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Total factor productivity growth in livestock production in Botswana: what is the role of scale and mix efficiency change in beef production?

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ABSTRACT

It is well established that improving livestock productivity has the potential to boost food security, income, and employment for rural communities. While the technical efficiency of the livestock sector has been extensively studied in both developing and developed countries, few studies have analysed total factor productivity (TFP) and its components (technical change, technical, scale, and mix efficiency changes). To fill this gap this study specifically analyses the TFP growth of 26 beef cattle producing districts in Botswana using the Färe-Primont index. This index does not only allow us to understand how TFP varies amongst the districts but also how it has changed over time (between 2007 and 2014) as well as examining what has been driving that change. We also employ a feasible generalised least squares estimator for panel data to identify sources of productivity and efficiency growth. Results show that livestock TFP increased during the study period, and that this was driven by technological change, whilst efficiency change (TFPE) decreased. Further, we found that the decline in scale-and mix efficiency change (OSME) was largely responsible for the slowdown of TFPE, with a relatively smaller decline in technical efficiency change (OTE) also contributing. Districts with foot and mouth disease (FMD) outbreaks and restricted access to export markets had lower TFP growth whilst proximity to livestock advisory centres (LAC), off-farm income, education and herd size were shown to enhance productivity and efficiency growth.

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1. Introduction

In many developing countries the livestock sector provides a variety of benefits to rural communities, such as food, income, and employment for farmers and others involved in the value chain (FAO 2016; Tarawali 2019). Despite recurring droughts and endemic animal diseases such as Foot-and-Mouth Disease (FMD), the sector in Botswana remains one of the most viable options for poverty reduction and job creation due to its labour-intensive nature (Statistics Botswana 2020). As a result, farmers and policymakers have long been interested in identifying ways in which livestock production, and productivity, could be increased (Steinfeld 2003; Temoso, Hadley, and Villano 2018). Herrero et al. (2014) points out that whilst yields of milk and meat are currently low in Sub-Saharan Africa, there are considerable opportunities available to enhance productivity through rapid technological change and

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efficiency improvements. Improving the efficiency and productivity of livestock production systems in developing countries is critical to increasing output and addressing food insecurity (Tarawali 2019).

Given the importance of this topic, many studies have been undertaken in both developed and developing countries to assess the productivity of livestock production systems (Minviel and Veysset 2021; Temoso, Hadley, and Villano 2015a; Temoso, Villano, and Hadley 2016; Otieno, Hubbard, and Ruto 2014; Gaspar et al. 2009; Bahta and Malope 2014; d'Alexis, Sauvant, and Boval 2014; Dakpo et al. 2018a). This includes empirical studies estimating partial measures of productivity such as output per animal and livestock feed conversion efficiencies (Mayberry et al. 2017; Mahabile, Lyne, and Panin 2005). While those studies are informative, they may also provide a partial picture of the performance of the sector as they often overestimate and/or underestimate productivity growth (Abed and Acosta 2018; Temoso, Villano, and Hadley 2016; Nin, Ehui, and Benin 2007). This is because partial indicators assume that the agricultural systems being assessed operate on equivalent scales of production and there are no interactions between production factors (Minviel and Veysset 2021).

To address the limitations of partial productivity indicators, many studies in the literature have estimated the technical efficiency of livestock production and its determinants. Examples include Otieno, Hubbard, and Ruto (2014), who compared the technical efficiency of Kenyan ranches, pastoralists, and nomadic beef farms, and Temoso, Villano, and Hadley (2016), who compared the technical efficiency changes of commercial and traditional agricultural districts in Botswana. Additionally, Trestini (2006) estimated the technical efficiency of Italian beef farms while Bahta and Malope (2014) compared the technical efficiency of beef cattle farms in Botswana, amongst others. However, none of these studies explicitly integrate estimates of total factor productivity (TFP) growth and measures of the mix (scope) and scale efficiency changes. As pointed out by West, Mugera, and Kingwell (2022), a farm/region that is technically efficient is not necessarily TFP efficient, hence, eliminating technical inefficiency may not necessarily translate into productivity improvements. These suggestions highlight the importance of estimating TFP and its finer components (i.e., technical change, scale, and mix efficiency changes), rather than just focusing on technical efficiency change. West, Mugera, and Kingwell (2022) also demonstrated that factors contributing to the variability in technical efficiency might not necessarily contribute to TFP efficiency changes for the same farms/regions. The implication of this is that the measures based strictly on technical efficiency and its determinants may not be appropriate for designing policies that enhance farm/regional productivity and competitiveness (West, Mugera, and Kingwell 2022).

Therefore, the first objective of this study is to assess the TFP growth of beef cattle-producing districts in Botswana over the 2007–14 period. By doing so, we contribute to the limited studies that measure livestock TFP and its sources (e.g., Dakpo et al. 2018a; Acosta and Luis 2019; Nin, Ehui, and Benin 2007; Rae et al. 2006). Botswana provides an interesting case study because of the sector's importance to the livelihoods and development of the country. While the agriculture sector contributes only about 2% to Botswana's Gross Domestic Product (Statistics Botswana 2022), the livestock sector, particularly the beef sector, remains an important export industry, as the only agricultural commodity exported to high-value markets in the European Union (Statistics Botswana 2020). Moreover, most of agricultural policies in Botswana have historically favoured the beef sector at the expense of other sectors, such as crop and small-stock livestock (Bahta and Malope 2014). Therefore, the results from this study will help in improving the understanding of how productivity and efficiency differ amongst the regions in Botswana, which is essential for informing policy designs that promote the competitiveness and viability of the sector (West, Mugera, and Kingwell 2022; Temoso, Villano, and Hadley 2015b).

To achieve our objectives, we adopted the Färe-Primont decomposition index, an approach developed by O'Donnell (2011). The index allows us to measure TFP, and it can also be decomposed into finer components of technical change (movements in the production frontier), technical efficiency change (movements towards or away from the frontier), scale efficiency change (movements around the frontier surface which captures economies of scale) and mix efficiency change (movements around the frontier which capture economies of scope) (O'Donnell 2011, 2018). In economic terms, technical change (progress) refers to the discovery of new technologies (i.e., new techniques, methods, and systems for transforming inputs into outputs) (O'Donnell 2018, 381). Here we employ an output-oriented measure of efficiency. Output-oriented measures of efficiency can be thought of as measures of how well firm managers have maximised outputs given predetermined inputs and environmental variables (i.e., determined in a previous period) (O'Donnell 2018, 216). Output-oriented technical efficiency (OTE) is defined as how well production technologies are selected and applied (i.e., how well a manager "picks books/recipes from the library" and "follows the instructions") (O'Donnell 2018, 382). The output-oriented scale efficiency (OSE) is a measure of how well a manager has captured economies of scale, which are the benefits gained by changing the scale of operations. Output oriented mix efficiency (OME) is a measure of how well the manager has captured economies of output substitution, where economies of output substitution are the benefits derived from substituting one output for another (e.g., producing less of output 1 to produce more of output 2).

The second objective of this study is to identify the main drivers of beef TFP growth in Botswana over the 8-year period. The calculation of the Färe-Primont index allows us to assess and compare TFP growth and its drivers both spatially (i.e., cross-sectional comparisons of the performance of agricultural districts within a given period) and temporally (i.e., comparisons of performance growth for a given district and/or against other districts over multiple periods). By doing so, our study will also provide insights into the role that scale and mix efficiency changes play in beef production in a developing country, an area that has previously been ignored in the literature. We are only aware of studies by Dakpo et al. (2018a) and Martinez-Cillero and Thorne (2019a), who used this approach to decompose TFP growth into finer components for beef farms in France and Ireland, respectively.

In addition, by disentangling TFP into its finer components, we can investigate whether districts that specialise in one system (beef cattle) are more productive (in terms of gains from economies of scale) than those with diverse (i.e., those that produce beef cattle and crops) production systems (in terms of gains from economies of scope). Current empirical evidence concerned with the role that economies of scale and scope play in agricultural productivity is mixed (De Roest, Ferrari, and Knickel 2018; d'Alexis, Sauvant, and Boval 2014). For example, De Roest, Ferrari, and Knickel (2018) argues that economies of scale can enhance productivity through the clustering of specialised farms in one region, which may lead to agglomeration benefits and related reductions in unit costs that enable those regions to have more comparative cost advantages for certain products than less specialised regions. On the other hand, some studies (e.g., d'd'Alexis, Sauvant, and Boval 2014) have demonstrated that diversification of production, such as mixing livestock with crops, can lead to better utilisation of (scarce) resources such as land, labour, and water. This study adds to that literature.

Finally, the third objective of this study is to identify the sources of TFP and efficiency growth in beef production in Botswana. We follow previous studies (e.g., Rahman and Salim 2013; Temoso and Myeki 2022) and employ an econometric approach, feasible generalised least squares (FGLS), to assess how different factors impact productivity and efficiency growth. FGLS was selected because it accounts for both the systematic effect of regional, and time-varying effects of explanatory variables (Rahman and Salim 2013). The results of such analysis can be very useful in improving the effectiveness of policy through more precise targeting.

The rest of the paper is organised as follows. Section 2 discusses the Färe-Primont index model as applied in this paper and explains the panel data econometric approaches used to identify the determinants of TFP growth and its components. Section 3 summarizes the panel data set used in the study, describes the variables, and presents descriptive statistics. The results are presented and discussed in Section 4, whilst the final section concludes.

2. Methodological framework

2.1 TFP growth and sources of the beef cattle production

In economics, there are many approaches used to measure productivity growth. These include index-based approaches such as Paasche, Laspeyres, Fisher, Malmquist and Tornqvist indices

(O'Donnell 2018). Amongst these, the most popular approach is the Malmquist TFP index which was proposed by Caves et al. (1982). Its popularity is due to fact that it can be computed without price data, unlike other approaches such as the Fisher and Tornqvist indices (O'Donnell 2018). Hence, most of the TFP studies focussing on African agriculture have adopted this approach (e.g., Conradie et al. 2019; Thirtle, Hadley, and Townsend 1995; Thirtle et al. 2003; Abed and Acosta 2018). However, as pointed out by O'Donnell (2011), the Malmquist index is not a complete index because it does not satisfy all the relevant properties of index numbers such as linear homogeneity, weak monotonicity, identity, proportionality, time reversal, and transitivity. For example, it is argued that the index fails the transitivity test because it cannot be used for multilateral and multiperiod comparisons. This implies that the use of this index may be unreliable for measuring TFP growth and its sources.

To avoid the theoretical drawbacks mentioned above, this study applies a Färe-Primont index to estimate TFP and efficiency change for the beef industry in Botswana across 26 agricultural districts. This index satisfies all the relevant axioms of index numbers, including the transitivity test and multiplicative completeness (O'Donnell 2011). The index is multilateral in the sense that it can be used to compare the TFP of multiple firms in each period and over time. It also satisfies the transitivity axiom, which allows a direct comparison of the productivity of two firms, which produces the same index value as an indirect comparison via a third firm (O'Donnell 2018). The significance of the transitivity axiom can be illustrated as follows: if firm R produced 5% more output than firm M and firm M produced 20% more output than firm A, then firm R's outputs will be 26% ($1.05 \times 1.2 = 1.26$) greater than firm A's. The multiplicative property of the index implies that it can be decomposed into measures of technical change and efficiency change. In addition, the estimated efficiency change can be further broken into measures of technical, scale, and mix efficiency changes (O'Donnell 2011).

2.2 Färe-Primont productivity change index and its decompositions

Following O'Donnell (2011), a Färe-Primont productivity change index for a production unit such as an agricultural district a between period t and $t+1$, can be expressed as:

$$TFP_a^{t+1} = \frac{D_0(X_0,\ y_a^{t+1},\ t_0)}{D_0(X_0,\ y_a^t,\ t_0)} \times \frac{D_I(\ x_a^t,\ y_0,\ t_0)}{D_I(x_a^{t+1},\ y_0,\ t_0)}, \tag{1}$$

where D_0 and D_I represent the Shephard output and input distance functions, whilst (x_0, y_0, t_0) is the vector of output and input quantities for the observation that is selected as a representative of the sample. As demonstrated by O'Donnell (2011), the transitivity property is verified by equation (1) since it is a fixed-weight index where (x_0, y_0, t_0) are the fixed vectors of inputs, outputs, and time, accordingly.

Furthermore, it can be demonstrated that from the right-hand side of equation (1), the first ratio is the input quantity index, whilst the subsequent ratio is the output quantity index. As a result, equation (1) represents the TFP index which is measured by taking the ratio of the output index over input index (O'Donnell 2011). Färe-Primont index aggregator functions are assumed to be non-negative and non-decreasing and the completeness property guarantees that the index can be decomposed into various measures of technological and efficiency changes.

Based on these assumptions and others such as transitivity that are discussed by O'Donnell (2011), estimates of efficiency can be defined as ratios of TFP as follows:

$$TFPE_t = \frac{TFP_t}{TFP_t^*} \leq 1 \tag{2}$$

where TFP_t^* is the maximum TFP possible for all the production units at period t. From equation (2), TFP change between period t and period $t+1$ can be expressed as:

$$TFP_{t,t+1} = \frac{TFP_{t+1}}{TFP_t} = \frac{TFP_{t+1}^*}{TFP_t^*} \times \frac{TFPE_{t+1}}{TFPE_t} \tag{3}$$

where TFP_{t+1}^*/TFP_t^* is the technological change of TFP change and the overall efficiency component or TFPE changes is represented by $TFPE_{t+1}/TFPE_t$. Furthermore, as shown in equation (4) below, TFPE change can be decomposed into Farrell output-oriented technical efficiency change (OTE_{t+1}/OTE_t) and into output-oriented scale mix efficiency (OSME) change ($OSME_{t+1}/OSME_t$). The OSME measures potential gains from economies of scale and scope:

$$TFP_{t,\,t+1} = \left(\frac{TFP^*_{t+1}}{TFP^*_t}\right) \times \left(\frac{OTE_{t+1}}{OTE_t}\right) \times \left(\frac{OSME_{t+1}}{OSME_t}\right) \tag{4}$$

Equally, equation (4) can be further broken down into finer components of efficiency as follows:

$$TFP_{t,\,t+1} = \left(\frac{TFP^*_{t+1}}{TFP^*_t}\right) \times \left(\frac{OTE_{t+1}}{OTE_t}\right) \times \left(\frac{OSE_{t+1}}{OSE_t}\right) \times \left(\frac{RME_{t+1}}{RME_t}\right) \tag{5}$$

where OSE_{t+1}/OSE_t is output-orientated scale efficiency change and RME_{t+1}/RME_t is residual mix efficiency change. According to O'Donnell (2011, 2012), RME represents the increase in productivity gained by a firm (that is, an agricultural district in our case) when it changes its output mix from a point of maximum productivity on an output and input mix restricted frontier to a point of maximum productivity on an unrestricted production frontier. A data envelopment analysis (DEA) method is adopted to estimate the Färe-Primont index through the *Productivity* R package (R Core Team 2021) developed by Dakpo, Desjeux, and Latruffe (2018b).

3. Determinants of TFP and efficiency changes in beef cattle production

One of the objectives of this study is to identify key determinants of productivity and efficiency change in beef cattle production in Botswana. Hence, following the estimation of TFP and efficiency changes, we applied a Feasible Generalised Least Squares (FGLS) panel data approach as per other studies on the determinants of TFP and its components (e.g., Rahman and Salim 2013; Temoso and Myeki 2022). As pointed out by Rahman and Salim (2013, 289) the advantage of this approach over other commonly used approaches, such as random and fixed effects models, is that it can accommodate both the systematic effects of the agricultural districts and time-varying effects of explanatory variables. The basic empirical model can be specified as:

$$Y_{kit} = \alpha + \beta X_{it} + u_i + \varepsilon_{kit} \tag{6}$$

where Y_k is the index of TFP change and/or its components ($k = 1, 2 \ldots .6$); X denotes the matrix of explanatory variables (i.e., drivers of TFP and its components), β represents vector parameters, and u_i represents unit specific random elements and which is independently and identically distributed (IID) as a normal distribution with mean zero and variance σ_u^2. It is assumed to be independent from ε_{kit} and X_{it}. The term ε_{kit} is the random and is assumed to be distributed as IID $N(0, \sigma_\varepsilon^2)$.

4. Data and the study area

This study utilised block-level data compiled from the Botswana annual agricultural surveys (2007–14) covering 26 agricultural districts and 6 agro-ecological regions. The surveys were collected through a stratified sampling framework. According to Statistics Botswana (2016), the total area of Botswana is divided into Primary Sampling Units (PSUs) of enumeration areas (blocks) for annual surveys. An agricultural block is a definable and demarcated land area marked on a map for identification and survey purposes. Botswana has 1202 blocks, and the number of sampled blocks ranged from 237 to 256 blocks over the eight years (Statistics Botswana 2016). Each block is made up of villages, cattle posts, and lands. The blocks can be combined to form 26 agricultural districts and 6 agro-ecological regions.

While most production input and output data were provided at the agricultural block level, some information, such as precipitation were missing for some blocks; thus, the block level data was aggregated to the agricultural district level to produce 208 observations of balanced panel data (26 agricultural districts over 8 years). This is also important because a TFP estimation in a DEA environment requires it to be balanced (Dakpo, Desjeux, and Latruffe 2018b). The beef cattle and crop outputs, stock size, other costs, labour costs, arable land area, and the number of Livestock Advisory Centres (LACs) were aggregated by adding the values for all blocks in a given district and year. Precipitation, household age, and mortality rates were calculated by taking averages for blocks in a given district and year. Crossbreeds, off-farm income, and household gender were calculated by adding all blocks in each district before calculating proportions and percentages.

Table 1 provides descriptive statistics for the data and variables used at the agricultural block level. The choice of both the factors of production and sources of TFP is motivated by previous studies in beef production (Bahta et al. 2015; Otieno, Hubbard, and Ruto 2014; Dakpo et al. 2018a; Martinez-Cillero and Thorne 2019a; Temoso, Villano, and Hadley 2016; Temoso, Hadley, and Villano 2015a). Beef cattle output is estimated by aggregating the value of cattle sold and home slaughtered from each agricultural block and year (Thirtle et al. 2003; Temoso, Villano, and Hadley 2016). The values of both production inputs and outputs were deflated using annual price indices (base year 2007) taken from the rural CPI published by Statistics Botswana. We used the rural CPI for both inputs and outputs because we lacked specific data to deflate each one. As shown in Table 1, the average beef cattle output is BWP191778 per block and year whilst the average output of crops is BWP37565: this illustrates the dominance of beef cattle production over other forms of agricultural production in Botswana.

In terms of the input variables, the average land size per block is 25.1 ha with a minimum of 0.27 ha and maximum of 79.3 ha. The average total cost of labour, which is estimated by adding permanent and temporary labour costs at the block level and year, is BWP3945. The average beef cattle stock, which is measured in beef cattle equivalents (Bahta et al. 2015) per block and year, is 259. We also included other production costs (other costs), which are estimated by adding the total feed costs and veterinary costs for each block and year (average other costs are valued at BWP12320).

Table 1. Descriptive statistics of beef production and determinants of TFP and efficiency changes.

Variable	description	Mean	Min	Max
Factors of production				
Beef cattle output	Total value of beef cattle output (Botswana Pula [BWP])	191,778	215.9	7,019,575
Crop output	Total value of crop output (BWP)	37,565	0	3,694,731
Stock size	Number of livestock used for production in beef cattle equivalent units	259	0.43	9,887
Other costs	Total costs of feed and veterinary inputs in each block and year in BWP	12,320	0	166,454
Labour cost	Total labour cost including permanent and temporary labour costs for agricultural production in each block (BWP)	3,945	0	236,789
Arable land area	Size of the arable land area in hectares for a given block in hectares (ha)	25.1	0.27	179.3
Precipitation	Annual mean precipitation for the block in millimetres (mm)	433	122	952.5
Sources of productivity change and its components		Mean	Min	Max
Herd size	Total number of cattle in a given block and year	10,953	7.83	163,009
Age of HH	Mean age of the household head (in years) in each block and year	53.0	41	61.9
Education of HH	Proportion of households' heads with at least primary education schooling	55.8	24.3	91.7
Mortality rates	Livestock mortality rates in each block and year. It is measured as the ratio of the total number of deaths to the total number of cattle during the survey year.	5.64	1.90	32.6
Gender of HH	Gender of households' heads (% of men to total) in a given block and year	59.3	24.9	91.7
Crossbreed	Proportion of crossbreeds in each district and year (%) in each block and year	21.7	0. 033	78.6
Off-farm income	Proportion of households with off-farm income (%) in each block and year	43.2	8.84	83.2
LAC	Number of livestock Advisory Centre (LACs) in a given block and year	1.12	0	4

Annual rainfall (precipitation) was included in the analysis to account for production environment variation; mean value over the sample is 433 mm ranging from a minimum of 122 mm to a maximum of 953 mm.

5. Results and discussion

The multiperiod and/or multilateral beef TFP indices and their components were estimated for the 26 agricultural districts for the period 2007–14 assuming variable returns to scale (VRS). The indices were obtained under the assumption that in each period all the districts experience the same production technology (i.e., represented as maximum TFP levels in Table 2). Following O'Donnell (2010) we allowed for technological regress to account for omitted variables and statistical noise as is common in DEA analysis. It is also the case that allowing for technological regress can help to account for poor environmental conditions such as droughts (Khan, Salim, and Bloch 2015), which are common in Botswana. Whilst the Färe-Primont index simultaneously produces input-and-output oriented efficiency measures, in this study, only output oriented measures are reported. This is because beef farmers are assumed to have more control over their outputs than most of their inputs (i.e., land, capital, and labour are quasi-fixed in practice) (Martinez-Cillero and Thorne 2019a).

6. Total factor productivity (TFP) estimates

As shown in Table 2, during the study period, the average TFP level for the sector was 0.389, with the largest TFP level of 0.456 recorded in 2012, whilst the smallest TFP level of 0.233 was observed in 2007. The results also show that during the period technical efficiency (OTE: 0.969) and scale efficiency (OSE: 0.961) were the largest contributors to TFP, with residual mix-efficiency level taking a value of 0.687. The implication of these results is that, on average, beef cattle farmers in Botswana are doing well in terms of pure technical efficiency (i.e., by improved management abilities of farmers and farming practices) and scale efficiency (improved beef productivity by increasing the size of their farm output). The lower mix efficiency level [RME] reflects the inability of farmers to derive economies of scope through changing optimal input and output mixes optimally in their production process (Dakpo et al. 2018a; Martinez-Cillero and Thorne 2019a).

6.1 TFP growth and its sources

While the TFP level and its components are informative, they do not provide insights into the dynamics of TFP and what has enhanced it over time. Table 3 and Figure 1 provide insights on the trends of TFP and efficiency of the sector for the study period. The results show that over the 8-year period, TFP increased by 7.02%, driven by technological change (9.30%), whilst efficiency

Table 2. TFP levels and its components for Botswana beef production, 2007–14.

Year	TFP	TFP*	TFPE	OTE	OSE	RME
2007	0.233	0.342	0.682	0.978	0.954	0.734
2008	0.273	0.405	0.674	0.961	0.978	0.714
2009	0.403	0.685	0.588	0.978	0.925	0.649
2010	0.441	0.602	0.734	0.984	0.976	0.762
2011	0.439	0.812	0.541	0.983	0.933	0.590
2012	0.456	0.720	0.634	0.938	0.976	0.697
2013	0.445	0.657	0.678	0.978	0.963	0.712
2014	0.418	0.696	0.600	0.951	0.987	0.638
Mean	0.389	0.615	0.641	0.969	0.961	0.687

Note: TFP is total factor productivity; TFP* is the maximum potential TFP; TFPE is total factor productivity efficiency level; OTE is output-oriented technical efficiency; OSE is output scale efficiency; RME is residual mix efficiency.

Table 3. Compound beef TFP change and its sources by sub-periods.

Period	dTFP	dTech	dTFPE	dOTE	dOSE	dOSME	dRME
Overall (2007–14)	7.02%	9.30%	−2.09%	−0.38%	0.46%	−1.70%	−2.14%
First (2007–10)	17.32%	15.20%	1.84%	0.19%	0.57%	1.67%	1.08%
Second (2010–4)	−2.11%	3.71%	−5.62%	−0.92%	0.39%	−4.76%	−5.07%

Note: dTFP is total factor productivity change; dTech is technical change; dTFPE is total factor productivity efficiency change; dOTE technical efficiency change; dOSE is scale efficiency change; dRME is residual mix efficiency change; dOSME is scale-and-mix efficiency change.

change (TFPE) decreased by 2.09%. These results are consistent with earlier studies in Botswana, which also found that technological change was the main source of productivity growth, whilst efficiency change has been either stagnant or declining (Thirtle et al. 2003; Temoso, Villano, and Hadley 2015b). Furthermore, when breaking down TFPE change into its components we found that the slowdown in efficiency was largely due to a decline in scale-and-mix efficiency (OSME at – 1.70%) as well as a marginal decline in technical efficiency (−0.30%).

To assess the potential effect of various policies and macroeconomic factors on the performance of the sector we divided the study period into two sub-periods (2007–10 and 2010–4). Doing so, we found the largest productivity growth to have occurred in the first sub-period (2007–10) where it increased by 17.3%. This growth was largely due to the increase in technological change (15.2%) and a marginal increase in TFPE (1.84%). Amongst the components of TFPE, scale and mix efficiency change (OSME) was the key source of growth whilst OTE only increased marginally. Conversely, during the latter period (2010–4) the industry experienced productivity slowdown (−2.11%) due to a decline in TFPE (−5.62%). Again, scale and mix efficiency change (OSME of – 4.76%) was the main contributor to the slowdown in TFP during the period.

What is evident from this analysis is that scale and mix efficiency change have been the key drivers of beef TFP efficiency in Botswana – influencing both the growth and slowdown of productivity. These results support the argument by West, Mugera, and Kingwell (2022) and O'Donnell (2018) which suggest studies that are strictly focused on technical efficiency may be misleading because they are not capturing other key components of productivity growth.

6.2 Analysis of livestock TFP growth and its components at the district level

This section presents results at the district level which can help in understanding regional differences in TFP growth as well as the key sources of performance. As shown in Table 4, TFP indices vary across

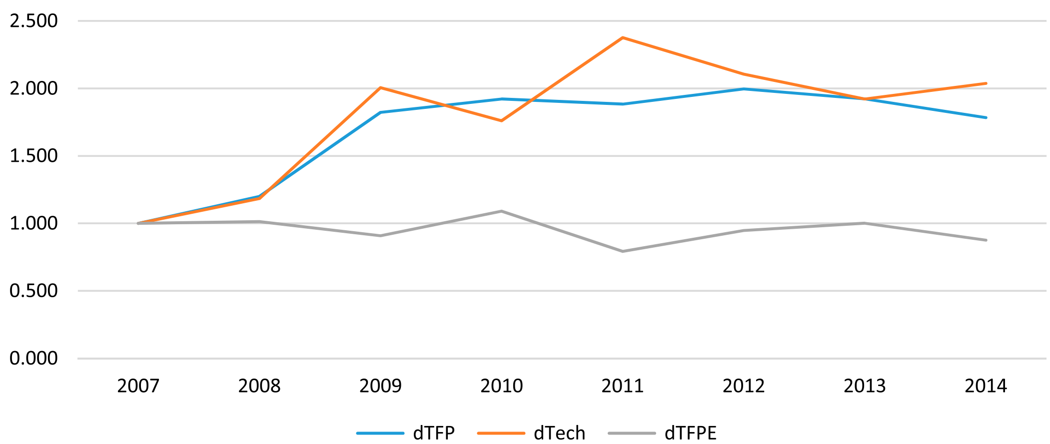

Figure 1. Productivity, technological and efficiency growth for the beef sector in Botswana. Note: dTFP is total factor productivity change; dTech is technological change; and dTFPE is total factor productivity efficiency change.

Table 4. TFP Growth and its components by agricultural district, 2007–14.

District	Region	dTFP	dTech	dTFPE	dOTE	dOSE	dOSME	dRME
Barolong	Southern	5.13%	9.30%	−3.82%	0.00%	−0.55%	−3.82%	−3.29%
Ngwaketse South	Southern	9.51%	9.30%	0.19%	0.00%	0.93%	0.19%	−0.74%
Ngwaketse North	Southern	5.21%	9.30%	−3.74%	−3.37%	1.57%	−0.38%	−1.92%
Ngwaketse Central	Southern	9.09%	9.30%	−0.19%	−2.34%	2.66%	2.19%	−0.45%
Ngwaketse West	Southern	5.78%	9.30%	−3.22%	−2.50%	0.97%	−0.75%	−1.70%
Bamalete/Tlokweng	Gaborone	5.83%	9.30%	−3.18%	0.00%	0.89%	−3.18%	−4.04%
Kweneng South	Gaborone	5.62%	9.30%	−3.37%	0.48%	0.63%	−3.84%	−4.44%
Kweneng North	Gaborone	1.45%	9.30%	−7.19%	−1.67%	0.67%	−5.61%	−6.24%
Kweneng West	Gaborone	6.56%	9.30%	−2.51%	−1.19%	−0.09%	−1.33%	−1.24%
Kgatleng	Gaborone	11.49%	9.30%	2.00%	0.88%	0.20%	1.11%	0.91%
Mahalapye East	Central	13.47%	9.30%	3.81%	0.00%	0.00%	3.81%	3.81%
Mahalapye West	Central	11.00%	9.30%	1.55%	0.00%	0.00%	1.55%	1.55%
Palapye	Central	10.97%	9.30%	1.53%	0.00%	0.00%	1.53%	1.53%
Serowe	Central	9.89%	9.30%	0.54%	0.00%	0.00%	0.54%	0.54%
Bobonong	Central	6.65%	9.30%	−2.43%	0.53%	1.70%	−2.94%	−4.57%
Letlhakane	Central	6.15%	9.30%	−2.89%	0.00%	0.00%	−2.89%	−2.89%
Selebi-Phikwe	Central	7.15%	9.30%	−1.97%	−0.84%	−0.04%	−1.14%	−1.10%
Tati	Francistown	−0.39%	9.30%	−8.87%	0.98%	0.15%	−9.76%	−9.89%
Tutume	Francistown	9.43%	9.30%	0.11%	0.00%	0.00%	0.11%	0.11%
Tonota	Francistown	0.03%	9.30%	−8.48%	1.94%	0.02%	−10.23%	−10.25%
Ngamiland West	Maun	8.78%	9.30%	−0.48%	0.00%	0.00%	−0.48%	−0.48%
Ngamiland East	Maun	8.42%	9.30%	−0.81%	0.00%	−1.06%	−0.81%	0.26%
Chobe	Maun	−3.97%	9.30%	−12.15%	0.00%	2.70%	−12.15%	−14.46%
Gantsi	Western	10.12%	9.30%	0.75%	0.00%	1.77%	0.75%	−1.00%
Hukuntsi	Western	10.71%	9.30%	1.29%	0.00%	0.00%	1.29%	1.29%
Tsabong	Western	8.42%	9.30%	−0.81%	−2.67%	−1.09%	1.91%	3.04%

Note: dTFP is total factor productivity change; dTech is technical change; dTFPE is total factor productivity efficiency change; dOTE technical efficiency change; dOSE is scale efficiency change; dOME is output scale efficiency change; dRME is residual mix efficiency change; dOSME is scale-and-mix efficiency change.

districts which may reflect the limiting factors of production involved in each district, where rearing of livestock may be more land intensive while crop production may be more labour intensive (Acosta and Luis 2019).

The results show that for the study period (2007–14), TFP grew by 8.07%, led by districts from the Central region (i.e., Mahalapye East, Mahalapye West, and Serowe). The strong TFPE growth for these districts is due to the increase in scale and mix efficiency change (OSME) which may reflect the ability to increase productivity through optimising crop and beef production (which is a common practice in the region). Mahalapye East had the largest TFP growth amongst the districts in Botswana which was due to both technological progress (10.17%) and an increase in overall efficiency (TFPE of 4.27%). Most of the TFPE change in the district is due to the increase in mix efficiency (RME at 4.27%). Whilst not directly comparable because of the different time periods and methodologies adopted, Thirtle et al. (2003) also found high TFP growth for Mahalapye (before it was demarcated into East and West). They attributed this growth to investment in and adoption of crop technologies in Botswana which were implemented under the ALDEP (Arable Lands Development Project) and ARAP (Accelerated Rainfed Arable Programme) policy programs.

As expected, the livestock specialising districts of Gantsi, Hukuntsi and Tsabong also experienced strong productivity growth. The results are expected because the farmers in these districts specialise in beef production and share many of the advantages enjoyed by commercial ranches (e.g., Sandveld ranches), which are co-located in the region. Hence, farmers in these districts may have improved their productivity by adopting the farm management skills and improved technologies used by commercial farmers (Thirtle et al. 2003). Other studies of agricultural productivity in Botswana have also found these districts to serve as a benchmark in Botswana (Temoso, Villano, and Hadley 2016; Irz and Thirtle 2004).

On the other side of the spectrum, Chobe (−4.05%) and Tati (−0.45%) districts were the only districts to experience negative TFP growth. The slowdown in productivity for these districts was largely due to a decline in scale and mix-efficiency change (OSME), which declined by 14.8% for Chobe and 12.33% for Tonota. The poor performance of the Chobe district is not surprising given that the district is subject to outbreaks of foot and mouth (FMD), animal – wildlife conflicts, and poor market access, which may constrain the productivity of the farmers in the district (Temoso, Villano, and Hadley 2016). Whilst Tati and Tonota districts experienced some growth in technical efficiency, it was not enough to compensate for the decline in scale and mix efficiency change, hence, overall efficiency (TFPE) declined. Even though the outbreaks of FMD in the two districts are not as common as in the Chobe district, there was a major outbreak in 2011 which disrupted production.

It is also evident from Table 4 that only one district (Kgatleng) was able to gain from all three components of TFPE: technical efficiency increased by 0.88%, scale efficiency by 0.20% and residual mix efficiency changed by 0.91%. Overall, the contribution of technical efficiency across the districts has been limited, with only 5 districts experiencing growth, 7 districts recording a decline and the majority (14 districts) experiencing no growth. As pointed out by Dakpo et al. (2018a, 367) "the deterioration of technical efficiency implies that most farmers are not able to catch up with those that define the frontier". In other words, farmers in the districts with declining technical efficiency were not able to adapt their practices to changes in technology.

6.3 Sources of beef TFP growth and its components

Table 4 presents results on the determinants of TFP and its components which were estimated using FGLS. Most of the variables have the expected signs. The LAC categorical variable, which represents the availability of livestock advisory centres in each district (ranging from zero to more than four LACs), is positive and statistically significant for TFP, TFPE, and RME. These results are expected because proximity to LACs allows farmers to access extension and veterinary services such as animal drugs and vaccines, animal equipment, and animal health advice which in turn enables them to enhance their efficiency and productivity (Malope, Mmopelwa, and Bahta 2016).

The effect of livestock mortality rates (*ln_mortality*) is negative and statistically significant for TFP, TFPE and TC. As highlighted by Temoso, Villano, and Hadley (2016) the negative impact of mortality on performance may be linked to the production environment and seasonal differences across the sector. Mortality rates are likely to be higher for farmers located in districts that are prone to disease and droughts. In addition, higher mortality rates may reflect lack of adoption and utilisation of better livestock technologies and management practices (Temoso, Villano, and Hadley 2016). Several prior studies have also found a negative effect of mortality rate on herd productivity (Mahabile, Lyne, and Panin 2005) and beef technical efficiency (Martinez Cillero et al. 2019b).

Although the coefficient for *herd size* was positive across all the components it was only statistically significant for three measures (TFP, TC and OME). This implies that farmers with large cattle herds are more productive, produce at the production frontier and are mix efficient. The results also show that the magnitude of the impact of herd size varies substantially across the performance measures: the effect is larger on TFP (0.0254) as compared to TC (0.0175) and OME (0.00156) measures. Previous studies in Botswana (Bahta et al. 2015; Mahabile, Lyne, and Panin 2005; Temoso, Villano, and Hadley 2016) and globally (West, Mugera, and Kingwell 2022; Rahman and Salim 2013; Ng'ombe 2017) have also found a positive effect of farm size on efficiency and productivity. The implication of these results is that the productivity of beef cattle farmers could be enhanced by increasing herd size, although pursuing productivity growth via this route is likely to be at odds with an aim of reducing negative impacts on the environment.

In terms of the socio-economic characteristics of the farmers, our results show that the gender (*malehh*) variable is positive and statistically significant for TFP, TFPE, OSE, and OME. This indicates that, on average, male farmers are more productive, scale, and mix efficient than their female compatriots. These results may reflect the structure of the beef sector in Botswana, which is male-dominated, with only a small proportion of female farmers participating in the sector. The descriptive statistics in section 3 show that on average less than half (41%) of farmers were female over the study period.

The coefficient estimated for age of farmer (*ageHH*) is positive and statistically significant for TFP, TFPE, and OSE. This suggests that, on average, older farmers are more productive and scale efficient than younger farmers. The possible explanation for this result is that older farmers may have accumulated more experience than their young counterparts. Moreover, the results may reflect the structure of the sector in Botswana, where most of the farmers are older, with an average age of 53 years (see Table 1). The coefficient for education is positive and significantly influences beef TFP. These results suggest that farmers with more years of education are more likely to adopt new technologies and improved livestock management skills, which in turn improves their productivity. Off-farm income was positive and statistically significant for OME and TFPE. According to Mahabile, Lyne, and Panin (2005), access to off-farm income can help farmers address the lack of credit which is common in Botswana. Off-farm income can be used to purchase livestock productivity-enhancing technologies such as vaccines, animal drugs and for investment in water infrastructure and hiring of farm labour (Table 5).

7. Conclusion and policy implications

This study applied a Färe-Primont index to measure total factor productivity and its components for the beef cattle sector in Botswana at the district level over an 8-year period (2007–14). The results show that during the study period the key drivers of productivity growth were technological change and scale-and-mix efficiency changes, whilst technical efficiency change was stagnant. Similar results were observed at the district level, where TFP change of Mahalapye East, the best-performing district, increased because of positive technological change and scale-and-mix efficiency change.

The results obtained from this study make a novel contribution to the literature on livestock total factor productivity and its sources in a developing country context. Existing TFP results, which are dominated by studies done in developed economies, cannot directly inform livestock policies in less developed countries due to differences in farming systems in terms of objectives (market-oriented versus home consumption), land tenure (secure versus communal), technology, and management practices. Compared to developed countries, livestock production in the developing world is, generally, highly fragmented and disorganised due to underinvestment in extension systems and other support services that are critical for increasing productivity and efficiency (Herrero et al. 2013). Our results show that changes in scale and mix efficiency were the primary drivers of beef TFP efficiency in Botswana, whilst the contribution of technical efficiency was limited during the study period. This contrasts with previous research on beef performance in developing countries, which attributed such growth to technical efficiency (Temoso, Hadley, and Villano 2015a; Otieno, Hubbard, and Ruto 2014; Temoso, Villano, and Hadley 2016), with no consideration given to the role of scale and mix efficiency change. This suggests that future research in developing countries should employ proper TFP index approaches, such as Färe-Primont, to gain a better understanding of what drives or constrains productivity.

The second objective of this study was to identify factors contributing to the variability of productivity and efficiency growth amongst the districts in Botswana. An FGLS panel data approach, which accounts for both the systematic effects of agricultural districts and time-varying of explanatory variables, was applied. Results show that access to LACs, off-farm income, having more years of schooling (education), and herd size enhance beef productivity and efficiency. High livestock mortality rates negatively affected the productivity and efficiency growth of the sector.

These results have important policy implications for the beef sector in Botswana. For example, the positive effect of the LAC variable on TFP and its components suggests that proximity to extension and veterinary services can enhance beef productivity and efficiency. This is probably because proximity to LACs can improve farmers' accessibility to productivity enabling farm inputs and

Table 5. Sources of TFP and efficiency growth in Livestock production in Botswana.

	(1) ln_TFP	(2) ln_TFPE	(3) ln_TC	(4) ln_OTE	(6) ln_OSE	(7) ln_OME
0.lac	0	0	0	0	0	0
1.lac	0.190***	0.173***	0.0312	0.0903***	−0.0342***	0.0179***
	(5.80)	(5.35)	(1.47)	(6.97)	(−11.84)	(4.65)
2.lac	0.186***	0.199***	−0.00259	0.0561***	−0.0279***	0.0238***
	(5.13)	(5.62)	(−0.11)	(4.38)	(−8.92)	(5.90)
3.lac	−0.0316	−0.0194	0.00641	0.0817***	0.0744***	0.0174***
	(−0.37)	(−0.29)	(0.10)	(5.93)	(7.35)	(3.40)
4.lac	0.359**	0.364**	0.00491	0.0539**	−0.0781**	0.0189***
	(2.68)	(3.19)	(0.08)	(2.95)	(−2.98)	(3.62)
ln_Herdsize	0.0254***	0.00705	0.0175***	0.000334	0.0000702	0.00156***
	(5.85)	(1.95)	(4.33)	(1.00)	(0.17)	(3.49)
ln_excross	−0.000724	0.00000457	0.000122	−0.0000538	−0.00330***	−0.000883
	(−0.15)	(0.00)	(0.03)	(−0.13)	(−9.01)	(−1.82)
ln_mortality	−0.0510***	−0.0133**	−0.0439***	−0.000462	−0.000912	0.00153**
	(−8.79)	(−2.73)	(−9.28)	(−0.97)	(−1.68)	(2.62)
ln_offinc	0.0169	0.0250***	−0.00184	−0.000508	0.00133	0.00466***
	(1.80)	(3.32)	(−0.22)	(−0.74)	(1.45)	(5.01)
malehh	0.000689*	0.000700**	0.000110	−0.0000108	0.0000519*	0.0000804**
	(2.53)	(2.98)	(0.43)	(−0.47)	(2.24)	(3.04)
ln_ageHH	0.0825*	0.0626	0.00754	−0.000789	0.00420	−0.000665
	(2.17)	(1.91)	(0.20)	(−0.25)	(1.25)	(−0.19)
ln_edu	0.0265*	0.00197	0.0147	−0.000164	−0.000867	0.00129
	(2.01)	(0.18)	(1.32)	(−0.16)	(−0.69)	(1.16)
Time trend	0.0990***	−0.000551	0.0986***	0.0000395	0.00136***	−0.000976***
Regional Dum	YES	YES	YES	YES	YES	YES
_cons	−0.482**	−0.399*	−0.0164	−0.0581***	0.0681***	−0.0315
	(−2.59)	(−2.52)	(−0.09)	(−3.59)	(4.03)	(−1.87)
N	192	192	192	192	192	192

Note: *t* statistics in parentheses; $^{*}p < 0.05$ $^{**}p < 0.01$ $^{***}p < 0.001$.
ln_TFP is logged values of total factor productivity (TFP); *ln_TFPE* is logged values of TFP efficiency; *ln_OTE* is logged values of output-oriented technical efficiency change; *ln_OSE* is logged values of output-oriented scale efficiency change; *ln_OME* is logged values of output-oriented mix efficiency change; *lac_dum* is dummy variable for livestock advisory centres; *ln_excross* is logged valued of share of exotic and cross bred livestock; logged values of ownership of transport; *ln_offinc* is logged values of off-farm income; *ln_edu* is logged values of number of years of education; *Regional Dum* is dummy variable for the six agro-ecological regions.

technologies such as drugs and vaccines and extension advice. Similarly, the positive effect of education on TFP growth implies that beef productivity could be increased through the enhancement of the educational levels of farmers. The negative effect of mortality rates suggests that policies and strategies targeted at reducing mortality rates can enhance beef productivity and efficiency growth of the sector.

Some limitations of the study should be noted. These include the use of non-parametric based TFP indices. TFP and efficiency scores estimated using DEA based indices may produce biased results because of their inability to account for statistical noise (i.e., they do not separate measurement errors from inefficiency scores), hence, future studies should use parametric based TFP indices which do not suffer from this shortcoming. Similarly, future studies should consider using more granular data to account for potential heterogeneities, for example, longitudinal farm level data to account for spatial and temporal heterogeneity that is likely to exist within and across agricultural districts.

Our study is limited to the years up to 2014 due to a lack of detailed data for the years after that. As a result, our analysis did not consider the country's recent agricultural dynamics, such as how it performed during recent droughts and how some macroeconomic trends may have influenced it. As a result, further research is required to answer those questions.

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No potential conflict of interest was reported by the author(s).

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