Agricultural productivity, efficiency and growth in a semi-arid country: a case study of Botswana

Omphile Temoso*
UNE Business School, University of New England, Armidale, NSW, Australia. E-mail: otemoso@myune.edu.au

Renato A Villano
UNE Business School, University of New England, Armidale, NSW, Australia. E-mail: rvillan2@une.edu.au

David Hadley
UNE Business School, University of New England, Armidale, NSW, Australia. E-mail: dhadley@une.edu.au

*Corresponding author

Abstract

This paper attempts to examine and revisit the trends in agricultural productivity in Botswana. Using secondary data from six regions of Botswana for the period 1979 to 2012, we estimate components of total factor productivity (TFP) using the Färe-Primont index. Estimates of technical change and changes in technical efficiency, scale efficiency and mix efficiency are obtained. The results show that the annual TFP has declined gradually over the period, predominantly due to a decline in technical efficiency and a slight decline in mix efficiency and scale efficiency. The regions with a significant proportion of arable agriculture performed worse than those that specialise in livestock production, thus confirming the comparative advantage of extensive livestock production in semi-arid countries such as Botswana. This study shows how the finer decomposition of TFP into different measures may assist in the identification of the main drivers of productivity and associated policies.

Key words: semi-arid; Botswana; Färe-Primont index; total factor productivity; mix efficiency

1. Introduction

Agriculture plays an important role in Botswana, providing food, income, employment and investment opportunities for the majority of the rural population (Van Engelen & Keyser 2013; MoA 2014). Almost 90% of the total rural labour force is directly or indirectly engaged in agriculture (Statistics Botswana 2014). However, over the last two decades, agricultural productivity in Botswana has declined, leading to a progressive increase in food imports (including staples such as sorghum and maize) (Van Engelen & Keyser 2013; MoA 2014; Statistics Botswana 2014; Thirtle *et al.* 2003). Low productivity in agriculture has also prohibited farmers from earning significant returns from their enterprises, and hence they have reduced farm incomes (Yaron *et al.* 2012). Poor agricultural productivity has been attributed to institutional and economic factors, as well as the harsh physical environmental and climatic conditions in Botswana, where there is recurring drought in many parts of the country (Yaron *et al.* 2012; GoB 2014). Some of the challenges faced by farmers in Botswana include: low and variable rainfall; poor soils; crop pests and animal diseases; undeveloped markets and input delivery technologies; and poor access to credit, extension services and labour (Yaron *et al.* 2012; Van Engelen & Keyser 2013).

Previous research on agricultural efficiency and total factor productivity (TFP) in Botswana and Southern Africa has taken various approaches. For example, Thirtle *et al*. (1993) used a Tornqvist-Theil index approach to study agricultural productivity in Zimbabwe. Recently, Conradie *et al*. 2009; 2013) used the same method as Thirtle *et al*. (1993) to study agricultural TFP in the Western Cape of South Africa. In the context of Botswana, Thirtle *et al*. (2003) applied a sequential Malmquist index that initially was proposed by Caves *et al*. (1982) and popularised by Färe *et al*. (1994) to analyse TFP in Botswana's agriculture for the period 1981 to 1986. Their study found that TFP grew at an average rate of 1.7% per annum, powered by technological change at 4% per year but offset by technical efficiency falling at 2.4% per annum. They also found that the commercial sector and the livestock-producing regions exploited new technologies and infrastructure better, whereas the traditional sector and arable areas were falling further behind the best practice frontier. Using a similar dataset as that of Thirtle *et al*. (2003), Irz and Thirtle (2004) applied a stochastic input distance approach to study the sources of productivity growth of the traditional and commercial agriculture sectors in Botswana. This study found that the technology level of the commercial agriculture sector was six times greater than that of traditional agriculture, and that the gap has been increasing due to technological regression in traditional agriculture and modern progress in commercial agriculture.

This paper presents an empirical analysis employing a method proposed by O'Donnell (2011a; 2012a). TFP is calculated using the Färe-Primont index and decomposing it into various measures of efficiency change (technical, scale and mix efficiency) and technical change. In Thirtle *et al*. (2003) and Irz and Thirtle (2004), the evaluation of farms' performance focused on estimating productivity growth using technical efficiency, scale efficiency and technological change and did not take into account possible inefficiencies attributed to the output (input) mix. Output (input) mix efficiency can be defined as the ability to improve overall productivity by changing the output (input) mix of the farm whilst holding the input (output) set fixed (O'Donnell 2010; Tozer & Villano 2013). In simple terms, this is the potential increase in productivity due to economies of scope rather than scale (Hadley *et al*. 2013; Tozer & Villano 2013). Finer decomposition measures of TFP should provide greater understanding with regard to the patterns and sources of growth in the agricultural sector in Botswana. Moreover, apart from accounting for possible inefficiencies attributed to output (input) mix, the Färe-Primont TFP index can also be used to make reliable multi-temporal (i.e. many periods) and/or multi-lateral (i.e. many firms) comparisons of TFP and efficiency (O'Donnell 2014).

Although much effort has been devoted to measuring the total factor productivity (TFP) of different agricultural sectors in Botswana (e.g. Thirtle *et al*. 2003; Irz & Thirtle 2004), the studies have produced mixed results and are now outdated. Therefore, this study enhances the literature by providing more recent estimates. The most recent estimates of Botswana's agricultural TFP only cover the period up to 1996 and therefore do not include any possible effects on the sector of the substantial policy measures initiated during the early 2000s. This study aims to fill this gap by revisiting measures of agricultural growth using an updated dataset and more recent methodology. Hence, the main contribution of this paper is twofold: (1) by obtaining decomposed measures of TFP, insights can be provided into the ways in which different policies can be designed to promote growth. For example, agricultural performance could be improved through technical efficiency-enhancing policies that include education and extension programmes; ensuring technical progress through increased funding for scientific research and development; and policies that enhance scale and mix efficiency, such as taxes and subsidies. (2) We investigate whether TFP varies across Botswana's regions, which differ in terms of natural conditions and economic development. Regional productivity estimates may assist policymakers in better identifying strategies to improve agricultural production. That is, by identifying the inefficient regions, policies designed to promote efficiency can be made more effective by directing the necessary help to areas of need.

From this point forward the paper is organised as follows. Section 2 discusses and outlines the methodology employed to construct the TFP indices and associated efficiency decompositions. It also gives more detail on the construction of the data variables and their sources. Section 3 presents the empirical estimates and an analysis of the results. The paper is concluded in section 4, where policy recommendations are proposed.

2. Analytical method and sources of data

TFP change can be decomposed into technical change and TFP efficiency changes, and TFP efficiency change can be further decomposed into technical, scale and mix efficiency change. We employed the methodology proposed by O'Donnell (2011a; 2012a), which is summarised in the following section.

2.1 The Färe-Primont TFP index

An index number is defined as a real number that measures changes in a set of related variables (Färe & Primont 1995). Conceptually, index numbers may be used for comparisons over time or space or both. Index numbers can also be categorised into two main groups: *price index* numbers, which may refer to consumer prices, input and output prices, export and import prices, etc., and *quantity index* numbers, which measure changes in quantities of outputs produced or inputs used by a firm or industry over time or across firms (Coelli *et al*. 2005). The Färe-Primont TFP index, which is based on two indices from Färe and Primont (1995: 36-38) is of the latter category and can be defined as a ratio of an aggregate output to an aggregate input:

$$TFP = \frac{Q(q)}{X(x)} \tag{1}$$

O'Donnell (2011a) shows that the estimated aggregate outputs and inputs can be represented as follows:

$$Q(q) = D_0(x_0, q, t_0) \tag{2}$$

$$X(x) = D_I(x, q_0, t_0) \tag{3}$$

where equations (2) and (3) are Shepherd output and input distance functions respectively (Shephard 1970) representing the production technology available in period *t*. Some of the characteristics that both of these distance functions have are that they are *linearly homogenous*, *non-negative* and *non-decreasing*. According to O'Donnell (2010), the *homogeneity* and *monotonicity* properties of these functions make them natural candidates to use as output and input aggregator functions. Then, as proposed by O'Donnell (2011a), the associated Färe-Primont index number for the TFP of firm *i* in period *t* relative to firm *h* in period *s* is:

$$TFP_{hs,it} = \frac{D_0(x_0, q_{it}, t_0) D_i(x_{hs}, q_0, t_0)}{D_O(x_0, q_{hs}, t_0) D_i(x_{it}, q_0, t_0)} \tag{4}$$

O'Donnell (2011a) explains that, when a transitive index is used, the *DPIN 3.0* software default will compare firm *i* in period *t* and firm 1 in period 1. Most of the economic measures of efficiency that can be defined as ratios of measures of TFP are given in O'Donnell (2011a). For example, O'Donnell (2008) shows the alternative output-oriented decompositions:

$$TFPE_{nt} = OTE_{nt} \times OSE_{nt} \times RME_{nt} \tag{5}$$
$$TFPE_{nt} = OTE_{nt} \times OME_{nt} \times ROSE_{nt} \tag{6}$$

where output-oriented technical efficiency (OTE) measures the productivity shortfall associated with operating below the production frontier, as noted by O'Donnell (2014), and the output-oriented scale efficiency (OSE) and output-oriented mix efficiency (OME) account for productivity shortfalls associated with diseconomies of scope. The measure of residual output-oriented scale efficiency (ROSE) is the ratio of TFP at a technically and mix-efficient point to the maximum TFP that is possible, and the residual mix efficiency (RME) "can be viewed as the component that remains after accounting for pure technical and pure scale efficiency effects" (O'Donnell 2012a: 263).

2.2 Estimation using DEA

DPIN 3.0 is used to estimate the production technology (and associated measures of productivity and efficiency) using data envelopment analysis (DEA) linear programming (LP) (O'Donnell, 2011a). The main assumption behind the use of DEA is that the (local) output distance functions representing the technology available in period *t* take the form (O'Donnell 2011b):

$$D_0(x_{it}, q_{it}, t) = (q'_{it}\alpha)/(\gamma + x'_{it}\beta) \tag{7}$$

The output-oriented problem involves finding the solutions for the unknown parameters in equation (7) to minimise technical efficiency: $OTE_{it}^{-1} = D_0(x_{it}, q_{it}, t)^{-1}$. The resulting linear program is:

$$D_0(x_{it}, q_{it}, t)^{-1} = OTE^{-1} = \min_{\alpha,\gamma,\beta}\left\{\gamma + x'_{it}\beta : \gamma\iota + X'\beta \geq Q'\alpha; q'_{it}\alpha = 1; \alpha \geq 0; \beta \geq 0\right\} \tag{8}$$

where Q is a $J \times M_t$ matrix of observed outputs, X is a $K \times M_t$ matrix of observed inputs, t is an $M_t \times 1$ unit vector, and M_t denotes the number of observations used to estimate the frontier in period t (O'Donnell 2011a). The *DPIN 3.0* software program uses a variant of this LP to compute indices of productivity and efficiency measures. To compute the Färe-Primont aggregates, *DPIN 3.0* first solves the following LP (O'Donnell, 2011a):

$$D_0(x_0, q_0, t_0)^{-1} = \min_{\alpha,\gamma,\beta}\left\{\gamma + x'_0\beta : \gamma\iota + X'\beta \geq Q'\alpha; q'_0\alpha = 1; \alpha \geq 0; \beta \geq 0\right\}, \tag{9}$$

after which the aggregated outputs and inputs of the Färe-Primont index can be solved as (O'Donnell 2011a)

$$Q_{it} = \left(q'_{it}\alpha_0\right)/\left(\gamma_0 + x'_0\beta_0\right) \tag{10}$$

$$X_{it} = (x'_{it}\eta_0)/(q'_0\phi_0 - \delta_0) \tag{11}$$

where α_0, β_0, γ_0, ϕ_0 and η_0 solve equation (10) and (11). The *DPIN 3.0* uses sample mean vectors as representative output and input vectors of equations (10) and (11). The representative technology in this LP is the technology obtained under the assumption of no technical change and allows the technology to exhibit variable returns to scale (VRS). In the case where technology is assumed to exhibit constant returns to scale (CRS), then *DPIN 3.0* sets $\gamma = \delta = 0$ (O'Donnell 2011a).

2.3 Data and variables

The data used for the analysis are constructed from various sources. The main source of the data is the agricultural database compiled by Thirtle *et al*. (2000; 2003), which reports the number of livestock (cattle, goats and sheep), land area, production and yield of all major principal crops (sorghum, maize, millet and beans/pulses) and annual rainfall for the period 1979 to 1996, the farm management surveys (Nyangayezi 1999; Acquah 2003), the agricultural census (Statistics Botswana 2008) and various issues of the annual agricultural statistics for the period 2006 to 2012 (Statistics Botswana, various issues).

Outputs: (i) the main principal *crops* (sorghum, maize, millet and beans/pulses) from the respective regions in Botswana are aggregated into physical quantities (metric tons) following Rahman and Salim (2013), hence are largely free from aggregation issues that arise from using value equivalents; (ii) the number of home slaughtered and sold per year for the three principal animals (viz. cattle, goats and sheep) for each region. *Livestock units* are expressed in sheep-equivalent units, as recommended by Hayami and Ruttan (1970), Thirtle *et al*. (2003) and Coelli and Rao (2005) (see Inputs (iii) below).

Inputs: (i) *Land* is the effective agricultural land used for crop and animal (in hectares); (ii) the *labour* variable is defined as the economically active population in agriculture; (iii) *livestock units* are the number of the main principal livestock animals (cattle, goats and sheep) converted into sheep equivalents – 1.0 livestock unit equates to 0.8 cattle and 0.1 sheep or goat; (iv) we have included one climate variable, which is *rainfall*, expressed in millimetres per region per annum (Thirtle *et al*. 2000; Tozer & Villano, 2013; Islam *et al*. 2014; Khan *et al*. 2014). In Botswana, as in other semi-arid countries, water is scarce, thus irrigation is almost non-existent (Statistics Botswana 2013; Van Engelen & Keyser 2013). As a result, agriculture, especially cropping practices, is influenced by rainfall, and rainfall consequently influences the amount of output that can be produced using a set of inputs.

2.4 Empirical model

The multilateral agricultural Färe-Primont TFP indices and their various components have been calculated for all six regions, covering the 34-year period from 1979 to 2012. In this study, an output-orientated approach was selected, since most farmers in Botswana, just as in other developing countries, usually attempt to maximise output from a given set of inputs, rather than the opposite (Coelli & Rao 2005). Also, inputs such as land are fixed, hence the choice of output orientation. The technology was obtained under the assumption that, in a given period, all regions in Botswana experience the same estimated rate of technical change. This involved using all the observations in the dataset to estimate a single frontier for each period, thus allowing for temporal variations in the production environment but disallowing spatial variations (O'Donnell, 2011a; 2012b) and allowing for the technology to exhibit variable returns to scale. We also allowed for technological progress, but restricted technological regress following a recommendation by Thirtle *et al*. (2003: 610), who point out that, "in the context of agriculture in Botswana, the most important exogenous variable is rainfall", and therefore an approach that accounts for the adverse effects of weather in terms of efficiency decline rather than technical regress is recommended (also see Alene, 2010).

2.5 Descriptive statistics

Descriptive statistics for the variables in the six regions are presented in Table 1. A comparison of these statistics across regions shows that, on average, the Central region has the largest share of

livestock output, followed by Gaborone, Southern, Maun, Francistown and Western. Similarly, in terms of crop output, the Central region leads the other regions, followed by Gaborone, Southern, Francistown, Maun and Western. Maun and the Western region seem to compare well with the other regions in terms of livestock output; however, the crop output is very low, which suggests that these regions specialise in livestock production. In terms of input use, the Central region leads with the largest share of land, labour and livestock units, followed by Gaborone and Southern.

Table 1: Major agricultural outputs and inputs for Botswana agriculture, 1979-2012

		Outputs		Inputs			
Region	**N**	**Livestock (LU)**	**Crops (tons)**	**Land (hectares)**	**Labour (persons)**	**Livestock units (LU)**	**Rainfall (millimetres)**
Southern	34	18 260 (5 060)	9 250 (8 320)	44 020 (20 170)	47 060 (14 500)	250 180 (43 220)	482 (115)
Gaborone	34	27 020 (10 530)	11 440 (15 030)	61 330 (24 610)	85 730 (28 300)	319 610 (64 980)	440 (129)
Central	34	66 000 (16 640)	17 420 (27 270)	66 420 (24 710)	100 400 (27 930)	771 880 (170 310)	414 (147)
Francistown	34	17 150 (7 100)	5 830 (6 520)	34 600 (16 640)	51 760 (17 920)	223 230 (69 120)	432 (153)
Maun	34	17 240 (9 570)	1 110 (840)	11 380 (4 760)	27 950 (9 510)	198 070 (69 810)	486 (115)
Western	34	13 700 (5 060)	81 (154)	1 600 (890)	10 140 (7 720)	185 580 (44 010)	342 (128)

Note: values in parentheses are standard deviations

3. Results and discussion

3.1 Agricultural productivity and efficiency growth in Botswana

The Färe-Primont index estimates of TFP (total factor productivity) levels and their components for Botswana agriculture are presented in Table 2. The average TFP level for the study period was estimated at 0.28, the technical efficiency level was estimated at 0.73, mix efficiency at 0.95 and scale efficiency at 0.96. The implication is that, over the study period, Botswana farmers were doing well in terms of scale and mix efficiencies, and the ability to devise economies of scale by altering both input and output mixes with existing technology (O'Donnell, 2008; 2012b), whilst low levels of technical efficiency (or the ability to produce outputs at a given set of inputs) contributed negatively to the low productivity levels in Botswana agriculture.

Table 2: Summary statistics of total factor productivity (TFP) and efficiency levels

	TFP	**Maximum TFP**	**TPFE**	**Technical efficiency (TE)**	**Scale efficiency (SE)**	**Mix efficiency (ME)**	**Scale- mix efficiency (SME)**
Mean	0.28	0.54	0.52	0.73	0.96	0.95	0.73
Maximum	0.38	0.67	0.82	0.99	0.99	1.00	0.86
Minimum	0.18	0.37	0.27	0.43	0.84	0.81	0.57
Standard deviation	0.05	0.11	0.17	0.18	0.03	0.04	0.08

The highest TFP level for the study period was 0.38, driven by technical and scale efficiency. The productivity levels in 1997 also coincided with the good rainfall recorded in that season (CSO 2006). This confirms that, in rain-fed farming systems, output quantity often tends to be influenced by the growing season rainfall (Islam *et al.* 2014). Indeed, agriculture in Botswana is an extensive system that uses minimal inputs and depends largely on unpredictable environmental conditions that

are beyond the control of farmers (Bendsen & Meyer 2003; Van Engelen & Keyser 2013; Zhou *et al*. 2013). Therefore, as the natural conditions, especially rainfall and temperature, change drastically, yields vary considerably from year to year and from crop to crop (Bendsen & Meyer 2003).

Figure 1 reports the cumulative levels of TFP change and its components relative to the base year, 1979. TFP changes (*d*TFP) were decomposed into technical change (*d*TECH) and total efficiency change (*d*TFPE). As shown in Figure 1, the average rate of TFP declines as sub-periods move forward. This is a worrisome result, especially for a country that has been investing a lot of money in improving agricultural productivity. Even worse, this negative growth has been maintained over a long period of time (34 years). Overall, the observed negative growth in TFP (1.35% per annum) over the 34-year period is predominantly due to negative growth in technical efficiency (2.40% p.a.) and a slight decline in mix efficiency (0.10% p.a.) and scale efficiency (0.10% p.a.), which is offset by technological progress, which grew at an annual rate of 1.75% per annum (Table 3). This implies that shifts in the best-practice frontier caused by technical change and infrastructural improvements – such as boreholes to water cattle – have contributed more to TFP growth compared to the contribution made by the best-practice enterprise mix (the ability to derive economies of scope by changing optimal output mixes) and alterations of input and output levels.
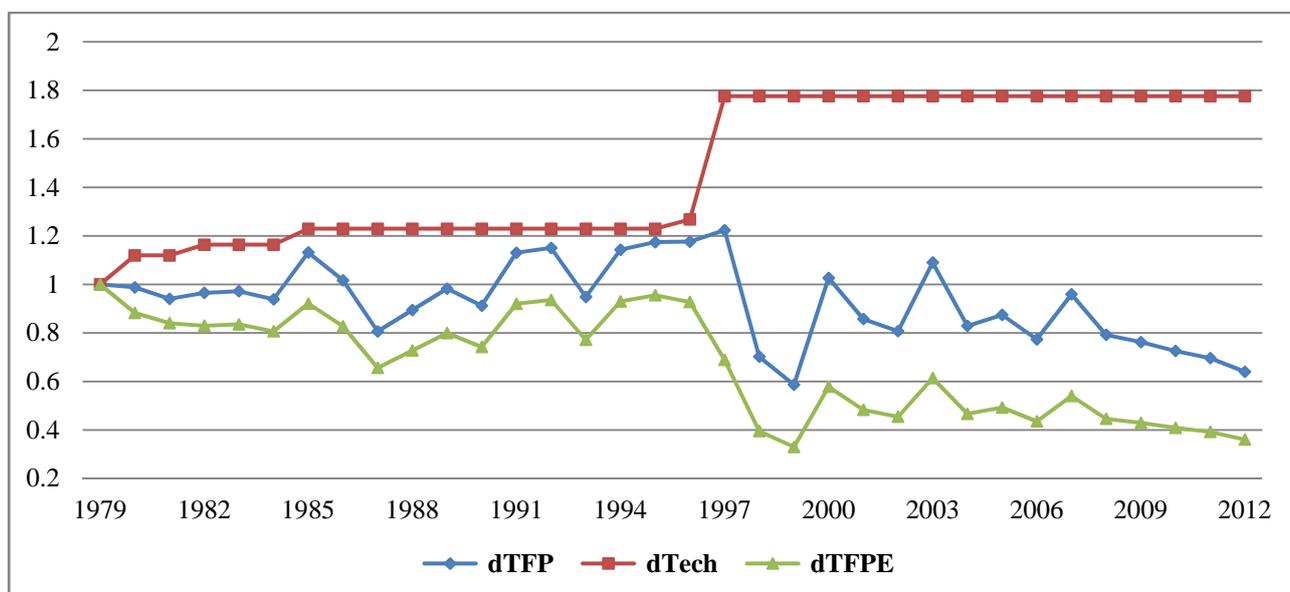
Figure 1: Total factor productivity (TFP) change and its components in Botswana

Table 3 reports the average annual growth rates of productivity and efficiency for different sub-periods. The first two sub-periods (1979 to 1996 and 1981 to 1996) in Table 3 enable us to compare our results to those of previous studies (e.g. Thirtle *et al*. 2003; Irz &Thirtle 2004). The other two sub-periods allow us to investigate performance under different policy reforms, for example the 1991 agricultural policy reforms are covered within the sub-period 1996 to 2002, and the 2002 agricultural policy reforms are included within the sub-period 2002 to 2012. Table 3 shows that productivity changes have fluctuated considerably throughout the sample period. Firstly, productivity is estimated to have grown at 0.95% p.a. for the sub-period 1979 to 1996; these estimates are higher than the -1.14% p.a. estimated by Irz and Thirtle (2004) for the same period. The difference between the results of this study and those of Irz and Thirtle (2004) are not surprising, considering the different approaches used (viz. non-parametric versus parametric methods). However, for the sub-period 1981 to 1996, we found that productivity grew by 1.7% p.a., which is consistent with the results of Thirtle *et al*. (2003), of 1.49% p.a. Our results complement those of Thirtle *et al*. (2003), with the main difference being that the approach we have used allows

us to disentangle changes in technical efficiency and scale-mix efficiency from the contribution of technical change to productivity growth.

Table 3: Average annual growth rates of total factor productivity and efficiency

Sub-periods	Total factor productivity change	Technical change	Total factor efficiency change	Technical efficiency change	Scale efficiency change	Mix efficiency change	Scale-mix efficiency change
1979 to 1996	0.95	1.40	-0.44	0.00	-0.10	-0.62	-0.36
1981 to 1996	1.49	0.83	0.66	0.22	-0.10	-0.35	0.33
1996 to 2002	-6.27	5.62	-11.89	-5.12	-0.15	1.38	-5.32
2002 to 2012	-2.33	0.00	-2.33	-4.83	-0.08	-0.10	1.89
1979 to 2012	-1.35	1.74	-3.09	-2.40	-0.10	-0.10	-0.58

For the period 1996 to 2002, Botswana's agriculture experienced a large decline in TFP of 6.27% p.a. The decline in productivity growth during this period could be due to the combination of the droughts that affected the whole country, and the impact of the outbreak of contagious bovine pleuropneumonia (CBPP) disease in the 1995/1996 season (Burgess 2006; Statistics Botswana 2013; Van Engelen & Keyser 2013). Approximately 12% of the entire cattle population of the country was culled in 1996 to eradicate the disease (Bendsen & Meyer 2003; Van Engelen & Keyser 2013). The outbreaks of diseases and the cattle culling did not just affect livestock production, but also crop farmers, who were faced with draft power shortages and had to reduce their areas under cultivation (Bendsen & Meyer 2003). The sub-period 1996 to 2002 also coincided with the National Agricultural Policy Reform, which was formulated in 1991 and revised in 2002 (MoA 2014). The main aims of this policy were to improve food security, diversify the production base, increase output and productivity, increase employment, and provide a secure, productive and sustainable environment for producers (GoB 2014; MoA 2014).[1] It is not possible to attribute the patterns of productivity we measure in this study directly to the effects of policy changes, but we can concur with the conclusions of other studies (MoA 2002; Seleka 2005) in stating that policy changes during this period did not lead to an improvement in productivity growth. Possible reasons for the failure of these policy changes (in addition to drought and disease, as noted above) include untargeted support services such as extension, and a lack of sector-wide strategies, which often led to disruptions caused by some policy interventions (MoA 2002).

The trend in agricultural productivity for the sub-period 2002 to 2012 (which covers the period of the 2002 agricultural policy reforms) improved slightly over that of the previous sub-period (1996 to 2002), although it still was negative, at 2.33% p.a. This indicates that the successful restocking of livestock in Botswana after 1997 and government subsidy programmes such as the National Master Plan for Agriculture and Dairy Development (NAMPAADD), the Integrated Support Programme for Arable Agriculture Development (ISPAAD) and the Livestock Management and Infrastructure Development Programme (LIMID) that were introduced during the period may have been effective in slightly improving productivity in Botswana, but not sufficient enough to prevent negative TFP growth.[2]

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[1] In its first phase (1991), this policy reform was dominated by farm-level programmes such as the arable lands development programme (ALDEP) and the accelerated rain-fed arable programme (ARAP). These programmes provided farmers with free access to capital and operating inputs (MoA, 2014) in order to further promote technology adoption and increase productivity (Seleka 1999; 2005).

[2] The objectives of NAMPAADD are to improve the performance of the agricultural sector by modernising it through the introduction of improved technologies and the efficient use and management of land and water resources, and by commercialising the sector (MoA 2002). The aims of ISPAAD, on the other hand, are to address the challenges facing arable farmers and the inherent low productivity of the arable subsector through provision of cluster fencing, the provision of potable water, etc. LIMID was implemented to address issues in the livestock sector by promoting food

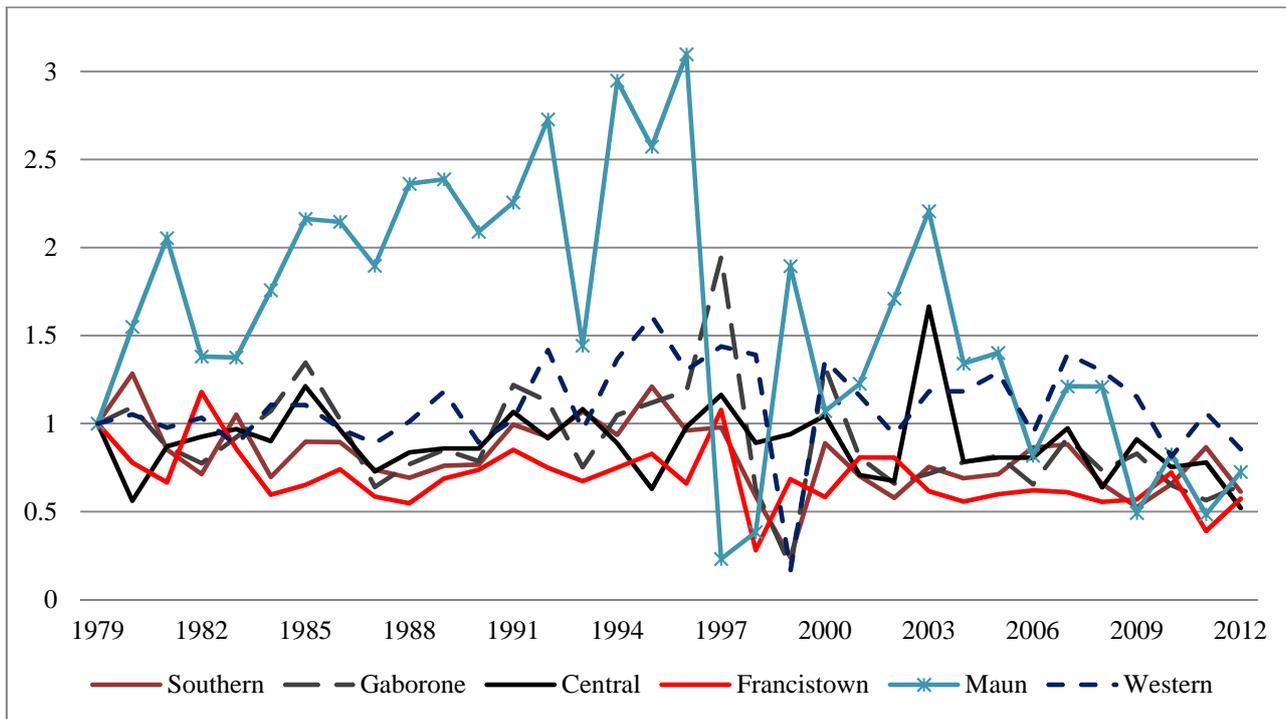**3.2 Regional productivity and efficiency growth**

The previous section analysed overall agricultural performance at the level of the national economy. However, the results said nothing about the complex dynamics driving agricultural productivity in the various regions of Botswana. Figure 2 presents the annual rate of productivity growth (TFP) at the regional level over the cumulative periods of 1979 to 1996, 1996 to 2002 and 2002 to 2012. Although all regions experienced a decline in productivity over the 34-year period, the region that experienced the smallest reduction in productivity was the Western region. In this region, TFP declined by 14.5% overall (0.47% p.a., composed of a 1.74% p.a. increase in technological progress and a decline in overall efficiency (TFPE) of 2.22% p.a.). In contrast, the greatest reduction in productivity was experienced by the Central region, at 1.98% p.a.

However, different sub-periods tell a different story from that of the overall study period. For example, for the first sub-period, from 1979 to 1996, three out of the six regions (Gaborone, Maun and Western) experienced positive TFP growth, led by Maun at 6.65% p.a. (Figure 3). For the second sub-period (1996 to 2002), there was only one region that had positive productivity growth (Francistown). During this period, Maun was the least productive region in Botswana, which is not surprisingly, since this is the region that was affected by the outbreak of CBPP that wiped out the entire cattle population in two of its three districts. For the last sub-period, from 2002 to 2012, Maun continued to be the least productive region in Botswana, which implies that the effects of the outbreak of CBPP disease have continued to have a negative impact on agricultural productivity in that region.

Thus, in summary, productivity in Botswana has declined over time, with the Central region experiencing the biggest fall (1.98% p.a.), followed by Francistown (1.7% p.a.) and Southern (1.5% p.a.), whilst regions such as Western and Maun experienced the smallest decline in productivity (Figure 2). Our findings are similar to those of previous studies by Thirtle *et al.* (2003) and Irz and Thirtle (2004), who also found that the regions with a reasonable proportion of livestock agriculture (i.e. Western and Maun) experienced a better TFP change over the study period than those regions with a significant proportion of arable agriculture. This confirms the fact that the soils and climate of Botswana are more suited to livestock production than to arable agriculture.

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security through improved the productivity of cattle, small stock and indigenous chickens; improving livestock management; improving range resource utilisation and conservation; and providing infrastructure for the safe and hygienic processing of poultry (meat) (MoA 2010).

Figure 2: Average annual growth rates of total factor productivity (TFP) by regions
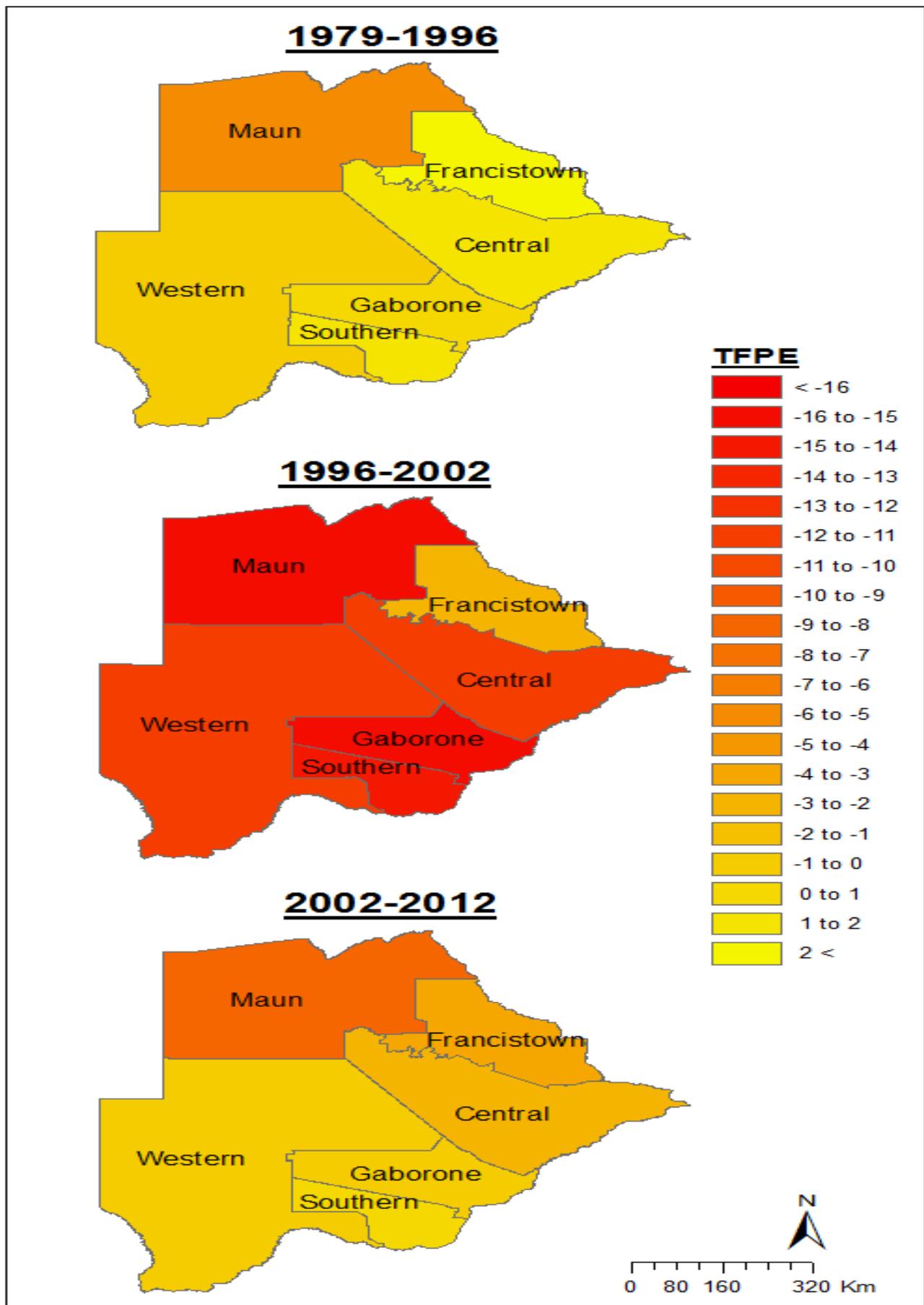
Figure 3: Average annual efficiency growth rates (%) by region: 1979 to 2012

O'Donnell (2008; 2011b) measures total factor productivity efficiency (TFPE) as an overall measure of firm performance, which can be defined as the ratio of actual TFP to the maximum TFP possible given the available technology. TFPE can be further decomposed into finer measures: technical, scale and mix efficiencies. Figure 3 summarises the regional-level TFPE growth over the cumulative periods of 1979 to 1996, 1996 to 2002 and 2002 to 2012. According to O'Donnell (2008; 2010), TFPE measures the overall productive efficiency of a firm as the ratio of observed TFP to the maximum TFP possible using the available technology. For the first sub-period, from 1979 to 1996, Francistown achieved the largest growth in terms of overall efficiency, followed by Southern (1.64% p.a.), Central (1.51% p.a.) and Gaborone (0.39% p.a.). The other two regions (Maun and Western), which also happen to be regions specialising in livestock, had negative growth in overall efficiency. For the second sub-period (1996 to 2002), none of the regions experienced positive efficiency growth. During this period, Maun and Gaborone experienced the largest decline in efficiency growth, whilst Francistown was the least affected region. For the last period of the study (from 2002 to 2012), only one region (Francistown) had positive efficiency growth, and once again Maun had the largest decline. The implications of these results are that, on average, the most inefficient farmers in Botswana are in the Maun region, whilst the most efficient are in the Francistown region. However, it must be noted that, when compared to the other regions, farmers in Maun region continue to face major constraints to agricultural production, such as pests and diseases – especially foot and mouth, animal-wildlife conflicts, and poor input and market access (this is the only region that is not allowed to sell livestock to the abattoirs that supply export markets). The performance of agriculture in this region therefore could be enhanced by effective the implementation of strategies aimed at addressing these challenges.

4. Conclusion and policy implications

The main aim of this study was to revisit measures of agricultural productivity growth in Botswana using an updated dataset and more recent methodology. We calculated the Färe-Primont index to obtain indicators of total factor productivity (TFP) in agriculture for six regions in Botswana, covering a 34-year period (1979 to 2012). TFP indices were decomposed into four main components: technical change, and changes in technical, scale and mix efficiency. The empirical results show that, during the study period, TFP declined due to a fall in overall efficiency (TFPE) of 3.09% p.a., in spite of a positive technological change (1.75% p.a.). The main driver of this decline was technical efficiency (2.40% p.a.) and a slight decline in mix efficiency (0.10% p.a.) and scale efficiency (0.10% p.a.).

The pattern of productivity growth over time fluctuated, with the first sub-period (1979 to 1996) exhibiting an annual growth rate of 0.95%. The largest decline in productivity growth (6.27% p.a.) occurred over the sub-period 1996 to 2002, possibly due to a combination of drought and the impact of the outbreak of CBPP disease. The trend in productivity for the period 2002 to 2012 improved slightly, although still was negative at 2.33% p.a. This implies that the successful restocking of livestock in Botswana and the policies introduced during that period may have contributed to this slight improvement in agricultural performance, but not sufficiently to reverse the negative productivity growth of previous periods. The estimates of overall efficiency vary from region to region, suggesting that there is scope for improving productivity by taking a differential regional approach to increasing efficiency. The study found that Botswana's agricultural performance is led by the regions that specialise in livestock production (Maun and Western), which is not surprising, given the soils and climate of Botswana.

Since the decline in overall efficiency (TFPE) was predominantly due to a decline in technical efficiency and a slight decline in mix efficiency and scale efficiency, any policy objectives that attempt to address these issues should be encouraged. The provision of relevant and accessible

extension services to farmers that deliver educational training, technology transfer and advice may help in improving farm management measures. As noted by Seleka (2005), strengthening individual farmers and farmer associations by improving their technical and entrepreneurial skills might play a significant role in eliminating the technical inefficiency that exists among farmers in Botswana.

Previous empirical literature on Botswana's agriculture has also indicated that technology transfer is slow due to the fact that the majority of farmers are less skilled in utilising new technologies, or are not aware of the benefits of existing programmes (Seleka 2005; MoA 2010; Van Engelen & Keyser 2013). For example, only about 2.43% of farmers accessed the infrastructure development component available under the LIMID 1 policy scheme (MoA 2010). Similarly, despite ISPAAD providing free access to fertilisers, uptake has been very low; only 10% of farmers utilised it in 2012 (Statistics Botswana 2014). It is also well established that smallholders in Botswana lack access to modern infrastructure; for example, only 45% of the farmers have access to roads and 22% to telecommunications (MFDP 2007). Low population density in semi-arid countries such as Botswana tends to make the opportunity cost of developing such infrastructure relatively high (Blench 2000). Thus, a key objective is to ensure that poor rural farmers have better access to – and the skills and organisation to take advantage of – existing policy schemes such as LIMID, ISPAAD and NAMPAADD. Within this framework, expanding the capacity for livestock production through the increased adoption of better livestock breeds, seed varieties and fertilisers, and the improvement of farm management, are potential facilitators for improving productivity and reducing rural poverty. In terms of addressing the issue of poor infrastructure, the provision of roads and telecommunications, boreholes, potable water and post-harvest facilities should also improve farmer productivity, where this is economical and practical.

Overall, in order to improve agricultural growth in Botswana there is a need for institutional strengthening and capacity building, infrastructure development, technology development and transfer, and institutional policy development and reforms. However, this study was limited to only the estimation of TFP and its various components. Various farm-specific factors (such as farm size, education and infrastructure) and government institutions (such as extension services and research development) are also significant in determining agricultural productivity. Therefore, the effects of these variables on agricultural productivity will need to be investigated in future studies.

Acknowledgements

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