MULTI-FACTOR AGRICULTURAL PRODUCTIVITY AND CONVERGENCE IN BOTSWANA, 1981-96[1]

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This paper calculates multi-lateral Malmquist multi-factor productivity (MFP) indices for agriculture in the eighteen regions and the commercial sector of Botswana from 1981 to 1996. The Malmquist is appropriate because prices do really exist for major inputs such as land and labour. The small size of the cross section is overcome by using the sequential version of the Malmquist, which accumulates the annual data, so increasing the stability of the frontier. The regional MFPs are the natural peer group for producing a national MFP, so the problem of choosing peers, in earlier work on international comparisons does not arise. The results show that the national MFP grew at an average rate 1.57% per annum. However, disaggregation by enterprise shows that the livestock MFP declined at a rate of 0.34% per annum while that for crops grew at 3.37% per annum. Decomposition of the Malmquist shows that there was positive technological change combined with decreasing efficiency. Comparisons of the regional results show a very clear pattern whereby the advantaged regions are able to exploit new technologies whereas the resource poor, geographically disadvantaged areas have been stagnant and have thereby fallen further and further behind the best practice frontier.

1. INTRODUCTION

This paper applies nonparametric Data Envelopment Analysis (DEA) methods to agriculture in the eighteen regions plus the commercial sector in Botswana for the period 1981 to 1996. This approach leads naturally to regional multilateral Malmquist multi-factor productivity (MFP) indices that are aggregated to give a MFP for the sector. The DEA approach is, of course, necessary because there are no prices for the major inputs such as land and labour in an African country at this stage of development, and thus the Tornqvist Theil approach is precluded.

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A number of studies have examined agricultural productivity differences between countries using the Malmquist productivity index (see for example Thirtle *et al*, 1995; Fulginiti & Perrin, 1997, 1998 and Arnade, 1998). The approach has been to construct the index with respect to a *contemporaneous* frontier technology, in which the frontier in year t+1 is compared only with that for year t, and all past history is ignored. The conventional Malmquist would also be somewhat unsatisfactory in this case, due the small size of the cross sectional sample. Thus, the sequential Malmquist, which accumulates the data, is used rather than the more common contemporaneous approach. This dimensionality problem has been somewhat neglected in empirical applications and can be crucial when the number of observations in the cross section is small relatively to the total number of inputs and outputs.

The remainder of this paper is organised as follows. Section 2 briefly describes the Malmquist productivity index with respect to the sequential frontier. Section 3 reports the MFP results, followed by a conclusion.

2. MALMQUIST PRODUCTIVITY INDEX AND SEQUENTIAL FRONTIERS

Tulkens and Van den Eeckaut (1995) differentiate between contemporaneous and sequential frontiers. In the contemporaneous approach, the frontier is constructed at *each period* using the observations at *that period only,* i.e. the frontier is constructed for each year separately. It is assumed that the frontiers at each year may be totally different from one another, with no a priori relationship between them. The frontier may move inwards, outwards, or intersect at any time, producing regress and progress in technology. This approach may be appropriate with a large number of observations and a short time period. In the sequential approach, the frontier is constructed at *each year* on the basis of all observations from *the first year up until the year considered*. In this way, the frontier may only shift towards the origin (in the input orientation) indicating only technological progress, or stagnation if the frontier does not move at all. No outward or intersecting shift is possible, thus excluding the possibility of technological decline.[1] Technical knowledge is assumed to accumulate over time, similar to an econometric model where there is no loss of information over the time period. This approach is especially appropriate where there are a small number of observations and a long time period.

The Malmquist productivity index with respect to the sequential frontier can be described briefly as follows. Let country $j = 1,2,..,J$ use inputs $x^t \in R^N_+$ to produce outputs $y^t \in R^M_+$ during the period $t=1,2,\ldots,T$. Production technology set can be defined as

$$S^{(1,t)} = \{(x^s, y^s) : x^s \text{ can produce } y^s\}, \ s = 1 \text{ up until } s = t \quad (1)$$

Alternatively, the production technology may also be represented with an input requirement set $L^{(1,t)}(y^t) = \{x^t : (x^t, y^t) \in S^{(1,t)}\}$. The within-period input distance functions are defined as

$$D_i^s(y^t, x^t) = \max\{\lambda : (x^t / \lambda) \in L^{(1,t)}(y^t)\} \quad (2)$$

and

$$D_i^{s+1}(y^{t+1}, x^{t+1}) = \max\{\lambda : (x^{t+1} / \lambda) \in L^{(1,t+1)}(y^{t+1})\} \quad (3)$$

The value of these distance functions is equal to or greater than one, but conventionally it is the reciprocals that are reported. Only if the value is equal to one are the countries efficient and therefore on the frontier.

The adjacent-period input distance functions may also be defined as

$$D_i^s(y^{t+1}, x^{t+1}) = \max\{\lambda : (x^{t+1} / \lambda) \in L^{(1,t)}(y^{t+1})\} \quad (4)$$

and

$$D_i^{s+1}(y^t, x^t) = \max\{\lambda : (x^t / \lambda) \in L^{(1,t+1)}(y^t)\} \quad (5)$$

These four input distance functions can be used to construct the Malmquist productivity index. Following Fare *et al*. (1994a) the Malmquist productivity index using input orientation for country *i* between period *s* and *s+1* is defined as

$$M_i^{s,s+1} = \left(\frac{D_i^s(y^t, x^t)}{D_i^{s+1}(y^{t+1}, x^{t+1})}\right)\left(\frac{D_i^{s+1}(y^{t+1}, x^{t+1})}{D_i^s(y^{t+1}, x^{t+1})}\frac{D_i^{s+1}(y^t, x^t)}{D_i^s(y^t, x^t)}\right)^{1/2} \quad (6)$$

The ratio in the first bracket captures technical efficiency change (TEC) and the ratio in the second bracket provides a measure of technological change (TC). TEC is greater than, equal to, or less than unity as technical efficiency accordingly improves, remains unchanged, or declines between periods *s* and *s+1*. TC is greater than or equal to unity, and shows whether the frontier is improving or stagnant. Since the Malmquist productivity index is the product of the two, by definition, it is also greater than, equal to, or less than unity. If the value of the index is greater than unity, it reveals improved productivity and if the value is less than unity, a decrease in productivity occurs. For detailed explanation of the methodology and the calculation see Grifell-Tatje and Lopez Sintas (1995) and Suhariyanto (1999).

3. MFP RESULTS AND CONVERGENCE

Agricultural total factor productivity and its components are calculated for 18 districts and the commercial sector in Botswana over the period 1981-1996 using data collected under a project conducted for the Department of Agricultural Planning and Statistics (Thirtle *et al*, 2000). The Malmquist productivity index is computed under the assumption of constant returns to scale using input orientation. The productivity is measured for aggregate agriculture, livestock and crops separately. For aggregate agriculture, the index is constructed using one a one output, five input (labour, seed, area, herds and draft power) technology. For livestock, there is one output and three inputs (labour, herds and feed) and for crops, one output and five inputs (labour, seed, area, draft power and rainfall). To reduce the effects of weather the data is smoothed using a three-year moving average.

3.1 Technical efficiency

Technical efficiency measures are defined as the ratio of potential inputs on the production frontier to observed inputs keeping output constant. A summary of results is in Table 1. Annual means for the levels of technical efficiency are reported for each district and the commercial sector. A value of one indicates that the district lies on the best practice frontier. In contrast, a value of less than one indicates that the district uses its agricultural inputs inefficiently. This means that the amount of all inputs can be reduced proportionally without reducing output.

The results show that on average, the estimated technical efficiency score in Botswana agriculture is 0.342, which reflects the difficult conditions faced by farmers in many regions. The scores are also very low for livestock and crops, when treated separately. However, the crop sub-sector is technically more efficient than livestock. These results show that Botswana does not yet manage its agricultural sector efficiently indicating that efficiency growth opportunities are available.

Turning to the district-by-district results, several points are worthy of note. First, the commercial sector is technically much more efficient than the traditional sector. It consistently defines the frontier of technology in most of the periods. Its average technical efficiency scores are 0.986 for aggregate agriculture, 0.852 for livestock and 0.820 for crops. The fact that technical efficiency in the commercial sector is much higher than that of the traditional sector is not surprising since the commercial sector is characterised by intensive agriculture while the traditional sector is extensive.

Table 1: Average technical efficiency in Botswana, 1981-1996

District	Aggregate agriculture	Livestock	Crops
Barolong	0.239	0.202	0.569
Ngwaketse South	0.239	0.206	0.683
Ngwaketse North	0.182	0.189	0.262
Southern Region	0.220	0.199	0.505
Bamalete	0.192	0.222	0.260
Kweneng North	0.198	0.191	0.430
Kgatleng	0.251	0.231	0.581
Kweneng South	0.207	0.211	0.366
Gaborone Region	0.212	0.214	0.409
Palapye	0.227	0.208	0.393
Mahalapye	0.230	0.205	0.413
Serowe	0.300	0.267	0.436
Bobonong	0.235	0.221	0.476
Central Region	0.248	0.225	0.429
Tutume	0.206	0.204	0.188
Tati	0.208	0.200	0.406
Francistown Region	0.207	0.202	0.297
Ngamiland West	0.305	0.235	0.158
Ngamiland East	0.517	0.277	0.081
Chobe	0.234	0.211	0.215
Maun Region	0.352	0.241	0.151
Ghanzi	0.917	0.311	0.022
Kgalagadi	0.622	0.238	0.015
Western Region	0.770	0.275	0.019
Commercial	0.986	0.852	0.820
National	0.342	0.257	0.357

Second, technical efficiency levels vary considerably among districts. Average technical efficiency scores for aggregate agriculture in Ghanzi and Kgalagadi, for example, are 0.917 and 0.622 respectively, while in Ngwaketse North it is only 0.182, which is the lowest technical efficiency score. In other districts, considerable inefficiency is also found.

Third, technical efficiency also varies considerably between agricultural sub-sectors. One district may have a high technical efficiency in livestock but a low technical efficiency in crops. In Ngwaketse South, for instance, average technical efficiency for crops is 0.683, but it is only 0.206 for livestock.

3.2 Productivity growth

Agricultural total factor productivity and its components are calculated for 18 districts and Commercial sector in Botswana over the period 1979-1996. Annual means of the Malmquist productivity index and its components are presented in Table 2.

Table 2: Annual means of MFP and its components in Botswana

	Aggregate agriculture			Livestock			Crops		
Year	TEC	TC	MFP	TEC	TC	MFP	TEC	TC	MFP
1981-82	0.899	1.125	1.012	0.916	1.094	1.001	0.862	1.089	0.939
1982-83	0.909	1.076	0.977	0.819	1.207	0.989	0.742	1.011	0.750
1983-84	1.054	1.024	1.079	0.925	1.161	1.074	0.658	1.002	0.659
1984-85	1.045	1.061	1.109	1.056	1.002	1.058	0.946	1.101	1.042
1985-86	0.891	1.142	1.017	0.999	1.004	1.004	1.181	1.002	1.183
1986-87	0.883	1.041	0.919	0.955	1.006	0.960	1.127	1.016	1.145
1987-88	0.889	1.029	0.915	0.875	1.008	0.882	1.279	1.115	1.425
1988-89	0.938	1.003	0.941	0.943	1.007	0.950	1.111	1.096	1.218
1989-90	0.949	1.031	0.978	0.984	1.011	0.994	1.136	1.015	1.153
1990-91	1.026	1.005	1.031	1.025	1.003	1.028	1.026	1.004	1.029
1991-92	1.082	1.008	1.091	1.000	1.003	1.003	1.076	1.043	1.122
1992-93	1.030	1.029	1.060	1.034	1.002	1.036	1.019	1.012	1.032
1993-94	0.985	1.032	1.016	1.008	1.001	1.010	0.926	1.002	0.928
1994-95	0.987	1.014	1.001	0.983	1.003	0.986	1.026	1.104	1.132
1995-96	1.121	1.018	1.141	0.971	1.005	0.976	0.870	1.153	1.003
Mean	0.976	1.040	1.016	0.964	1.033	0.996	0.985	1.050	1.034
Growth (%)	-2.37	4.03	1.57	-3.57	3.26	-0.43	-1.51	4.96	3.37

Since the Malmquist productivity index is multiplicative, the averages are also multiplicative, that is, the geometric rather than arithmetic mean is appropriate. Then, the product of the geometric means of the technical efficiency change (TEC) and technical change (TC) is equal to the geometric mean of the Malmquist MFP index, and all is consistent. Improvements in agricultural productivity and its components occur when the values of the indices are greater than one. The value of the index at a point in time minus one indicates the percentage of growth.

Agricultural productivity increases slightly over the 1979-1996 period at an annual growth rate of 1.57 per cent. This masks a great variation in productivity change from year to year. During the period of the study, technical change dominates technical efficiency change as the main source of productivity growth. The rate of change in technical efficiency is -2.37 per cent while technical progress approximates to an average growth rate of 4.03 per cent per year. This means that the production frontier has shifted inward while the gap between standard practice and best practice widens. Innovation (technical change) appears to be the main source of agricultural productivity growth in Botswana, suggesting that it has benefited modestly from the introduction of new agricultural technology. This fact is clearly shown in Figure 1, which illustrates annual averages of MFP, TEC and TC indices over time.

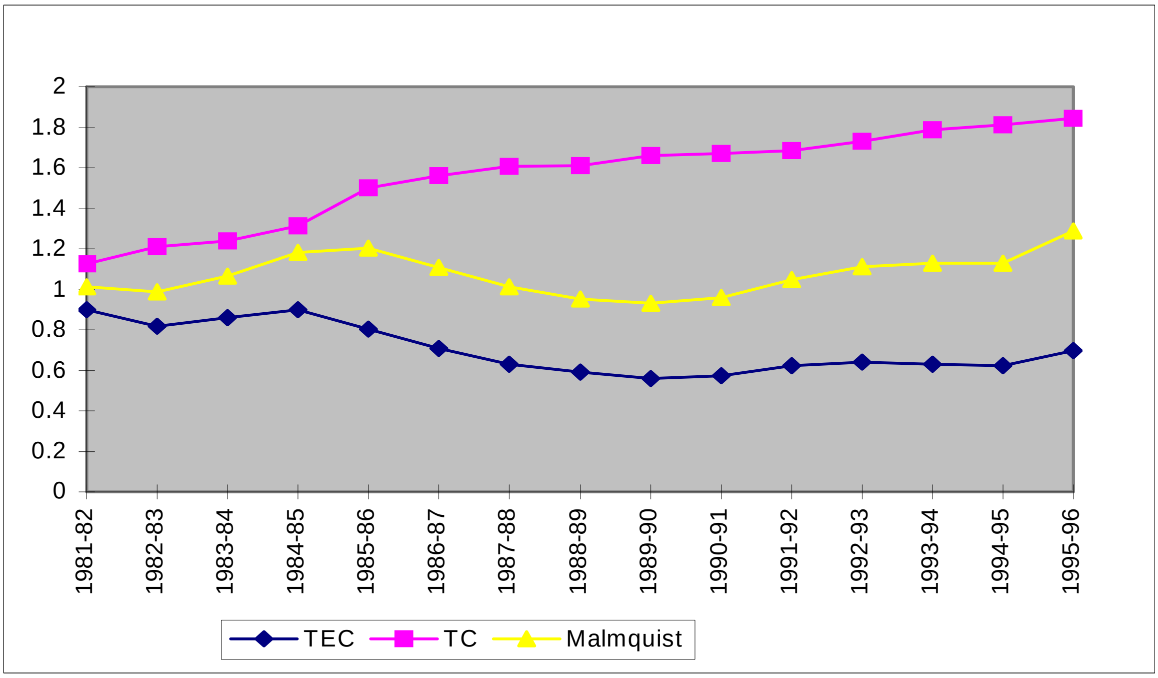

Figure 1: Aggregate agriculture: The Malmquist index and its components

For the crop sub-sector, productivity also increases at an average growth rate of 3.37 per cent but for livestock it decreases slightly at an annual rate of 0.43 per cent. Notice that for livestock and crop sub-sectors, the main reason for agricultural productivity growth is also technical progress. The contribution of technical efficiency change to productivity growth is minor since they experience a loss of technical efficiency. However, it is clear that the rate of technical change for crops is higher than that for livestock. The fall in technical efficiency for livestock is also the sharpest.

The pattern of productivity growth for livestock is different from that of aggregate agriculture, as Figure 2 shows. In this sub-sector, the number of districts having a negative productivity growth is ten (all districts in Southern region, three districts in Gaborone region, two in Central and two in

Francistown region). These ten districts have experienced a sharp decrease in technical efficiency. The loss of technical efficiency is considerable and cannot be substituted by improvement in technology, which causes a decrease in productivity. The highest productivity growth for livestock is found in Maun region. Ngamiland East has the highest productivity growth (4.82 per cent), followed by Chobe (3.95 per cent) and Ngamiland West (3.52 per cent). In these three districts, livestock productivity increases due to both innovation (technical progress) and efficiency improvements.

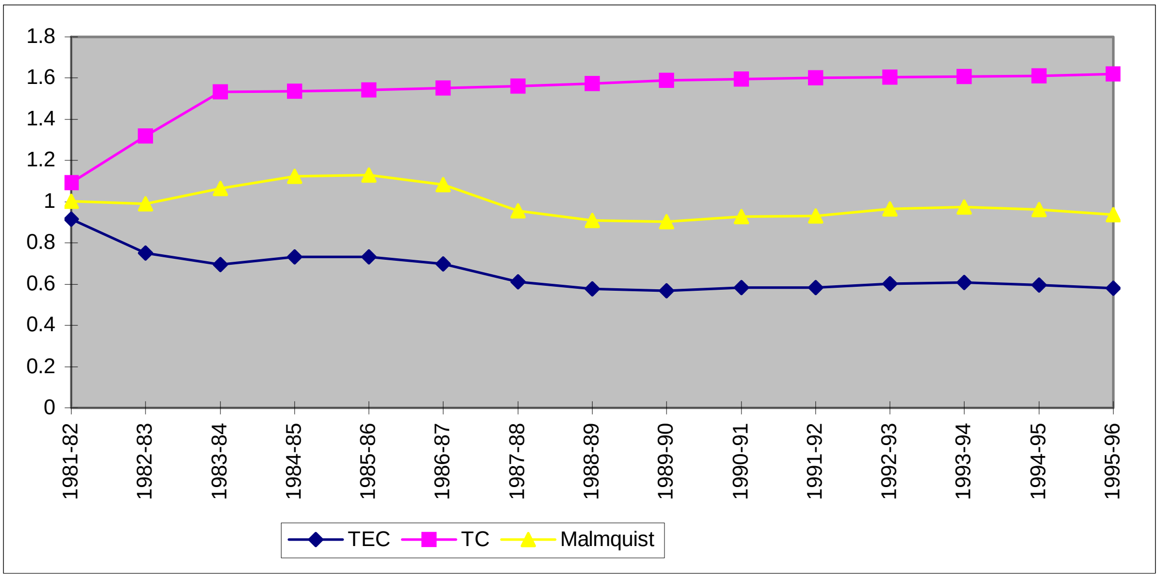

Figure 2: Livestock: The Malmquist index and its components

Table 3 presents annual growth rates of the Malmquist productivity index and its components during the 1979-1996 period. For aggregate agriculture, the results show that only five out of 18 districts have negative productivity growth. The rest of the districts and Commercial sector have positive productivity growth. Three districts (Ngwaketse South, Mahalapye, Kgalagadi) have less than one percent positive growth, five are between one and two percent and five districts plus the Commercial sector grow at more than two percent per annum. Note that the agricultural productivity increases are mainly due to improvement in innovation (technical progress).

All of them, except Ngamiland East, Chobe, Ghanzi and Commercial sector, have experienced a fall in technical efficiency. The highest productivity growth is found in the Commercial sector (9.48 per cent) followed by Ghanzi (6.68 per cent) and Ngamiland East (6.12 per cent).

The results provide a less gloomy picture about crop productivity in Botswana, which is summarised in Figure 3. The estimate shows that only five

Table 3: Annual growth rates (per cent) of MFP and its components, 1981-1996

	Aggregate agriculture			Livestock			Crops		
District	**TEC**	**TC**	**MFP**	**TEC**	**TC**	**MFP**	**TEC**	**TC**	**MFP**
Barolong	-5.83	4.02	-2.04	-5.79	3.20	-2.77	-7.11	2.29	-4.98
Ngwaketse South	-2.48	2.95	0.40	-4.30	3.00	-1.43	-2.78	5.76	2.82
Ngwaketse North	-5.86	3.35	-2.71	-5.72	3.21	-2.69	-3.79	6.38	2.34
Southern region	-4.74	3.44	-1.46	-5.27	3.14	-2.30	-4.58	4.79	-0.01
Bamalete	-3.43	5.54	1.92	-1.61	3.12	1.46	-3.18	4.63	1.30
Kweneng North	-3.02	4.26	1.12	-4.11	3.27	-0.97	2.68	2.26	5.00
Kgatleng	-2.33	4.35	1.92	-5.13	3.12	-2.17	3.00	3.85	6.96
Kweneng South	-5.35	3.26	-2.27	-6.56	3.16	-3.61	0.43	8.09	8.55
Gaborone region	-3.54	4.35	0.66	-4.37	3.17	-1.34	0.70	4.69	5.42
Palapye	-0.49	3.09	2.59	-2.99	3.17	0.08	1.64	6.58	8.33
Mahalapye	-5.24	5.58	0.05	-6.16	3.01	-3.33	2.10	6.24	8.47
Serowe	-1.08	3.03	1.91	-1.60	3.72	2.06	3.72	3.99	7.86
Bobonong	-0.37	3.18	2.81	-3.97	3.18	-0.92	5.66	7.67	13.77
Central region	-1.81	3.72	1.83	-3.69	3.27	-0.54	3.27	6.11	9.58
Tutume	-3.84	3.61	-0.37	-4.85	3.13	-1.87	-0.43	5.24	4.79
Tati	-4.81	4.86	-0.18	-9.74	3.42	-6.66	6.41	5.65	12.42
Francistown region	-4.33	4.24	-0.28	-7.33	3.27	-4.29	2.93	5.45	8.54
Ngamiland West	-0.58	1.82	1.23	0.41	3.09	3.52	-7.63	3.73	-4.18
Ngamiland East	3.94	2.09	6.12	1.57	3.21	4.82	-8.88	3.30	-5.88
Chobe	0.61	3.55	4.18	0.63	3.30	3.95	-4.20	4.17	-0.21
Maun region	1.30	2.49	3.82	0.87	3.20	4.10	-6.92	3.73	-3.45
Ghanzi	0.00	6.68	6.68	-0.83	3.14	2.28	-9.76	6.28	-4.09
Kgalagadi	-4.22	4.71	0.29	-2.57	3.10	0.45	-2.10	2.29	0.14
Western region	-2.13	5.69	3.44	-1.71	3.12	1.36	-6.01	4.27	-2.00
Commercial	0.00	9.48	9.48	-3.78	4.44	0.50	-2.41	6.18	3.63
National	-2.37	4.03	1.57	-3.57	3.26	-0.43	-1.51	4.96	3.37

out of 18 districts have negative growth during the 1976-1996 period. They are Barolong, Ngamiland West, Ngamiland East, Chobe and Ghanzi. Note that three of these five districts are located in Maun region, which have a very high productivity in livestock. This fact indicates that farmers in Maun region should concentrate more on livestock to be better off. The other 13 districts and Commercial sector have experienced an increase in productivity. The sources of this growth can be determined from the last three columns of Table 3.

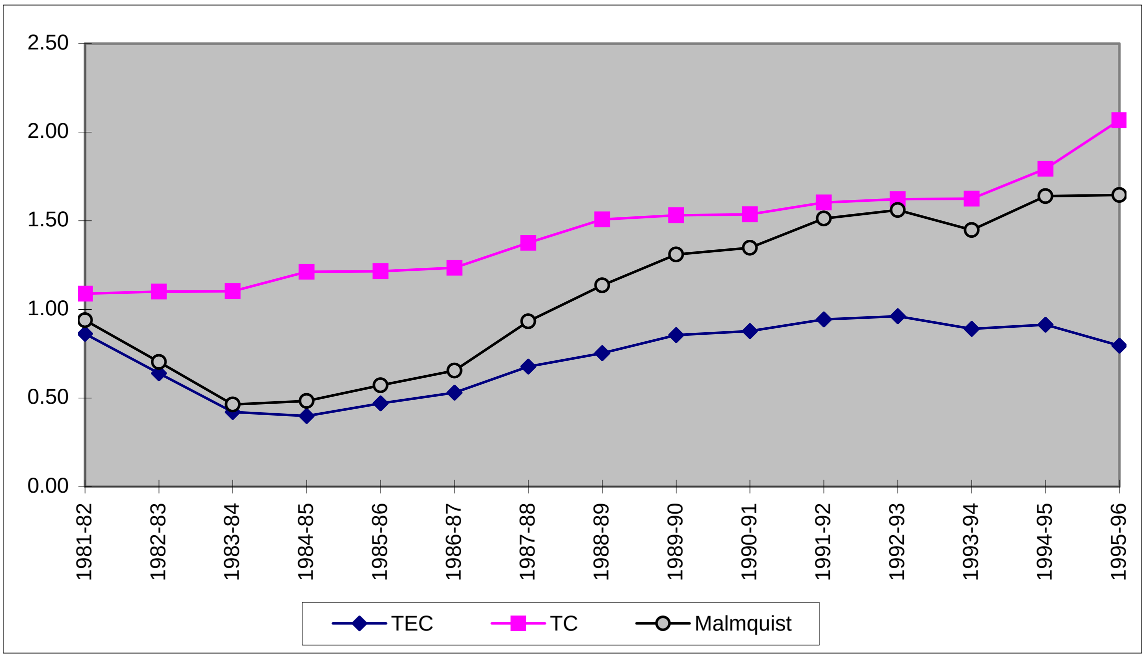

Figure 3: Crops: The Malmquist index and its components

Technical efficiency in many districts has improved and there is a significant technological progress. Bobonong has the highest productivity growth (13.77 per cent), followed by Tati (12.42 per cent) and Kweneng South (8.55 per cent). These three districts have a negative productivity growth in livestock, indicating that the farmers will be better off if they concentrate more on crops than livestock.

3.1. Regional convergence in productivity

The purpose of this section is to observe the behaviour of agricultural productivity growth rate over time, focusing on the question of whether convergence in agricultural productivity is occurring in 18 districts and the commercial sector in Botswana from 1976-1996. As the level of trade and technological interaction between districts increases over time, productivity levels are expected to converge. Convergence, therefore, implies a tendency for districts with low levels of productivity at the beginning of the period to grow more rapidly than those with high productivity initially. Thus, if the gap in agricultural productivity differences among districts is narrowing, the poor are catching up.

Beta convergence, tests the tendency of districts with relatively low initial levels of productivity to grow relatively faster than high level productivity districts. This implies a negative correlation between districts' initial level of productivity and their growth rates. Defining the average growth rate of productivity for each district *i* between periods *0* and *T* as $g_{i,T} = T^{-1}(y_{i,t} - y_{i,0})$, a test of Beta convergence is carried out by running regressions with the subsequent growth rate as the dependent variable and the initial level of productivity as the explanatory variable as follows,

$$G_{I,t} = \alpha + \beta y_{i,0} + \varepsilon_{i,T} \quad (7)$$

where α and β are parameters and $\varepsilon_{i,T}$ is an error term with a zero mean and finite variance. The economies converge if the value of β is negative and significant. In this case, the convergence is said to be *absolute* since initial level of productivity is the only independent variable used. In contrast, if the value of β >0, divergence takes place.

In order to see the behaviour of agricultural MFP over time, the plots of cumulative MFP index for each district and the commercial sector in Botswana is presented in Figure 4

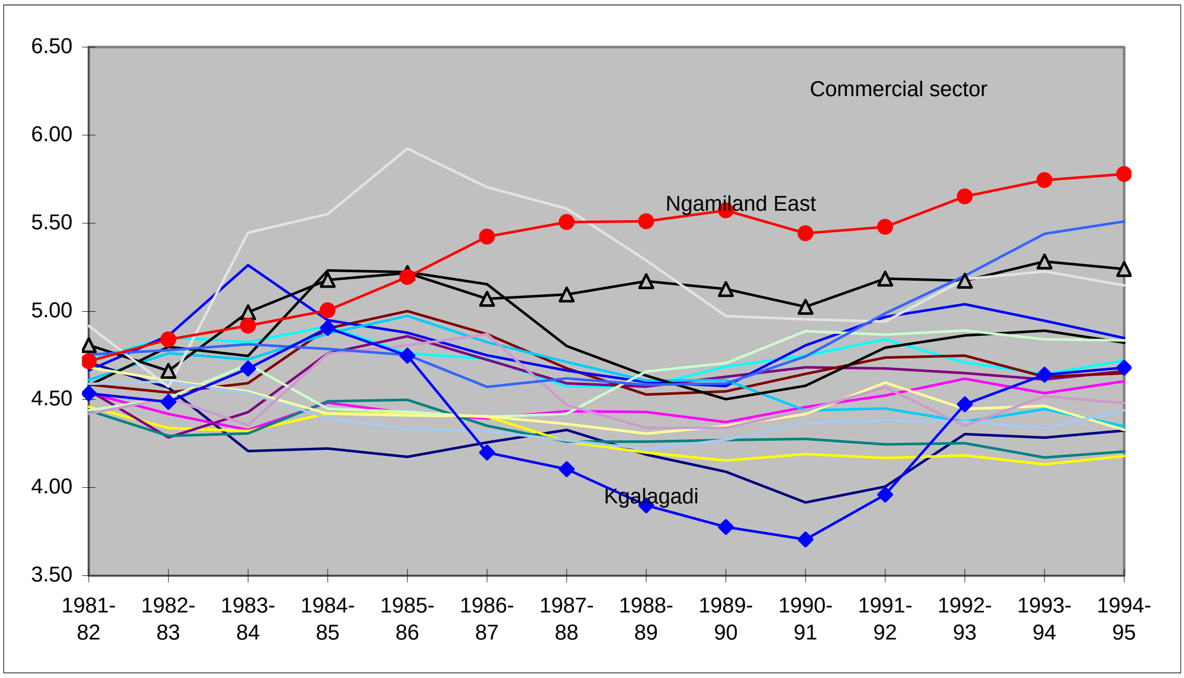

Figure 4: Log of total factor productivity

Contrary to the prediction based on the theory, the Figure provides no evidence of Beta convergence. In fact, the districts that initially have high productivity levels tend to grow faster than low productivity districts. While agricultural productivity grows rapidly in the commercial sector and

Ngamiland East, it is constant or decreases in other districts such as Barolong. As a result, the dispersion of agricultural MFP among districts over time has widened.

To test for Beta convergence, the growth rate of productivity is regressed on its initial level and a constant, as in equation (7). The regression results are reported in Table 4. The estimated parameter β, which is the coefficient of the initial productivity level, is positive and highly significant, which is strong evidence that agricultural productivity in Botswana's districts does not converge. In fact, there is divergence and districts with low levels of productivity at the beginning of the period grow less rapidly than the high productivity districts. Comparisons of the regional results show a very clear pattern whereby the advantaged regions are able to exploit new technologies whereas the resource poor, geographically disadvantaged areas have been stagnant and have thereby fallen further and further behind the best practice frontier.

Table 4: Testing for *Beta* convergence

Period	Variable	Coefficient	SE	t statistics	R^2
1979-1996	α	-57.511*	21.527	-2.67	0.31
	β	12.835*	4.661	2.75	

** Both coefficients are significant at >99 per cent*

6. CONCLUSION

The MFP indices show that for the agricultural sector there has been growth in productivity (output per unit of inputs) at the rate of 1.57 per cent per annum. The Figures suggest that at the sector level there was some growth in the early years and again at the end of the period, but the dominant effect is the influence of the many years of poor rainfall in the middle of the period. Thus, the trend is hard to determine, but it is reasonable to accept the fairly modest growth rate reported above. Decomposing the sector shows that there is even more variation and no evidence of growth for the dominant animal sector. Indeed, the livestock MFP **declines** at 0.43 per cent per annum. Thus, the sectoral growth result is determined by crop output, which grew at 3.37 per cent per annum, but again with considerable variation due to the weather. Analysis of the MFP series for the eighteen regions and the commercial sector shows that there is no evidence of convergence. That is, the poorer regions stay poorer, rather than catching up. There is also no clear evidence that the commercial sector performed significantly better than the traditional farmers.

NOTE

1. *This is appropriate in this case since it avoids the effects of the serious droughts from being classified as technological regress. Instead, their effect is manifested as efficiency losses, which is more reasonable.*

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