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AN ANALYSIS OF THE PRODUCTIVITY OF THE VICTORIAN WATER INDUSTRY

Staff Research Paper No. 12/1

TECHNICAL REPORT

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Contents

1 Introduction

This technical paper presents the analysis and research into productivity trends and comparative productivity levels of the Victorian water industry in the context of a benchmarking study covering water utilities across Australia. It also explores the reasons for productivity change and differences between utilities. It should be read as an adjunct to the accompanying summary report, which contains most of the conclusions and observations drawn from the analysis. The summary report has a glossary which explains technical terms used in this report also.

This study is intended to be relevant to economic regulation in the Victorian water sector.

1.1 The data

The data set used in this study is described in Appendix A. It is primarily based on statistical reports published by the Water Services Association of Australia (WSAA) and the National Water Commission (NWC). This has been supplemented by data obtained directly from water utilities, city councils and other agencies, particularly for drinking water quality, bulk water purchases and water restrictions.

There are 54 utilities included in the sample, all of which have both water supply and sewage collection functions.[1] For larger utilities the data series typically extends from 1997-98 to 2009-10, while for smaller utilities data was available for 2005-06 to 2009-10. The data sample is an unbalanced panel of 409 observations, with on average 7.6 years of data per utility.

Care needs to be taken when interpreting the results of this analysis in light of limitations in the quality and completeness of the data set. Although the WSAA and NWC data is the best available, it is dependent on the quality of information reported by water utilities, which may be variable. In some instances of data incompleteness, interpolation has been necessary.

[1] In some localities, where water supply and sewerage are provided by separate bodies, those bodies have been combined. Examples include Water Corporation Kalgoorlie-Boulder and City of Kalgoorlie-Boulder, Water Corporation Bunbury and Aqwest.

1.2 Structure and approach

This report is in three parts. Chapter 2, presents the index number approach to estimating productivity levels over time and between utilities. This involves constructing a Total Factor Productivity (TFP) index for each utility in each year. This provides information on:

- the trend in productivity for each utility
- the comparative levels of productivity of the different utilities.

Chapter 3 is an econometric study of the productivity frontier using distance functions. The econometric approach permits productivity change to be decomposed into its sources, including:

- technology improvement and the reduction in the inefficiency of utilities
- returns to scale effects due to changes in the level of outputs
- effects of other variables included in the model.

Chapter 4 discusses some other findings and comparisons between the index and econometric approaches.

2 Total Factor Productivity Indexes

This chapter calculates Total Factor Productivity (TFP) for the Australian water industry using a productivity index approach. Trends in productivity are calculated using fixed weighted indexes of inputs and outputs. These indexes can also be used to compare productivity levels, after making suitable adjustments for scale and density factors. This provides one method for ascertaining the relative technical efficiency of water utilities.

The index-based approach is primarily used as a cross-check for the econometric methodologies presented in chapter 3. It is relatively transparent because the sources of changes in TFP can most readily be traced back specific data.

2.1 Index Method

The rate of change in TFP is defined as the rate of change in an index of outputs less the rate of change in an index of inputs. The conventional Törnquist and Fisher indexes are chain indexes (ie, the weights change over time), but this study uses a different approach, called a Cobb-Douglas index. The weights are fixed over time and across utilities in the sample.

The measurement of the outputs and inputs used in the analysis is set out in chapter 2 of the Summary Report. It explains the methodologies used for quality-adjustment of water supply and sewerage services, normalising water supply for the effect of temporary water restrictions TWRs) and the measurement of capital and non-capital inputs. These are important aspects of this analysis. The measurement of capital raises particular issues.

In this study, all of the outputs and inputs are expressed as a ratio to the sample mean for that variable across all firms and time periods. This "normalisation", together with the use of fixed index weights, is sufficient to allow the construction of a comparative TFP index. This can be used to compare TFP levels between firms and over time. See Appendix C for an explanation of the methodology.

2.1.1 Cost elasticity output weights

Conventional output and input index approaches commonly use revenue shares as weights for the output index and cost shares for the input index weights. Similarly, in this study the weights for the input index are the shares of each input in average cost.[2] However, a different approach is taken to the output weights.

Revenue share weights are only valid if all outputs are priced and their prices are proportionate to their marginal cost of production. In regulated infrastructure industries this is often not the case. For example, Economic Insights[3] highlighted the importance of unpriced functional outputs in infrastructure industries— e.g. supply security or drinking water quality. Further, providers of essential services commonly have considerable flexibility in how costs are recovered and the charging structure may reflect historical factors, convenience, or other revenue raising objectives— i.e. not necessarily reflecting marginal costs.

In such circumstances, the appropriate output weights should be based on the marginal cost of each output. Specifically, the weights should be the 'cost elasticity shares', defined as the cost elasticity of the *i*th output, divided by the sum of the cost elasticities, summed over all outputs.[4] The calculation of these weights is detailed in Appendix B.

2.2 "Raw" TFP indexes

The resulting TFP indexes for each utility are shown in Table 2.1 and the rates of change are shown in Table 2.2. In the following section an adjustment is made to these indexes with the aim of taking out the influence of economies of scale on productivity, to better compare the relative efficiencies of utilities of different size. For this reason we refer to the information in Tables 2.1 and 2.2 as the "raw" TFP index. A large value for an index represents a higher level of productivity, when compared either over time or between utilities.

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2 This is consistent with economic theory if factor inputs are paid at their opportunity costs, so that the factor income shares are the value-based weights. In the water industry the input markets are not all competitive. For example, bulk water is supplied by other natural monopolies. For this study it is assumed that bulk water charges are cost-reflective.

3 Economic Insights, *Total Factor Productivity Index Specification Issues* (report prepared for Australian Energy Market Commission, December 2009).

4 Melvyn Fuss, 'Productivity Growth in Canadian Telecommunications', *The Canadian Journal of Economics*, 27(2) (May 1994), p 374. Note: Economic Insights suggests that when functional outputs are used, the appropriate output weights are the differences between the marginal cost and the price for each output. Fuss' method is used here.

Table 2.1 **"Raw" TFP Comparative Index**

Name	1st year	TFP index - water			TFP index - sewerage			TFP index - combined		
		Year 1	2006	2010	Year 1	2006	2010	Year 1	2006	2010
Major urban Victoria										
Barwon Water	1998	0.737	0.681	0.657	0.904	0.949	0.926	0.822	0.802	0.760
City West Water	1998	1.091	1.316	1.337	1.079	1.341	1.417	1.104	1.318	1.368
South East Water Ltd	1998	1.241	1.399	1.421	1.152	1.277	1.270	1.200	1.337	1.338
Yarra Valley Water	1998	1.224	1.390	1.367	1.171	1.294	1.254	1.211	1.375	1.321
Average - major urban Vic		**1.073**	**1.196**	**1.196**	**1.077**	**1.215**	**1.217**	**1.084**	**1.208**	**1.197**
Major urban Non-Vic										
ACTEW	1998	0.571	0.670	0.607	0.682	0.830	0.803	0.642	0.751	0.688
Hunter Water Corporation	1998	0.734	0.771	0.778	0.775	0.802	0.770	0.763	0.789	0.765
Sydney Water Corporation	1999	1.121	1.263	1.092	0.870	1.068	0.993	0.951	1.096	1.011
Brisbane Water	1998	1.136	1.199	1.177	1.161	1.159	1.170	1.146	1.160	1.168
Gold Coast Water	1998	1.032	1.047	0.997	0.983	1.056	1.011	0.974	1.056	0.990
SA Water - Adelaide	1998	0.851	0.947	0.860	1.175	1.236	1.235	0.959	1.066	1.008
Water Corporation - Perth	1998	0.848	0.907	0.864	0.856	1.004	1.025	0.890	0.987	0.958
Average - major urban non-Vic		**0.899**	**0.972**	**0.911**	**0.929**	**1.022**	**1.001**	**0.904**	**0.986**	**0.941**
Regional Victoria										
Central Gippsland Water	1999	0.619	0.512	0.546	0.799	0.697	0.586	0.731	0.633	0.586
Central Highlands Water	1998	0.587	0.503	0.466	0.960	0.825	0.782	0.768	0.635	0.593
Coliban Water	1998	0.652	0.616	0.565	0.922	0.673	0.663	0.811	0.670	0.629
Goulburn Valley Water	1998	0.609	0.635	0.574	0.876	0.745	0.734	0.746	0.735	0.674
East Gippsland Water	2006	..	0.490	0.458	..	0.550	0.585	..	0.536	0.514
GWMWater	2006	..	0.428	0.498	..	0.790	0.738	..	0.549	0.585

Name	1st year	TFP index - water			TFP index - sewerage			TFP index - combined		
		Year 1	2006	2010	Year 1	2006	2010	Year 1	2006	2010
North East Water	2006	..	0.538	0.524	..	0.683	0.718	..	0.621	0.622
Wannon Water	2006	..	0.438	0.405	..	0.712	0.712	..	0.557	0.533
Western Water	2005	0.605	0.635	0.619	0.796	0.777	0.768	0.702	0.712	0.679
South Gippsland Water	2006	..	0.508	0.447	..	0.742	0.673	..	0.626	0.554
Westernport Water	2006	..	0.598	0.629	..	0.681	0.664	..	0.589	0.612
Average - regional Vic		**0.614**	**0.541**	**0.530**	**0.871**	**0.725**	**0.702**	**0.752**	**0.631**	**0.609**
Regional Non-Vic										
Gosford City Council	1998	0.535	0.859	0.844	0.779	0.820	0.880	0.525	0.813	0.832
Wyong Shire Council	2006	..	0.825	0.719	..	0.826	0.850	..	0.817	0.768
Albury City Council	2006	..	0.645	0.397	..	0.849	0.753	..	0.726	0.452
Coffs Harbour City Council	2006	..	0.589	0.557	..	0.642	0.608	..	0.630	0.588
MidCoast Water	2006	..	0.499	0.476	..	0.599	0.595	..	0.521	0.517
Port Macquarie Hastings Council	2006	..	0.495	0.543	..	0.785	0.768	..	0.626	0.661
Shoalhaven City Council	2006	..	0.556	0.565	..	0.619	0.604	..	0.589	0.581
Tweed Shire Council	2006	..	0.540	0.601	..	0.689	0.677	..	0.588	0.663
Wagga Wagga	2006	..	0.442	0.435	..	0.872	0.821	..	0.592	0.575
Ballina Shire Council	2006	..	0.778	0.767	..	0.713	0.708	..	0.773	0.766
Bathurst Regional Council	2006	..	0.619	0.601	..	0.789	0.797	..	0.714	0.698
Bega Valley Shire Council	2006	..	0.451	0.445	..	0.545	0.501	..	0.511	0.465
Byron Shire Council	2006	..	0.838	0.861	..	0.632	0.627	..	0.708	0.741
Clarence Valley Council	2006	..	0.253	0.364	..	0.788	0.736	..	0.372	0.499
Country Energy	2006	..	0.454	0.440	..	0.759	0.673	..	0.599	0.560
Dubbo City Council	2006	..	0.462	0.551	..	0.694	0.686	..	0.556	0.638
Eurobodalla Shire Council	2006	..	0.432	0.376	..	0.564	0.628	..	0.476	0.456

Name	1st year	TFP index - water			TFP index - sewerage			TFP index - combined		
		Year 1	2006	2010	Year 1	2006	2010	Year 1	2006	2010
Kempsey Shire Council	2006	..	0.370	0.359	..	0.604	0.596	..	0.482	0.476
Lismore City Council	2006	..	0.809	0.781	..	0.651	0.648	..	0.762	0.755
Orange City Council	2006	..	0.515	0.575	..	0.738	0.779	..	0.620	0.660
Queanbeyan City Council	2006	..	0.906	0.918	..	0.886	0.857	..	0.898	0.893
Tamworth Regional Council	2006	..	0.488	0.517	..	0.733	0.703	..	0.595	0.602
Wingecarribee Shire Council	2006	..	0.493	0.544	..	0.554	0.550	..	0.543	0.572
Power and Water - Darwin	1998	0.384	0.680	0.640	0.813	1.151	1.069	0.587	0.870	0.834
Power and Water - Alice Springs	2006	..	0.474	0.514	..	0.932	0.908	..	0.594	0.660
Ipswich Water	2002	0.731	0.751	0.759	0.710	0.736	0.822	0.760	0.769	0.795
Logan Water	2003	0.802	0.851	0.907	0.808	1.175	0.706	0.806	0.959	0.744
Water Corporation - Mandurah	2006	..	0.836	0.773	..	0.714	0.718	..	0.858	0.782
Aqwest/Water Corp Bunbury	2007	..	0.660	0.811	..	0.705	0.737	..	0.703	0.781
Kalgoorlie-Boulder	2006	..	0.410	0.326	..	1.016	1.279	..	0.649	0.555
Water Corporation - Albany	2006	..	0.612	0.582	..	0.683	0.559	..	0.708	0.618
Average - regional non-Vic		**0.613**	**0.600**	**0.598**	**0.778**	**0.757**	**0.737**	**0.670**	**0.665**	**0.651**
Simple Average – all utilities		**0.800**	**0.827**	**0.809**	**0.913**	**0.930**	**0.914**	**0.852**	**0.873**	**0.850**

Source: ESC.

Table 2.2 **"Raw" TFP – Average Compound Rates of Change (per cent)**

Name	TFP change water		TFP change sewerage		TFP change - combined	
	Pre '06	'06 to '10	Pre '06	'06 to '10	Pre '06	'06 to '10
Major urban Victoria						
Barwon Water	-1.0	-0.9	0.6	-0.6	-0.3	-1.3
City West Water	2.4	0.4	2.8	1.4	2.2	0.9
South East Water Ltd	1.5	0.4	1.3	-0.1	1.4	0.0
Yarra Valley Water	1.6	-0.4	1.3	-0.8	1.6	-1.0
Average - major urban Vic	**1.1**	**-0.1**	**1.5**	**0.0**	**1.2**	**-0.3**
Major urban Non-Vic						
ACTEW	2.0	-2.4	2.5	-0.8	2.0	-2.2
Hunter Water Corporation	0.6	0.2	0.4	-1.0	0.4	-0.8
Sydney Water Corporation	1.7	-3.6	3.0	-1.8	2.0	-2.0
Brisbane Water	0.7	-0.5	0.0	0.2	0.1	0.2
Gold Coast Water	0.2	-1.2	0.9	-1.1	1.0	-1.6
SA Water - Adelaide	1.3	-2.4	0.6	0.0	1.3	-1.4
Water Corporation - Perth	0.9	-1.2	2.0	0.5	1.3	-0.7
Average - major urban non-Vic	**1.1**	**-1.6**	**1.3**	**-0.6**	**1.2**	**-1.2**
Regional Victoria						
Central Gippsland Water	-2.7	1.6	-1.9	-4.2	-2.1	-1.9
Central Highlands Water	-1.9	-1.9	-1.9	-1.3	-2.3	-1.7
Coliban Water	-0.7	-2.1	-3.9	-0.4	-2.4	-1.5
Goulburn Valley Water	0.5	-2.5	-2.0	-0.4	-0.2	-2.1
East Gippsland Water	..	-1.7	..	1.5	..	-1.0
GWMWater	..	3.9	..	-1.7	..	1.6
Lower Murray Water	..	1.4	..	-0.8	..	0.3
North East Water	..	-0.7	..	1.2	..	0.0
Wannon Water	..	-1.9	..	0.0	..	-1.1
Western Water	5.1	-0.7	-2.3	-0.3	1.4	-1.2
South Gippsland Water	..	-3.1	..	-2.4	..	-3.0
Westernport Water	..	1.3	..	-0.6	..	1.0
Average - regional Vic	**0.1**	**-0.5**	**-2.4**	**-0.8**	**-1.1**	**-0.9**
Regional Non-Vic						
Gosford City Council	6.1	-0.4	0.6	1.8	5.6	0.6
Wyong Shire Council	..	-3.4	..	0.7	..	-1.5
Albury City Council	..	-11.4	..	-2.9	..	-11.2
Coffs Harbour City Council	..	-1.4	..	-1.3	..	-1.7
MidCoast Water	..	-1.2	..	-0.2	..	-0.2
Port Macquarie Hastings Council	..	2.3	..	-0.6	..	1.4
Shoalhaven City Council	..	0.4	..	-0.6	..	-0.4
Tweed Shire Council	..	2.7	..	-0.4	..	3.1
Wagga Wagga	..	-0.4	..	-1.5	..	-0.7
Ballina Shire Council	..	-0.4	..	-0.2	..	-0.3
Bathurst Regional Council	..	-0.8	..	0.2	..	-0.6

Name	TFP change water		TFP change sewerage		TFP change - combined	
	Pre '06	'06 to '10	Pre '06	'06 to '10	Pre '06	'06 to '10
Bega Valley Shire Council	..	-0.3	..	-2.1	..	-2.4
Byron Shire Council	..	0.7	..	-0.2	..	1.1
Clarence Valley Council	..	9.5	..	-1.7	..	7.6
Country Energy	..	-0.8	..	-3.0	..	-1.7
Dubbo City Council	..	4.5	..	-0.3	..	3.5
Eurobodalla Shire Council	..	-3.4	..	2.7	..	-1.1
Kempsey Shire Council	..	-0.7	..	-0.3	..	-0.3
Lismore City Council	..	-0.9	..	-0.1	..	-0.2
Orange City Council	..	2.8	..	1.4	..	1.6
Queanbeyan City Council	..	0.3	..	-0.8	..	-0.2
Tamworth Regional Council	..	1.4	..	-1.0	..	0.3
Wingecarribee Shire Council	..	2.5	..	-0.2	..	1.3
Power and Water - Darwin	7.4	-1.5	4.4	-1.8	5.0	-1.1
Power and Water - Alice Springs	..	2.0	..	-0.6	..	2.6
Ipswich Water	0.7	0.3	0.9	2.8	0.3	0.8
Logan Water	2.0	1.6	13.3	-12.0	6.0	-6.1
Water Corporation - Mandurah	..	-1.9	..	0.1	..	-2.3
Aqwest/Water Corp Bunbury	..	5.3	..	1.1	..	2.7
Kalgoorlie-Boulder	..	-5.5	..	5.9	..	-3.8
Water Corporation - Albany	..	-1.3	..	-4.9	..	-3.3
Average - regional non-Vic	**4.0**	**0.0**	**4.8**	**-0.6**	**4.2**	**-0.4**
Simple Average all utilities	**1.6**	**-0.6**	**1.3**	**-0.5**	**1.4**	**-0.7**

Source: ESC.

The index-based TFP estimates in the foregoing tables show that over the period 2006 to 2010:

- The productivity of the four major Victorian urban water utilities decreased by an estimated 0.3 per cent per annum.
- The productivity of the largest non-Victorian urban utilities showed a large productivity decline of approximately 1.2 per cent per year.
- In regional Victoria, productivity decreased by an estimated 0.9 per cent per year.
- The productivity of the regional urban utilities in other states reduced by an estimated 0.4 per cent per annum.

In the pre-2006 period there appears to have been some productivity growth on average, although the sample of utilities in the regional areas in this period is too small to draw clear conclusions. The major (capital city) utilities in Victoria and other states appear to have enjoyed productivity growth of around one per cent during the pre-2006 period.

2.3 Growth of inputs and outputs

Table 2.3 provides a different breakdown of the rate change in TFP between 2006 and 2010 by showing the rates of change in the indexes of outputs and inputs. The big impacts on productivity growth appear to have arisen mainly from strong growth in inputs in some localities, including regional Victoria.

Table 2.3 **Input & output indexes –Percentage changes 2006 to 2010**

	Output index	Input index	TFP
Major urban Victoria			
Barwon Water	0.6	2.0	-1.3
City West Water	3.2	2.3	0.9
South East Water Ltd	1.7	1.7	0.0
Yarra Valley Water	0.8	1.8	-1.0
Average - major urban Vic	**1.6**	**1.9**	**-0.3**
Major urban Non-Vic			
ACTEW	-0.1	2.1	-2.2
Hunter Water Corporation	0.7	1.5	-0.8
Sydney Water Corporation	-0.1	1.9	-2.0
Brisbane Water	-0.2	-0.4	0.2
Gold Coast Water	-0.6	1.0	-1.6
SA Water - Adelaide	0.8	2.2	-1.4
Water Corporation - Perth	2.2	2.9	-0.7
Average - major urban non-Vic	**0.4**	**1.6**	**-1.2**
Regional Victoria			
Central Gippsland Water	0.2	2.2	-1.9
Central Highlands Water	1.5	3.2	-1.7
Coliban Water	0.6	2.1	-1.5
Goulburn Valley Water	-0.8	1.4	-2.1
East Gippsland Water	0.9	1.9	-1.0
GWMWater	0.1	-1.5	1.6
Lower Murray Water	1.4	1.1	0.3
North East Water	1.8	1.7	0.0
Wannon Water	1.0	2.1	-1.1
Western Water	3.4	4.3	-0.8
South Gippsland Water	0.9	4.0	-3.0
Westernport Water	3.4	2.4	1.0
Average - regional Vic	**1.2**	**2.1**	**-0.9**
Regional Non-Vic			
Gosford City Council	0.8	0.2	0.6
Wyong Shire Council	0.4	1.9	-1.5
Albury City Council	-10.1	1.2	-11.2
Coffs Harbour City Council	1.3	3.1	-1.7
MidCoast Water	1.6	1.8	-0.2
Port Macquarie Hastings Council	1.9	0.5	1.4
Shoalhaven City Council	1.7	2.1	-0.4

	Output index	Input index	TFP
Tweed Shire Council	6.8	3.6	3.1
Wagga Wagga	1.5	2.2	-0.7
Ballina Shire Council	2.1	2.3	-0.3
Bathurst Regional Council	1.1	1.7	-0.6
Bega Valley Shire Council	0.9	3.4	-2.4
Byron Shire Council	2.3	1.1	1.1
Clarence Valley Council	5.4	-2.1	7.6
Country Energy	-0.4	1.3	-1.7
Dubbo City Council	4.5	1.0	3.5
Eurobodalla Shire Council	1.2	2.3	-1.1
Kempsey Shire Council	-0.5	-0.2	-0.3
Lismore City Council	0.7	0.9	-0.2
Orange City Council	2.3	0.7	1.6
Queanbeyan City Council	0.8	0.9	-0.2
Tamworth Regional Council	3.0	2.6	0.3
Wingecarribee Shire Council	3.7	2.4	1.3
Power and Water - Darwin	2.3	3.4	-1.1
Power and Water - Alice Springs	4.6	1.9	2.6
Ipswich Water	3.1	3.1	0.1
Logan Water	9.1	7.1	1.8
Water Corporation - Mandurah	4.1	6.6	-2.3
Aqwest/Water Corp Bunbury	6.0	2.3	3.6
Kalgoorlie-Boulder	1.1	5.1	-3.8
Water Corporation - Albany	1.6	5.1	-3.3
Average - regional non-Vic	**2.1**	**2.2**	**-0.1**
Simple Average – all utilities	**1.6**	**2.1**	**-0.5**

Source: ESC.

2.4 Adjustment for scale

An objective comparison between the productivity levels of utilities requires adjustment for given factors that may influence productivity. Such adjustments can be more readily accommodated in the econometric approach than the index approach. But at a minimum, the differences in the scale of utilities should be adjusted-for in the index approach. Table 2.4 shows TFP scores that have been adjusted for scale.

The method of adjustment is details are provided in Appendix B. This scale-adjusted TFP index provides a better indicator of the relative efficiency of the different utilities than the "raw" TFP index. However, it does not add much to the analysis of trends, which have been discussed in the previous section.

Table 2.4 **Scale-adjusted TFP Comparative Index**

Name	1st year	TFP index - water			TFP index - sewerage			TFP index - combined		
		Year 1	2006	2010	Year 1	2006	2010	Year 1	2006	2010
Major urban Victoria										
Barwon Water	1998	0.957	0.854	0.813	1.015	1.045	1.010	1.001	0.951	0.891
City West Water	1998	1.198	1.362	1.349	1.098	1.318	1.372	1.177	1.342	1.364
South East Water Ltd	1998	1.165	1.266	1.268	1.069	1.159	1.144	1.131	1.222	1.210
Yarra Valley Water	1998	1.127	1.242	1.207	1.075	1.167	1.123	1.123	1.245	1.185
Average - major urban Vic		**1.112**	**1.181**	**1.159**	**1.064**	**1.172**	**1.162**	**1.108**	**1.190**	**1.162**
Major urban Non-Vic										
ACTEW	1998	0.724	0.822	0.738	0.755	0.902	0.867	0.767	0.875	0.795
Hunter Water Corporation	1998	0.846	0.865	0.864	0.811	0.826	0.789	0.845	0.856	0.823
Sydney Water Corporation	1999	0.838	0.921	0.795	0.705	0.854	0.793	0.748	0.845	0.779
Brisbane Water	1998	1.148	1.165	1.137	1.125	1.098	1.105	1.145	1.123	1.126
Gold Coast Water	1998	1.208	1.162	1.103	1.039	1.081	1.033	1.092	1.136	1.062
SA Water - Adelaide	1998	0.817	0.892	0.801	1.104	1.149	1.141	0.918	1.006	0.944
Water Corporation - Perth	1998	0.781	0.805	0.753	0.785	0.901	0.911	0.826	0.889	0.851
Average - major urban non-Vic		**0.909**	**0.947**	**0.884**	**0.904**	**0.973**	**0.948**	**0.906**	**0.961**	**0.911**
Regional Victoria										
Central Gippsland Water	1999	0.921	0.753	0.792	0.971	0.842	0.703	0.992	0.851	0.780
Central Highlands Water	1998	0.870	0.745	0.681	1.165	1.001	0.941	1.039	0.859	0.794
Coliban Water	1998	0.963	0.890	0.806	1.117	0.805	0.787	1.094	0.888	0.827
Goulburn Valley Water	1998	0.944	0.951	0.860	1.092	0.910	0.897	1.045	1.004	0.920
East Gippsland Water	2006	..	0.899	0.831	..	0.757	0.800	..	0.858	0.817
GWMWater	2006	..	0.722	0.834	..	1.034	0.963	..	0.822	0.872
Lower Murray Water	2006	..	1.013	1.055	..	1.083	1.041	..	1.079	1.079

Name	1st year	TFP index - water			TFP index - sewerage			TFP index - combined		
		Year 1	2006	2010	Year 1	2006	2010	Year 1	2006	2010
North East Water	2006	..	0.845	0.812	..	0.859	0.894	..	0.880	0.872
Wannon Water	2006	..	0.699	0.643	..	0.903	0.901	..	0.799	0.761
Western Water	2005	0.938	0.981	0.931	0.992	0.966	0.940	0.984	0.995	0.930
South Gippsland Water	2006	..	0.963	0.839	..	1.041	0.937	..	1.030	0.902
Westernport Water	2006	..	1.199	1.226	..	0.987	0.947	..	1.012	1.029
Average - regional Vic		**0.927**	**0.888**	**0.859**	**1.067**	**0.932**	**0.896**	**1.031**	**0.923**	**0.882**
Regional Non-Vic										
Gosford City Council	1998	0.776	1.230	1.194	0.934	0.976	1.039	0.699	1.070	1.085
Wyong Shire Council	2006	..	1.206	1.051	..	0.994	1.023	..	1.092	1.027
Albury City Council	2006	..	1.150	0.707	..	1.148	1.019	..	1.136	0.707
Coffs Harbour City Council	2006	..	1.050	0.985	..	0.868	0.819	..	0.987	0.914
MidCoast Water	2006	..	0.815	0.710	..	0.770	0.783	..	0.762	0.763
Port Macquarie Hastings Council	2006	..	0.854	0.923	..	1.041	1.009	..	0.954	0.997
Shoalhaven City Council	2006	..	0.863	0.872	..	0.771	0.750	..	0.826	0.811
Tweed Shire Council	2006	..	0.924	1.007	..	0.910	0.883	..	0.891	0.988
Wagga Wagga	2006	..	0.762	0.739	..	1.157	1.080	..	0.902	0.867
Ballina Shire Council	2006	..	1.537	1.516	..	1.025	1.017	..	1.314	1.301
Bathurst Regional Council	2006	..	1.224	1.171	..	1.135	1.135	..	1.213	1.173
Bega Valley Shire Council	2006	..	0.904	0.880	..	0.790	0.720	..	0.879	0.789
Byron Shire Council	2006	..	1.775	1.789	..	0.947	0.928	..	1.272	1.310
Clarence Valley Council	2006	..	0.474	0.662	..	1.098	1.006	..	0.607	0.794
Country Energy	2006	..	0.944	0.913	..	1.123	0.996	..	1.059	0.990
Dubbo City Council	2006	..	0.888	1.045	..	0.981	0.963	..	0.924	1.049
Eurobodalla Shire Council	2006	..	0.802	0.697	..	0.781	0.869	..	0.770	0.736
Kempsey Shire Council	2006	..	0.754	0.733	..	0.885	0.873	..	0.839	0.830

Name	1st year	TFP index - water			TFP index - sewerage			TFP index - combined		
		Year 1	2006	2010	Year 1	2006	2010	Year 1	2006	2010
Lismore City Council	2006	..	1.598	1.542	..	0.935	0.931	..	1.294	1.282
Orange City Council	2006	..	1.003	1.105	..	1.052	1.102	..	1.042	1.097
Queanbeyan City Council	2006	..	1.754	1.765	..	1.259	1.211	..	1.501	1.483
Tamworth Regional Council	2006	..	0.905	0.938	..	1.014	0.962	..	0.961	0.957
Wingecarribee Shire Council	2006	..	0.893	1.021	..	0.778	0.767	..	0.893	0.932
Power and Water - Darwin	1998	0.662	1.050	0.971	1.078	1.430	1.316	0.896	1.216	1.149
Power and Water - Alice Springs	2006	..	0.984	1.067	..	1.379	1.344	..	1.051	1.166
Ipswich Water	2002	1.124	1.117	1.101	0.881	0.895	0.846	1.058	1.044	0.990
Logan Water	2003	1.160	1.171	1.165	0.967	0.974	0.954	1.069	1.063	1.070
Water Corporation - Mandurah	2006	..	1.373	1.228	..	0.920	0.907	..	1.260	1.118
Aqwest/Water Corp Bunbury	2007	..	1.324	1.559	..	1.022	1.043	..	1.209	1.299
Kalgoorlie-Boulder	2006	..	0.823	0.645	..	1.473	1.838	..	1.117	0.944
Water Corporation - Albany	2006	..	1.210	1.133	..	0.982	0.796	..	1.202	1.039
Average - regional non-Vic		**0.930**	**1.076**	**1.059**	**0.965**	**1.017**	**0.998**	**0.930**	**1.043**	**1.021**
Simple Average – all utilities		**0.970**	**1.023**	**0.990**	**1.000**	**1.024**	**1.001**	**0.994**	**1.030**	**0.994**

Source: ESC.

2.4.1 Observations

The scale adjusted TFP indexes in Table 2.4 indicate that:

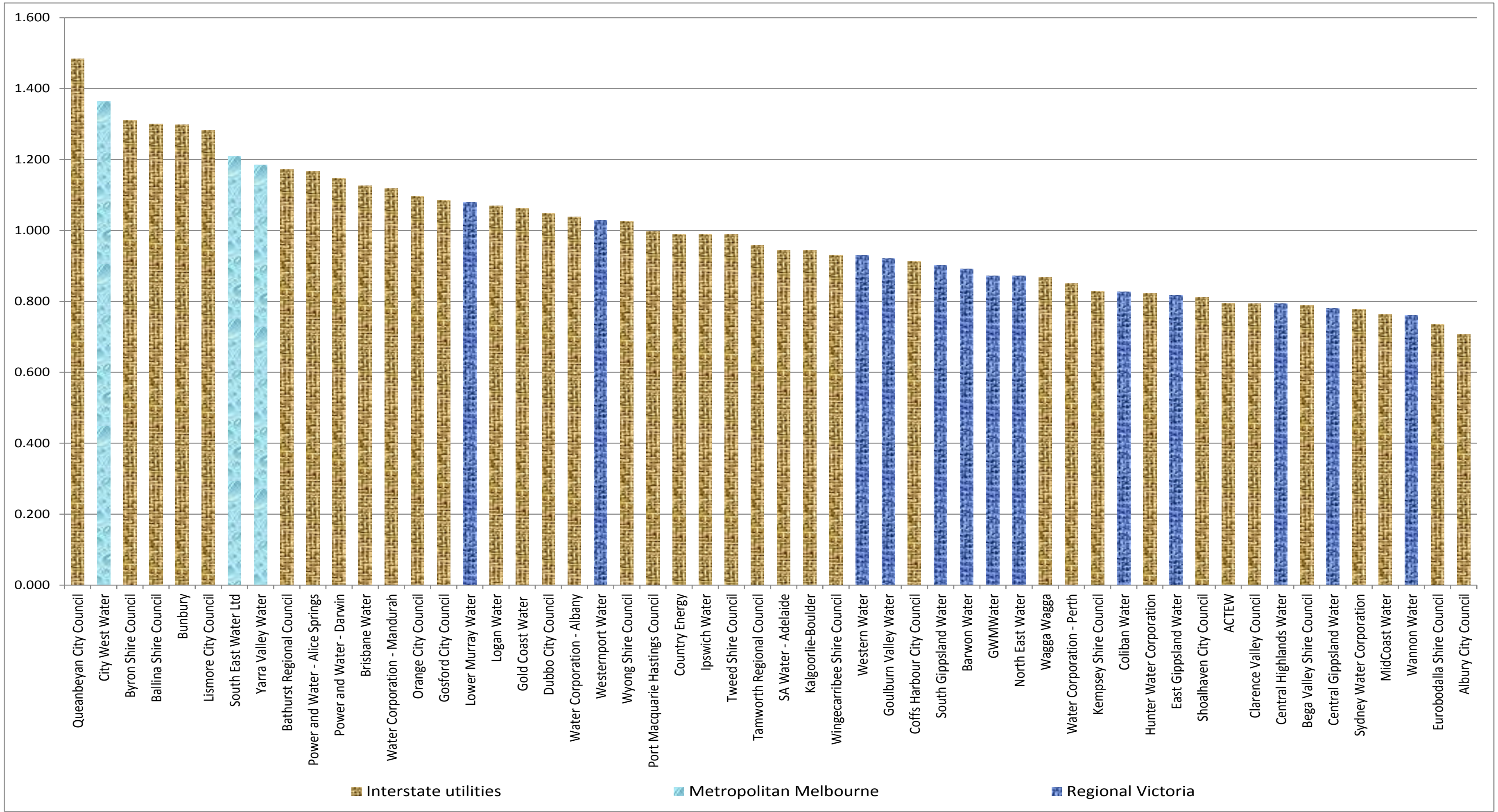
- The four major Victorian urban water utilities in 2006 and in 2010 had productivity levels for combined water and sewerage services that were on average approximately 16 per cent higher than the average firm in the sample.
- Among the major water utilities in other states, Brisbane Water and Gold Coast Water were the only utilities with above-average levels of efficiency. The remainder were estimated to have below average productivity. The group as a whole were nine per cent less efficient than the average water utility. Perhaps the investments in desalination plants by Water Corporation Perth and Sydney Water have impacted on their measured productivity.
- The relative productivity of regional Victorian urban utilities appears to be significantly below average, including behind the smaller utilities in other states. They are estimated to be 12 per cent below the average Australian water utility.
- Interstate regional water utilities, as a group, had average levels of productivity approximately two per cent above average.

The adjusted TFP rates of change (not presented), when compared with the "raw" trends shown in Table 2.2, indicate a small positive contribution to productivity change attributable to organic growth in consumer numbers. Absent this small economies-of-scale effect, the productivity of the major metropolitan Victorian utilities would have declined at a slightly faster rate.

2.4.2 Relative productivity

Figure 2.1 presents comparative estimates of the scale-adjusted productivity of each utility, ranked from highest to lowest. This data is for 2010, and is also shown in Table 2.4. The Melbourne metropolitan and Victorian regional utilities are shown separately. While the Melbourne water utilities are among the highest in relative technical efficiency, Victorian regional water utilities are mostly below average efficiency. Some are among the least efficient in the sample.

Figure 2.1 **Relative productivity estimates – Scale adjusted index 2010**



Source: ESC

3 Econometric Analysis

An alternative approach to index-based productivity measurement is to estimate a distance function to identify the efficiency frontier. This approach seeks to measure the degree to which some utilities may be inefficient. Technical inefficiency means that a utility is either:

- not using the minimum quantity of inputs needed to produce a given output or
- not producing the maximum outputs from a given set of inputs.

These two perspectives are called the “input oriented” and “output oriented” measures of technical efficiency. For utility industries the former perspective is usually considered more relevant because these businesses have less choice over outputs.[5]

This study estimates an input distance function. A distance function is an index measure of technical inefficiency. It is defined as the maximum possible value of a scaling factor, $\rho > 1$, such that if all input quantities were divided by ρ, the same set of outputs could still be produced by that reduced set of inputs. Thus, it represents an index of the ratio between actual inputs and minimum inputs (when used in the same proportions). The detailed mathematical specification of the distance function is set out in Appendix C.

In the econometric approach it is technically possible to separately estimate changes in the efficiency frontier that are due to technical progress, reduced inefficiency and scale effects. The ability to make this decomposition in practice will depend on data quality and measures available, and the sample size. Where the specification relies on measures of time to identify both the rates of technological change and changes in inefficiency, there is likely to be less confidence that these two distinct phenomena have been adequately separated. For this reason we report these two sources of productivity changes combined.

[5] Coelli, T, Estache A, Perelman S, Trujillo L (2003) *A Primer on Efficiency Measurement for Utilities and Transport Regulators*, WBI Development Studies.

3.1 Estimating the Stochastic Frontier model

The first econometric approach to estimating the efficiency frontier in this study is a stochastic frontier analysis (SFA) of the input distance function. SFA is a method of estimating a function representing the frontier of a set of data – that is, an upper or lower bound function, depending on whether the model is a maximum or minimum value function, such as a production function or a cost function respectively. SFA is an appropriate econometric method for estimating economic relationships which define an optimum, such as cost functions, profit functions and production functions among others. Appendix D documents the estimation of several alternative SFA models and the selection of the preferred SFA model from among these.

There are many SFA specifications relating to the assumed stochastic pattern of firm-specific inefficiencies. The specification chosen is the Battese-Coelli model of time-varying decay in inefficiency with comparative inefficiencies between utilities follow a truncated-normal distribution. Our preferred SFA model is shown in Table 3.1. The rate of decay in the inefficiency is represented by the parameter "eta", and the mean of the truncated-normal distribution is equal to "mu".

The SFA approach is quite different to the index-based approach discussed the previous chapter. The TFP index is a constructed measure, which implicitly assumes a simple relationship between inputs and outputs. The stochastic frontier model is estimated econometrically, and allows a wider range of interactions between inputs and outputs, including over time, as well as some environmental factors. That said, the results for comparative technical efficiency of utilities derived from the SFA model are broadly similar to the index approach.

The technical efficiency (TE) estimates from the stochastic frontier model are shown in Figure 3.1, represented as a ranking of all the utilities in the sample, and normalised such that the technical efficiency of the average utility is equal to 1.0. These measures relate to 2010. The three Melbourne water retailer-distributors and the regional Victorian utilities are separately highlighted. The degree of technical *inefficiency* of a utility can be measured by the difference between the most efficient firms and its own level of efficiency.

Figure 3.1 suggests that the Melbourne metropolitan water utilities are just inside the top 20 per cent of utilities in terms of overall technical efficiency ranking. The regional Victorian utilities mostly lie in the bottom half of the rankings.

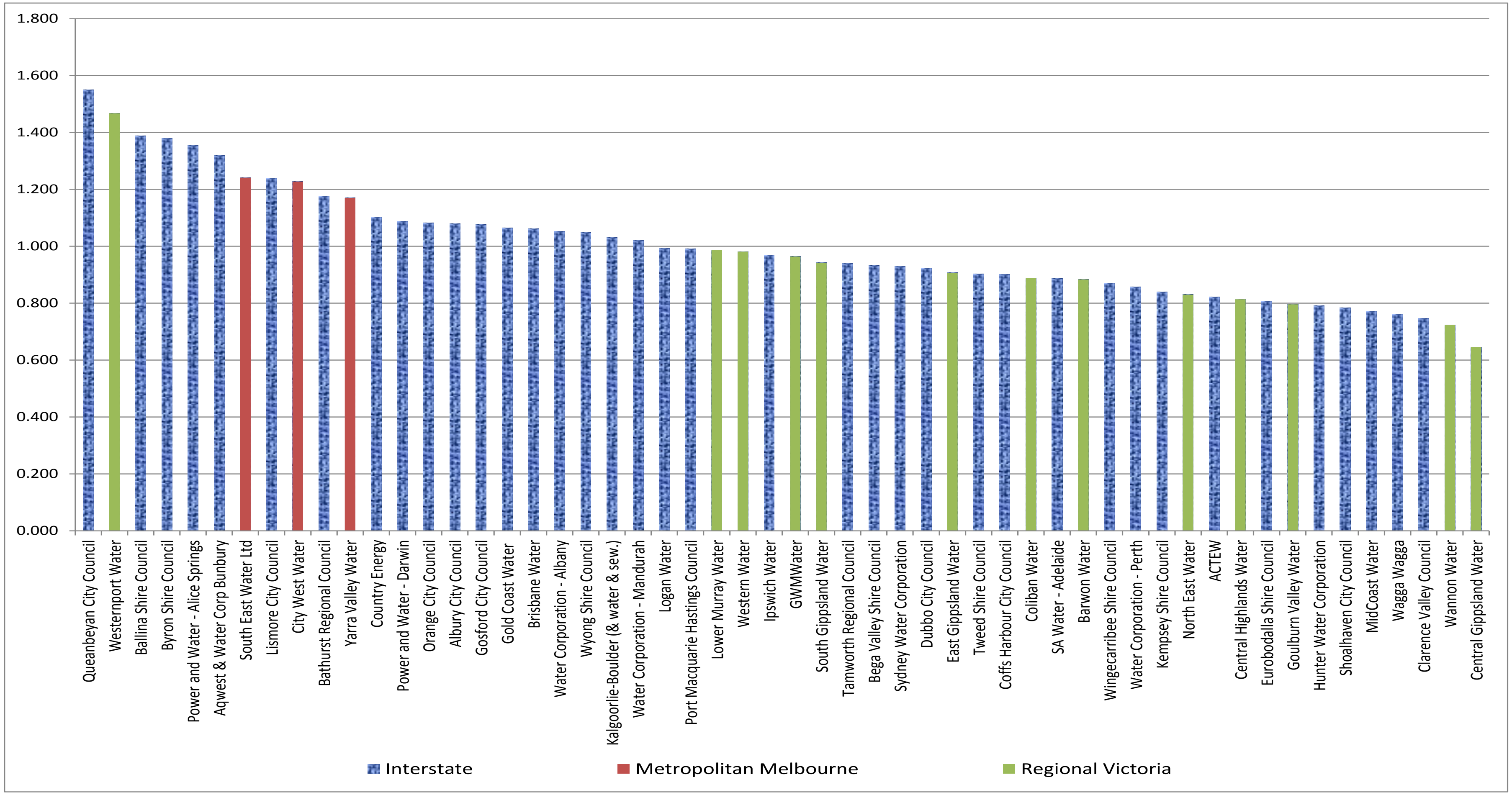
Table 3.1 **Estimated parameters of preferred SFA model**[a]

Coefficients:	**Parameter**	**SE**	**z-statistic**
y1 (customers)	-0.7636007	0.0278423	-27.43
y2 (water supplied)	-0.0329476	0.0127322	-2.59
y3 (sewerage collected)	-0.0708802	0.0214646	-3.3
x1 (Acc. capital)	0.1204192	0.0299793	4.02
x2 (Phys. Capital)	0.8150499	0.0351036	23.22
y11	-0.2750267	0.0513882	-5.35
y12	0.0561704	0.0144539	3.89
y13	0.1715392	0.0441251	3.89
y22	-0.0080029	0.0041242	-1.94
y23	-0.0567654	0.0161748	-3.51
y33	-0.0937649	0.0427499	-2.19
x11	0.052657	0.0172404	3.05
x12	-0.0279639	0.0253825	-1.1
x22	0.1428687	0.0443724	3.22
y1x1	-0.0204756	0.0325551	-0.63
y2x1	0.0028413	0.0127683	0.22
y3x1	-0.0036244	0.0198802	-0.18
y1x2	-0.1058987	0.0479817	-2.21
y2x2	0.0273159	0.0188537	1.45
y3x2	0.0853402	0.0367011	2.33
time	0.0171346	0.0033132	5.17
tsq	-0.0005777	0.0003459	-1.67
y1t	-0.0014002	0.002251	-0.62
y2t	0.0004947	0.0008395	0.59
y3t	0.0033746	0.0022131	1.52
x1t	0.0067539	0.0017521	3.85
x2t	-0.012937	0.0030772	-4.2
z1 (%wastewater=trade waste)	0.0574783	0.0235785	2.44
z2 (% cust. with sewerage)	-0.3938163	0.0654837	-6.01
z3 (groundwater%)	-0.004613	0.0042235	-1.09
_cons	0.7050222	0.0975813	7.22
mu	0.5224585	0.0621201	8.41
eta	-0.0224415	0.0053435	-4.2
sigma2	0.0482458	0.0128722	
gamma	0.9803079	0.0057206	
sigma_u2	0.0472958	0.012885	
sigma_v2	0.0009501	0.0000746	
Goodness of fit:			
Log Likelihood	690.9		

[a] Model “SFA3-1” in Appendix D.

Source: ESC.

Figure 3.1 **Technical efficiency estimates – Stochastic Frontier model**



Source: ESC.

3.1.1 Sources of TFP change

The stochastic frontier model can be used to derive estimates of TFP changes defined by the Malmquist TFP index, as modified by Orea.[6] As mentioned, it can also be used to provide estimates of the sources of TFP change in terms of reduced technical inefficiency, technological progress, returns-to-scale effects, and changes in any environmental variables included in the model. Appendix C explains the mathematical form of the distance function, the Malmquist index and its decomposition.

The resulting estimates over the period 2006 to 2010 are shown in Table 3.2. This period has been chosen because virtually all firms are present in the sample throughout this period, so that the panel is almost completely balanced. (Trends can be difficult to interpret when the panel is unbalanced.)

The estimates shown in Table 3.2 indicate:

- The productivity of the four largest Victorian utilities declined incrementally, by 0.1 per cent on average each year between 2006 and 2010.
- The productivity of the largest non-Victorian water utilities declined at an average annual rate of 0.6 per cent over the same period.
- In regional Victoria, productivity declined on average over all of these utilities, by 0.8 per cent per year.
- The productivity of interstate regional utilities declined by an estimated 0.4 per cent per year over the same period.
- The average annual change in TFP over all utilities in the sample was estimated to be –0.5 per cent per year.

The effects of changes in scale and changes in the exogenous factors taken into account in the model were of minor importance, and taken together had virtually no impact on the productivity trend outcomes. This implies that the trends must be related either to reduced technical efficiency, adverse technological change or the influence of other factors not taken into account in the analysis. Technical change can be adverse, for example, if technical regulation imposes higher input requirements to achieve a given output.

[6] Luis Orea (2002) 'Parametric Decomposition of a Generalized Malmquist Productivity Index', *Journal of Productivity Analysis*, v18:1.

Table 3.2 **TFP changes per utility, stochastic frontier model – 2006-2010**

	ΔOutputs	ΔInputs	ΔTFP	Combined effect of changes in technology & inefficiency	Environmental variable effects	Returns-to-scale effect	Unexplained residual
Major urban Victoria							
Barwon Water	1.3	2.1	-0.8	-1.2	-0.5	0.1	0.9
City West Water	3.1	2.1	1.0	0.9	0.0	0.7	-0.6
South East Water Ltd	1.5	1.6	-0.1	0.1	-0.1	0.2	-0.4
Yarra Valley Water	1.3	1.8	-0.5	0.1	0.0	0.2	-0.8
Average - major urban Vic	**1.8**	**1.9**	**-0.1**	**0.0**	**-0.1**	**0.3**	**-0.2**
Major urban Non-Vic							
ACTEW	0.5	1.4	-0.9	-0.4	0.0	0.1	-0.6
Hunter Water Corporation	0.8	1.4	-0.7	-0.6	0.0	0.0	-0.1
Sydney Water Corporation	0.3	1.7	-1.4	0.9	-0.3	0.1	-2.0
Brisbane Water	0.1	0.0	0.1	0.2	-0.3	0.0	0.1
Gold Coast Water	-0.1	0.9	-1.1	0.6	0.0	-0.1	-1.6
SA Water - Adelaide	0.9	2.0	-1.1	-0.4	0.0	0.1	-0.7
Water Corporation - Perth	2.1	2.4	-0.3	-0.2	-0.2	0.1	0.0
Average - major urban non-Vic	**0.8**	**1.4**	**-0.6**	**0.1**	**-0.1**	**0.0**	**-0.6**
Regional Victoria							
Central Gippsland Water	0.6	3.9	-3.3	-2.5	0.1	0.1	-0.9
Central Highlands Water	1.4	3.8	-2.3	-1.7	-0.2	0.2	-0.6
Coliban Water	0.7	2.0	-1.3	-1.5	0.1	0.0	0.1
Goulburn Valley Water	-1.1	1.6	-2.6	-1.7	-0.2	-0.1	-0.6
East Gippsland Water	1.0	3.1	-2.1	-2.2	-0.7	0.1	0.7
GWMWater	0.5	-1.2	1.7	-1.9	-0.2	0.0	3.8

	ΔOutputs	ΔInputs	ΔTFP	Combined effect of changes in technology & inefficiency	Environmental variable effects	Returns-to-scale effect	Unexplained residual
Lower Murray Water	1.3	1.8	-0.5	-1.2	-0.1	0.1	0.7
North East Water	1.8	2.0	-0.3	-1.6	-0.1	0.2	1.2
Wannon Water	0.9	1.8	-0.9	-1.8	-0.6	0.1	1.4
Western Water	2.7	3.9	-1.2	-1.6	-0.4	0.3	0.5
South Gippsland Water	1.3	3.7	-2.3	-1.5	-0.1	0.3	-1.1
Westernport Water	3.2	2.1	1.1	-0.9	0.6	0.8	0.7
Average - regional Vic	**2.0**	**2.9**	**-0.8**	**-1.7**	**-0.2**	**0.2**	**0.5**
Regional Non-Vic							
Gosford City Council	2.5	0.2	2.3	-0.2	0.2	0.7	1.7
Wyong Shire Council	0.3	1.6	-1.3	-0.2	-0.4	0.1	-0.8
Albury City Council	-3.5	1.4	-4.9	-0.5	0.5	-0.5	-4.4
Coffs Harbour City Council	1.2	2.8	-1.7	-0.6	-0.5	0.2	-0.8
MidCoast Water	1.3	2.3	-1.0	-1.3	0.0	0.2	0.1
Port Macquarie Hastings Council	2.1	1.3	0.8	-0.3	0.3	0.4	0.4
Shoalhaven City Council	1.2	1.8	-0.6	-1.4	-0.8	0.1	1.5
Tweed Shire Council	4.5	3.1	1.4	-0.3	-0.1	1.0	0.8
Wagga Wagga	1.4	2.2	-0.8	-2.1	0.4	0.0	0.9
Ballina Shire Council	1.8	1.8	-0.1	0.0	-0.8	0.6	0.2
Bathurst Regional Council	1.5	1.7	-0.2	-0.3	0.0	0.4	-0.2
Bega Valley Shire Council	1.8	3.5	-1.7	-1.4	-1.0	0.3	0.3
Byron Shire Council	2.1	1.3	0.8	0.4	1.0	0.6	-1.3
Clarence Valley Council	4.8	0.2	4.6	-2.3	0.6	-0.1	6.4
Country Energy	0.7	1.9	-1.2	-0.6	0.0	0.3	-0.9
Dubbo City Council	1.7	1.0	0.7	-0.7	-0.1	0.4	1.0

	∆Outputs	∆Inputs	∆TFP	Combined effect of changes in technology & inefficiency	Environmental variable effects	Returns-to-scale effect	Unexplained residual
Eurobodalla Shire Council	1.2	2.7	-1.5	-1.7	-0.6	0.1	0.7
Kempsey Shire Council	0.1	-0.5	0.5	-1.2	0.4	0.0	1.3
Lismore City Council	1.7	0.5	1.2	-0.2	0.0	0.3	1.0
Orange City Council	1.3	1.1	0.2	-0.7	-0.7	0.2	1.4
Queanbeyan City Council	0.5	0.6	-0.2	0.5	0.0	0.1	-0.8
Tamworth Regional Council	2.6	3.3	-0.7	-1.4	-0.1	0.4	0.4
Wingecarribee Shire Council	2.8	2.0	0.9	-1.3	-0.8	0.1	2.7
Power and Water - Darwin	2.2	2.9	-0.8	-0.4	0.4	0.6	-1.4
Power and Water - Alice Springs	-3.4	2.3	-5.7	-0.2	-0.1	-1.2	-4.2
Ipswich Water	3.2	3.2	0.0	-1.0	-0.2	0.3	0.9
Logan Water	9.3	6.6	2.6	-0.3	0.8	1.1	1.0
Water Corporation - Mandurah	3.9	5.5	-1.6	-0.7	-1.0	0.2	-0.1
Aqwest/Water Corp Bunbury	5.8	2.5	3.3	0.2	0.9	1.6	0.6
Kalgoorlie-Boulder	3.3	4.4	-1.0	0.8	-1.7	1.8	-1.9
Water Corporation - Albany	1.5	3.9	-2.4	-0.6	-0.2	0.3	-1.8
Average - regional non-Vic	**3.6**	**4.1**	**-0.4**	**-0.6**	**-0.1**	**0.3**	**0.2**
Simple Average – all utilities	**1.6**	**2.1**	**-0.5**	**-0.7**	**-0.1**	**0.3**	**0.1**

(a) Measured by calculating the Malmquist index.

Source: ESC.

3.2 Estimating the Random Effects model

A second econometric approach is to estimate a random effects model of the input distance function. In this model each firm in the sample has an individual constant linear effect (similar to a different intercept for each utility), and these individual effects are normally distributed between firms.

The difference between each utility's random effect and that of the best utility is sometimes interpreted as a measure of technical inefficiency. However, it actually reflects both the utility's technical efficiency and other utility-specific effects. The same issue is relevant to the stochastic frontier model.[7]

The random effects model is shown in Table 3.3. It provides a reasonable fit to the sample data, partly because a high proportion of the random variation in the data is associated with the cross-sectional utility-specific random effect. This model may help to improve the accuracy of, or to corroborate, estimates of the comparative levels of inefficiency between utilities, and the trends in TFP.

The associated estimates of utility-specific effects are shown in Figure 3.2. The TFP results are discussed in section 3.2.1.

[7] A second round of analysis could be carried out to find determinants of the firm-specific effects. In this way, cross-sectional environmental variables can be utilised, and a better measure of residual inefficiency can in principle be derived. This has been tested, but the variables that were used had little or no explanatory power.

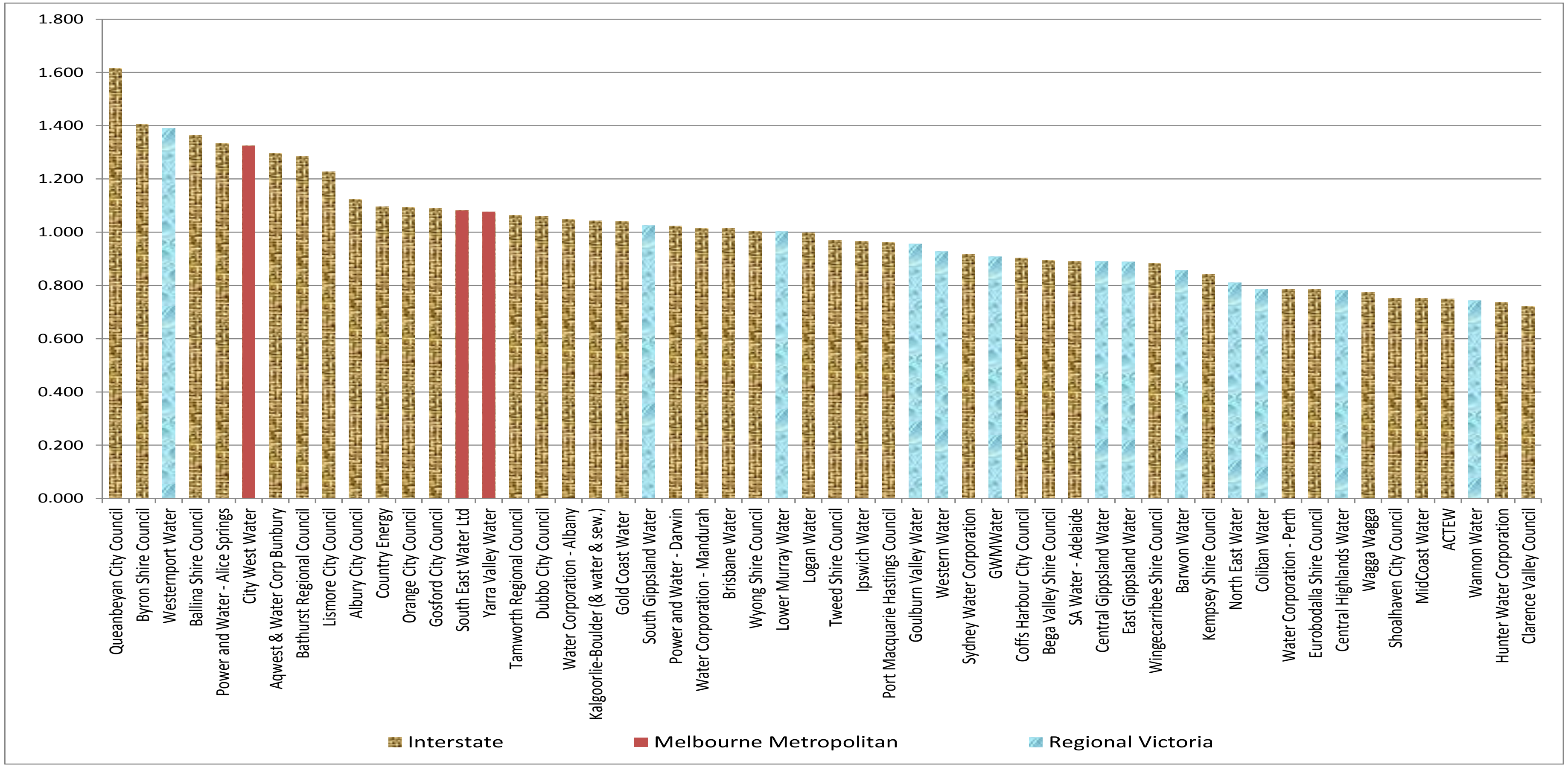
Table 3.3 **Estimated parameters of preferred random effects model**[a]

Coefficients:	Parameter	SE	z-statistic
y1 (customers)	-0.7558817	0.0377989	-20
y2 (water supplied)	-0.0295888	0.0129444	-2.29
y3 (sewerage collected)	-0.0670473	0.0224746	-2.98
x1 (Acc. capital)	0.0800036	0.0384853	2.08
x2 (Phys. Capital)	0.9082608	0.0394587	23.02
y11	-0.246024	0.0550794	-4.47
y12	0.0538799	0.0148136	3.64
y13	0.1537338	0.0444544	3.46
y22	-0.0072373	0.0042004	-1.72
y23	-0.0597542	0.016516	-3.62
y33	-0.0793711	0.0431396	-1.84
x11	0.0647651	0.0181444	3.57
x12	-0.0285311	0.0260843	-1.09
x22	0.1269401	0.0441675	2.87
y1x1	-0.0614105	0.0344459	-1.78
y2x1	0.0103829	0.013101	0.79
y3x1	0.0157787	0.019988	0.79
y1x2	-0.0468454	0.0494662	-0.95
y2x2	0.016982	0.0194851	0.87
y3x2	0.0462764	0.0367091	1.26
time	0.0051665	0.0025099	2.06
tsq	-0.0004734	0.0003362	-1.41
y1t	-0.0004172	0.0022519	-0.19
y2t	-0.0005372	0.0008207	-0.65
y3t	0.0035013	0.0022157	1.58
x1t	0.0043693	0.0014145	3.09
x2t	-0.0183671	0.0026558	-6.92
z1 (%wastewater=trade waste)	-0.0250229	0.0270675	-0.92
z2 (% cust. with sewerage)	-0.3766264	0.0677364	-5.56
z3 (groundwater%)	-0.0009077	0.0044094	-0.21
_cons	0.3706467	0.0846468	4.38
sigma_u	0.1904143	0.0237582	
sigma_e	0.0314125	0.0012372	
rho	0.9735061	0.0071135	
Goodness of fit:			
Log Likelihood	685.7		

[a] Model “RE1-1” in Appendix D.

Source: ESC.

Figure 3.2 **Technical efficiency estimates – Random effects model**



Source: ESC.

3.2.1 Trends in TFP

The estimates of changes in TFP and the sources of change derived from the random effects model are shown in Table 3.4 relating to the period 2006 to 2010. Some key points to note from Table 3.4 are:

- The average annual decline in TFP over all utilities in the sample was 0.4 per cent per year. This is very similar to the SFA estimate, but not quite as large as the decline suggested by the index-based approach.
- The decline in productivity appears to have been due to a combination of adverse technological change and increased inefficiency, which offset a small positive returns-to-scale effect.
- The TFP of the major Victorian urban utilities is estimated to have remained constant. Productivity improvements at City West Water offset reductions at Yarra Valley Water and Barwon Water.
- Productivity declined on average by 0.7 per cent per year for utilities in the major cities of other states on average. Large capital expenditure in desalination plants may have contributed to this outcome.
- Regional Victorian utilities showed a fall in productivity of 0.8 per cent on average each year. Significant capital expenditures by some regional water utilities may have contributed to this productivity underperformance.
- In other regions, productivity decreased at approximately 0.2 per cent per annum, on average.

These findings are similar to those from the SFA model.

Table 3.4 **TFP changes per utility, random effects model – 2006-2010**

	ΔOutputs	ΔInputs	ΔTFP	Combined effect of changes in technology & inefficiency	Environmental variable effects	Returns-to-scale effect	Unexplained residual
Major urban Victoria							
Barwon Water	1.4	1.9	-0.5	-0.9	-0.2	0.2	0.4
City West Water	3.1	2.2	0.8	0.7	0.0	0.6	-0.4
South East Water Ltd	1.5	1.6	0.0	-0.1	-0.1	0.2	-0.1
Yarra Valley Water	1.1	1.5	-0.4	0.0	0.0	0.2	-0.5
Average - major urban Vic	**1.8**	**1.8**	**0.0**	**-0.1**	**-0.1**	**0.3**	**-0.2**
Major urban Non-Vic							
ACTEW	0.4	1.5	-1.0	0.1	0.0	0.1	-1.2
Hunter Water Corporation	0.9	1.5	-0.5	-0.2	0.0	0.1	-0.4
Sydney Water Corporation	0.1	1.5	-1.4	1.2	-0.3	0.0	-2.3
Brisbane Water	-0.1	-0.3	0.3	0.2	-0.2	0.0	0.3
Gold Coast Water	-0.1	0.8	-0.9	0.6	0.0	0.0	-1.5
SA Water - Adelaide	1.0	1.7	-0.7	-0.1	0.0	0.1	-0.7
Water Corporation - Perth	2.1	2.4	-0.3	0.1	-0.3	0.2	-0.3
Average - major urban non-Vic	**0.6**	**1.3**	**-0.7**	**0.3**	**-0.1**	**0.1**	**-0.9**
Regional Victoria							
Central Gippsland Water	0.4	2.6	-2.1	-1.3	0.1	0.1	-1.0
Central Highlands Water	1.5	3.1	-1.6	-1.2	-0.1	0.3	-0.6
Coliban Water	1.0	1.9	-0.9	-1.3	0.1	0.1	0.2
Goulburn Valley Water	-1.0	1.4	-2.4	-1.2	-0.2	-0.2	-0.8
East Gippsland Water	1.1	2.7	-1.5	-2.1	-0.6	0.2	1.0
GWMWater	0.8	-1.1	1.9	-2.2	-0.1	0.1	4.1

	∆Outputs	∆Inputs	∆TFP	Combined effect of changes in technology & inefficiency	Environmental variable effects	Returns-to-scale effect	Unexplained residual
Lower Murray Water	1.4	1.7	-0.3	-1.5	-0.1	0.2	1.0
North East Water	1.7	2.0	-0.3	-1.3	-0.1	0.3	0.8
Wannon Water	0.9	1.8	-0.9	-1.1	-0.4	0.2	0.4
Western Water	2.8	3.7	-0.9	-1.6	-0.4	0.6	0.5
South Gippsland Water	1.5	3.7	-2.2	-1.3	-0.1	0.4	-1.2
Westernport Water	3.4	1.9	1.6	-1.6	0.6	1.0	1.5
Average - regional Vic	**1.3**	**2.1**	**-0.8**	**-1.5**	**-0.1**	**0.3**	**0.5**
<u>Regional Non-Vic</u>							
Gosford City Council	1.8	0.1	1.8	-0.1	0.2	0.5	1.2
Wyong Shire Council	0.2	1.6	-1.4	-0.3	-0.4	0.1	-0.8
Albury City Council	-1.8	1.5	-3.3	-0.8	0.5	-0.3	-2.6
Coffs Harbour City Council	1.1	2.8	-1.7	-0.6	-0.5	0.3	-0.8
MidCoast Water	1.1	2.1	-1.0	-0.8	0.0	0.2	-0.4
Port Macquarie Hastings	2.0	1.2	0.9	-0.4	0.3	0.5	0.5
Shoalhaven City Council	0.8	1.8	-0.9	-1.1	-0.7	0.1	0.8
Tweed Shire Council	4.4	3.0	1.4	-0.1	-0.1	1.0	0.6
Wagga Wagga	1.5	2.1	-0.6	-1.9	0.3	0.2	0.8
Ballina Shire Council	1.5	1.9	-0.4	-0.8	-0.7	0.5	0.7
Bathurst Regional Council	1.5	1.7	-0.2	-0.7	0.0	0.4	0.1
Bega Valley Shire Council	2.0	3.4	-1.4	-1.2	-0.9	0.5	0.3
Byron Shire Council	2.2	1.3	0.9	-0.3	1.0	0.7	-0.4
Clarence Valley Council	4.3	-0.6	4.9	-2.0	0.6	0.7	5.7
Country Energy	0.2	1.6	-1.4	-0.6	0.0	0.1	-0.9
Dubbo City Council	1.5	1.0	0.5	-0.5	-0.1	0.4	0.7
Eurobodalla Shire Council	0.7	2.6	-1.9	-1.4	-0.6	0.1	-0.1

	∆Outputs	∆Inputs	∆TFP	Combined effect of changes in technology & inefficiency	Environmental variable effects	Returns-to-scale effect	Unexplained residual
Kempsey Shire Council	0.2	-0.4	0.6	-1.2	0.1	0.0	1.7
Lismore City Council	1.6	0.6	1.0	-0.8	0.0	0.2	1.5
Orange City Council	1.3	1.0	0.2	-1.1	-0.7	0.3	1.8
Queanbeyan City Council	0.6	0.8	-0.2	-0.6	0.0	0.2	0.2
Tamworth Regional Council	2.5	3.0	-0.6	-1.3	-0.1	0.6	0.2
Wingecarribee Shire Council	2.1	2.0	0.1	-1.4	-0.7	0.4	1.8
Power and Water - Darwin	2.4	2.9	-0.5	-0.3	0.4	0.6	-1.2
Power and Water - Alice Springs	-0.4	2.0	-2.4	-0.2	0.0	-0.1	-2.1
Ipswich Water	3.2	3.2	0.0	-1.0	-0.2	0.6	0.5
Logan Water	9.4	7.1	2.3	-0.3	0.8	1.6	0.3
Water Corporation - Mandurah	4.0	5.4	-1.5	-1.1	-1.0	0.6	0.1
Aqwest/Water Corp Bunbury	5.9	2.4	3.5	-0.5	0.9	1.7	1.4
Kalgoorlie-Boulder	2.3	4.1	-1.9	1.0	-1.6	0.8	-2.1
Water Corporation - Albany	1.5	4.1	-2.5	-1.1	-0.2	0.4	-1.6
Average - regional non-Vic	**2.0**	**2.2**	**-0.2**	**-0.8**	**-0.1**	**0.4**	**0.2**
Simple Average – all utilities	**1.6**	**2.0**	**-0.4**	**-0.7**	**-0.1**	**0.4**	**0.1**

Source: ESC.

4 Observations & Comparisons

Three different methods of estimating Total Factor Productivity (TFP) trends and relative technical efficiency levels have been used in this paper. The index-based approach is the most transparent because the sources of changes in TFP can most readily be traced back to specific data points. However, it is not preferred because it does not take account of a range of interactions and some environmental factors that the econometric approaches can.[8] The stochastic frontier model and the random effects model produce results that are broadly consistent with each other, while not being wholly dissimilar to the findings of the index-based approach. This corroboration tends to enhance confidence in the results.

We consider it valuable to present the results of all three models alongside each other. However, our preferred method is the SFA model, both conceptually and in terms of goodness-of-fit.

4.1 Sources of productivity change

4.1.1 Returns to scale

The returns-to-scale can be measured by the scale elasticity, which measures the ratio of incremental outputs to incremental inputs for an efficient firm. This can be estimated for each individual utility in the sample. The average scale elasticity of all firms, in the stochastic frontier model was 1.21, and in the random effects model it was estimated to be 1.27. Thus, if an efficient firm were to increase inputs uniformly by 1 per cent, it could increase outputs by approximately 1.2 per cent. Conversely, an increase in outputs of 1 per cent would require inputs to increase by 0.8 per cent.

Scale economies were significantly higher among a handful of the smallest utilities in the sample. However, aside from this group, there was little or no discernible relationship between the scale elasticities of utilities and their size for

[8] The environmental factors that were included in the econometric models were (a) groundwater as a proportion of all sourced water; and (b) sewerage-connected customers as a per cent of all customers, and (c) trade waste as a proportion of all wastewater.

the rest of the sample. Virtually all were in the range 1.0 to 1.4. The presence of scale economies does not necessarily imply that there are gains to consolidation of utilities, since these scale efficiencies may relate to the size and density of the urban areas supplied.

The index of outputs (normalised and quality adjusted) generally increased over the period 2006 to 2010. This generated an improvement in productivity due to the returns-to-scale effect, but this effect was only small.

4.1.2 Other factors

The influence of temporary water restrictions (TWRs) has been adjusted-for in the normalisation of water supplied.

The effects of measured certain environmental factors (namely the relative importance of groundwater sources in water supply, the proportion of customer connected to sewerage and importance of trade waste in sewage treatment) have been controlled-for. While there effects were statistically significant, the overall importance of changes in these variables was minor.

4.1.3 Technology and inefficiency

Improvement in technology refers to the productivity gains made by best-practice utilities due to the ability to deploy new organisational or production methods. Changes in inefficiency refer to changes in the relativity of other utilities to the best practice utilities. The effects of technology change and changes in technical efficiency are, in practice, difficult to disentangle using models that seek to identify each effect through a steady time-related trend. Hence that decomposition is not reported here because of the lack of certainty that it is meaningful. It might be speculated that technology change is unlikely to have been substantial in a relatively "traditional" industry, such as the water industry. If so, then most of the observed trends in productivity would be attributable to changes in the degree of technical inefficiency. That is, declines in productivity would be attributable largely to reduced efficiency.

4.2 Total Factor Productivity trends

Table 4.1 compares the estimated TFP trends from all three of the models presented in this paper, and shows the average of the estimates for the period 2006 to 2010.

There are large discrepancies in the estimates for Albury City Council, Logan Water, and Power & Water Alice Springs. Other notable instances of discrepancy between estimates are Clarence Valley Council, Dubbo City Council and

Kalgoorlie-Boulder (water & sewerage combined). The random effects and SFA models in most cases provide similar results. While an average result for all three approaches could be used, there would be very little difference to using the SFA model, except for the utilities mentioned.

Table 3.5 shows that ranking of utilities based on their technical efficiency under all three approaches used in this study and the average overall. The technical efficiency estimates from the SFA model have been "normalised" so that the mean is equal to one. (The other two methods produce means close to one.) It is assumed that the utility-specific effects in these models mainly reflect comparative technical efficiency.

The results from the three approaches showed the following similarities.

- City West Water, South East Water and Yarra Valley Water were usually, but not consistently, ranked in the upper end of the ordering (top 25 per cent). Barwon Water was consistently ranked in the lower part of the ordering (bottom 25 per cent).
- Several of the largest interstate utilities were consistently ranked toward the bottom of the technical efficiency range. These included: ACTEW, Hunter Water Corporation, Sydney Water Corporation and Water Corporation – Perth.
- Brisbane Water and Gold Coast Water had above average technical efficiency. However, the three methods produced widely varying technical estimates for Brisbane Water.
- In regional Victoria, Westernport Water was ranked among the more efficient utilities when econometric models, but of average efficiency by the index-based approach. Several regional Victorian water utilities were among the least efficient nationally. These included Central Gippsland Water, Central Highlands Water, Coliban Water, East Gippsland Water, North East Water and Wannon Water.
- Among the interstate regional utilities, the following were generally ranked in the top 25 per cent for technical efficiency: Ballina Shire Council; Bathurst Regional Council, Byron Shire Council, Lismore City Council, Power & Water Alice Springs, Power & Water Darwin, Queanbeyan City Council, Orange City Council, and Aqwest/Water Corp. Bunbury.

Table 4.1 **Total Factor Productivity – Average Rates of Change**
(per cent compound rate over period 2006 to 2010)

Name	Index approach	Random effects model	SFA model	Average
Major urban Victoria				
Barwon Water	-1.3	-0.5	-0.8	-0.9
City West Water	0.9	0.8	1.0	0.9
South East Water Ltd	0.0	0.0	-0.1	0.0
Yarra Valley Water	-1.0	-0.4	-0.5	-0.6
Simple average - major urban Vic	**-0.3**	**0.0**	**-0.1**	**-0.2**
Major urban Non-Vic				
ACTEW	-2.2	-1.0	-0.9	-1.4
Hunter Water Corporation	-0.8	-0.5	-0.7	-0.7
Sydney Water Corporation	-2.0	-1.4	-1.4	-1.6
Brisbane Water	0.2	0.3	0.1	0.2
Gold Coast Water	-1.6	-0.9	-1.1	-1.2
SA Water - Adelaide	-1.4	-0.7	-1.1	-1.0
Water Corporation - Perth	-0.7	-0.3	-0.3	-0.4
Simple average - major urban non-Vic	**-1.2**	**-0.7**	**-0.6**	**-0.8**
Regional Victoria				
Central Gippsland Water	-1.9	-2.1	-3.3	-2.4
Central Highlands Water	-1.7	-1.6	-2.3	-1.9
Coliban Water	-1.5	-0.9	-1.3	-1.2
Goulburn Valley Water	-2.1	-2.4	-2.6	-2.4
East Gippsland Water	-1.0	-1.5	-2.1	-1.6
GWMWater	1.6	1.9	1.7	1.7
Lower Murray Water	0.3	-0.3	-0.5	-0.2
North East Water	0.0	-0.3	-0.3	-0.2
Wannon Water	-1.1	-0.9	-0.9	-0.9
Western Water	-1.2	-0.9	-1.2	-1.1
South Gippsland Water	-3.0	-2.2	-2.3	-2.5
Westernport Water	1.0	1.6	1.1	1.2
Simple average - regional Vic	**-0.9**	**-0.8**	**-0.8**	**-0.8**
Regional Non-Vic				
Gosford City Council	0.6	1.8	2.3	1.6
Wyong Shire Council	-1.5	-1.4	-1.3	-1.4
Albury City Council	-11.2	-3.3	-4.9	-6.5
Coffs Harbour City Council	-1.7	-1.7	-1.7	-1.7
MidCoast Water	-0.2	-1.0	-1.0	-0.7
Port Macquarie Hastings Council	1.4	0.9	0.8	1.0
Shoalhaven City Council	-0.4	-0.9	-0.6	-0.6
Tweed Shire Council	3.1	1.4	1.4	2.0
Wagga Wagga Council/Riverina Water	-0.7	-0.6	-0.8	-0.7
Ballina Shire Council	-0.3	-0.4	-0.1	-0.2

Name	Index approach	Random effects model	SFA model	Average
Bathurst Regional Council	-0.6	-0.2	-0.2	-0.3
Bega Valley Shire Council	-2.4	-1.4	-1.7	-1.8
Byron Shire Council	1.1	0.9	0.8	0.9
Clarence Valley Council	7.6	4.9	4.6	5.7
Country Energy	-1.7	-1.4	-1.2	-1.4
Dubbo City Council	3.5	0.5	0.7	1.5
Eurobodalla Shire Council	-1.1	-1.9	-1.5	-1.5
Kempsey Shire Council	-0.3	0.6	0.5	0.3
Lismore City Council	-0.2	1.0	1.2	0.7
Orange City Council	1.6	0.2	0.2	0.7
Queanbeyan City Council	-0.2	-0.2	-0.2	-0.2
Tamworth Regional Council	0.3	-0.6	-0.7	-0.3
Wingecarribee Shire Council	1.3	0.1	0.9	0.7
Power and Water - Darwin	-1.1	-0.5	-0.8	-0.8
Power and Water - Alice Springs	2.6	-2.4	-5.7	-1.8
Ipswich Water	0.8	0.0	0.0	0.3
Logan Water	-6.1	2.3	2.6	-0.4
Water Corporation - Mandurah	-2.3	-1.5	-1.6	-1.8
Aqwest/Water Corp Bunbury	2.7	3.5	3.3	3.1
Kalgoorlie-Boulder (sewerage & water)	-3.8	-1.9	-1.0	-2.2
Water Corporation - Albany	-3.3	-2.5	-2.4	-2.8
Simple average - regional non-Vic	**-0.4**	**-0.2**	**-0.4**	**-0.3**
Simple Average - all utilities	**-0.7**	**-0.4**	**-0.5**	**-0.5**

Source: ESC.

Table 3.5 **Comparison of technical efficiency indicators with alternative models**

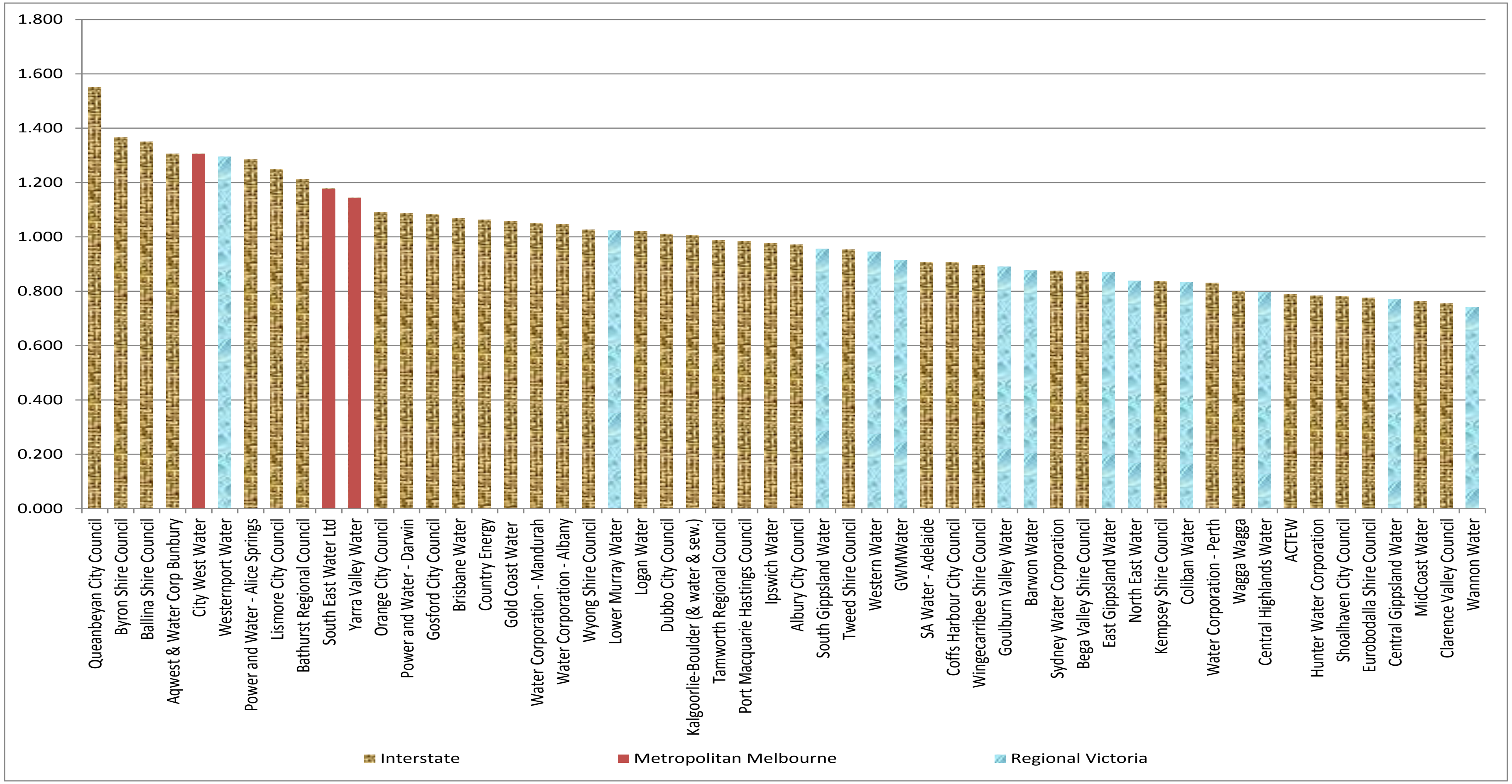
Name	Index approach		Random effects		Stochastic frontier		Average	
	Scale-adj. TFP index	Ranking	Technical efficiency	Ranking	Firm-specific effect	Ranking	Technical efficiency	Ranking
Major urban Victoria								
Barwon Water	0.891	35	0.857	41	0.884	39	0.877	37
City West Water	1.364	2	1.325	6	1.227	9	1.305	5
South East Water Ltd	1.210	7	1.081	14	1.241	7	1.177	10
Yarra Valley Water	1.185	8	1.077	15	1.170	11	1.144	11
Average - major urban Vic	**1.162**		**1.085**		**1.130**		**1.126**	
Major urban Non-Vic								
ACTEW	0.795	45	0.750	51	0.822	44	0.789	47
Hunter Water Corporation	0.823	42	0.738	53	0.791	48	0.784	48
Sydney Water Corporation	0.779	50	0.917	33	0.929	32	0.875	38
Brisbane Water	1.126	12	1.014	24	1.062	18	1.067	15
Gold Coast Water	1.062	18	1.042	20	1.064	17	1.056	17
SA Water - Adelaide	0.944	28	0.892	37	0.887	38	0.908	33
Water Corporation - Perth	0.851	39	0.786	45	0.857	41	0.831	44
Average - major urban non-Vic	**0.911**		**0.877**		**0.916**		**0.901**	
Regional Victoria								
Central Gippsland Water	0.780	49	0.891	38	0.645	54	0.772	51
Central Highlands Water	0.794	47	0.782	47	0.814	45	0.797	46
Coliban Water	0.827	41	0.787	44	0.888	37	0.834	43
Goulburn Valley Water	0.920	32	0.957	31	0.796	47	0.891	36
East Gippsland Water	0.817	43	0.890	39	0.907	34	0.871	40
GWMWater	0.872	36	0.908	34	0.964	28	0.915	32
Lower Murray Water	1.079	16	1.004	26	0.987	25	1.023	21

Name	Index approach: Scale-adj. TFP index	Index approach: Ranking	Random effects: Technical efficiency	Random effects: Ranking	Stochastic frontier: Firm-specific effect	Stochastic frontier: Ranking	Average: Technical efficiency	Average: Ranking
North East Water	0.872	37	0.811	43	0.830	43	0.838	41
Wannon Water	0.761	52	0.744	52	0.724	53	0.743	54
Western Water	0.930	31	0.927	32	0.981	26	0.946	31
South Gippsland Water	0.902	34	1.025	21	0.942	29	0.957	29
Westernport Water	1.029	21	1.391	3	1.467	2	1.296	6
Average - regional Vic	**0.882**		**0.926**		**0.912**		**0.907**	
Regional Non-Vic								
Gosford City Council	1.085	15	1.089	13	1.077	16	1.084	14
Wyong Shire Council	1.027	22	1.004	25	1.048	20	1.026	20
Albury City Council	0.707	54	1.125	10	1.079	15	0.971	28
Coffs Harbour City Council	0.914	33	0.905	35	0.901	36	0.907	34
MidCoast Water	0.763	51	0.751	50	0.772	50	0.762	52
Port Macquarie Hastings Council	0.997	23	0.962	30	0.992	24	0.983	26
Shoalhaven City Council	0.811	44	0.752	49	0.784	49	0.782	49
Tweed Shire Council	0.988	26	0.969	28	0.902	35	0.953	30
Wagga Wagga	0.867	38	0.774	48	0.761	51	0.801	45
Ballina Shire Council	1.301	4	1.364	4	1.387	3	1.351	3
Bathurst Regional Council	1.173	9	1.284	8	1.176	10	1.211	9
Bega Valley Shire Council	0.789	48	0.895	36	0.932	31	0.872	39
Byron Shire Council	1.310	3	1.406	2	1.380	4	1.366	2
Clarence Valley Council	0.794	46	0.722	54	0.747	52	0.754	53
Country Energy	0.990	24	1.097	11	1.102	12	1.063	16
Dubbo City Council	1.049	19	1.059	17	0.924	33	1.011	23
Eurobodalla Shire Council	0.736	53	0.785	46	0.807	46	0.776	50
Kempsey Shire Council	0.830	40	0.841	42	0.839	42	0.837	42

Name	Index approach Scale-adj. TFP index	Ranking	Random effects Technical efficiency	Ranking	Stochastic frontier Firm-specific effect	Ranking	Average Technical efficiency	Ranking
Lismore City Council	1.282	6	1.227	9	1.240	8	1.250	8
Orange City Council	1.097	14	1.094	12	1.082	14	1.091	12
Queanbeyan City Council	1.483	1	1.617	1	1.550	1	1.550	1
Tamworth Regional Council	0.957	27	1.064	16	0.940	30	0.987	25
Wingecarribee Shire Council	0.932	30	0.885	40	0.871	40	0.896	35
Power and Water - Darwin	1.149	11	1.025	22	1.087	13	1.087	13
Power and Water - Alice Springs	1.166	10	1.335	5	1.354	5	1.285	7
Ipswich Water	0.990	25	0.967	29	0.969	27	0.975	27
Logan Water	1.070	17	0.999	27	0.993	23	1.020	22
Water Corporation - Mandurah	1.118	13	1.016	23	1.020	22	1.051	18
Aqwest/Water Corp Bunbury	1.299	5	1.298	7	1.320	6	1.305	4
Kalgoorlie-Boulder	0.944	29	1.044	19	1.032	21	1.006	24
Water Corporation - Albany	1.039	20	1.049	18	1.053	19	1.047	19
Average - regional non-Vic	**1.021**		**1.045**		**1.036**		**1.034**	
Simple Average – all utilities	**0.987**		**1.001**		**1.000**		**0.996**	

Source: ESC.

Figure 3.4 **Technical efficiency estimates – Average of three models**



Source: ESC.

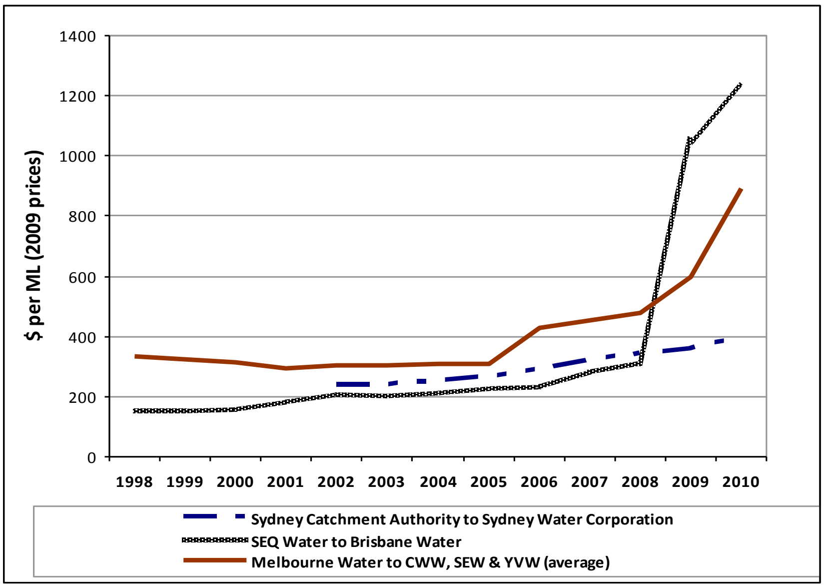
4.3 Bulk water supply

This study examines the productivity of water retail/distribution utilities only. Bulk water suppliers such as Melbourne Water, SEQ Water and Sydney Catchment Authority are not included in the analysis. The inputs of the water retailer/distributors include the quantities of bulk water supplied, but do not reflect the efficiency of bulk water suppliers.

An examination of the productivity or cost efficiency of bulk water suppliers is outside the scope of this analysis. Figure 4.1 shows comparative bulk water prices of the three mentioned bulk water suppliers. Over the period 2001-02 to 2009-10, Melbourne bulk water charges were on average 33 per cent higher than the average of the other two interstate capital city bulk water suppliers. However, these utilities differ in the services they provide. Melbourne Water provides catchment management, reservoirs, treatment and transmission pipeline transportation. The Sydney Catchment Authority provides catchment management and reservoirs, but is not responsible for treatment or transmission. SEQ Water's role has changed over time. Previously, it was largely a supplier of untreated water.[9] More recently it has joined with two other bulk water suppliers to form the South East Queensland water grid, whose role encompasses water treatment, transmission and desalination, similar to that of Melbourne Water. The bulk water prices of SEQ Water approximately trebled in 2009 in association with this restructuring and investment in desalination.

[9] *WSAA facts* 2005, p 94.

Figure 4.1 **Real Bulk water prices ($ per ML 2009 prices)**



Data sources: Melbourne Water, Sydney Water, SEQWater.

Appendix A | Data Sample

The study uses a sample of 54 firms from seven states and territories in Australia, with 409 observations in total. All of the utilities are combined water and sewerage distributors. Utilities that are purely bulk water suppliers, such as Melbourne Water and the Sydney Catchment Authority, are not included in the sample.

The data is primarily sourced from:

- the Water Supply Association of Australia's *WSAAfacts*, 2001 to 2005, for large utilities
- the National Water Commission's (NWC) *National Performance Report 2009-10*, for large and small utilities
- water utilities, city councils and other agencies regarding additional information.

The NWC reports data for the 73 largest water authorities in Australia, but there are also numerous smaller authorities supplying small remote communities that are not included. Of the utilities covered by the NWC, some businesses were excluded from the sample because:

- they were expected to have insufficient or poor data, or
- industry structural changes meant that it was not possible to establish sufficiently continuous data, or
- they are bulk water suppliers, not covered in this analysis.

These exclusions largely affect coverage in Tasmania, rural South Australia and northern Queensland.

Table A.1 lists the utilities covered in the sample, the main sources of information, the sample period and number of observations for each utility.

Table A.1 **Australian urban water utilities sample**

#	Utility	Sources	Sample Period	Observations
	Australian Capital Territory			
1	ACTEW	WSAA & NWC	'98 to '10	13
	New South Wales			
2	Hunter Water Corporation	WSAA & NWC	'98 to '10	13
3	Sydney Water Corporation	WSAA & NWC	'99 to '10	12
4	Gosford City Council	WSAA & NWC	'98 to '10	13
5	Wyong Shire Council	NWC	'06 to '10	5
6	Albury City Council	NWC	'06 to '10	5
7	Coffs Harbour City Council	NWC	'06 to '10	5
8	MidCoast Water	NWC	'06 to '10	5
9	Port Macquarie Hastings Council	NWC	'06 to '10	5
10	Shoalhaven City Council	NWC	'06 to '10	5
11	Tweed Shire Council	NWC	'06 to '10	5
12	Wagga Wagga Council & Riverina Water	NWC	'06 to '10	5
13	Ballina Shire Council	NWC	'06 to '10	5
14	Bathurst Regional Council	NWC	'06 to '10	5
15	Bega Valley Shire Council	NWC	'06 to '10	5
16	Byron Shire Council	NWC	'06 to '10	5
17	Clarence Valley Council	NWC	'06 to '10	5
18	Country Energy	NWC	'06 to '10	5
19	Dubbo City Council	NWC	'06 to '10	5
20	Eurobodalla Shire Council	NWC	'06 to '10	5
21	Kempsey Shire Council	NWC	'06 to '10	5
22	Lismore City Council	NWC	'06 to '10	5

#	Utility	Sources	Sample Period	Observations
23	Orange City Council	NWC	'06 to '10	5
24	Queanbeyan City Council	NWC	'06 to '10	5
25	Tamworth Regional Council	NWC	'06 to '10	5
26	Wingecarribee Shire Council	NWC	'06 to '10	5
	Northern Territory			
27	Power and Water – Darwin	WSAA & NWC	'98 to '10	13
28	Power and Water – Alice Springs	NWC	'06 to '10	5
	Queensland			
29	Brisbane Water	WSAA & NWC	'98 to '10	13
30	Gold Coast Water	WSAA & NWC	'98 to '10	13
31	Ipswich Water	WSAA & NWC	'02 to '05 & '08 to '10	7
32	Logan Water	WSAA & NWC	'03 to '10	8
	South Australia			
33	SA Water - Adelaide	WSAA & NWC	'98 to '10	13
	Victoria			
34	Barwon Water	WSAA & NWC	'98 to '10	13
35	City West Water	WSAA & NWC	'98 to '10	13
36	South East Water Ltd	WSAA & NWC	'98 to '10	13
37	Yarra Valley Water	WSAA & NWC	'98 to '10	13
38	Central Gippsland Water	WSAA & NWC	'99 to '10	12
39	Central Highlands Water	WSAA & NWC	'98 to '10	13
40	Coliban Water	WSAA & NWC	'98 to '10	13
41	Goulburn Valley Water	WSAA & NWC	'98 to '10	13
42	East Gippsland Water	NWC	'06 to '10	5
43	GWMWater	NWC	'06 to '10	5

#	Utility	Sources	Sample Period	Observations
44	Lower Murray Water	NWC	‘06 to ‘10	5
45	North East Water	NWC	‘06 to ‘10	5
46	Wannon Water	NWC	‘06 to ‘10	5
47	Western Water	WSAA & NWC	‘05 to ‘10	6
48	South Gippsland Water	NWC	‘06 to ‘10	5
49	Westernport Water	NWC	‘06 to ‘10	5
	Western Australia			
50	Water Corporation – Perth Metropolitan	WSAA & NWC	‘98 to ‘10	13
51	Water Corporation - Mandurah	NWC	‘06 to ‘10	5
52	Aqwest & Water Corporation – Bunbury	NWC	‘07 to ‘10	4
53	Kalgoorlie-Boulder (sewerage) & Water Corporation (water)	NWC	‘06 to ‘10	5
54	Water Corporation - Albany	NWC	‘06 to ‘10	5
	Total	**54**	**(Avg: 7.6)**	**409**

Appendix B | Index-based TFP measurement

This appendix explains the method of calculating the Total Factor Productivity (TFP) growth rates and index numbers presented in chapter 2.

Defining the indexes

The TFP growth rate for utility *i* in period *t* was calculated according to the following formula:

Equation (A.1) $$d \ln TFP_{i,t} = d \ln Y_{i,t} - d \ln X_{i,t}$$

$$= \sum_j M_j d \ln y_{j,i,t} - \sum_k C_k d \ln x_{k,i,t}$$

Where:

- Y is the aggregate output index and y_j is the quantity of output j.
- X is the aggregate input index and x_k is the amount of input *k*.
- M_j are the output index fixed weights
- C_k are the input index fixed weights.

The total TFP index is:

$$TFP = Y/X = \prod_j (y_{j,i,t})^{M_j} \Big/ \prod_k (x_{k,i,t})^{C_k}$$

Although a chain weighted index is superior to a fixed weighted index for time series, when cross-sectional data is used a fixed weighted index such as the Cobb-Douglas form can be useful. It is also convenient to use fixed weights because an unbalanced panel[10] is used in this analysis. Otherwise the weights would vary with changes in the composition of the sample of utilities over time.

[10] See the definition of panel data in the glossary.

Calculating the weights

The index weights are shown in Table B.1. They are rounded approximations based on the following analysis.

- The weights for the input index are based on average cost shares. When calculating the average cost share weights, the average cost shares of each input, across all utilities, was first calculated separately for each year. Then the average of those yearly cost share weights was calculated.
- For weighting the outputs, marginal cost elasticities with respect to each output are used, based on estimates derived from an estimated econometric cost function. These estimates are subject to limitations in part because the cost function has been estimated only for the purpose of estimating the output index weights. There has not been the degree of scrutiny or specification testing that would be employed to develop a preferred cost function model.

Table B.1 **Index weights**

	Water only	*Sewage only*	*Combined*
Input cost share weights			
Capital inputs – quasi-physical	0.64	0.64	0.64
– accounting-based	0.16	0.16	0.16
Non-capital inputs	0.20	0.20	0.20
Output cost elasticity weights			
Customers	0.89	0.89	0.80
Water supply, normalised & quality adjusted	0.11	..	0.10
Sewage collected, quality adjusted	..	0.11	0.10

Source: ESC.

Regression model used for normalisation

The scale-adjustment by regressing the log of the raw TFP indexes against the log of customer numbers as a measure of scale. The fitted values of TFP from this regression represented the component of TFP explained by scale factors. The raw TFP was divided by the fitted TFP scores to obtain the scale-adjusted TFP.

The results of regressing of the log of raw TFP against the log of customer numbers (measuring scale) are shown in Table B.3. The scale-adjusted TFP indexes were derived by dividing the raw TFP indexes by the predicted values using the equations in Table B.3.

Table B.3 **Econometric models for scale-adjustment**

	Constant	**Scale parameter**	**R^2**
Combined water & sewerage	-0.1161	0.1645	0.6396
(t-stat)	(-11.27)	(26.87)	
Water	-0.1672	0.2074	0.6103
(t-stat)	(-12.10)	(25.25)	
Sewerage	-0.0598	0.1220	0.4905
(t-stat)	(-5.77)	(19.79)	

Source: ESC.

The relatively low values of R^2 in these models indicate that scale is not the only reason that productivity differs between utilities. Much of the variation is due to differences in technical efficiency, for example. However, scale is a significant factor in the variation in raw TFP. This suggests there is merit in the scale-adjustment of the raw TFP index. By filtering out this effect, these indexes are likely to provide a better basis for comparing productivity between utilities.

Appendix C Distance functions, TFP & decomposition

The purpose of this chapter is to document the research choices and methodologies.

Model specification

The input-oriented distance function is related to technical efficiency as follows:

(Equation C.1) $$D_I(x,y) = 1/TE_I(x,y) \geq 1$$

Broadly speaking it represents the ratio of the inputs actually used to the minimum input set required to produce a given output. This ratio is a scaling factor for inputs when used in the same proportions. That is, it measures the maximum degree to which inputs can be equiproportionately reduced while still producing the same set of outputs.

The distance is a function of the inputs (x's) and outputs (y's). In log form:

(Equation C.2) $$\ln D_I = F(x,y,t,z) = u \geq 0$$

where *t* is a measure of time and *z* represents other variables that influence the technology sets available to different firms. (For example, they may have different natural endowments of weather and topography and serve urban areas with different characteristics.) The variable *u* is a measure of firm-specific *inefficiency*. If *u* = 0, the firm is operating at best practice — it is on the efficiency frontier. Another way of putting this is, for given values of *y*, *t* and *z*, the set of x's that satisfy *u*=0 represent the 'input isoquant'. The function F(.) is increasing in *x* and decreasing in *y*.

In this study the input-oriented distance function is specified in a translog form as shown in equation C.3.

(Equation B.3) $$F(x,y,t,z)=\alpha_0+\sum_{k=1}^{K}\alpha_k \ln x_{k,i,t}+\sum_{m=1}^{M}\beta_m \ln y_{m,i,t}$$

$$+\frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K}\alpha_{kl}\ln x_{k,i,t}\ln x_{l,i,t}+\frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{M}\beta_{mn}\ln y_{m,i,t}\ln y_{n,i,t}$$

$$+\sum_{k=1}^{K}\sum_{m=1}^{M}\delta_{km}\ln x_{k,i,t}\ln y_{m,i,t}+\gamma_1 t+\frac{1}{2}\gamma_2 t^2+\sum_{k=1}^{K}\psi_k \ln x_{k,i,t}t$$

$$+\sum_{m=1}^{M}\xi_m \ln y_{m,i,t}t+\sum_{j=1}^{J}\theta_j z_{j,i,t}$$

Where:

- There is a panel of i = 1 … I producers over t = 1 … T periods.
- There are K inputs, x_k, M outputs, y_m and J environmental variables, z_j.

In equation C.3 the 'environmental' variables (z's), have been included linearly. This is the approach used by Saal, Parker & Weyman-Jones (2007). Alternative approaches permit some or all of the environmental variables to instead interact with the distribution of the inefficiency term. Some of these approaches have also been tested in this study.

Econometric specification

The econometric version of the distance function is derived by imposing linear homogeneity in inputs by normalising by one of the inputs. The normalised inputs are: $\tilde{x}_k = x_k / x_K$ (k = 1 … K–1). Also, a "white noise" error term, (v_{it}) is included to take account of measurement error and other sources of random disturbance. The estimating equation is then:

(Equation C.4) $$-\ln x_{K,i,t}=F(\tilde{x},y,t,z)-u_{i,t}+v_{i,t}$$

There are various different SFA econometric approaches involving different specifications of the firm-specific inefficiency, u_{it}. In the Battese-Coelli SFA specification used in this study, u_{it} is a strictly positive random variable with a cross sectional component (u_i) and a common time trend component, and u_i has a truncated normal distribution. In the random effects model, $u_{it} = u_i$ and is a symmetric random variable. There is no time-trend component.

Calculation of productivity change & decomposition

The calculation of the change in TFP, and its decomposition, can be derived by taking the total derivative of equation B.2:

(Equation C.5) $$d\ln D_I = \sum_k \frac{\partial F}{\partial x_k} dx_k + \sum_m \frac{\partial F}{\partial y_m} dy_m + \frac{\partial F}{\partial t} dt + \frac{\partial F}{\partial z} dz = du$$

Because linear homogeneity in inputs has been imposed, $\eta_X = \sum_k \left(\partial F / \partial x_k\right) = 1$

Thus equation B.6 represents a weighted average rate of change in all inputs.

(Equation C.6) $$d\ln X = \sum_k \left(\partial F / \partial x_k\right) d\ln x_k$$

But the same need not be for outputs. That is: $\eta_Y = -\sum_m \left(\partial F / \partial y_m\right)$ need not be equal to one (recall that D_I is decreasing in y). Normalisation is needed for the weighted average rate of change in outputs as shown in equation B.7.

(Equation C.7) $$d\ln Y = -\left(1/\eta_Y\right) \sum_m \left(\partial F / \partial y_m\right) d\ln y_m$$

Equation B.5 can then be re-written and expanded:

(Equation C.8) $$du = d\ln X + \left[\left(1 - \frac{1}{\eta_Y}\right) \sum_m \frac{\partial F}{\partial y_m} d\ln y_m\right] - d\ln Y + \frac{\partial F}{\partial t} dt + \frac{\partial F}{\partial z} dz$$

Rearranging gives:

(Equation C.9) $$d\ln M_I = \left[\left(1 - \frac{1}{\eta_Y}\right) \sum_m \frac{\partial F}{\partial y_m} d\ln y_m\right] + \frac{\partial F}{\partial t} dt + \frac{\partial F}{\partial z} dz - du$$

where $d\ln M_I$ is the rate of change in the input-oriented Malmquist index:

(Equation C.10) $$d\ln M_I = d\ln Y - d\ln X$$

The terms on the right-hand side of equation C.9 are respectively:

- the returns-to-scale effect
- the effect of technological change
- effects due to changes in the 'environmental' variables, and

- changes in firm-specific inefficiency.

The foregoing derivation is in continuous time, but in practice discrete time approximations are used.

Appendix D | Choice of econometric specification

The appendix explains the process of selecting the preferred econometric models.

Stochastic Frontier Analysis (half-normal model)

The specification of the stochastic frontier analysis (SFA) is the Battesse-Coelli half-normal model. When the distance function takes the form of equation B.3, we will refer to this as the SFA1 specification.

Some references suggest that it may be difficult to identify the time-varying inefficiency parameter within this specification if time trend terms are also included in the distance function. We also test the Battesse-Coelli model with the time trend terms excluded from equation B.3, and refer to this model as SFA2.

Five different specifications of the capital inputs are tested:

1. include both the accounting-based and quasi-physical measures
2. include on the accounting based measure
3. include only the quasi-physical measure
4. use a simple average of both measures
5. use a weight average, with 75 per cent weight given to the quasi-physical measure.

The choice between the models is based on the generalised likelihood ratio test. If model A is a special case of model B, then the test statistic is: $W = 2 \times (LLR_B - LLR_A)$, where LLR refers to the log likelihood ratio. This statistic is distributed as a chi-squared distribution with degrees of freedom equal to the number of restrictions—i.e. the difference between the number of parameters in the general and restricted models.

In the models tested here, the number of restrictions (or 'degrees of freedom') is either 7 or 13, and at the 0.05 level of significance, the critical values of the test statistic are 14.1, and 22.4 respectively. If the test statistic (W) is less than the test statistic, we would reject the unrestricted model in favour of a restricted model. The values of W in each case are shown in the following Table, indicating that the unrestricted model, in which two different measures of capital inputs are used, is preferred to any of the restricted models.

Table D.1 summarises the specification tests for the stochastic frontier model relating to the presence of the time-trend terms and the choice of capital stock measures. This test shows that in all cases the restrictions are rejected and the unrestricted model, SFA1-1 is preferred. In this model, the time trend parts of equation B.3 are retained and both measures of the capital stock are included in the model.

Table D.1 **Likelihood Ratio Tests of SFA specifications**

	DF	LLR	W	Critical value
SFA1-1		679.3		
SFA1-2	7	357.7	643.2	20.3
SFA1-3	7	653.4	51.8	20.3
SFA1-4	7	586.7	185.2	20.3
SFA1-5	7	651.6	55.4	20.3
SFA2-1	7	633.9	90.8	20.3
SFA2-2	13	321.5	715.6	29.8
SFA2-3	13	618.0	122.6	29.8
SFA2-4	13	546.1	286.4	29.8
SFA2-5	13	619.9	118.8	29.8

Table D.2 presents other information relevant to the adequacy of the models—namely, the average elasticities of the distance function with respect to the outputs and inputs. Since these are the averages of the output and input index weights, they should all have values between zero and one.

Table D.2 shows that in model SFA1.1:

- The most important output is customer connections, with a weight of 85 per cent in the output index. Water supplied has a weight of almost 5 per cent and sewerage collected has a weight of almost 10 per cent.
- Combined capital inputs have an overall weight of over 90 per cent in the input index. Of the two capital input measures, the quasi-physical measure is more important than the accounting-based measure. The ratio of relative importance of these two capital measures is approximately 80:20.

Table D.2 **SFA output & inputs elasticities**

	Outputs			Inputs		
	Cust.	Water	Sewerage	K(account)	K(physical)	Non-cap
SFA1-1	0.86	0.04	0.09	0.19	0.73	0.08
SFA1-2	0.89	0.02	0.09	0.55	-	0.45
SFA1-3	0.93	0.01	0.06	-	0.89	0.11
SFA1-4	0.95	0.02	0.03	0.89		0.11
SFA1-5	0.96	0.00	0.04	0.90		0.10
SFA2-1	0.89	0.04	0.08	0.11	0.78	0.11
SFA2-2	0.94	0.00	0.06	0.49	-	0.51
SFA2-3	0.94	0.02	0.05	-	0.90	0.10
SFA2-4	0.94	0.01	0.05	0.87		0.13
SFA2-5	0.95	0.01	0.04	0.91		0.09

The result of the foregoing specification tests is that model SFA1-1 is preferred to the other models described above. Table D.3 presents the SFA1-1 model.

Table D.3 **SFA1-1: Estimated parameters of SFA model using both capital measures**

Coefficients:	Parameter	SE	z-statistic
y1 (customers)	-0.8102219	0.0286987	-28.23
y2 (water supplied)	-0.0340251	0.0129613	-2.63
y3 (sewerage collected)	-0.0759281	0.0217661	-3.49
x1 (Acc. capital)	0.1193783	0.0317855	3.76
x2 (Phys. Capital)	0.8160023	0.0351111	23.24
y11	-0.2801527	0.0513981	-5.45
y12	0.0533225	0.0143432	3.72
y13	0.1683209	0.0409592	4.11
y22	-0.0090322	0.004189	-2.16
y23	-0.0515315	0.0160551	-3.21
y33	-0.0972225	0.0389776	-2.49
x11	0.0446414	0.0176033	2.54
x12	-0.02596	0.0254884	-1.02
x22	0.1277387	0.0450754	2.83
y1x1	-0.0209589	0.0333183	-0.63
y2x1	-0.0007941	0.0128128	-0.06
y3x1	-0.0022866	0.0199593	-0.11
y1x2	-0.1231619	0.0482603	-2.55
y2x2	0.0312971	0.0187998	1.66
y3x2	0.0945624	0.0367253	2.57
time	0.0156311	0.0030546	5.12
tsq	-0.000617	0.0003516	-1.76
y1t	-0.0029482	0.0022206	-1.33
y2t	0.0005285	0.0008424	0.63
y3t	0.0036452	0.0022351	1.63

Coefficients:	Parameter	SE	z-statistic
x1t	0.0065555	0.0018528	3.54
x2t	-0.0126866	0.0031197	-4.07
z1 (%wastewater=trade waste)	0.0966114	0.0280948	3.44
z2 (% cust. with sewerage)	-0.4074316	0.0671692	-6.07
z3 (groundwater%)	-0.0066438	0.0044387	-1.50
_cons	0.5508629	0.0844842	6.52
mu	(omitted)		
eta	-0.0240583	0.0050064	-4.81
sigma2	0.249343	0.0600982	
gamma	0.9961542	0.0010216	
sigma_u2	0.2483841	0.0601109	
sigma_v2	0.0009589	0.0000751	
Goodness of fit:			
Log Likelihood	679.3		

Source: ESC.

Random Effects Model

This section discusses the specification of the random effects model. The same five alternative specifications of capital inputs have been tested. The results are shown in Table D.4. Once again, the restricted forms of capital inputs specification are all rejected and the unrestricted model, RE1-1 is preferred. Both measures of the capital stock are included in this model.

Table D.4 **Likelihood Ratio Tests of SFA specifications**

	DF	LLR	W	Critical value
RE1-1		685.7		
RE1-2	7	355.9	659.6	20.3
RE1-3	7	664.0	43.4	20.3
RE1-4	7	572.2	227.0	20.3
RE1-5	7	654.2	63.0	20.3

Table D.5 shows that in model RE1.1:

- Among the outputs, customer connections have a weight of 90 per cent; water supplied 3 per cent and sewerage collected 7 per cent.
- Combined capital inputs have an overall weight of approximately 90 per cent in the input index. The relative importance of the quasi-physical and accounting-based measures is approximately 85:15.

Table D.5 **RE output & inputs elasticities**

	Outputs			Inputs		
	Cust.	**Water**	**Sewerage**	**K(account)**	**K(physical)**	**Non-cap**
RE1-1	0.90	0.03	0.07	0.15	0.76	0.10
RE1-2	0.97	0.01	0.02	0.58	-	0.42
RE1-3	0.94	0.01	0.05	-	0.88	0.12
RE1-4	0.97	0.02	0.01	0.86		0.14
RE1-5	0.96	0.01	0.02	0.88		0.12

The specification tests for the random effects model have resulted in a preference for the RE1-1 over the other models set out above. Table D.6 presents the SFA1-1 model.

Table D.6 **RE1-1: Estimated parameters of SFA model using both capital measures**

Coefficients:	**Parameter**	**SE**	**z-statistic**
y1 (customers)	-0.7558817	0.0377989	-20
y2 (water supplied)	-0.0295888	0.0129444	-2.29
y3 (sewerage collected)	-0.0670473	0.0224746	-2.98
x1 (Acc. capital)	0.0800036	0.0384853	2.08
x2 (Phys. Capital)	0.9082608	0.0394587	23.02
y11	-0.246024	0.0550794	-4.47
y12	0.0538799	0.0148136	3.64
y13	0.1537338	0.0444544	3.46
y22	-0.0072373	0.0042004	-1.72
y23	-0.0597542	0.016516	-3.62
y33	-0.0793711	0.0431396	-1.84
x11	0.0647651	0.0181444	3.57
x12	-0.0285311	0.0260843	-1.09
x22	0.1269401	0.0441675	2.87
y1x1	-0.0614105	0.0344459	-1.78
y2x1	0.0103829	0.013101	0.79
y3x1	0.0157787	0.019988	0.79
y1x2	-0.0468454	0.0494662	-0.95
y2x2	0.016982	0.0194851	0.87
y3x2	0.0462764	0.0367091	1.26
time	0.0051665	0.0025099	2.06
tsq	-0.0004734	0.0003362	-1.41
y1t	-0.0004172	0.0022519	-0.19
y2t	-0.0005372	0.0008207	-0.65
y3t	0.0035013	0.0022157	1.58
x1t	0.0043693	0.0014145	3.09
x2t	-0.0183671	0.0026558	-6.92
z1 (%wastewater=trade waste)	-0.0250229	0.0270675	-0.92
z2 (% cust. with sewerage)	-0.3766264	0.0677364	-5.56

Coefficients:	Parameter	SE	z-statistic
z3 (groundwater%)	-0.0009077	0.0044094	-0.21
_cons	0.3706467	0.0846468	4.38
mu	(omitted)		
Sigma_u	0.1904143	0.0237582	-4.81
Sigma_e	0.0314125	0.0012372	
rho	0.9735061	0.0071135	
Goodness of fit:			
Log Likelihood	685.7		

Source: ESC.

Stochastic Frontier Analysis (truncated normal specification)

Earlier in this appendix several stochastic frontier models were presented, all assuming a half-normal distribution for inefficiency. Based on the likelihood ratio test, we preferred the SFA1-1 model among those alternatives. In this section a variant on the SFA1-1 model is tested, which relaxes the assumption that the inefficiency parameter has a half-normal distribution by assuming a truncated normal distribution instead. The half-normal model is a special case of the truncated normal model when the mean of the distribution ("mu") is equal to zero. In the truncated normal case it is an estimated parameter that can be non-zero. This new model is labelled SFA3-1, and in Table D.7. This model is in all other respects the same as SFA1-1.

Table D.7 **SFA3-1: SFA model using truncated normal distribution**

Coefficients:	Parameter	SE	z-statistic
y1 (customers)	-0.7636007	0.0278423	-27.43
y2 (water supplied)	-0.0329476	0.0127322	-2.59
y3 (sewerage collected)	-0.0708802	0.0214646	-3.3
x1 (Acc. capital)	0.1204192	0.0299793	4.02
x2 (Phys. Capital)	0.8150499	0.0351036	23.22
y11	-0.2750267	0.0513882	-5.35
y12	0.0561704	0.0144539	3.89
y13	0.1715392	0.0441251	3.89
y22	-0.0080029	0.0041242	-1.94
y23	-0.0567654	0.0161748	-3.51
y33	-0.0937649	0.0427499	-2.19
x11	0.052657	0.0172404	3.05
x12	-0.0279639	0.0253825	-1.1
x22	0.1428687	0.0443724	3.22
y1x1	-0.0204756	0.0325551	-0.63
y2x1	0.0028413	0.0127683	0.22
y3x1	-0.0036244	0.0198802	-0.18
y1x2	-0.1058987	0.0479817	-2.21

Coefficients:	Parameter	SE	z-statistic
y2x2	0.0273159	0.0188537	1.45
y3x2	0.0853402	0.0367011	2.33
time	0.0171346	0.0033132	5.17
tsq	-0.0005777	0.0003459	-1.67
y1t	-0.0014002	0.002251	-0.62
y2t	0.0004947	0.0008395	0.59
y3t	0.0033746	0.0022131	1.52
x1t	0.0067539	0.0017521	3.85
x2t	-0.012937	0.0030772	-4.2
z1 (%wastewater=trade waste)	0.0574783	0.0235785	2.44
z2 (% cust. with sewerage)	-0.3938163	0.0654837	-6.01
z3 (groundwater%)	-0.004613	0.0042235	-1.09
_cons	0.7050222	0.0975813	7.22
mu	0.5224585	0.0621201	8.41
eta	-0.0224415	0.0053435	-4.2
sigma2	0.0482458	0.0128722	
gamma	0.9803079	0.0057206	
sigma_u2	0.0472958	0.012885	
sigma_v2	0.0009501	0.0000746	
Goodness of fit:			
Log Likelihood	690.9		

Source: ESC.

In model SFA3-1 the z-statistic for the parameter "mu" is 8.41 > 1.96, which indicates that the parameter is significantly different from zero. The likelihood ratio test of the unrestricted model (truncated normal) compared to the restricted model, involves a single restriction, and the critical value of W is 3.84. However, W = 23.2, which is greater than the critical value, and therefore the half-normal model can be rejected in favour of the truncated normal model.

A specification test of this kind cannot be used to choose between the stochastic frontier and random effects models because neither model is a nested (or restricted) version of the other. The model SFA5 has a slightly higher log likelihood function (690.6) than the preferred random effects model RE1 (685.7).