrast to the traditional system, the commercial beef production system has exclusive grazing rights with fenced pastures on private land (i.e., both freehold and TGLP ranches) (Burgess, 2006; Malope and Batisani, 2008). The individual tenure system which characterises ranching systems, allows management to control for both livestock management and grazing (Jahnke, 1982). The establishment of the majority of livestock ranches in southern Africa can be traced back to the 20th century when they were created in order to improve upon traditional livestock production systems and to increase supply in order to meet the increasing demands for meat in urban areas and for export, as well as to reduce risk of pasture degradation (de Ridder and Wagenaar, 1986). This system favours rotational grazing and rotational-rest systems by which an area is grazed until there is very little forage left before cattle are moved to a new paddock (Burgess, 2006).

Beef production under this system is solely for commercial purposes and is highly specialised; employing modern animal husbandry practices and strategic feeding to produce high-value beef animals (Statistics Botswana, 2008). Breeding control is a common practice; breeding cows are kept apart from young, immature bulls and steers, and heifers (Burgess, 2006; Rennie et al., 1977). Death rates and losses are usually lower and offtake rates are higher than in the traditional production system. The hiring of labour for herding and other livestock related work is normal practice in this system. Use of purchased inputs such as vaccines, tick treatments, feed supplements, improved bulls or artificial insemination is also commonly used. On average, commercial farmers are relatively wealthier than traditional farmers are and this allows them to have better access to finance and marketing (Burgess, 2006). Unlike traditional beef producers who sell under duress, commercial beef producers raise their cattle in order to profit by their sales (Bahta and Malope, 2014; Behnke, 1987; van Engelen et al., 2013). However, it is important to note that livestock farmers in communal areas may also produce for both household and market consumption on a regular basis. Nevertheless, commercial farmers' exhibit improved herd, pasture and husbandry management and therefore are better equipped to increase productivity and take advantage of the latest industry developments such as advanced breed genetics, fodder and disease response mechanisms.

Research in Botswana has shown that one of the major limitations to beef production and productivity is that the majority of farmers practice traditional production management which is a constraint to productivity due to: low efficiency, low technological adoption, poor access to input and output markets, and lack of land tenure security. For example, Rennie et al. (1977) compared the productivity differences between beef cattle managed in commercial ranches and the traditional system. They found that there are deficiencies in reproductive performance and mothering ability under the traditional production system. de Ridder and Wagenaar (1984) compared the two systems on a per-hectare basis. Their study found that ranches were more productive on a per animal basis when measured in terms of calving rate, mortality and weaning rates. However, the traditional systems were 95% more productive than ranching in terms of live-weight production equivalents. Similarly, Behnke (1985) found that productivity per cow under the commercial production system was better than the traditional system. The conclusions from these studies in the 1970s and 1980s are that: cattle productivity tends to be related to herd size rather than land tenure; production costs tend to decline with herd size - indicating the existence of economies of scale; and finally, large herds tend to be more drought resilient than small herds.

Mahabile et al. (2005) attempted to identify factors driving productivity among commercial and traditional livestock farms in Southern Botswana. They found that secure land tenure was the most influential factor in promoting investment and livestock productivity in Botswana. Barnes et al. (2008) compared the performance of three livestock production systems; small-scale livestock farms, cattle-post system and TGLP ranches. They found that small-scale farmers were inherently efficient and provided important household income. However, private returns were largely attributable to subsidies and economic efficiency was very low because of open access.

3. Material and methods

The focus of this paper is to compare the production technologies and measure the productivity growth of both commercial and traditional beef production systems in Botswana. To enable a comparison of productivity to be made between the two systems it is necessary to employ a method that can accommodate the heterogeneity they encompass. Hence, we use the concept of the meta-production function as an envelope of neoclassical production functions (Battese et al., 2004; O'Donnell et al., 2008). This assumes that commercial farmers, operating in an environment of private land tenure, and traditional farmers on communal land are operating under different production technologies, which are represented in the form of group-specific frontiers. This methodology enables estimation of technology gaps for producers under different production technologies relative to the potential technology available to the industry as a whole. It also enables the decomposition of TE scores into group-specific efficiency and technology differences.

3.1. The stochastic frontier model

We define separate stochastic production frontiers (SPFs) for commercial and traditional farming systems following a model proposed by Aigner et al. (1977) and Meeusen and van den Broeck (1977):

$$Y_{it} = f(x_{it};\beta)\exp(v_{it} - u_{it}) \quad i = 1, 2\ldots, N \quad i = 1, 2\ldots T \tag{1}$$

Where Y_{it} represents the output (or its natural logarithm) of the i-th firm in the t-th time period; x_{it} is an $(1\times k)$ vector containing input quantities (their natural logarithms) of the i-th firm in the t-th period, β is a $(k\times 1)$ vector of unknown parameters to be estimated. The $v_{it}s$ are assumed to be independent and identically distributed random errors which have normal distribution with mean zero and unknown variance $N(0,\sigma_v^2)$ (Aigner et al., 1977). $v_{it}s$ are non-negative unobserved random variables associated with technical inefficiency of production, such that, for the given technology and levels of inputs, the observed output falls short of its potential output. Following Battese and Coelli (1995), u_{it} is obtained by truncation (at zero) of normal distribution with mean $z_{it}\delta$, and variance, σ^2; z_{it} is a $(1\times m)$ vector of explanatory variables associated with technical inefficiency of production of firms over time; and δ is an $(m\times 1)$ vector of unknown coefficients.

Eq. (1) specifies the stochastic frontier production function in terms of the original production values. However, the $u_{it}s$, are assumed to be a function of a set of explanatory variables, $z_{it}s$ and an unknown vector of coefficients δ. Following Battese and Coelli (1995) we define the technical inefficiency effect, u_{it} in Eq. (1) as follows:

$$u_{it} = z_{it}\delta + w_{it} \tag{2}$$

where w_{it} is a random variable that is defined by the truncation of the normal distribution with zero mean and variance, σ^2, such that the point of truncation is $-z_{it}\delta$ i.e.,$w_{it} > -z_{it}\delta$. The technical inefficiency effects are modelled in terms of various explanatory variables that include farmer and management characteristics and period of observation. The method of maximum likelihood is used for simultaneous estimation of the parameters of the stochastic frontier and the model for technical inefficiency effects.

The TE of the each firm is estimated by comparing output of the i-th firm at the t-th period and is defined as follows:

$$TE_{it} = \exp(-U_{it}) = \exp(-z_{it}\delta - W_{it}) \tag{3}$$

The quantities obtained in Eq. (3) represent the performance of firms relative to individual production technologies. After estimating the production function in Eq. (3) for each group separately, it is necessary to verify if the two groups share the same production technology. This can be achieved using a likelihood ratio test (LR) which compares the values of the log-likelihood functions of the pooled data for all groups (the null hypothesis) to the alternative hypothesis that individual production frontiers should be used. If the null hypothesis that the production frontier for the pooled data is rejected in favour of individual frontiers, then the data should not be pooled and the metafrontier model should be used to estimate and compare the TE of the two beef production systems (Battese et al., 2004).

3.2. The metafrontier model

Following O'Donnell et al. (2008) a deterministic *metafrontier* can be represented as:

$$Y_{it}^{*} = f\left(x_{it}\beta^{k}\right) \tag{4}$$

Where, Y_{it}^{*} denotes MF output and β^k represent the vector of parameters for the MF production model, respectively, provided the following condition is satisfied:

$$x_{it}'\beta \geq x_{it}'\beta^{k} \text{ for all } k = 1, 2\ldots K. \tag{5}$$

Thus the constraints provided by Eq. (5) imply that an individual k-th production frontier (group frontier) will not be any greater than the metafrontier (also see Appendix 1).

The approach proposed by O'Donnell et al. (2008) envelops the estimated group frontiers by solving an optimisation problem as follows:

$$\begin{aligned} &\min_{\beta} \sum_{i=1}^{L}\sum_{i=1}^{T}\left[\ln f(x_{it};\beta) - \ln f\left(x_{it};\hat{\beta}^{k}\right)\right] \\ &\text{s.t. } \ln f(x_{it};\beta) \geq \ln f\left(x_{it};\hat{\beta}^{k}\right) \text{ for all } i \text{ and } t; \end{aligned} \tag{6}$$

where $\hat{\beta}^k$ is the estimated coefficient vector associated with the group-k stochastic frontier. The assumption of log-linearity, as is used in this study, simplifies to a linear programming problem:

$$\min_{\beta} \bar{x}'\beta \qquad \text{s.t } x'_{it}\beta \geq x'_{it}\hat{\beta}^k \text{ for all } i \text{ and } t, \tag{7}$$

where $\bar{x}$ is the arithmetic average of the x_{it} - vectors over all firms in all periods (O'Donnell et al., 2008).

The LP problem defined by Eq. (7) is estimated with *SHAZAM* econometric software. The software also produces estimates of meta-technology gap ratios and technical efficiencies with respect to metafrontier using the following decomposition of Eq. (2):

$$Y_{it} = \exp\left(-u_{it}^k\right) \times \frac{f\left(x'_{it};\beta^k\right)}{f\left(x'_{it};\beta\right)} \times f\left(x'_{it};\beta\right) + \exp\left(v_{it}^k\right) \tag{8}$$

On the right hand side of Eq. (8), the first term is the TE relative to the group stochastic production frontier. In relation to the problem being investigated, the second term can be defined as an indicator of the technology gap for the group relative to the available technology in the whole industry; which is defined by the metafrontier function (Battese et al., 2004; O'Donnell et al., 2008). An increase of an MTR implies a decrease in the productivity gap that could be attributed to the differences as outlined in section 6.2. The mathematical expression for TE of each beef production system relative to the MF (the whole beef industry) can be expressed as the product of each firm in each time period MTR (it) against each firm TE for each production system (k):

$$TE_{it}^* = TE_{it}^k \times MTR_{it}^k \tag{9}$$

3.3. Data and empirical model

To estimate this model we use district level data from the annual agricultural surveys covering six agro-ecological zones in Botswana (Statistics Botswana, various years). Statistics Botswana collects general information for the various production systems for each year through a stratified sampling framework. Explicit stratification is undertaken such that all agricultural districts (26 traditional agricultural districts and 17 commercial agricultural districts) become their own strata (Statistics Botswana, 2008).[1] According to Statistics Botswana (2008), the stratification along ecological zones is expected to increase precision and improve the accuracy of survey data with the view that homogeneity of the variables is relatively high. Differences between agroecosystems can have an effect on the efficiency and productivity levels of farms located in different regions to a different degree (O'Donnell et al., 2008; Temoso et al., 2015b). Vegetation in Botswana is closely related to the climatic conditions prevailing in a given region, this range from the low shrub savannah in the southwest to the woodland savannah in the northeast (Burgess, 2006). The Western region is generally characterised by lower and erratic rainfall, and the Kalahari *sandveld* vegetation with lower phosphorus content in herbage (Burgess, 2006). In contrast, the regions in the eastern part of the country (Central, Francistown, Gaborone and Southern) generally have higher rainfall and more vegetation with higher nutritive value.

Traditional farmers have mixed size herds (mainly practiced within the communal land tenure system) and commercial farms (carried out in freehold, leasehold and TGLP land tenure systems) are generally characterised by large herd sizes. Therefore, based on Statistics Botswana definitions, it is possible to isolate the productivity of beef farms according to different production systems (and land tenure system).

[1] In this study, we only use 9 years since Statistics Botswana did not collect data on farms in 2005. Also for commercial farms, instead of 17 districts we only used 15 districts since some districts had missing information on inputs and outputs for most of the years.

3.3.1. Production function model variables

The following are the variables that enter the beef production function model:

Output: The value of the cattle sold and home slaughtered for each year in each agricultural district (Irz and Thirtle, 2004; Thirtle et al., 2003). These values are deflated to base year (2004) prices using the Rural CPI published by Statistics Botswana.

Herd size: Average annual beef cattle herd size kept in a year, adjusted with relevant conversion factors (Bahta and Malope, 2014; Otieno et al., 2014). The variable is usually used as a proxy for the stock of capital in livestock production studies (Iraizoz et al., 2005). To account for different sizes of the animals we have disaggregated herd composition according to size and purpose; bulls as male breeders, cows and heifers as female breeders, oxen for draught power etc.

Labour: Labour costs are comprised of both family and hired labour. The hired labour costs are calculated using the number of full-time equivalents of hired labourers (i.e., herdsmen and general workers) per district. For family labour input, we used adult equivalents (people over 12 years old) per cattle household to represent family labour. Both labour components are then valued using data on minimum annual wages in a particular district (Iraizoz et al., 2005; Otieno et al., 2014). These costs are deflated to 2004 prices using the Rural CPI published by Statistics Botswana.

Other costs: The values of other costs in livestock production were deflated to base year (2004) prices using the Rural CPI published by Statistics Botswana. Note, however, that the costs of variable inputs such as medicines and water are not available.

Regional dummy variables: These are included in the frontier model to capture environmental constraints (due to differences in soils and grass types) on production and which we hypothesise may cause the frontier to shift by location. The geographical distribution of cattle production ranges from the more arid areas receiving less than 400 mm of rainfall per annum (Western region) (and where cropping is rarely practised) to semi-arid areas with annual rainfall between 400 and 650 mm per annum in the eastern parts of the country (and where crops are grown).

Time: A linear time trend is used to capture technological change (TC).

3.3.2. Inefficiency effects model variables

The following are the variables that enter the inefficiency effects model, which explains some of the drivers of productivity.

Herd size: herd size is measured as the average number of livestock units per farm in a given agricultural district. It has been acknowledged in the previous literature that the way farmers in Botswana manage their cattle almost entirely depends on herd size (Bahta and Malope, 2014; Mahabile et al., 2005). Herd size is an important determinant of livestock performance due to the associated economies of scale.

Breeding: the ratio of total number of exotic breeds to total number of livestock during the survey year (Statistics Botswana). This may indicate the breed preference of farmers and or adoption rates of advanced livestock breeds. Beef cattle breeds in Botswana can be typically grouped into three groups: indigenous; exotic (advanced) and cross breeds.

Biological factors (*birth*, *mortality* and *off-take rates*): these parameters give an indication of population dynamics and productivity. They reflect the degree of managerial effort exerted in improving productive efficiency. According to Otte and Chilonda (2002) the basic production parameters of fertility and mortality rates inform management decisions on the trade-off between sale, consumption and investment in herd growth. Thus, they provide insight into herd/flock management levels and associated costs and returns (Nyangayezi, 1999). These parameters will also reflect the production environment in a particular season and geographical location. For example, during the 1981 to 1987 period, the drought in Botswana caused a decrease in birth rates and increase in mortality rates (CAR, 2005).

Off-take rates: this refers to the ratio of livestock sold to total number purchased and home slaughtered (Statistics Botswana, 2008). Low off-take rates have been attributed to poor management, lack of marketing facilities, limited investment opportunities and the need to build large herds for draught power purposes (Nyangayezi, 1999).

Mortality (death) rates: the ratio of total number of deaths to total number of livestock during the survey year (Statistics Botswana, 2008). Lower mortality rates might reflect the use of better technologies and/or management. The numbers of breeding animals are dependent upon reduced mortality rates which are related to disease impacts, nutritional deficiencies and inadequate management (Alexandre and Mandonnet, 2005). Increasing reproductive performance reduces mortality rate, accelerates growth rate and improves carcass merit (Alexandre and Mandonnet, 2005). The expectation is that beef farms with lower mortality rates are using better technologies and managing their livestock farms well and hence they are more likely to attain higher efficiency.

Calving (birth) rates: the ratio of total number of births to total number of livestock during the survey year (Statistics Botswana, 2008). This is one of the most important parameters in determining the technical and financial performance of the beef production system (van Engelen et al., 2013). Without a calf there is no weaner and thus no beef, but the cow still has to be fed and cared for and is at risk of disease and death (van Engelen et al., 2013).

Market: cattle are usually slaughtered for home consumption or sold to the Botswana Meat Commission (BMC) for exports. The growing local market is served by municipal abattoirs, middleman and local butcheries. In recent years (as compared to the situation in the 1980s) farmers in Botswana have tended to opt to sell to the local market rather than export markets. According to Jefferis (2005), when domestic demand exceeds exports this may reflect the dissatisfaction of farmers with prices offered by the BMC – the only entity allowed to sell to the export market. Low levels of sales are also associated with prevailing high transaction costs; for example, farmers often complain about inadequate animal transport, delays in issuing of animal identification-related permits, and slow payments by BMC. High transaction costs such as distance to the market, market information, and speed of payment affects cattle marketing decisions (including choice of market outlets) of cattle farmers in Botswana.

Regional dummy variables: these are included in the inefficiency model to capture environmental constraints (due to differences in soils and grass types) on production efficiency that may exist within the six agro-ecological regions in Botswana.

Tenure dummy variable: this variable was included in both the production frontier and the inefficiency effects models of the commercial production system to capture the production and efficiency differences between the farms under freehold land tenure systems and those under TGLP ranches. It has been established that although TGLP ranches are classified as commercial farmers, they are actually practicing traditional production methods. TGLP ranches practice dual grazing, that is, they graze their livestock within their ranches until there is very little forage left before cattle are moved to communal land (Malope and Batisani, 2008). The TGLP ranches are also characterised by absentee management, poor cooperation among group ranchers, and poor infrastructure development (Barnes et al., 2008; Mahabile et al., 2002). Due to data limitations (i.e. our small sample size) we could not separate commercial production into two groups, thus instead we use this *tenure* dummy variable to distinguish between them.

3.3.3. Empirical Model

Descriptive statistics for variables included in the stochastic production frontier and inefficiency effects model are presented in Table 1. On average, traditional farms produce more beef than commercial beef farms. In both production systems the variability of beef production (measured by standard deviation) is high, thus reflecting the fluctuation of output over the study period. In terms of input use, on average commercial farms seem to be spending more money purchasing other inputs than traditional farms. As expected, the average herd size for traditional beef farms is small (19.8 LU per farm) when compared to that of commercial farms (305 LU/farm). Similarly, commercial farms have high off-take rates, low death rates, sell more to the export market (BMC), and use more cross and exotic breeds. On the other hand, traditional farms use more local breeds and cross breeds, and death and birth rates are significantly higher than is the case for their commercial counterparts.

Table 1
Descriptive statistics for beef production systems in Botswana, 2004 to 2013.

Variables	Traditional production		Commercial production	
	Average values	SD	Average values	SD
Beef output (000's BWP)	5614.61	4110.34	3455.76	6526.18
Labour (000's BWP)	3986.29	2805.95	74.54	90.48
No. of cows (000's LU)	50.86	35.26	11.38	14.68
Other costs (BWP)	19.24	13.74	2324.83	7729.41
Herd size (LU/farm)	19.84	11.18	305.31	480.34
Offtake rate rates (%)	7.55	3.38	13.09	14.57
Birth rates (%)	55.33	9.59	38.51	17.76
Death rates (%)	9.75	8.73	4.39	2.39
Export market access (%)	35.11	23.45	50.84	28.96
Local breed (%)	55.03	19.63	8.08	11.95
Exotic breed (%	4.44	7.07	34.83	23.18
Crossbreed (%)	40.53	19.73	57.08	25.91
Land tenure dummy			0.4	0.49
No. of observations	234		135	

Notes: these are the average values for the whole study period, 2004 to 2013. SD is the standard deviations.

Appendix 2 presents tests of various null hypotheses, given the specifications of the stochastic frontier with inefficiency effects model (Battese and Coelli, 1995). There are two standard functional forms used in the productivity literature; Cobb-Douglas and translog functions. Using a likelihood-ratio test we tested the null hypothesis that a Cobb-Douglas frontier is an adequate representation of the data, against the null hypothesis that the translog function is more appropriate. The Cobb-Douglas frontier is rejected as an adequate representation, and the hypothesis of no technical change was rejected given the specifications of the translog frontier. The null hypotheses that the inefficiency effects in the model are not random and that explanatory variables in the model for technical inefficiency effects have zero coefficients, are strongly rejected by the data.

One of the objectives of this study is to test whether the traditional and commercial sectors share the same beef production technologies, and this can be tested with a generalised likelihood test comparing the pooled model and group frontiers. As shown in the last row of Appendix 1, the null hypothesis was rejected and thus the use of pooled model is not appropriate in this case. Thus, we should use group frontiers. We specify our empirical model as follows:

$$\ln y_{it(k)} = \alpha_{0(k)} + \sum_{j=1}^{3} \beta_{j(k)} \ln X_{ij(k)} + t + \frac{1}{2}\sum_{j=1}^{3}\sum_{s=1}^{3} \beta_{js(k)} \ln X_{ij(k)} \ln X_{is(k)} + \frac{1}{2}t^2 + D_{ij(k)} + V_{i(k)} - U_{i(k)} \quad (10)$$

Where, j represents the j-th of i-th firm ($i = 1, 2\ldots N_k$) in the k-th group ($k = 1$ and 2); $\beta_{ij}(k) = \beta_{ji}(k)$ for all j and k; Y_i represents the value of beef in Botswana Pula (BWP); X_{i1} is the herd size (number of cattle) in livestock units[2]; X_{i2} represents total cost of labour (including family labour); X_{i3} is other livestock costs expressed in BWP; t and t^2 represent a smooth and time varying trend that is included to capture technological change (TC); which often causes economic relationships to change over time (Coelli et al., 2005). D_1 to D_5 are dummy variables for five regions in Botswana (Gaborone, Central, Francistown, Maun and Western) with the Southern region as the base against which these are compared. We also included a dummy variable in the commercial sector model specification in order to identify production on farms under TGLP ranches from that on freehold farms. All variables except dummy and time variables are mean-corrected, which implies that the first-order estimates of the model represent the corresponding elasticities.

Following the technical inefficiency effects model (Battese and Coelli, 1995), μ is defined for the kth group as:

$$\mu_{ij(k)} = \delta_0 + \sum_{j=1}^{8} \delta_j Z_{ji} + \sum_{s=1}^{7} \delta_s D_{si} \tag{11}$$

Where δ_{js} ($j = 0,1,\ldots, 8$) and $s = (0,1,\ldots,6)$ are unknown parameters; Z_1 is herd size (livestock units per household), Z_2 is off-take rates (per centage), Z_3 is birth rates (per centage), Z_4 is deathrates (per centage), Z_5 is the per centage of farmers selling to the BMC abattoirs, Z_6 is the per centage of exotic breeds in a given district and Z_7 is the per centage of cross breeds used in a given district. D_1 to D_5 represent regional dummy variables for Gaborone, Central, Francistown, Maun and Western regions respectively. D_6 represents a dummy variable for land tenure.

4. Results and discussion

4.1. Stochastic production frontier estimates

The maximum likelihood estimates for the parameters in the stochastic frontier are presented in Table 2. The signs of the first order coefficients of the commercial and traditional beef production frontiers and the metafrontier production function are as expected; exhibiting positive and significant parameters (with the exception of the insignificant cost variable for traditional beef production) thus satisfying the monotonicity and concavity properties of a well behaved production function.

The elasticity of output with respect to livestock units (LU) is large (and highly statistically significant) for both production systems, which implies that a 1% change in the number of cows has a larger influence on beef production than the same relative change of any other input. This is especially the case in traditional beef production, where a 1 % increase in LU increases beef production by 0.83% per annum, ceteris paribus. The second important factor of production in the traditional beef production system is labour, contributing 0.26. In the case of commercial production system the coefficient of labour is significant and contributes 0.40 to beef production - which is similar in magnitude as the estimate for LU (0.46), followed by other costs at 0.15. The sum of the elasticity parameters gives an indication of returns to scale. A null hypothesis test of constant returns to scale (CRTS) could not be rejected in both traditional and commercial production systems.

All the coefficients of the regional dummies in the commercial beef production system are negative and significantly different from zero, implying that production technologies in these regions fall behind that of the base region (Southern region). The relative efficiency of beef production in the Southern region is probably associated with the better access to nutritious vegetation and close proximity to Lobatse (which is

Table 2
Commercial and traditional beef production estimates in Botswana, 2004 to 2012.

	Commercial beef production		Traditional beef production		Metafrontier	
Beef output	Coefficient	SE	Coefficient	SE	Coefficient	SE
Labour	0.403**	0.188	0.263***	0.090	0.201***	0.005
Livestock units (LU)	0.456***	0.123	0.825***	0.089	0.900***	−0.002
Costs	0.151**	0.071	−0.017	0.048	−0.006***	−0.002
Time	−0.044	0.030	0.006	0.012	0.046***	−0.001
$Labour^2$	−0.054	0.359	0.183	0.152	−0.120***	−0.002
LU^2	0.164	0.248	0.162	0.196	0.262***	0.002
$Costs^2$	0.174***	0.045	0.026	0.033	0.168***	−0.001
Labour × LU	0.332	0.479	−0.475	0.349	0.036***	−0.001
Labour × Costs	−0.146	0.197	−0.012	0.123	−0.002***	0.006
LU × Costs	−0.364***	0.119	−0.077	0.136	−0.444	−0.002
Labour × Time	−0.048	0.034	−0.041***	0.013	−0.036***	0.000
LU × Time	0.035**	0.018	0.012	0.012	−0.014***	−0.001
Costs × Time	−0.003	0.011	0.011	0.007	0.021***	0.002
$Time^2$	0.003	0.003	−0.001	0.001	−0.012***	0.000
Gaborone	−0.317***	0.111	0.050*	0.027	−0.065***	0.000
Central	−0.287***	0.087	0.048*	0.030	−0.070***	0.003
Francistown	−0.347***	0.074	0.015	0.036	−0.105***	−0.002
Maun	−0.292**	0.125	−0.016	0.041	−0.134***	0.000
Western	−0.229**	0.094	0.061*	0.033	−0.053***	0.000
Tenure	0.340***	0.068	–	–	0.278***	0.003
Constant	0.394***	0.125	0.107***	0.038	0.192***	0.021
Log-likelihood	38.82		238.91			
Returns to scale	1.01		1.07		1.096	

Note:
* Implies statistically significant at 10% level.
** Imply statistically significant at 5% level.
*** Imply statistically significant at 1% level.

the main marketing centre for the export market) and Gaborone (the capital and largest city in Botswana) (Temoso et al., 2015b) that this region enjoys. In the case of traditional beef production, only three regions (Gaborone, Central and Western) have estimated coefficients that are statistically significantly different from zero and the magnitudes of those coefficients are small but positive suggesting that beef cattle production technology in these regions has been shifting outwards compared to the Southern region, albeit only marginally. As expected the land tenure variable contributes positively to beef production, thus implying that beef farms under freehold land produce more output than those from TGLP ranches. This is probably due to the fact that the farmers under freehold land tenure own individual tenure rights and therefore are more likely to undertake long-term investment in land and infrastructure, which then contribute positively to production. The private tenure system also increases their access to formal credit.

4.2. Factors affecting performance of commercial and traditional beef cattle production

The technical inefficiency effects model presented in Table 3 is jointly estimated with the production frontier in the previous section. A negative coefficient indicates that the variable has a negative effect on technical inefficiency (i.e. it has led to an increase in TE). Under commercial beef production, herd size is significant and is associated with higher productive efficiency. The positive relationship between herd size and production efficiencies may be related to the benefits from economies of size and it is consistent with results from other studies (e.g. Bahta and Malope, 2014; Iraizoz et al., 2005; Samarajeewa et al., 2012). This result suggests a possible strategy of increasing farm size (in this case measured in terms of herd size) to improve performance in the beef sector. However, herd size has a positive sign under the traditional production system which reflects diseconomies of size. This result agrees with results found by other studies (Mahabile et al., 2002; Migot-Adholla et al., 1991) and which argue that open access to grazing land encourages high stocking rates which in turn lead to low herd productivity and low calving and high mortality rates; and which

[2] Statistics Botswana reports the herd composition by age and gender, therefore to capture the differences in the herd composition we converted using the livestock unit coefficients: 0.2, 0.6, 0.75, 08 and 1 for calves, heifers, cows, steers and bulls respectively (see, Otieno et al., 2014 and Temoso et al., 2015a, 2015b).

Table 3
Factors affecting performance of beef production for commercial and traditional farms, 2004 to 2012.

Commercial beef production			Traditional beef production		
Beef output	Coefficient	Standard error	Beef output	Coefficient	Standard error
Tenure	2.062*	1.249	Tenure	–	–
Herd size	−0.001	0.001	Herd size	0.002	0.022
Offtake rate	−0.153***	0.048	Offtake rate	−0.853***	0.110
Birth rate	0.009	0.011	Birth rate	−0.004	0.017
Death rate	−0.190	0.129	Death rate	−0.001	0.031
Market	−0.021*	0.012	Market	−0.009	0.016
Exotic breed	−0.100**	0.035	Local breed	0.034	0.029
Cross breeds	−0.085***	0.024	Crossbreed	0.028	0.028
Gaborone	−6.613	11.345	Gaborone	0.167	0.751
Central	−0.446	0.690	Central	1.666**	0.817
Francistown	−1.800	1.398	Francistown	0.690	0.803
Maun	−1.331	1.512	Maun	−0.378	0.740
Western	−0.596	0.836	Western	2.887***	1.068
Time	−0.034	0.104	time	−0.091	0.083
Constant	9.435***	2.989	Constant	180.606	166.200

Note:
* Implies statistically significant at 10% level.
** Imply statistically significant at 5% level.
*** Imply statistically significant at 1% level.

consequently discourage investment in improvements such as water sources and better breeds. However, it has been argued by Wang et al. (2013, p. 438) that, "*the relationship between herd size and efficiency may vary depending on whether the average herd size in the sample exceeds the optimal herd size*".

Among the biological efficiency coefficients, off-take rates are positive and significant at the 1% level in both production systems. Commercial off-take rates are consistently higher than those in the traditional sector, reflecting a greater market orientation (CAR, 2005). However, in some instances, for example, during drought seasons, small herd owners tend to sell their animals at a rate equal to, or in excess of, the offtake rates of large commercially managed herds as a drought risk management strategy (Behnke, 1987). Although insignificant, the birth rates coefficient has positive effects on TE for traditional farms and has a, surprisingly, negative (although statistically insignificant) effect for commercial farms. This latter result is counter to our prior expectation that birth rates would have a positive effect on efficiency under commercial production since those farms are highly equipped to adopt the latest technologies and because animals are likely to be better fed and managed than those under traditional management (de Ridder and Wagenaar, 1984; Mahabile et al., 2005).

Our results show that the use of exotic and cross breeds has a positive relationship with efficiency under commercial beef production. Use of cross breeds is popular among commercial farmers in Botswana because of their potential to improve productivity and their suitability to the adverse production environment compared to indigenous breeds. The market coefficient also leads to improvement in efficiency under the commercial beef production system. This implies that selling to the export market has benefits to commercial farmers. However, in the case of traditional beef farms the impact of the export market is insignificant. This is probably due to the fact that in recent times traditional farmers are opting to sell to the local market rather than the BMC; this reflects dissatisfaction by farmers with prices offered by the BMC (Jefferis, 2005). Inaccessibility to markets and high costs of transport to the BMC collection points is also one of the biggest challenges that traditional beef producers face in more remote areas (Bahta and Malope, 2014).

The regional dummies were included to investigate whether TE may be related to the geographical location. Geographical location may account for factors such as differences in soils, vegetation, weather and climate, and infrastructure that are not included in the production function but that may affect the level of output (Samarajeewa et al., 2012). We found that under the traditional beef production system, farms located in Central and Western regions are the only significant regional dummies, implying that the performance of beef farms located in these regions lags behind those in the Southern region in terms of efficiency performance.

4.3. Technical efficiency and technological gap analysis

Table 4 presents summary statistics for TE, MTR and MFs. The mean TE for commercial farms is higher than the mean TEs for traditional farms. In order to compare total factor productivity (TFP) across farming systems with different technologies, the MTRs need to be taken into account. A higher (lower) MTR implies a smaller (larger) technology gap between the group production frontier and the metafrontier (MF). The estimated MTRs for the commercial and traditional beef farms are 0.92 and 0.89, respectively, illustrating the technological gaps between the two beef production systems. The MTRs for commercial farms are higher than the traditional production system thus defining the potential technology available for the beef industry in Botswana. This was expected given that the commercial farms are better equipped to adapt to new and advanced technologies and hence improve their production. Our results suggest that on average, commercial farmers have more effectively implemented livestock management practices to mitigate the productivity-reducing effects of an unfavourable production environment than have traditional farmer.

From Table 4, it does appear that commercial farms are more efficient within and as compared to traditional farms. The mean TE*, which can also be interpreted as total factor productivity (TFP), is 0.74 for commercial farms, this is higher than the traditional farms (0.71) reflecting their higher production capacity due to the ability to increase their productivity through better farm management and better access to the latest industry developments such as advanced breed genetics, fodder and disease response mechanisms. The implication of this result is that policies targeting optimal resource utilisation could improve beef production of commercial farms by up to 26% and traditional farms by as much as 30% compared to total potential output given existing technologies and inputs.

Figs. 1 and 2 show the annual growth rates of TE with respect to group (farming system) and to the metafrontier (whole beef industry). What is evident from both figures is that TFP (TE*) has been gradually increasing in both systems, especially for the commercial farms, where it grew by 116% for the period 2004 to 2013. According to our results, the main contributor to TFP in both systems was TE, whilst production technology slightly contributed to the growth in commercial production. These results agree with the analysis of Temoso et al. (2015b) which found that technological change in the traditional sector had declined for the period 2004 to 2012. In their study the Western region was the only region that experienced positive production technology growth, and this growth was attributed to the fact that the communal grazing areas in the Western region share many of the advantages of commercial ranches.

Table 4
Summary statistics of technical efficiency and technological gap estimates.

Name	Mean	Standard deviation	Minimum	Maximum
TE (Commercial)	0.806	0.160	0.251	0.999
TE (Traditional)	0.790	0.124	0.390	0.998
MTR (Commercial)	0.915	0.064	0.718	1.000
MTR (Traditional)	0.893	0.126	0.509	1.000
TE* (Commercial)	0.740	0.163	0.222	0.970
TE* (Traditional)	0.706	0.150	0.305	0.995

Note: MTR refers to metatechnology ratios, whilst TE is the technical efficiency with respect to group frontier and TE* is technical efficiency with respect to the metafrontier.

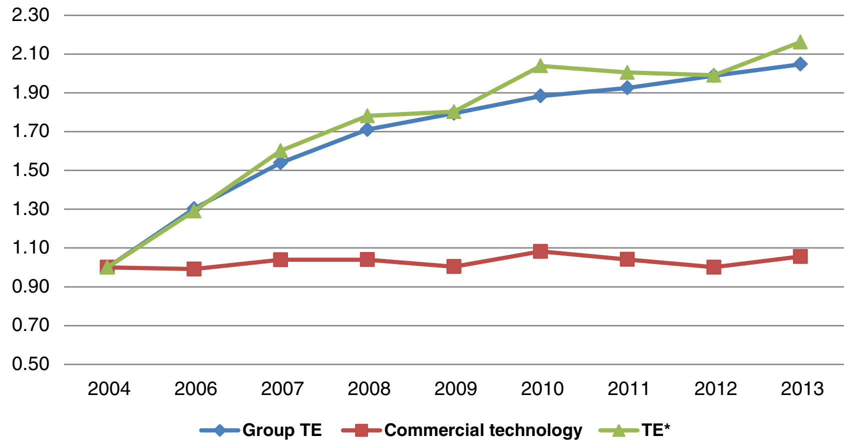


Fig. 1. Annual growth rates of commercial beef production technology and TE, 2004 to 2013.

5. Conclusions

In this paper we have estimated productivity and technological differences between the commercial and traditional beef production systems in Botswana. Given that the two production systems use different sets of technologies (different in terms of human capital, economic infrastructure, resource endowments and socio-economic environment) two separate production frontiers were estimated. The results show that, as expected, both productive performance and production technologies are consistently lower in traditional farming than on commercial farms. Upon the computation of the metafrontier, commercial beef production technology is found to be more advanced than the traditional and it defines the potential production technology available for the beef industry in Botswana. On average productivity and production technologies have been gradually increasing in both systems, especially for the commercial farms, where productivity grew by 106% between 2004 and 2013, driven mainly by improvements in TE.

Using regional dummy variables we found that the farms located in the Southern region; regardless of whether they are commercial or traditional farms tend to perform better than those from other regions. This is probably associated with their better access to nutritious vegetation and close proximity to Lobatse (which is the main marketing centre for the beef export market). We found that beef farms under freehold land tenure are generally more efficient than those under TGLP land tenure. The majority of farmers under freehold land tenure own individual tenure rights and are therefore more likely to make long-term investments in land and infrastructure which then contribute positively to production. The private tenure system also increases their probability of access to formal credit.

The results indicate that the use of improved breeds, high off-take rates and selling to the BMC (the only exporting abattoirs in Botswana) improves TE. However, these impacts were not consistent across production systems. Under the commercial beef production system the main factors that are found to have a positive influence on TE include: use of controlled cattle breeding methods, access to the export market and herd size. Our results show that both farming systems have the potential to overcome technology constraints and achieve the highest attainable productivity level through improvements in; beef cattle technologies, farmer capacity in production and marketing, and the effectiveness of the technology transfer process. The average farm's beef production could be increased by up to 30% and 26% for traditional and commercial farming system respectively, if all the inefficiency in production were eliminated. As a result, policies that aim to encourage more efficient beef production under traditional farming should focus on lifting individual TE performance, which could be achieved by promoting the use of extension services. Farmers should be encouraged to utilise existing agricultural support programs such as LIMID (Livestock Management and Infrastructure Development) which aims to improve livestock management and range resource utilisation. The slow adoption rates of existing subsidised programs and technologies that the government and donor agencies have implemented in the past may also be one of the limiting factors in improving livestock production in Botswana, therefore monitoring and evaluation of extension services and agricultural support programs should be done regularly to manage and assess their efficiency and effectiveness.

More empirical research needs to be done to investigate productivity and the technological differences between the two beef production systems using farm level data from the same agro-ecological region. Also,

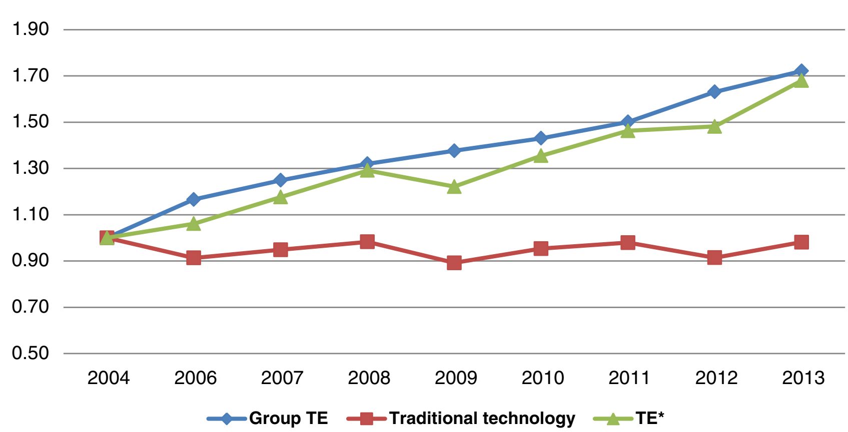
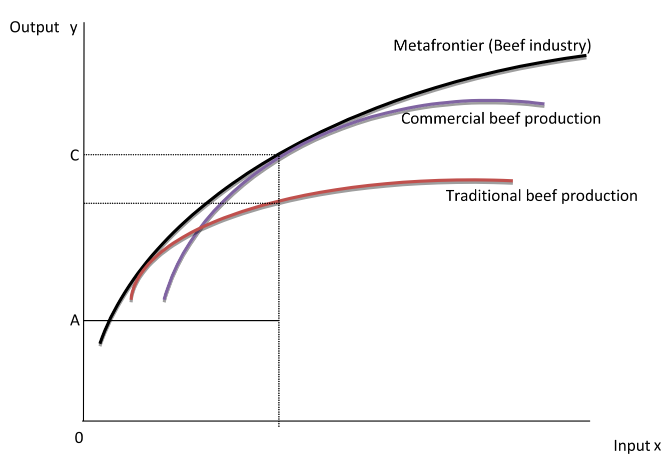


Fig. 2. Annual growth rates of traditional beef production technology and TE, 2004 to 2013.

with more data within the commercial production system, there is potential to separate farmers according to land tenure system (i.e., TGLP ranches versus freehold ranches) thus allowing investigation of the relationship between farm size, land tenure and productivity on which the empirical evidence remains mixed. Results from such investigations may then lead to the better design and implementation of policy aimed at improving the productivity and competitiveness of beef farming in Botswana.

Finally, we should reiterate here that this paper is narrowly focused upon the economic aspects of production systems. Since we did not have the necessary data we have not included the effects of stocking rates, forage allowance, production intake and forage utilisation efficiency. According to Henderson et al. (2016), improving productivity may bring some environmental benefits such as reductions in emissions of greenhouse gases and/or natural resource use. It has been argued by other researchers (Hansen, 1996; Tisdell, 1988) that some agricultural systems may be highly productive but not necessarily sustainable. Improving the sustainability of beef production in Botswana will require further work which combines the modelling of the economic production system with agronomic and ecological models of grazing systems. Since the majority of livestock production in Botswana takes place on rangeland, there is need for stakeholders (including researchers and policymakers) to adopt an inclusive approach that takes in into account these aspects of beef production systems. Studies such as Cortez-Arriola et al. (2014) and Henderson et al. (2016) discuss the extent of productivity gaps in animal science and also demonstrate how the economic and environmental performance of the livestock production systems could be measured.

Appendix 1. Technical efficiency (TE) and metatechnology ratios (MTR) of beef production systems in Botswana



Appendix 2. Hypotheses tests

	Test statistic	Critical value	Decision
Model 1 (Traditional)			
CD vs.TL	19.70	15.51(8)	Reject H0 at 5%
No technical change	16.43	5.99(2)	Reject H0 at 5%
Time varying vs time invariant model	11.74	7.81(3)	Reject H0 at 5%
Technical inefficiency	214.53	22.36(13)	Reject H0 at 1%
Constant returns to scale	1.07	3,84(1)	Accept H0 at 1%
Model 2 (Commercial)			
CD vs.TL	43.94	16.92(9)	Accept H0 at 1%
No technical change	248.08	5.99(2)	Reject H0 at 5%
Time varying vs time invariant model	19.28	7.81(3)	reject H0 at 5%
Technical inefficiency = 0	61.51	16.92(9)	Reject H0 at 1%
Constant returns to scale	1.01	3,84(1)	Accept H0 at 1%
Pooled vs. group frontiers	148.30	76.15(50)	Reject H0 at 1%

References

Abdulai, A., Tietje, H., 2007. Estimating technical efficiency under unobserved heterogeneity with stochastic frontier models: application to northern German dairy farms. Eur. Rev. Agric. Econ. 34 (3), 393–416.

Aigner, D., Lovell, C.A., Schmidt, P., 1977. Formulation and estimation of stochastic frontier production function models. J. Econ. 6 (1), 21–37.

Alexandre, G., Mandonnet, N., 2005. Goat meat production in harsh environments. Small Rumin. Res. 60 (1), 53–66.

Bahta, S., Malope, P., 2014. Measurement of competitiveness in smallholder livestock systems and emerging policy advocacy: an application to Botswana. Food Policy 49, 408–417.

Barnes, J.I., Cannon, J., Macgregor, J., 2008. Livestock production economics on communal land in Botswana: effects of tenure, scale and subsidies. Dev. South. Afr. 25 (3), 327–345.

Battese, G.E., Coelli, T.J., 1995. A model for technical inefficiency effects in a stochastic frontier production function for panel data. Empir. Econ. 325–332.

Battese, G., Rao, D.P., O'Donnell, C.J., 2004. A metafrontier production function for estimation of technical efficiencies and technology gaps for firms operating under different technologies. J. Prod. Anal. 21 (1), 91–103.

Behnke, R.H., 1985. Measuring the benefits of subsistence versus commercial livestock production in Africa. Agric. Syst. 16 (2), 109–135.

Behnke, R.H., 1987. Cattle accumulation and the commercialization of the traditional livestock industry in Botswana. Agric. Syst. 24 (1), 1–29.

Burgess, J., 2006. Country Pasture/Forage Resource Profiles: Botswana. Food and Agriculture Organisation of the United Nations, Rome, Italy.

Centre for Applied Research (CAR), 2005. Crop livestock systems development in southern Africa: priorities for future research. Botswana Livestock Crop Report. Centre for Applied Research, Gaborone, Botswana.

Coelli, T., Rao, D.P., O'Donnell, C., Battese, G., 2005. An Introduction to Efficiency and Productivity Analysis. Springer, New York.

Cortez-Arriola, J., Groot, J.C., Massiotti, R.D.A., Scholberg, J.M., Aguayo, D.V.M., Tittonell, P., Rossing, W.A., 2014. Resource use efficiency and farm productivity gaps of smallholder dairy farming in North-west Michoacán, Mexico. Agric. Syst. 126, 15–24.

Cullis, A., Watson, C., 2005. Winners and losers: privatising the commons in Botswana. Securing the Commons No.9. International Institute for Environment and Development, Herdfordshire, UK.

de Ridder, N., Wagenaar, K., 1984. A comparison between the productivity of traditional livestock systems and ranching in eastern Botswana. ILCA Newsletter Vol. 3 (3). International Livestock Centre for Africa, Addis Abbaba, Ethiopia, pp. 5–7.

de Ridder, N., Wagenaar, K., 1986. Energy and protein balances in traditional livestock systems and ranching in eastern Botswana. Agric. Syst. 20 (1), 1–16.

Hansen, J., 1996. Is agricultural sustainability a useful concept? Agric. Syst. 50 (2), 117–143.

Henderson, B., Godde, C., Medina-Hidalgo, D., van Wijk, M., Silvestri, S., Douxchamps, S., ... Cacho, O., 2016. Closing system-wide yield gaps to increase food production and mitigate GHGs among mixed crop–livestock smallholders in sub-Saharan Africa. Agric. Syst. 143, 106–113.

Iraizoz, B., Bardaji, I., Rapun, M., 2005. The Spanish beef sector in the 1990s: impact of the BSE crisis on efficiency and profitability. Appl. Econ. 37 (4), 473–484.

Irz, X., Thirtle, C., 2004. Dual technological development in Botswana agriculture: a stochastic input distance function approach. J. Agric. Econ. 55 (3), 455–478. http://dx.doi.org/10.1111/j.1477-9552.2004.tb00110.x.

Jahnke, H.E., 1982. Livestock Production Systems and Livestock Development in Tropical Africa (Vol. 35). Kieler Wissenschaftsverlag Vauk, Kiel, Germany.

Jefferis, K., 2005. How trade liberalization can contribute to resolving the crisis in the beef and cattle sector. Paper Presented at the Trade Facilitation and Capacity Building Project of the Southern Africa Global Competitiveness Hub, Gaborone, Botswana.

Mahabile, M., Lyne, M., Panin, A., 2002. Factors affecting the productivity of communal and private livestock farmers in Southern Botswana: a descriptive analysis of sample survey results. Agrekon 41 (4), 326–338.

Mahabile, M., Lyne, M.C., Panin, A., 2005. An empirical analysis of factors affecting the productivity of livestock in southern Botswana. Agrekon 44 (1), 99–117.

Malope, P., Batisani, N., 2008. Land reforms that exclude the poor: the case of Botswana. Dev. South. Afr. 25 (4), 383–397.

Maxwell, D., Wiebe, K., 1999. Land tenure and food security: exploring dynamic linkages. Dev. Chang. 30 (4), 825–849.

Meeusen, W., van den Broeck, J., 1977. Efficiency estimation from Cobb-Douglas production functions with composed error. Int. Econ. Rev. 435–444.

Migot-Adholla, S., Hazell, P., Blarel, B., Place, F., 1991. Indigenous land rights systems in sub-Saharan Africa: a constraint on productivity? World Bank Econ. Rev. 5 (1), 155–175.

Ministry of Agriculture, Botswana (MoA), 1991. National Policy on Agricultural Development. Department of Printing & Publishing, Gaborone, Botswana.

Nyangayezi, M., 1999. Farm Management Survey Results 1988 Survey: 1978–1988 Survey Comparisons. Ministry of Agriculture, Gaborone, Botswana.

O'Donnell, C.J., Rao, D.P., Battese, G.E., 2008. Metafrontier frameworks for the study of firm-level efficiencies and technology ratios. Empir. Econ. 34 (2), 231–255.

Otieno, D.J., Hubbard, L., Ruto, E., 2014. Assessment of technical efficiency and its determinants in beef cattle production in Kenya. J. Dev. Agric. Econ. 6 (6), 267–278.

Otte, M., Chilonda, P., 2002. Cattle and Small Ruminant Production Systems in sub-Saharan Africa. A Systematic Review. Food and Agriculture Organisation of the United Nations (FAO), Rome, Italy.

Place, F., 2009. Land tenure and agricultural productivity in Africa: a comparative analysis of the economics literature and recent policy strategies and reforms. World Dev. 37 (8), 1326–1336.

Rennie, T., Light, D., Rutherford, A., Miller, M., Fisher, I., Pratchett, D., Trail, J., 1977. Beef cattle productivity under traditional and improved management in Botswana. Trop. Anim. Health Prod. 9 (1), 1–6.
Samarajeewa, S., Hailu, G., Jeffrey, S., Bredahl, M., 2012. Analysis of production efficiency of beef cow/calf farms in Alberta. Appl. Econ. 44 (3), 313–322.
Statistics Botswana. (various years). 2006, 2007, 2008, 2009, 2010, 2012 and 2013 Annual Agricultural Survey Report. Gaborone, Botswana: Statistics Botswana.
Statistics Botswana, 2008. Revised 2004 Botswana Agricultural Census Report. Statistics Botswana, Gaborone, Botswana.
Temoso, O., Villano, R., Hadley, D., 2015a. Agricultural productivity, efficiency and growth in a semi-arid country: a case study of Botswana. Afr. J. Agric. Resour. Econ. 10 (3), 192–206.
Temoso, O., Hadley, D., Villano, R., 2015b. Perfomance measurement of extensive beef cattle farms in Botswana. Agrekon 54 (4), 87–112.
Thirtle, C., Piesse, J., Lusigi, A., Suhariyanto, K., 2003. Multi-factor agricultural productivity, efficiency and convergence in Botswana, 1981–1996. J. Dev. Econ. 71 (2), 605–624. http://dx.doi.org/10.1016/S0304-3878(03)00027-0.
Tisdell, C., 1988. Sustainable development: differing perspectives of ecologists and economists, and relevance to LDCs. World Dev. 16 (3), 373–384.
van Engelen, A., Malope, P., Keyser, J., Neven, D., 2013. Botswana Agrifood Value Chain Project Beef Value Chain Study. Food and Agriculture Organisation of the United Nations (FAO), Rome, Italy Retrieved from http://www.fao.org/3/a-i3158e.pdf.
Wang, T., Park, C.P., Bevers, S., Teague, R., Cho, J., 2013. Factors affecting cow-calf herd performance and greenhouse gas emissions. J. Agric. Resour. Econ. 38 (3), 435–456.