What is the appropriate level of aggregation for productivity indices? Comparing district, regional and national measures

B Conradie[1], J Piesse[2] & C Thirtle[3]

Abstract

This paper examines the appropriate level of aggregation for the construction of total factor productivity (TFP) indices. The dataset covers the magisterial districts and statistical regions of the Western Cape for the years 1952 to 2002. Over these five decades agricultural production in the Western Cape grew twice as fast as in the country as a whole but this average masks substantial regional variation. Results show that TFP growth was negative in the Karoo, moderate in the Swartland, Overberg and Southern Cape, and generally above 2% per year in the Boland and Breede River Valleys, where there is extensive irrigation.

Keywords: Total factor productivity; Western Cape; South Africa

1. Introduction

The National Agricultural Marketing Council has funded a study to investigate agricultural productivity in the Western Cape at the Magisterial District level, from 1952 to 2002. This is important since there has been no work on total factor productivity in South African agriculture since Thirtle *et al*. (1993), which looked only at the national aggregate. The dangers of this high level of aggregation are clear since Olmstead and Rhode (1993) showed that Hayami and Ruttan's (1985) demonstration of induced innovation in US agriculture does not withstand scrutiny at the regional level. Whilst the hypothesis is an adequate description of agricultural development in the Midwest, it does not sit at all easily with the data for the rest of the country, especially the Pacific Coast states.

The considerable level of disaggregation used in this paper allows careful scrutiny of the forces driving technical change, which are normally lost in the aggregation process. It shows very different patterns of productivity growth,

[1] *Dr Beatrice Conradie is senior lecturer in Economics at the Nelson Mandela Metropolitan University, Saasveld; E-mail: beatrice.conradie@nmmul.com; Tel: +29 44 801 5111.*
[2] *Dr Jenifer Piesse is Professor of International Business in the Department of Management, King's College London and the Department of Agricultural Economics, University of Stellenbosch; E-mail: jenifer.piesse@kcl.ac.uk; Tel: +44 (0)207 848 4164.*
[3] *Dr Colin Thirtle is Professor of Development Economics at Imperial College London and at the University of Pretoria; E-mail: C.Thirtle@ic.ac.uk; Tel: +44 (0)207 594 9337.*

particularly at the statistical area level. Since regions specialise in particular enterprises, it allows this aspect of agricultural diversity to show its effects on productivity. Extensive animal rearing has lower growth than field crops, which in turn fare far worse than horticulture (vegetables, fruit and wine). It should come as no surprise that the Karoo, which was shedding labour and reducing intensification, has little in common with the Western Cape winelands, where the emphasis is far more on improving product quality and intensification was still in process. Numerous other comparisons show how limited aggregate data are for reaching any policy relevant conclusions for advising local Departments of Agriculture.

The next section briefly outlines the theory behind TPF indices. Section 3 describes the available data and the problems involved in transforming it into consistent productivity statistics. The most interesting comparisons are reported and discussed in Section 4. Section 5 draws policy conclusions from this analysis.

2. Theory

Indices of total factor productivity (TFP) in agriculture measure aggregate output per unit of aggregate input, providing a guide to the efficiency of agricultural production. The methods used for dealing with capital items and farm produced inputs are explained in Thirtle *et al*. (1993), which also explains the Tornqvist-Theil aggregation procedure. The indices for each item are expressed as the logarithm of the ratio of two successive input or output quantities weighted by a moving average of the share of the input in total cost or of the output in total value, respectively. In equation (1) the X_j are the inputs or outputs and the C_j the shares.

$$\hat{X} = \frac{1}{2}\sum_{j}(C_{jt} + C_{j\,t-1})\ln\left(\frac{X_{jt}}{X_{j\,t-1}}\right) \qquad 1$$

The ratio of the output aggregate to the input aggregate is chained to accumulate the changes over time. Chambers (1988, pp. 242-243) shows that if productivity change is Hicks-neutral and the underlying quadratic production technology is the translog, then equation (1) is an exact measure rather than an approximation. Diewert has called an index that is exact for a flexible functional form[4], such as the translog, a superlative index.

[4] *A second-order approximation of an unknown underlying production function is referred to as a flexible functional form.*

3. District level data

Data collection and manipulation to construct consistent TFP indices constitutes the major part of this project to date. The data are from all the available Farm Censuses, which are for 1952, 1956, 1960, 1965, 1971, 1976, 1981, 1988, 1993 and 2002. Thus, there are only 10 observations per district, as prior to 1952 these data are too incomplete to produce reasonable results. The Abstract of Agricultural Statistics compiled by the Directorate Statistical Information of the National Department of Agriculture (Department of Agriculture, 1999), is a useful source of information for the period after 1950.

The aggregation of outputs and inputs, the X_j, in equation (1), usually starts from the lowest level. Thus, all the individual fruit crops were aggregated using the Tornqvist-Theil method, as were all the vegetables and wine. These were then aggregated to give the horticulture category. The other categories of output, aggregated in the same way, are livestock and livestock products, poultry and field crops. Then these four series are aggregated again to give a single output. The outputs should all be measured in physical terms, but in some instances, such as poultry, they were consistently reported only as current values. In such cases, a price deflator matching the input category was constructed and used to deflate the series, giving the equivalent of a physical series and so making the years comparable.

Table 1: Western Cape: 31 districts and nine regions

	Regions	Districts in each
1.	Cape Town	Cape Town – Wynberg – Simonstown – Bellville
2.	Boland	Stellenbosch – Kuilsrivier, Paarl, Somerset West – Strand, Wellington
3.	Overberg	Caledon – Hermanus, Bredasdorp, Swellendam, Heidelberg
4.	Southern Cape	Mossel Bay, George, Knysna, Riversdale
5.	Little Karoo	Oudtshoorn, Calitzdorp, Ladismith, Uniondale
6.	Breede River Valley	Worcester, Ceres, Tulbagh, Robertson, Montagu
7.	Swartland	Malmesbury – Moorreesburg, Hopefield – Vredenburg, Piketberg
8.	Olifants River Valley	Clanwilliam, Vanrhynsdorp – Vredendal
9.	Karoo	Beaufort West, Laingsburg, Murraysburg, Prince Albert

The inputs were aggregated from a similarly low level into labour (in man hours), land (in hectares) and intermediate inputs. The capital stock inputs are the herds of animals and machinery and equipment. Both the elements of intermediate inputs and machinery and equipment were simply added in current values and then deflated. It is the service flow from a capital stock that enters to the index, so for machinery and equipment it is depreciation (straight line over 10 years) and running costs.

4. Comparisons of national, district and regional productivity indices

National and provincial productivity

Aggregation is necessary to reduce the amount of information if it is too great to give a clear picture, but it also destroys information. For South African agriculture, the national aggregate index of Thirtle *et al*. (1993) showed that for 1947 to 1991, TFP grew at 1.26% per annum, but before 1965, there was no TFP growth at all. Then, growth was a healthy 2.15% per annum until 1981, after which it accelerated to 2.88% per year. However, the Western Cape is a distinct agro-climatic region, as it is the only winter rainfall area, and this is reflected in the output mix, which is dominated by deciduous fruit and wine grapes. Thus, there is little reason to expect results like those for the aggregate, and the Cape itself is heterogeneous.

Table 2 reports growth rates[5], first showing that over the full period TFP for the Western Cape grew at 1.22% per annum, which is not significantly different from the national average. This is the difference between the rate of output grow and that for inputs. However, the timing is different, as Figure 1 shows. Whereas TFP growth at the national level began in 1965, for the Cape it falls from 1965 to 1971 and then grows until the last period, when there is a decline again. For the early period, up to 1971, growth is not significantly different from zero. From 1971 onwards the estimate is 0.89% per annum, whereas the national figure is over 2%. However, the story for the province is one of moderate TFP grow, driven by intensification, resulting from output growing faster than inputs.

[5] *The growth rates are estimated by regressing the logarithm of TFP on a constant and a time trend. This is the method recommended by the FAO for averaging the disparate changes over the period.*

Table 2: Growth in inputs, outputs and TFP for the Western Cape regions and districts from 1952 to 2002

Area	Input	Output	TFP	Input	Output	TFP	Input	Output	TFP
		1952 – 2002			**1952 – 1971**			**1971 – 2002**	
Western Cape	0.0210	0.0332	0.0122	0.0271	0.0396	0.0125	0.0185	0.0274	0.0089
	10.66	16.19	4.79	2.91	6.38	1.10	7.12	5.22	1.62
		1952 – 2002			**1952 – 1965**			**1965 – 2002**	
Karoo	0.0017	-0.0055	-0.0072	0.0027	0.0212	0.0185	-0.0085	-0.0132	-0.0114
	0.74	-1.78	-2.81	0.24	3.23	1.20	-2.45	-3.69	-3.26
		1952 – 2002			**1952 – 1976**			**1976 – 2002**	
Olifants River Valley	0.0280	0.0452	0.0172	0.0357	0.0416	0.0058	0.0253	0.0440	0.0187
	14.04	16.62	4.25	10.00	6.28	0.68	4.64	5.14	1.46
Breede River Valley	0.0257	0.0479	0.0222	0.0329	0.0320	-0.0008	0.0228	0.0579	0.0351
	13.70	13.46	4.82	8.32	4.36	-0.09	5.68	5.18	2.95
Swartland	0.0277	0.0330	0.0053	0.0361	0.0317	-0.0044	0.0229	0.0400	0.0171
	12.30	7.32	1.36	8.63	3.26	-0.50	4.25	2.60	1.42
Malmesbury-Moorreesburg	0.0317	0.0354	0.0037	0.0461	0.0413	-0.0048	0.0215	0.0315	0.0099
	9.98	6.23	0.80	8.70	3.83	-0.50	3.77	1.62	0.60
Piketberg	0.0254	0.0337	0.0083	0.0263	0.0244	-0.0019	0.0284	0.0561	0.0277
	15.65	8.44	2.43	9.04	3.10	-0.25	5.53	11.40	26.20
		1952 – 2002			**1952 – 1971**			**1971 – 2002**	
Vredenburg-Hopefield	0.0130	0.0185	0.0054	0.0185	0.0562	0.0377	0.0085	0.0006	-0.0079
	4.95	2.48	1.01	1.62	1.87	1.94	1.54	0.04	-0.73

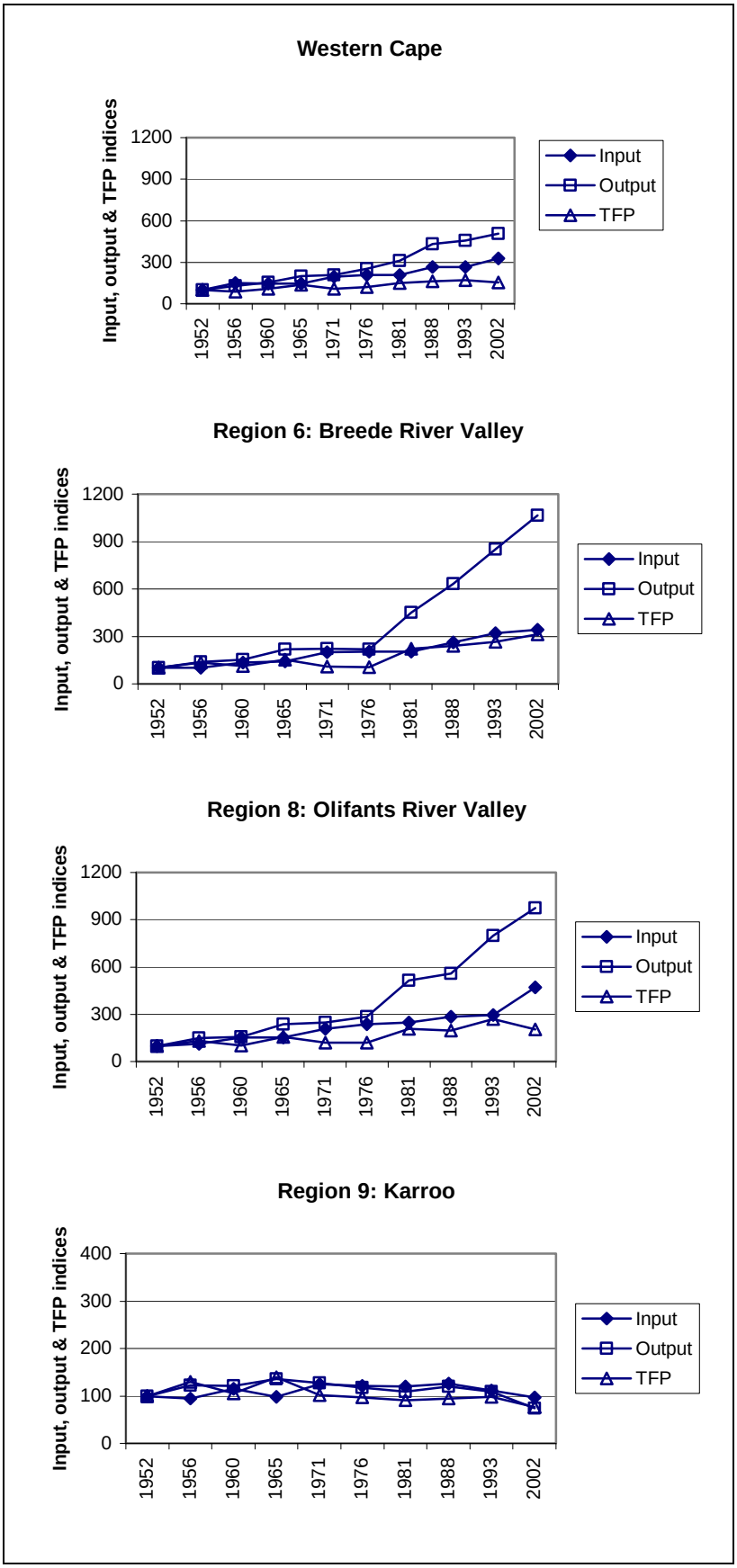

Figure 1: TFP growth for selected regions of the Western Cape, 1952 to 2002

Disaggregation to the regional level

The last panel in Figure 1 shows how different individual regions can be from the aggregate. The Karoo shows little evidence of TFP growth and indeed, Table 2 shows that TFP declined at 0.72% per annum between 1952 and 2002. The increase in inputs is not significantly different from zero, so there is no intensification, and output actually fell at 0.55% per annum. The Figure shows that unlike the nation or the province, if there is any growth it is up to 1965. However, Table 2 shows that the growth rate estimate of 1.85% per annum for this period is not significant. From 1965 onwards, when the country and province had good TFP growth, the Karoo has TFP decline at 1.14% per annum. Likewise, as the province intensified, agriculture in the Karoo became less intensive, but inputs did not decrease fast enough to keep pace with the fall in output. Table 2 shows that inputs fell at 0.85% per annum from 1971 onwards and output at 1.32%. These very different results reflect the output mix. The Karoo is dominated by sheep, so the post war wool boom is the most hopeful period. Once that was over, the arid climate did not allow much change in outputs, so the region has suffered a long, slow decline.

The picture for the Breede River Valley in Figure 1 has almost nothing in common with the Karoo. Table 2 reports the growth rate for the full period as 2.22% per annum, which is well above the figure for the country and the province. Again, this reflects the total difference in the output mix, as the Breede River Valley produces wine and fruit for canning, with periods in which ostrich and lucerne were important. Prior to 1976, there is intensification, with inputs growing at 3.3% per annum, but as output grew at only 3.2%, the growth in TFP is not significantly different from zero. Post 1976, there is a huge change, as Table 2 shows a slowing of input growth, combined with a big increase in output growth, to 5.8% per annum. Together, these changes give a TFP growth rate of 3.51%, which is way above the figure for the province or the country. Whereas the growth in outputs before 1976 reflects the developing wine industry, the take off after that date is mainly dependent on canned fruit, mostly for export. The main change that enabled this impressive productivity increase was not irrigation per se, as this dates back to the 1920s. Rather, it is the significant improvements in the productivity of irrigation water as the system evolved from primitive ditches and channels to culminate in modern drip irrigation.

The next region, which is the Olifants River Valley, has much in common with the Breede River. Figure 1 shows similar patterns for outputs, inputs and TFP, but they are less pronounced. Indeed, the Olifants is the 'poor man's Breede River', with similar developments occurring later. It is much smaller, the soil

and climate are less suitable for agriculture and it is penalised by high transport costs, due to the distance to the main market of Cape Town. Table 2 reports a TFP growth rate of 1.72%, due to outputs growing faster than inputs. As with the Breede River, the Table shows that TFP growth in the early period was insignificant. Again, input growth slowed in the second period, while output growth was maintained, so TFP grew at a more modest 1.87% per annum. Here, the take off is due to the introduction of irrigation and also rural electrification, as these amenities became available.

The fourth and last region considered here is Swartland, which is depicted first in Figure 2. For the full period, the results suggest intensification similar to that in the last two regions, but with no significant growth in productivity. The Figure suggests that this is because the history is more complex, as there is intensification, with input and output growth, up to 1971, followed by decline, recovery and decline again. Thus, the regressions for the early and later periods show outputs growing faster than inputs and significant TFP growth of 1.71% per annum in the later years, despite the downturn in 1993. Swartland grows predominantly wheat, but with increasing quantities of grapes and other fruit, such as plums around its border areas. It is not irrigated and the fall in output, despite an increase in inputs, that caused TFP to fall in 1976 is probably due to less than average rainfall. The poor year in 1993 is different, as inputs fell as well as outputs. This follows in the wake of deregulation of the wheat market, so it is one instance where policy effects seem to have a measurable impact. The effect is short lived, as inputs and outputs both recover in 2002.

Disaggregation of Swartland: Productivity at the district level

Finally, this study further considers the three districts that constitute the Swartland region, to see if this still lower level of aggregation can shed more light on somewhat confusing results for this region. The dominant district in this region, in terms of the weights used in aggregation, is Malmesbury-Moorreesburg and this is clear in Figure 2, which shows that the Swartland series are driven by Malmesbury-Moorreesburg. For all three series, the characteristics and turning points are the same and the only real difference is that TFP growth is not significantly different from zero in the later period. If the dominant district has no TFP growth in any period, another district must be responsible for this positive result at the regional level.

Figure 2 shows that Piketberg is the probable cause, as growth seems to be the dominant feature of all district series. The main crop is wheat, but with increasing amounts of more valuable apples, pears, peaches and table grapes. Switching to higher valued crops is one factor that drives TFP growth (Amadi *et*

al., 2004), so this is perhaps why Piketberg has both intensification and TFP growth for the full period, of 0.83%. This conjecture is reinforced by the lack of TFP growth in the first period, followed by a huge increase in output growth in the later period, to 5.6%, which gave TFP growth of 2.77%.

Indeed, this does seem to be the main cause of TFP growth in Swartland, as the final picture in Figure 2 shows that Vredenburg-Hopefield is unlikely to be contributory. This is an arid, non-irrigated region and this is reflected in the larger than usual variances of all three series, but particularly of output. There is less intensification than in the other districts and no TFP growth over the full period. However, provided that the very good year in 1971 is not caused by an aberration on the part of the statisticians (which is always possible), there is substantial intensification, with rapid output grow at 5.6% per annum, that causes a 3.77% per annum increase in TFP. Thus, probably due to nothing more systematic than the weather, Vredenburg runs counter to the overall trend, in having TFP growth in the early period, but nothing significant in the later period.

5. Conclusion

This paper presents productivity statistics at the provincial, regional and magisterial district level. These results are compared with a view to discovering the extent to which information on the rates and causes of productivity change are hidden by the aggregation process in series such as the national averages. There are very great differences between and within regions, which are not apparent at higher levels of aggregation. At lower levels, the effects of crop and animal mix become clear, as do differences in soil and climate. Causes of TFP change such as switching to higher valued outputs can also be identified. Finally, it is also possible, at these lower levels to see the impact of important changes like the introduction of irrigation and rural electrification. In aggregate statistics, these local events are not noticed, as they are continuous over time and space. Thus, a good case can be made for the collection of local information and the estimation of localised productivity measures to provide a basis for supplying locally relevant policy advice. It should be obvious that there is no "one size fits all" in the matter of improving agriculture, which has always been a very location specific activity.

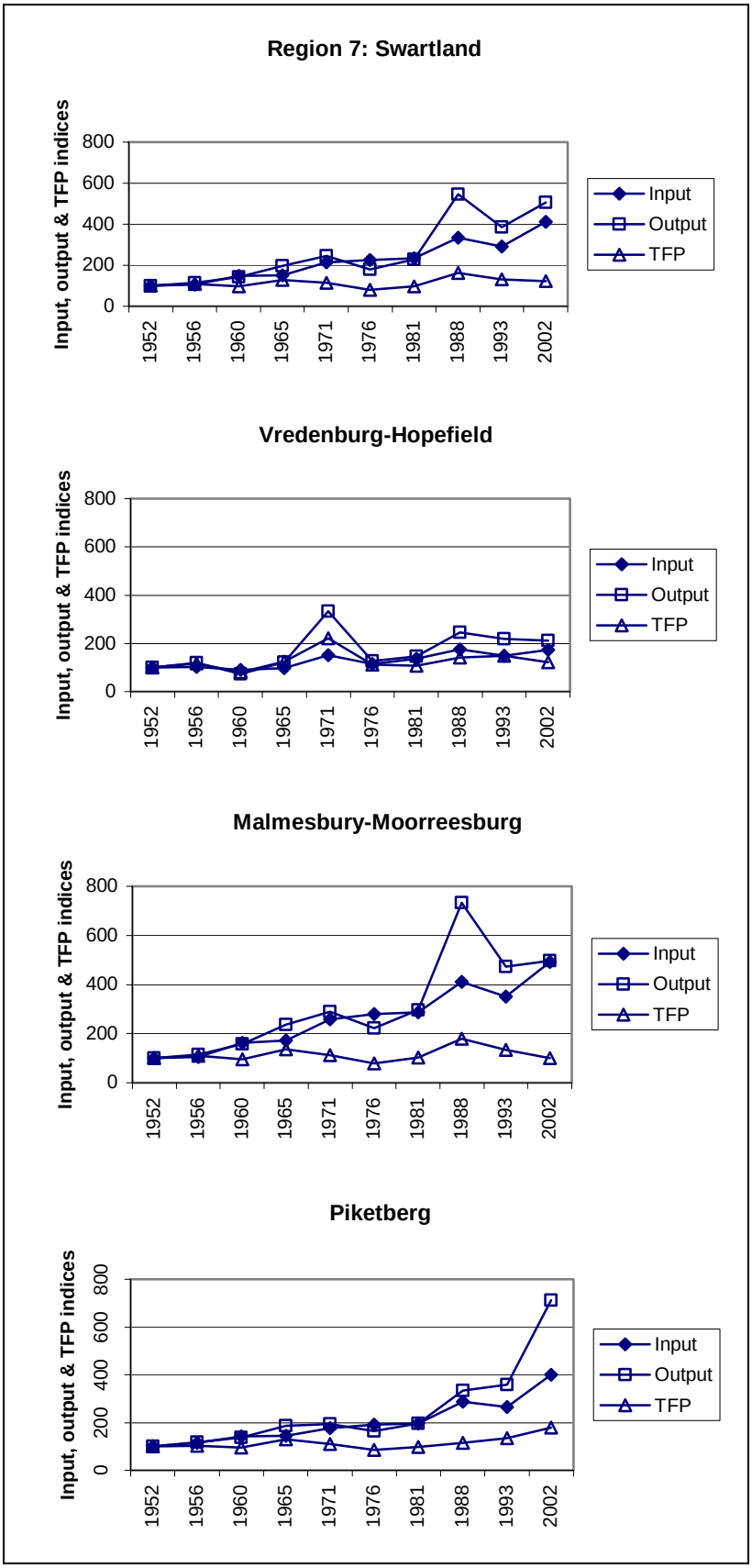

Figure 2: TFP growth for the districts of Swartland, 1952 to 2002

Our analysis raises several inadequacies, particularly in the data. First, the information available on rapidly growing sectors such as poultry, pigs and dairying is simply not correct. For example, it is obvious that Worcester should have a substantial numbers of chickens and the latest census records 412, while Wellington recorded millions at that point in time. Second, to enable researchers to compare over time, it is necessary to have current price values and appropriate deflators or even more simply we need prices and quantities to disentangle which of the two is changing. For several important variables, including farm machinery, this was not possible. As a result we had to use national level price deflators which probably caused errors in the data.

The other measurement problems are more subtle but not less important. Chemical and mechanical inputs have improved enormously over the last fifty years, but the data is inadequate for performing any kind of quality adjustment. Very simply a few drops of new generation pesticides replace barrels of copper sulphate, which is one of the earliest pesticides in the sample. There is also very obvious under-recording of animal outputs where there is substantial under-recorded home slaughtering[6]. Similarly, there is an important bakkie trade in slightly substandard fruit which remains unrecorded. Some other farm outputs are sporadically recorded (ostriches and wildflower harvesting) and some are not recorded at all (thatch reed and grass and honey). These items may be fairly constant but the error is bigger if there is rapid change in new land use practices, for example, converting sheep farms into game farms especially if this involves camping sites and provision of lodging and food. Perhaps even worse as a source of error is the diversification of income sources on wine estates, which now offer golfing, conference facilities, housing estates and wildlife viewing.

For the rest of the country perhaps the most important lesson is that it makes little sense to only record commercial agriculture whilst ignoring the substantial black smallholder sector. It is conceivable that as land is taken out of the commercial sector to be redistributed to previously disadvantaged South Africans, the productivity of commercial agriculture could improve as less efficient units are withdrawn. At the same time the subsistence and semi-subsistence sectors could experience TFP gains, yet as a national average productivity could be falling.

Acknowledgements

We thank the National Agricultural Marketing Council for their support and funding for this project.

[6] *We thank Nick Vink, who has made this point on numerous occasions.*

References

Amadi J, Piesse J & Thirtle C (2004). Crop level productivity in the Eastern counties of England, 1970-95. *Journal of Agricultural Economics* 55(2):367-383.

Chambers RG (1988). *Applied production analysis: a dual approach*. Cambridge: Cambridge University Press.

Department of Agriculture (1999). *Abstract of Agricultural Statistics: 1999*. Pretoria: Department of Agriculture.

Hayami Y & Ruttan V (1985). *Agricultural development: an international perspective* (rev. ed.). Baltimore: Johns Hopkins University Press.

Olmstead A & Rhode P (1993). Induced innovation in American agriculture: a reconsideration. *Journal of Political Economy* 101:100-118.

Thirtle C, Sartorius von Bach H & Van Zyl J (1993). Total factor productivity in South African agriculture, 1947-91. *Development Southern Africa* 10(3):301-318.