Australian Government
National Water Commission

Productivity, efficiency and technological progress in Australia's urban water utilities

Andrew C Worthington, Griffith University

Waterlines Report Series No 62, October 2011

Waterlines

A SERIES OF WORKS COMMISSIONED BY THE NATIONAL WATER COMMISSION ON KEY WATER ISSUES

Waterlines

This paper is part of a series of works commissioned by the National Water Commission on key water issues. The report is based on work undertaken by Andrew C Worthington and Griffith University as part of a National Water Commission Fellowship which was awarded to Mr Worthington in 2009–10. The Commission's Fellowship Program was established in 2007 to develop future leaders for Australia's water sector by advancing knowledge and building capacity in the sector. The program contributes to the National Water Initiative (NWI) by supporting water professionals with at least 10 years experience to undertake research in areas that could make a significant contribution to knowledge of Australia's water management and use.

Online ISBN: 978-1-921853-37-1

Productivity, efficiency and technological progress in Australia's urban water utilities, October 2011

Author: Andrew C Worthington

Published by the National Water Commission
95 Northbourne Avenue
Canberra ACT 2600
Tel: 02 6102 6000
Email: *enquiries@nwc.gov.au*

Date of publication: October 2011

Cover design by: Angelink
Cover photo courtesy of Michelle McAulay

An appropriate citation for this report is:
Worthington, AC 2011, *Productivity, efficiency and technological progress in Australia's urban water utilities*, Waterlines Report, National Water Commission, Canberra

Disclaimer

This paper is presented by the National Water Commission for the purpose of informing discussion and does not necessarily reflect the views or opinions of the Commission.

Australian Government
National Water Commission

Griffith UNIVERSITY

Contents

Tables

Figures

Abbreviations and acronyms

ACT	Australian Capital Territory
ACW	ACTEW
ALB	Albury City Council
AQW	Aqwest – Bunbury Water Board (water supply)
AWA	Australian Water Association
BAL	Ballina Shire Council
BAR	Barwon Water
BAT	Bathurst Regional Council
BEG	Bega Valley Shire Council
BRI	Brisbane Water
BYR	Byron Shire Council
CGW	Central Gippsland Water
CHW	Central Highlands Water
CIT	City West Water
CLA	Clarence Valley Council
COAG	Council of Australian Governments
COF	Coffs Harbour City Council
COL	Coliban Water
DUB	Dubbo City Council
EGW	East Gippsland Water
GCW	Gold Coast Water
GFW	Goldenfields Water (Reticulation)
GOS	Gosford City Council
GOU	Goulburn Valley Water
GWM	GWM Water
HWC	Hunter Water Corporation
IPS	Ipswich Water

KMP	Kempsey Shire Council
LIS	Lismore City Council
LOG	Logan Water
LOW	Lower Murray Water
MCW	MidCoast Water
NCP	National Competition Policy
NEW	North East Water
NSW	New South Wales
NT	Northern Territory
NWC	National Water Commission
ORC	Orange City Council
PAD	Power and Water – Darwin
PAS	Power and Water – Alice Springs
PMQ	Port Macquarie Hastings Council
QLD	Queensland
QUE	Queanbeyan City Council
RIV	Riverina Water
SA	South Australia
SAW	SA Water – Adelaide
SEW	South East Water Ltd
SGW	South Gippsland Water
SHL	Shoalhaven City Council
SWC	Sydney Water Corporation
TAM	Tamworth Regional Council
TFP	Total factor productivity
TWE	Tweed Shire Council
VIC	Victoria
WA	Western Australia
WAN	Wannon Water
WAY	Water and Waste Services (Mackay Regional Council)

WCA	Water Corporation – Albany
WCG	Water Corporation – Geraldton (water supply)
WKB	Water Corporation – Kalgoorlie–Boulder (water supply)
WMN	Water Corporation – Mandurah
WPT	Water Corporation – Perth
WSA	Western Water
WSAA	Water Services Association of Australia
WSP	Westernport Water
WSR	Wingecarribee Shire Council
WYS	Wyong Shire Council
YAR	Yarra Valley Water

Acknowledgements

The author would like to thank Nancy Gonzalez, Peter McLoughlin, and the project reference group for helpful comments, suggestions and forbearance in the preparation of this report. The author also gratefully acknowledges the financial support of the National Water Commission and the technical contribution of Helen Higgs to the chapter on economies of scale and scope. The author dedicates his contribution to the report to the memory of his late brother, Mark Worthington.

Executive summary

This report presents the outcomes of a research project to measure and analyse efficiency, productivity and technological change in Australia's major urban water utilities using detailed utility-level data from the National Water Commission's National Performance Reports. In this report, urban water utilities include those entities involved in the treating, transmitting, distributing and retailing potable water. The project aims are to:

examine existing research on efficiency and productivity measurement in urban water utilities,

provide quantitative measures of efficiency, productivity and technological change and the impact of various factors on efficient and productive outcomes in the sector,

assay the scope and source of productivity and technological improvements that have taken place in recent years,

identify key productivity drivers and impediments to productivity growth in urban water utilities, and

feed any newly developed multidimensional metrics into future developments in the National Performance Reports.

The review of efficiency and productivity measurement in urban water utilities evidences an increasing literature concerning the application of efficiency measurement techniques to urban water utilities worldwide. Confirmation exists that these techniques are finding application in guiding regulatory policy and industry practice.

For the most part, the input-output relationship modelled in urban water utility behaviour follows a production approach. This principally views water utilities as producers of physical water outputs, typically the volume of potable water and/or the number of properties supplied with water as a function of operating expenditure. Past studies have generally made little allowance for qualitative outputs such as customer satisfaction and water quality.

Problematically, this specification is often the result of limited data availability and the inability of some methodologies to reflect the regulatory obligations of water utilities to provide water to households in their services areas. It also seldom reflects the capital-intensiveness of water utilities or the fullest range of input factors upon which they draw in the production process.

One common global theme is the recognition that the discretionary (controllable) and non-discretionary (non-controllable) resources available to a particular utility have an important influence on relative performance in diverse contexts. These potentially encompass both physical environmental circumstances, as well as constraints arising from organisational, managerial and regulatory policy.

The first empirical analysis examines the productivity growth of major Australian urban water utilities over the period 2005–06 to 2008–09 using non-parametric methods. The input is total operating expenditure and the outputs are chemical and microbiological compliance, real losses (litres/service connection/day), water quality and service complaints (per 1000 properties), and the inverse of water main breaks.

The results here suggest annual productivity growth of 1.04 per cent, largely attributable to efficiency gains. There appears to have been little gain from technological improvements (0.17–0.29 per cent). Of the reasons given for the lack of technological progress, the most likely is regulatory and compliance costs.

A second empirical analysis uses stochastic functions of operating and capital costs to calculate output-specific and overall economies of scale and scope over the period 2005–06 to 2008–09 employing a similar input-output specification as earlier, though with a finer distinction to the drivers of operating and capital expenditure.

The evidence suggests that economies of scale are maximised at about 90 000 connected properties. On this basis, horizontal aggregation (or disaggregation) to this level should provide efficiency gains, especially if the aggregated (or disaggregated) utilities can achieve the increase (or decrease) in scale without additional network costs. The analysis also suggests strong and persistent economies of scope across all utility sizes, thereby supporting vertical integration in the urban water utility sector.

The final empirical analysis concerns the measurement of technical operating and capital efficiency in a single year. Though this employs a similar input-output specification, a different approach allows for the direct inclusion of the uncontrollable contextual inputs that impact upon measured efficiency. The results indicate that a relatively high level of operating and capital efficiency prevails across the sector and that measured efficiency improves further with allowance for the efficiency impact of the scale of operations.

From a number of recommendations throughout the report, one of the more important is the need to understand better the actual decision-making framework urban water utilities use when deciding upon inputs and outputs, particularly given the multiple and often conflicting objectives in the sector. A second recommendation is that data collections include a fuller set of information relating to operating and capital inputs, including energy, labour, and capital inputs and input prices. In time, this should permit a fuller assessment of productivity and efficiency in urban water utilities in future empirical work.

The major limitation of this analysis is that because of time and other resource limitations, the focus has been on the role of urban water utilities in potable water services and there has been no attempt to model wastewater services. As wastewater services can represent up to half of the costs of the typical urban water utility, this is likely to understate the potential economies of scope that exist in the sector between potable water and wastewater services.

The main recommendation for future research is further investigation into the nature of the constraints placed on productive behaviour in urban water utilities and their efficiency impacts as a means of better informing regulatory, institutional and governance reform.

1 Introduction

1.1 Report background

The National Water Commission (NWC) identified urban water (including regulation, markets and water-sensitive cities) as a priority area in its second round of research fellowships in 2010. This report is the principal output of a fellowship project entitled ‘Productivity, efficiency, and technological progress in Australia’s urban water utilities’ conducted by the author from April 2010 to May 2011.

A number of factors have combined to reignite global interest in water policy as it relates to urban water utilities in the 21st Century. Starting from their essential nature as natural monopolies operating within network industries, countries around the world with initially similar settings in delivery networks and treatment systems have progressively evolved very different approaches to urban water utilities, especially in the chosen mix of privately and publicly owned entities and the extent of regulatory intervention governing pricing and standards.

However, recent circumstances have added impetus to these longstanding developments. These include declining rainfall associated with climate change, pressing needs for maintaining and expanding expensive water supply infrastructure, jurisdictional, sectoral and environmental conflicts over existing surface and groundwater supplies, and rapid population growth and urbanisation. In response, governments worldwide have refocused on improving the management and delivery of urban water services.

There is now concern about the ability of the urban water sector as it stands to achieve productive and efficient outcomes and thereby reassure key stakeholders, especially users, of the sustainability of the sector and this key resource, evidenced in Australia by the tasking of the Productivity Commission in 2010 to identify pathways for achieving improved resource allocation and efficiency. At least part of this relies on the conventional view that the inherent conditions of urban water utilities (supply variability, high transport costs, scale economies and public health requirements) place significant limits on the scope for effective competition and efficient markets in urban water.

Part also concerns the observation that the inefficiencies associated with current pricing arrangements, water restriction regimes, and deficiencies in supply and demand planning and investment processes, have caused additional and ongoing problems for the sector in terms of deteriorating infrastructure, threats to water quality, rising supply costs and reductions in consumer welfare. A final part draws on the apparent inability of the urban water sector to maintain a pace of reform consistent with both the rural water sector and other utilities, including gas, energy and telecommunications (Frontier Economics 2008).

1.2 Aims and scope

The aim of this project is to measure and analyse efficiency, productivity and technological change in Australia’s major urban water utilities using detailed utility-level data, namely, that newly publicly available in the NWC’s (2007, 2008, 2009, 2010a) National Performance Reports. The National Performance Report covers many critical performance areas of water resources, health, customer service, asset management, environmental, finance and pricing, and includes information from 73 water utilities supplying around 17.2 million Australians with urban water services.

An important point to note concerning this report is that the urban water sector conventionally comprises three interrelated sub-sectors: (i) potable water, (ii) wastewater (or sewerage) and (iii) stormwater (including drainage and flood mitigation). While the National Performance Reports include details on the first two sub-sectors, the focus of the present study is potable water, even though there is some recognition given its interplay with wastewater through recycled water.

It is clear from the second-most recent National Performance Report (2010a) that the Australian urban water utility sector continues to undergo a dramatic period of change that invokes a natural focus on efficiency and other performance outcomes. For instance, while total urban water supplied in 2008–09 of 1 182 695 ML was 8 per cent lower than in 2005–06, operating expenditure had increased substantially. This was arguably driven by higher input costs, increasing water conservation expenditure, and costs in managing superannuation liabilities, such that average operating expenditure across all utilities had increased by about 21 per cent. Even more dramatically, sectoral capital expenditure had increased from $2.6 billion in 2005–06 to $8.1 billion in 2008–09, a 210 per cent increase linked with large-scale desalination, recycling and pipeline projects. Correspondingly, the sector witnessed a substantial increase in the use of recycled water, from just 160 654 mega litres (ML) in 2005–06 to 227 083 ML in 2008–09 (a 41 per cent increase), and the operation or planned completion of desalination plants in several states where none existed before.

These conditions paint a picture of an urban water sector under stress with inevitable consequences for efficient outcomes. Here, and as noted by the Productivity Commission (2011), the prolonged use of water restrictions and consumption targets, the use of mandated measures and/or subsidies to reduce the consumption of potable water from bulk water supplies, and large investments in rainfall-independent supply capacity are major defining factors in the past decade. Moreover, in some regional areas, deficient operational, maintenance, and investment practices have led to inadequate water quality and /or exemptions granted for compliance with standards. Accordingly, the project aims are as follows:

Examine existing research on efficiency and productivity measurement in urban water utilities to both inform the present study and provide guidance for future research in this important area.

Provide quantitative measures of efficiency, productivity and technological change and the impact of various factors on efficient and productive outcomes in the sector, including the role of contextual factors (such as the environment) and conceptualisations of performance (public sector and regulated markets).

Assay the scope and source of productivity and technological improvements that have taken place in recent years, and the prospects for further ongoing improvements as a means of ensuring the sustainability of individual utilities and the sector as a whole given the existing planning, regulation, pricing, market and institutional context.

Identify key productivity drivers and impediments to productivity growth in urban water utilities as a means of identifying areas for attention in regulatory reform and industry development and establish best-practice benchmarks for improving practice in the industry.

Help feed any newly developed multidimensional metrics into future developments in the National Performance Reports as a means of further improving stakeholders’ understanding of Australia’s urban water utilities and assisting utilities to improve their performance.

1.3 Theoretical framework

An increasing number of studies worldwide have sought to estimate and measure efficiency and productivity in urban water utilities. Three main measures of efficiency meet the needs of researchers, managers, and policymakers in this regard. First, technical efficiency refers to the use of productive resources in the most technologically efficient manner. Put differently, technical efficiency implies the maximum (minimum) possible output (input) from (for) a given set of inputs (outputs), where inputs are the resources or factors used by the utility and outputs are the products of the utility. Within the context of water utilities, technical efficiency then refers to the physical relationship between the resources used (say, pipelines, labour, energy and equipment), some service outcome, including the number of households served, and the quantity and quality of potable water supplied.

Second, allocative efficiency reflects the ability of a utility to use these inputs in optimal proportions, given their respective prices and the available production technology. In other words, allocative efficiency is concerned with choosing between the different technically efficient combinations of inputs used to produce the maximum possible outputs. Consider, for example, a change to a fully automatic meter reading system. Electronic meters may need fewer labour inputs (for reading the meter) but do require the use of another resource in the form of electronic technology. As different combinations of inputs are being used, and notwithstanding differences in the quality of the outputs (such as the easier detection of meter tampering and improved accuracy), the choice of metering is then based on the relative costs of these different inputs. Finally, when taken together, allocative efficiency and technical efficiency determine the degree of productive efficiency (also known as total economic efficiency). Thus, if an urban water utility uses its resources completely allocatively and technically efficiently, then it has achieved total economic efficiency. Alternatively, to the extent that either allocative or technical inefficiency is present, then the organisation will be operating at less than total economic efficiency.

The empirical measurement of economic efficiency centres on determining the extent of efficiency in a given organisation or industry. Most recently, economists have employed frontier efficiency techniques to measure the productive performance of water utilities, primarily in the form of technical efficiency. These techniques use a production possibility frontier to map the various technically efficient output combinations a utility is capable of producing. To the extent a utility falls beneath this frontier, it is technically inefficient. This invokes a natural focus on frontier or best-practice production, that is, the maximum theoretically or empirically (relative to current industry practice) possible output.

Similarly, if a utility uses some combination of inputs to place it on its production frontier, but these do not coincide with their relative prices, it is allocatively inefficient. Finally, recognising expansion of the production frontier over time through technological improvements, regulatory reform, and improved workplace practices, we can decompose total factor productivity (TFP) improvements into technical efficiency improvements, for those utilities catching up to the existing frontier, and the technological gains possible for all, including efficient, utilities. Accordingly, if we can determine production frontiers that represent the best currently known production techniques, we can use this idealised yardstick to evaluate the economic performance of actual utilities.

1.4 Research process and other outputs

The author has undertaken this project under the guidance of a Reference Group with membership including representatives from the NWC and other stakeholders. To facilitate that interaction, the study has involved the following processes:

Formal presentations and submission of report drafts: The author presented a discussion paper on the project in June 2010 at the Commission's offices. Successive drafts of the report were also prepared and circulated to the Reference Group and the feedback incorporated in the final report. A second presentation to the NWC coincided with the delivery of the final report in August 2011.

Academic papers: several papers have already been prepared and included in working paper series and presented at conferences and seminar series:

Worthington AC 2010, 'A review of frontier approaches to efficiency and productivity measurement in urban water utilities', *Griffith Business School Discussion Papers in Economics*, No. 2010-10. ISSN 1836-8123.

Worthington AC and Higgs H 2011, 'Economies of scale and scope in Australia's urban water utilities', Paper presented to the *International Graduate School of Business, University of South Australia*, 13 April.

Worthington AC 2010, 'Efficiency, technology, and productivity change in Australian urban water utilities', Paper presented to the W*estern Economic Association International 9th Biennial Pacific Rim Conference*, Brisbane, 26–29 April.

Worthington AC and Higgs H 2011, 'Economics of scale and scope in Australian urban water utilities', *Lancaster University Management School, University of Lancaster*, 7 June.

Worthington AC and Higgs H 2011, 'Economies of scale and scope in Australia's urban water utilities', *Griffith Business School Discussion Papers in Economics* (forthcoming).

Worthington AC 2011, 'Efficiency, technology, and productivity change in Australian urban water utilities', *Griffith Business School Discussion Papers in Economics* (forthcoming).

Feedback from public dissemination and academic comments are included in the final report. Three further working and conference papers will result from the report with five papers subsequently finalised and submitted for publication in refereed journals.

1.5 Report structure

The remainder of this report is structured as follows:

Chapter 2 provides a necessarily brief overview of the Australian urban water utility sector, including its operations, structure, governance and ownership and regulation.

Chapter 3 reviews existing efficiency and productivity studies of urban water utilities in Australia and elsewhere.

Chapter 4 employs a non-parametric approach to measure the changes in efficiency, technology and productivity of major Australian urban water utilities over time.

Chapter 5 applies parametric techniques to estimate economies of scale and scope in operating and capital costs in major Australian urban water utilities.

Chapter 6 uses a non-parametric technique to consider the cross-sectional variation in operating and capital expenditure efficiency in major Australian urban water utilities.

Chapter 7 summarises the report, points out the major limitations and policy implications of the analysis therein and provides some directions for future research.

2 An overview of the Australian urban water utility sector

2.1 Introduction

This chapter provides a brief overview of the Australian urban water utility sector. According to the recent Productivity Commission (2011) inquiry, the Australian urban water sector comprises three sub-sectors, potable water, wastewater and stormwater, and includes both the entities that supply these services to customers, along with the institutions that govern and regulate the sector. The focus of this report is more narrow in that we consider only the entities directly involved in treating, transmitting, distributing and retailing potable water, even though many of these entities are also often involved in wastewater and recycled wastewater distribution, transmission, treatment and discharge, and stormwater distribution, transmission and treatment. We do not consider the role and functions of regulatory and other institutions involved in the urban water sector

The chapter comprises four sections. Section 2.2 discusses the operations of urban water utilities. Section 2.3 outlines the structure of the sector. Section 2.4 examines the governance and ownership of urban water utilities. Section 3.5 highlights the regulation of the entities in the sector and the reform process. Section 2.6 provides some concluding remarks.

2.2 Operations

As discussed, the focus of this report is on entities involved in the provision of potable water. This sector variously purchases/harvests bulk water, stores and treats water to an acceptable standard, and transports water through transmission and distribution networks for retail delivery. However, there is a range of behaviour with most utilities providing both potable water and wastewater services, and a few providing water or wastewater services only. Further, some urban water utilities are involved exclusively in the supply of bulk water while others incorporate this alongside treatment, transmission and retail supply.

Table 2.1 Sources of water, percentage of water sourced, 2008-09

Jurisdiction	Water sourced	Surface water	Groundwater	Desalination	Recycled water	Bulk water
NSW – metropolitan	24.5	97.1	1.0	–	1.9	0.0
NSW – regional	8.2	71.4	10.0	–	3.5	15.1
Victoria	27.0	86.9	4.0	–	4.1	5.0
Queensland	13.0	35.4	0.6	–	5.2	58.8
South Australia	7.5	83.2	2.0	–	14.6	0.1
Western Australia	13.2	33.2	50.4	10.7	1.9	3.8
Tasmania – metropolitan	1.8	100.0	–	–	–	–
Northern Territory	2.3	69.9	28.0	–	2.1	–
ACT	2.1	91.4	–	–	8.6	–
Total	100.0	74.0	9.7	1.4	4.2	10.8

Source: Adapted from Productivity Commission (2011).

In terms of the costs associated with the provision of urban water services, the Productivity Commission (2011) draws on the experience of Sydney Water where approximately 50 percent of a typical bill from a potable water and wastewater provider is associated with water supply and the remainder with wastewater. Of the potable water component, about 40 per cent relates to bulk water supply, 14 per cent with treatment and 45 per cent with transport and distribution and the small remainder with retailing.

Table 2.2 Average water and sewerage operating expenditure per property ($)

Number of connected properties	2005–06	2006–07	2007–08	2008–09	Growth rate (%)
10 000 to 20 000	778	787	754	781	0.13
20 000 to 50 000	664	667	682	669	0.25
50 000 to 100 000	575	614	614	649	4.12
100 000+	448	467	496	541	6.49

Source: Adapted from Productivity Commission (2011)

However, this breakdown can vary by each utility's geographic and other situation. For example, the cost of bulk water will vary depending on the nature of the source harvested and the infrastructure needed to collect and transport the water. Similarly, older assets, higher levels of treatment, stringent health and environmental standards, and the number of connections are all positively associated with costs.

Given the above, it is clear that the urban water utility sector is capital intensive with a high proportion of fixed costs, largely relating to the infrastructure needed to store, treat and transport water. As shown in Figure 2.1, the primary sources of water across all Australian jurisdictions are surface water (74%), followed by bulk water (as purchased from other utilities using a variety of sources (11%), groundwater (10%) and then recycled water (4%), though urban water utilities in Western Australia and the Northern Territory are relatively more dependent on groundwater.

Table 2.3 Total water and sewerage capital expenditure ($ millions)

Number of connected properties	2005–06	2006–07	2007–08	2008–09	Growth rate (%)
10 000 to 20 000	214.3	320.0	341.0	330.1	15.49
20 000 to 50 000	250.4	355.7	534.2	551.6	30.12
50 000 to 100 000	189.8	368.5	418.9	481.9	36.42
100 000+	1 866.8	2 076.9	2 894.3	4 112.4	30.12

Source: Adapted from Productivity Commission (2011)

As shown, Tasmania, metropolitan NSW, Victoria and South Australia are relatively more dependent on surface water, South Australia and the ACT on recycled water, and Queensland and regional NSW on external bulk water purchases. However, we could expect this to change in the next few years, with the ending of the prolonged drought freeing up surface water supplies, and the expansion in recycling and desalination capacity. With operating costs, a significant component is energy costs associated with the transport of water.

Table 2.4 Average utility income per property ($)

Number of connected properties	2005–06	2006–07	2007–08	2008–09	Growth rate (%)
10 000 to 20 000	1 319	1 353	1 342	1 342	0.58
20 000 to 50 000	1 142	1 126	1 205	1 218	2.17
50 000 to 100 000	1 150	1 133	1 188	1 148	-0.06
100 000+	1 049	1 053	1 033	1 150	3.11

Source: Adapted from Productivity Commission (2011)

Figures 2.2 to 2.5 respectively highlight the variation in operating and capital expenditures, income and profitability in urban water utilities over time and across different utility sizes as determined by the number of connections. As shown, operating expenditure per connected property is generally higher in smaller utilities, though the growth rate in recent years has been between 16 and 25 times higher in larger utilities (50 000 to 100 000 and 100 000+ connected properties, respectively).

Table 2.5 Net profit after tax ($ millions) and net profit after tax ratio

Number of connected properties	2006–07 $ mil.	2007–08 $ mil.	2008–09 $ mil.	2006–07 %	2007–08 %	2008–09 %
10 000 to 20 000	80.8	51.3	30.8	21	11	6
20 000 to 50 000	76.9	17.5	-15.1	8	5	-4
50 000 to 100 000	53.1	36.4	-0.2	9	6	-5
100 000+	1 421.8	1 134.5	1 107.4	20	16	16

Source: Adapted from Productivity Commission (2011)

In terms of capital expenditure, total capital expenditure has grown by in excess of 30 per cent per year in the last four years, with the exception of smaller utilities where it has grown by 15 per cent. In terms of income growth, income per connected property is generally higher in small utilities, but the growth in income per property in the last few years has been highest in very large utilities (100 000+ connected properties). Finally, profitability as measured by net profits after tax has also declined in utilities in of all sizes, though the level of profitability and the decline in profitability has generally been higher and slower in the largest urban water utilities.

2.3 Structure

One of the most defining features of Australia's urban water utilities—comprising in 2008–09 32 major urban, 51 non-major urban and 194 minor urban providers—is the considerable variance in structure across the several jurisdictions (states). There is also considerable variation across metropolitan and regional urban areas. At the wholesale water level, the ACT, the Northern Territory and South Australia each have a one urban bulk water supplier, NSW has two, Tasmania and Victoria both three, Queensland several, and about twenty in Western Australia (though most are very small or isolated). Of these, some are responsible for only urban water, which may or may not be the same entity engaged in the downstream retail business, while others are responsible for both rural and urban bulk water business.

A similar picture emerges at the retail level. Here, urban water services are sometimes very highly concentrated (as in the ACT, Northern Territory and South Australia), whereas Victoria has three metropolitan and 13 regional urban retail businesses, and NSW and Queensland each have three businesses centred on their largest population centres (Sydney and Southeast Queensland) and more than 100 local government or other suppliers. Even among the 73 largest urban water suppliers potentially considered in this analysis, there is astonishing variability in size, with businesses serving anywhere between ten thousand and 1.7 million households (the two hundred or so smaller utilities in Australia serve anything from a few hundred to a few thousand households).

Table 2.6 Urban water utilities and service arrangements

Jurisdiction	Bulk supply	Retail water
New South Wales	Sydney Catchment Authority Sydney Desalination Pty Ltd (subsidiary of Sydney Water) State Water Corporation	Sydney Water Corporation Hunter Water Corporation Gosford Wyong Joint Water Authority + 105 local water utilities
Victoria	Melbourne Water + 13 regional urban water utilities	Yarra Valley Water South East Water City West Water + 13 regional urban water businesses
Queensland	Seqwater WaterSecure Sun Water + local government-owned providers	Queensland Water Utilities Allconnex Water Unitywater + 71 local water utilities
South Australia	SA Water	SA Water Small Local Government providers
Western Australia	Water Corporation + local government providers	Water Corporation Busselton Water Aqwest Water (Bunbury) Hamersley Iron Pty Ltd
Tasmania	Southern Water Ben Lomond Water Cradle Mountain Water	Southern Water Ben Lomond Water Cradle Mountain Water
Northern Territory	Power and Water Corporation	Power and Water Corporation
ACT	ACTEW	ACTEW

Source: Adapted from Productivity Commission (2011)

2.4 Ownership and governance

The urban water utility sector in Australia was once exclusively the preserve of vertically integrated government-owned and operated regional and local monopolies. While this remains the situation in some of the smaller state capitals, including Adelaide, Perth, Canberra and Darwin, and in most regional urban areas regardless of jurisdiction (state), there have been significant changes in the ownership of the entities involved in urban water supply starting in the 1990s. In terms of private sector involvement, this can include most urban water utility operations (as in Adelaide) or only some parts (such as private sector ownership and operation of treatment and desalination plants (as in Sydney and Melbourne). However, even where there has not been a shift to private ownership, within public ownership there has been substantial change, with local government ownership often shifting to state-government or joint-local government ownership of larger corporatised and commercialised regional combinations.

For the most part, ownership has changed least in regional urban utilities with government ownership largely remaining, though the tier of government involved in ownership can vary, with regional urban utilities in Queensland, NSW and Tasmania being mostly local government owned and those in Victoria being state government owned. There is also evidence of the dominant model of corporatisation observed in metropolitan areas, particularly in Victoria and Tasmania. In Queensland, the regional urban water utilities are almost all local government owned, along with two commercial water boards (Gladstone Area Water Board and Mount Isa Water Board) and one local government water corporation (Wide Bay Water Corporation). In NSW, the majority of regional water utilities are again local government owned, but alongside some country council and water supply authorities.

Changes in regional urban water utility ownership have been most substantial in recent years in Victoria and Tasmania where the move has been largely from smaller local to larger state government-owned regional entities. In Victoria, the local government-owned utilities have amalgamated into a much smaller number of state-owned, catchment-based utilities. In Tasmania, this has extended to just a few local-government owned entities providing urban water services to both metropolitan and non-metropolitan areas.

Dramatic changes in ownership are more evident in metropolitan areas with the increasing involvement of the private sector in at least parts of the urban water utility sector. For example, in Sydney there has been the separation of the bulk supply and treatment and retail functions, with the state government-owned Sydney Catchment Authority operating the former with mostly privately-owned treatment plants and the corporatised Sydney Water taking responsibility for the later, including a subsidiary owning the city's desalination plant.

In Melbourne, a similar separation of bulk and treated water has taken place, with state government-owned Melbourne Water working alongside three geographically distinct retailer–distributors in the form of state government-owned City West Water, South East Water and Yarra Valley Water. Once again, a private company operates the state's desalination plant. In Queensland's southeast, the traditionally separate local government providers now comprise three local government-owned retailer–distributors (Allconnex Water, Queensland Urban Utrilities and Unitywater) and a soon to be single bulk water supplier. Finally, for some time, water services in Adelaide have been contracted to a private company.

2.5 Reform and regulation

Over the last three decades, the Australian urban water utility sector has moved progressively through the reform process, very often at the instigation of national bodies appointed by the Commonwealth or cooperative arrangements between the Commonwealth and the States. In the early 1980s, urban water utilities first began to implement a user-pays water tariff for residential customers while by the early 1990s, the first Australian urban water authorities were being corporatised.

Subsequent national-level sources of reform include the Industry Commission (1992) inquiry into water resources, the Council of Australian Governments (COAG) (1994) setting of a strategic framework for the efficient and sustainable reform of the water industry, the COAG (1995) implementation of the National Competition Policy (NCP) and its incentivisation of jurisdictions effectively implanting water reforms within the earlier strategic framework. The reforms also include the COAG (2004) National Water Initiative (NWI) and the establishment of the National Water Commission (NWC) to assist and assess progress on the NWI reforms and COAG (2008) actions to enhance the national water reform framework concerning the security of supply of urban water (Productivity Commission (2011, xviii). Most recently, it includes the Productivity Commission (2011) being tasked with examining the case for microeconomic reform in the urban water sector and to identify pathways to achieve improved resources allocation and efficiency.

Recently, the Productivity Commission (2011: xxii) has re-emphasised that the "outcomes of the [urban water] sector over time depend, in large part, on government policies and regulations designed to achieve objectives relating to provision of services, affordability, public health and the environment". More specifically, a variety of governmental policies and regulations are commonly set relating to price setting, the security and reliability of supply, water quality standards, water use efficiency and conservation, and water affordability for low-income households. They also include the supply of water for amenity and environmental purposes and mandates applying to the sources of bulk water supply and the disposal and recycling of wastewater and stormwater (Productivity Commission, 2011).

Of the wide range of regulations that affect the urban water utility sector, the Productivity Commission (2011) has highlighted pricing, third-party access arrangements and licensing as the most important. Once again, these vary considerably by jurisdiction. In terms of the arguably most important regulatory control, namely, price setting, the basic model is that prices in metropolitan urban water utilities tend to be set by state governments or state government agencies while non-metropolitan urban water utility prices (if separate and applicable) are set by the utilities themselves (as in NSW and Queensland). However, an evolving feature is the centralisation of price determination for all urban water utilities shifting to either the state government alone (as in South Australia, Western Australia and the Northern Territory) or an independent agency (including Essential Services Commissions in Victoria and South Australia, the Independent Competition and Regulatory Commission in the ACT and the Independent Pricing and Regulatory Tribunal of NSW).

2.6 Concluding remarks

This chapter provides a necessarily brief overview of the operations, structure, ownership and governance and reform and regulation of the Australian urban water utility sector. Key features of this sector include recent substantial increases in operating expenditure and declining profitability and the considerable variance in industry structure and ownership across jurisdictions (states). A major finding is the considerable effect of regulation, especially that regarding pricing, on the sector.

It is clear that these conditions have the potential to impact upon the conditions in which urban water utilities operate. By nature, urban water utilities are constrained geographically, while the findings in this chapter suggest the substantial institutional, governance and regulatory conditions that will prevail within and across the several jurisdictions will also affect behaviour and outcomes.

3 A review of efficiency and productivity measurement in urban water utilities

3.1 Introduction

The purpose of this chapter is to provide a comprehensive review of the empirical literature on efficiency and productivity measurement in urban water utilities. This informs the empirical analyses in subsequent chapters about the methods used in previous work on urban water utilities, in both Australia and elsewhere. There is particular attention to the specification of inputs and outputs in past efficiency studies and some of the limitations associated with the availability of suitable data.

The chapter comprises seven sections. Section 3.2 details the scope of the survey. Section 3.3 outlines the contribution and limitations of the survey. Section 3.4 considers the choice of empirical approach and Section 3.5 discusses the context and outcomes of extant studies. Section 3.6 examines the specification of inputs and outputs in the efficiency models and Section 3.7 highlights the role of ownership and regulation in the outcomes. Section 3.8 provides some concluding remarks.

3.2 Scope of survey

If we can determine production frontiers that represent total economic efficiency using the best currently known production techniques, then we can use this idealised yardstick to evaluate the economic performance of actual organisations and industries. By comparing the actual behaviour of organisations against the idealised benchmark of economic efficiency, we can determine the degree of efficiency exhibited by some real-world agency.

This survey concentrates on selected efficiency and productivity studies of urban water utilities using frontier efficiency measurement techniques published since 1990. We searched EconLit, the Journal of Economic Literature electronic database, to identify journal articles that were representative of the contexts and techniques associated with efficiency measurement in urban utilities. References therein helped identify other relevant articles. We also used Google Scholar to locate books and book chapters and yet unpublished conference, working papers and government reports.

Of the 27 studies in Table 3.1, 30 per cent are based on urban water utilities in the UK, 11 per cent each in the US and Australia, seven per cent in Spain, and the remainder in other contexts (including Mexico, Brazil, Italy, Slovenia, Malaysia and Canada). About 41 per cent employ cross-sectional observations with the balance relying on panel (pooled time-series, cross-sectional) data. However, despite their dissimilar contexts and techniques, these studies share a common step-by-step empirical procedure that determines first the choice of frontier efficiency measurement approach, second the specification of inputs and outputs to be used in the selected approach, and finally, the method used to explain efficiency differences and the factors thought to be associated with these differences.

Table 3.1 Selected applications in urban water utilities

Author(s)	Methodology	Sample	Specification	Technique	Findings
Norman and Stoker (1991)	Data envelopment analysis	28 water-only companies, England and Wales, 1987–88.	Inputs: Manpower, power, chemical and others costs (including an allowance for capital renewal) Outputs: Potable water, properties supplied, average pumping head, length of mains, average peak. Input-orientated constant returns-to-scale.	Descriptive analysis.	Output quantities largely fixed, need to define measures of service quality.
Lambert, Dichev and Raffiee (1993)	Data envelopment analysis	238 public and 33 private utilities, US, 1989.	Inputs: Labour, energy used, materials used, Outputs: Capital value Wholesale and retail water delivered; Input-orientated variable returns-to-scale.	Descriptive analysis.	No significant differences in scale efficiencies between private and public utilities. Most inefficiency results from the overuse of capital.
Bhattacharyya, Harris, Narayanan and Raffiee (1995)	Stochastic frontier analysis	190 public and 31 private utilities, US, 1992.	Dependent: Variable costs. Independent: Volume of water; energy, labour, materials; water input produced or available for delivery, stock of capital; water input source (surface, ground, both), system loss, age of distribution pipelines, number of emergency breakdowns, length of distribution pipeline, customer type (residential or commercial).	Descriptive analysis.	Cost inefficiency higher in private utilities. Cost inefficiency also positively correlated with size and that major influence on cost inefficiency is breakdowns.
Cubbin and Tzanidakis (1998)	Data envelopment analysis	29 companies, England and Wales, 1992–93	Inputs: Operating expenditure. Outputs: Water delivered, length of mains, proportion of water delivered to non-households. Input-orientated constant returns-to-scale.	Descriptive analysis.	Regression analysis and DEA both suitable for measuring efficiency in water utilities.
Thanassoulis (2000)	Data envelopment analysis	21 water and sewerage companies, 10 water-only companies, England and Wales, 1992–93	Input: Operating expenditure. Outputs: Number of supply connections, length of main, amount of water delivered, measured water, unmeasured water, expenditure on volume. Input-orientated variable returns-to-scale.	Descriptive analysis	Comparison of DE measures of efficiency with efficiency estimates provided by industry regulator.

Author(s)	Methodology	Sample	Specification	Technique	Findings
Anwandter and Ozuna (2002)	Data envelopment analysis	110 water utilities, Mexico, 1995.	Inputs: Personnel, electricity, materials, chemicals, outside services, other costs, specific wastewater treatment costs. Outputs: Water supply, primary treatment, secondary treatment. Non-discretionary inputs: Water losses (proxy for age of capital stock), population density, non-residential users. Input-orientated variable returns-to-scale.	Descriptive analysis, second-stage regression.	Decentralisation to the municipal level and appointment of autonomous regulator had no positive influence on efficiency in the absence of competition reform.
Estache and Rossi (2002)	Stochastic frontier analysis	50 water companies in 29 Asia-Pacific countries, 1995.	Dependent: Operational costs. Independent: Average salary, number of clients, daily production, number of connections, population density in area served, percentage of water from surface sources, number of hours of water availability per day, percentage of metered connections, qualitative treatment variables (chlorination, desalination)	Descriptive analysis.	Cost efficiency not significantly different in private and public sector utilities.
Thanassoulis (2002)	Data envelopment analysis	10 water and sewerage companies, England and Wales, 1994	Inputs: Operating expenditure. Outputs: resident population, length of sewer pipes, size of area served, capacity of pumping in sewerage network. Input-orientated constant returns-to-scale.	Descriptive analysis.	Highlighting of generic influences on efficiency measurement and use of comparative measures.
Bottasso and Conti (2003)	Stochastic frontier analysis	10 water and sewerage companies, 12 water-only companies, England and Wales, 1995–2001	Dependent: Operational expenditure. Independent: Water delivered, price of labour and capital. Explanatory: Sewerage dummy, length of mains, average pumping head, proportion of river sources on total water sources, population density, volume of water introduced into the distribution system.	Descriptive analysis.	Operating costs inefficiency has decreased over time with inefficiency differential between firms narrowing. Technical and structural requirements impact on cost efficiency.
Tupper and Resende (2004)	Data envelopment analysis	20 Brazilian water and sewerage utilities, 1996–2000	Inputs: Labour costs, operational costs, capital costs. Outputs: Water produced treated sewerage, population served-water, population served-treated sewage. Output-orientated variable returns-to-scale.	Descriptive analysis, second-stage regression.	Network densities and accounted-for water ratio influence efficiency.

Author(s)	Methodology	Sample	Specification	Technique	Findings
Woodbury and Dollery (2004)	Data envelopment analysis and Malmquist indices	73 water supply authorities, New South Wales, Australia, 1999–2000	Inputs: Management, maintenance and operation, energy and chemical, and capital replacement costs. Outputs: Number of assessments (services to properties), annual water consumption, water quality index (compliance with chemical and physical requirement and microbiological requirements, water service index (water quality complaints, service complaints and average customer outage). Non-discretionary inputs: Population, properties per kilometre of main, location, rainfall, percentage residential, unfiltered water, groundwater.	Descriptive analysis, second-stage regression.	Technical inefficiencies more substantial than scale inefficiencies. Need for inclusion of service quality outputs.
Aubert and Reynaud (2005)	Stochastic frontier analysis	211 water utilities, Wisconsin, 1998–2000.	Dependent: Variable costs. Independent: Volume of water sold, number of customers, price of labour and electricity, amount of capital, dummies for water purchased, surface water and average pumping depth.	Descriptive analysis.	Efficiency scores partly explainable by regulatory framework.
Fraquelli and Moiso (2005)	Stochastic frontier analysis	18 territorial regions, Italy, 1975–2005	Dependent: Total costs. Independent: Network length, number of employees, population served, ratio of population to network length, labour, electricity, materials, services and capital costs.	Descriptive analysis.	Inefficiency partly explained by network characteristics.
Coelli and Walding (2006)	Data envelopment analysis and Malmquist indices	Australia, 18 water services businesses, 1995–96 to 2002–03	Inputs: Operating and capital expenditure. Outputs: Number of properties connected, volume of water delivered. Input-orientated constant returns-to-scale.	Descriptive analysis.	Need for improvement in specification of capital and provision of water industry price deflators.
Erbetta and Cave (2006)	Data envelopment analysis	10 water and sewerage companies, England and Wales, 1993–2005	Inputs: Number of household and non-household water connections, number of household and non-household sewerage connections, physical amount of wastewater, labour, other operating expenditure, capital expenditure. Outputs: Volume of delivered potable and non-potable water. Non-discretionary inputs: Water losses, water population density, sewerage population density, time trend, regulatory change dummies. Input-orientated variable returns-to-scale.	Descriptive analysis, second-stage regression.	Regulatory change promoted reduction in technical inefficiency. Price-cap regulation brings inputs closer to their cost-minimising level. Environmental factors influence observed efficiency.

Author(s)	Methodology	Sample	Specification	Technique	Findings
García - Sánchez (2006)	Data envelopment analysis	24 Spanish water utilities, 1999.	Inputs: Staff, treatment plants, delivery network. Outputs: Water delivered, number of connections, chemical analyses performed. Non-discretionary inputs: Population, persons per household, municipal area, tourist index, average temperature, income, area of greenbelts, economic activity, number of houses, population density. Input-orientated variable returns-to-scale.	Second-stage regression.	Network and population density has a significant influence on efficiency.
Kirkpatrick, Parker and Zhang (2006)	Stochastic frontier analysis and data envelopment analysis	110 public and private water utilities, Africa, 2000.	Dependent/Input: Operating and maintenance expenditure. Independent: Labour price, material price of water distributed, number of water treatment works. Output: Water delivered, hours of piped water per day. Input-orientated variable returns-to-scale.	Descriptive analysis.	No evidence of better performance of private utilities over state-owned utilities. Impact of water technology, transactions costs and regulation on efficiency scores.
Saal and Parker (2006)	Malmquist indices and stochastic frontier analysis	10 public regional water authorities and 29 private statutory water and sewerage companies, England and Wales, 1993-2003.	Inputs: Inputs: fixed physical capital, operating expenditure. Outputs: Water delivered and number of connected properties. Non-discretionary inputs: population served per kilometre length of mains (density), average pumping head and average quality compliance, dummy for water and sewerage company. Input-orientated constant and variable returns-to-scale.	Descriptive analysis.	Scope for use of techniques in measuring operational efficiency. Inappropriate to assume water authorities and water and sewerage companies share a common frontier.
da Silva e Souza, Coelho de Faria and Moreira (2007)	Stochastic frontier analysis	149 public and 15 private companies, Brazil 2002	Dependent: Average costs. Independent: Volume of water produced, prices of capital and labour, average tariff. Explanatory: Private and public utilities, population density, percentage of above groundwater sources, regional dummies.	Single-stage regression.	No evidence that private and public utilities differ in estimated efficiency. Significant impact of environmental factors.

Author(s)	Methodology	Sample	Specification	Technique	Findings
García-Valiñas and Muñiz (2007)	Data envelopment analysis	3 water supplying municipalities, Spain, 1985–2000.	Input: Operational expenditures. Output: Volume of water delivered, length of mains, population supplied. Non-discretionary input: Rainfall. Input-orientated constant returns-to-scale.	Descriptive analysis.	Inclusion of non-discretionary factors increases observed level of efficiency.
Saal, Parker and Weyman-Jones (2007)	Stochastic frontier analysis	England and Wales, 10 water and sewerage companies, 1985–2000	Dependent: Water customers, connections with sewerage customers, physical water supply, physical sewerage load; quality adjustment indices (water and sewerage). Independent: Capital stock, current cost operating profits less current cost depreciation, infrastructure renewal expenditures, non-capitalised employment, labour.	Descriptive analysis.	Technical change improved after privatisation but not productivity growth. Excessive size of water supply companies contributed negatively to productivity growth.
Filippini, Hrovatin, and Zoric (2008)	Stochastic frontier analysis	52 water utilities, Slovenia, 1997–2003	Dependent: Total annual cost. Independent: Prices of labour, capital and materials, water supplied, number of customers, size of service area, treatment dummy, dummies for surface water, groundwater and low water losses.	Descriptive analysis.	Inefficiency estimates depend on econometric specification. Diseconomies of scale in larger utilities.
Picazo-Tadeo, Sáez-Fernández, and González-Gómez. (2008)	Data envelopment analysis	40 Spanish water utilities (with 20 providing sewerage services), 2001.	Inputs: Delivery network, sewer network, labour, operational costs. Outputs: Population served, water delivered, treated sewage. Output-orientated constant returns-to-scale.	Descriptive analysis.	Accounted-for water does not influence ranking of utilities. Quality matters in measuring technical efficiency.
Guder, Kittlaus, Moll, Walter and Zschille (2009)	Data envelopment analysis	373 water utilities, Germany, 2006.	Input: Total revenue. Outputs: Number of water meters, water delivered to households and non-households (industrial and other), network length, population. Non-discretionary inputs: Length of network, leak ratio, groundwater ratio, elevation differences, dummy for former East Germany. Input-orientated constant and variable returns-to-scale.	Second stage regression.	Substantial differences in technical inefficiency after inclusion of structural factors. Network density and share of groundwater negatively influence efficiency.

Author(s)	Methodology	Sample	Specification	Technique	Findings
Reznetti and Dupont (2009)	Data envelopment analysis	64 Canadian water utilities, 1996.	Inputs: Labour costs, materials costs, delivery network. Outputs: Water delivered. Non-discretionary inputs: Extreme temperatures, precipitation, dummy for surface water, population density, elevation, proportion of residential demand, number of dwellings. Input-orientated variable returns-to-scale.	Second-stage regression.	Differences in elevation, population density, and proportion of residential water use private dwelling have significant impact on efficiency.
Byrnes, Crase, Dollery and Villano (2010)	Malmquist indices	14 Victorian water utilities and 38 NSW water utilities, 2000–04.	Input: Total operating costs. Outputs: Complaints index and total potable water delivered. Non-discretionary inputs: Proportion of residential consumption, water losses, production density, customer density, large and very large utilities, share of groundwater, filtration and reticulation dummies, dam maintenance, temperature, rain days, rainfall, rainfall intensity, state identifier, yearly dummies.	Second-stage regression.	Water restrictions reduce efficiency and larger utilities characterised by higher efficiency.
Munisamy (2010)	Data envelopment analysis	6 water supply authorities and 11 privatised water companies, Malaysia, 2005.	Inputs: Operating expenditure, network length, volume of non-revenue water. Outputs: Volume of water delivered, number of connections, size of service area. Input-orientated constant and variable returns-to-scale.	Descriptive analysis.	Scale inefficiencies in (smaller) private sector utilities, technical inefficiencies in public providers.

Notes: Single dates are calendar or financial year cross-sections, intervals are time-series. Stochastic frontier analysis specification comprises dependent, independent and explanatory variables. Specification for data envelopment analysis and Malmquist indices is discretionary input(s), discretionary output(s) and non-discretionary input(s). All stochastic frontier analysis studies usually discuss the estimated coefficients, significance and elasticities for the production and cost parameters, as well as the measures of efficiency obtained. Descriptive analysis includes the analysis of distributions (mean, standard deviations) and/or efficiency by groups within sample and correlation between efficiency scores obtained by different techniques. Second-stage regression involves regressing the efficiency scores from data envelopment analysis, Malmquist indices, or stochastic frontier analysis on additional explanatory variables in a separate regression. Single-stage regression refers to a stochastic frontier model with efficiency estimated simultaneously with the coefficients on the explanatory variables.

3.3 Contribution and survey limitations

At least two studies, Walter et al. (2009) and Abbott and Cohen (2009), have partly surveyed efficiency measurement as it applies to urban water utilities. However, these include a more general range of methods and applications (including data envelopment analysis, stochastic frontiers, average cost and production functions, and partial and total factor productivity (TFP) indices. They also tend to focus on the implications of the results for economies of scale and scope in the latter and the role of regulation and ownership in the former, not the steps used to obtain these measures.

The current work is the first attempt to examine comprehensively each of the main frontier efficiency measurement approaches as they apply to urban water utilities. Moreover, apart from discussing the strengths and weaknesses of the different approaches, this paper also examines the steps faced by researchers as they move from a selected approach, to the specification of inputs and outputs, to the means of explaining efficiency differences and their policy implications. This highlights the empirical problems that have received attention in the literature, and the efforts by researchers to overcome these problems. It therefore provides guidance to those conducting empirical research in efficiency and productivity, and an aid for policymakers, managers and practitioners interpreting the outcomes of frontier efficiency studies.

The present survey does suffer from two major limitations. First, there is no attempt to compare frontier efficiency techniques with non-frontier approaches, principally the estimation of production and cost functions using least squares regression. Least squares regression approaches generally place emphasis on comparisons with average performance [see, most recently, Fabbri and Fraquelli (2000), Antonioli and Filippini (2001), Torres and Morrison (2006), Mosheim (2006), Garcia et al. (2007), Nauges and van den Berg (2008) and Bottaso and Conti (2009)]. However, with relatively few exceptions, these techniques are confined to the period before 1990 and are now increasingly superseded by the more recent frontier approaches. Nevertheless, there is discussion of many of the issues involving the specification of the inputs and outputs in frontier efficiency analysis of urban water utilities in these studies, so there is sometimes selective reference.

Second, this survey is necessarily general in that there are many and substantial differences in the objectives and behaviour of urban water utilities across countries. In varying degrees, this relates to regulatory and competition differences in their respective markets. Consider just urban water utilities in Australia, the US and the UK. In Australia, large, publicly-owned, corporatised water utilities operate under regulated prices in each state [such as the Independent Pricing and Regulatory Tribunal (IPART) in NSW setting prices for Sydney, the Hunter, Gosford, Wyong and Broken Hill]. In contrast, small water and sewerage utilities owned by local councils (in NSW) set their own prices under the *Water Act 1912*, the *Water Supplies Authorities Act 1987*, *Local Government (Water Services) Regulation 1999* and the *Local Government Act 1993*, with the latter stipulating that water services are provided independently of other council functions. This, of course, lies under the overarching goals of the National Water Initiative (NWI) in providing safe, reliable and efficient water services to urban areas in a sustainable manner

In contrast, in the US, community water systems encompass a mix of private and public ownership with state public utility commissions regulating rates of return with federal regulations by the Environmental Protection Agency and others stipulating standards for water quality and environmental protection. Finally, in the UK, large privatised regional water authorities holding responsibility for water and sewerage service and small public limited liability water-only companies operate under a price cap administered by the Office of Water Services (Ofwat) with environmental and drinking water regulation respectively administered by the Environmental Agency and the Drinking Water Inspectorate. Unfortunately, it is not possible to deal at length with the exceedingly complex regulatory and other conditions found in the many sample countries in this survey.

3.4 Choice of efficiency measurement approach

All efficiency measures assume the production frontier of the fully efficient organisation is known. As this is usually not the case, the production frontier must be estimated using sample data. Two approaches are possible. These are: (i) a non-parametric frontier constructed such that no observed point should lie outside it (known as the mathematical programming approach); or (ii) a parametric function fitted to the data, again such that no observed point should lie outside it (known as the econometric approach). These approaches use different techniques to envelop the observed data, and therefore make different accommodations for random noise and for flexibility in the structure of the production technology.

First, the econometric approach specifies a production or other function and normally recognises that deviation away from this given technology (as measured by the error term) is composed of two parts, one representing randomness (or statistical noise) and the other inefficiency. The usual assumption with the two-component error structure is that the inefficiencies follow an asymmetric half-normal distribution and the random errors are normally distributed. The random error term is generally thought to encompass all events outside the control of the utility, including both uncontrollable factors directly concerned with the 'actual' production function (such as differences in operating environments) and econometric errors (such as misspecification of the production function and data measurement errors). This type of reasoning has primarily led to the development of the stochastic frontier approach which seeks to take these external factors into account when estimating the efficiency of some real-world utility [with work by Bhattacharyya et al. (1995), Estache and Rossi (2002), Aubert and Reynaud (2005), da Silva e Souza et al. (2007), and Fillippini et al. (2008)].

In the production form of stochastic frontier analysis, an output is a function of inputs. Unfortunately, it is difficult to incorporate multiple outputs in this form, though not with a cost frontier where costs are a function of multiple outputs, inputs and input prices. Accordingly, given the multiple outputs in urban water utilities, the frontiers we typically see in water utility efficiency analysis are cost frontiers. A simpler earlier version of the econometric approach, known as the 'deterministic frontier approach' assumes that all deviations from the estimated frontier comprise inefficiency, but is presently unapplied to urban water utilities. Stochastic frontiers can be estimated using a range of general statistical software, which through user programming and maximum likelihood methods can be adapted for the desired estimation (including GAUSS, SAS, EViews, etc.). However, specialised software is now also available for estimating stochastic frontiers, including LIMDEP 9.0 *www.limdep.com/* and Frontier 4.1 *www.uq.edu.au/economics/cepa/*.

Second, and in contrast to the econometric approach, which attempts to determine the absolute economic efficiency of utilities against some imposed benchmark, the mathematical programming approach seeks to evaluate the efficiency of a utility relative to other organisations in the same industry. The most commonly employed version of this approach is a linear programming tool referred to as 'data envelopment analysis' (DEA). DEA essentially calculates the economic efficiency of a given utility relative to the performance of other utilities producing the same sorts of services, rather than against an idealised standard of performance. DEA is also a non-stochastic method in that it assumes all deviations from the frontier are the result of inefficiency. Norman and Stoker (1991), Thanassoulis (2000), Tupper and Resend (2004), García-Sánchez (2006), Reznetti and Dupon (2009) and Munisamy (2010) have applied this approach to urban water utilities. A less-constrained alternative to DEA sometimes employed in the analysis of efficiency (though presently unapplied to urban water utilities) is known as 'free-disposal hull'. Once again, most general purpose mathematical optimisation software (GAMS, SAS, Solver in Microsoft Excel) can be adapted to solve DEA problems, though specialised applications are increasingly common, including LIMDEP 9.0 *www.limdep.com/*, DEAP 2.1 *www.uq.edu.au/economics/cepa/*, Frontier Analyst *www.banxia.com*, DEASoft 2.0 *www.deasoftware.co.uk/*, and OnFront 2.0 *www.emq.com*.

Useful technical introductions to DEA may be found in Thanassoulis (2001), Ramanathan (2003), Ray (2004) and Cooper et al. (2006).

Applications that use Malmquist productivity indexes (as derived from DEA-like linear programs) to measure changes in efficiency over time are also found in the urban water utility literature. In this approach, a production frontier representing the efficient level of output that can be produced from a given level of input is constructed, and the assumption made that this frontier can shift over time. Different frontiers are thus obtained for different time periods and these correspond to differences in the available technology. When inefficiency is assumed to exist, the relative movement of any given utility over time will therefore depend on both its position relative to the current frontier (technical efficiency) and the position of the frontier (technical change). If inefficiency is ignored, then productivity growth over time will be unable to distinguish between improvements that derive from a utility ‘catching up’ to its own frontier, or those that result from the frontier itself shifting up over time for all utilities included (or the industry). Studies of urban water utilities using this technique include Woodbury and Dollery (2004), Coelli and Walding (2006), Saal and Parker (2006), and Byrnes et al. (2010).

The discussion thus far addresses two separate, though conceptually similar, theoretical approaches to the assessment of efficiency. These are the econometric frontier approach (principally DFA and stochastic frontier analysis), and the mathematical programming approach (including DEA and Mamquist indices). Table 3.1 details the approach taken by selected studies. While the selection of any particular approach is likely to be subject to both theoretical and empirical considerations, it may be useful to summarise the strengths and weaknesses of each. The emphasis here is not on selecting a superior theoretical approach, we should emphasise that the mathematical programming and econometric approaches address different questions, serve different purposes and have different informational requirements. An important subtle terminological distinction at this point is that the mathematical programming approach strictly involves ‘measurement’ or ‘calculation’, while the econometric approach comprises ‘estimation’.

The first approach is the construct of the deterministic frontier. While not applied to water utilities during the survey period, it is evident in the broader efficiency literature, and serves as a useful benchmark for the more complex techniques. Using statistical techniques, a deterministic frontier is derived, such that all deviations from this frontier are assumed the result of inefficiency. That is, no allowance is made for noise or measurement error. Once again, in the primal (production) form the ability to incorporate multiple outputs is difficult, whilst using the dual cost frontier such extensions are possible. However, if the cost frontier approach is employed, it is not possible to decompose inefficiency into allocative or technical components, and therefore all deviations are attributed to overall cost inefficiency.

In terms of computational procedure, the deterministic frontier necessitates a large sample size for statistical reasons. In addition, it is generally regarded as a disadvantage that the distribution of the technical inefficiency has to be specified, i.e. half-normal, normal, exponential, log-normal, etc. Ideally, this would be based on knowledge of the economic forces that generate such inefficiency, though in practice this may not be feasible. If there are no strong a priori arguments for a particular distribution, choice is normally on analytical tractability. Similarly, the choice of a particular technology is imposed on the sample, and once again this may be a matter of empirical convenience (i.e. Cobb–Douglas, translog, etc). Moreover, the choice of a particular production function may place severe restrictions on the types of analysis possible, and therefore the content of managerial and policy prescriptions, using this particular approach.

The second approach discussed, namely the stochastic frontier, removes some of the limitations of the deterministic frontier. Its chief advantage lies in that it introduces a disturbance term representing noise, measurement error, and exogenous shocks beyond the control of the water utility. This permits the decomposition of deviations from the efficient frontier into two components, inefficiency and noise. However, in common with the deterministic approach, an assumption regarding the distribution (usually normal) of this noise must be made along with those required for the inefficiency term and the production technology. The main effect here is that under both approaches, especially the stochastic frontier, considerable structure is imposed upon the data from stringent parametric form and distributional assumptions. In addition, stochastic frontier estimation usually uses information on prices and costs in addition to quantities, and these may introduce additional measurement errors combined with the more demanding requirements for data.

The programming approach (DEA and Malmquist indices) differs from both statistical frontier approaches (deterministic and stochastic frontier) in that it is non-parametric, and from the stochastic frontier in that it is non-stochastic. Thus, no (direct) accommodation is made for the types of bias resulting from environmental heterogeneity, external shocks, measurement error, and omitted variables. Consequently, the entire deviation from the frontier is assessed as being the result of inefficiency. This may lead to either an under or over-statement of the level of inefficiency, and as a non-stochastic technique there is no possible way in which probability statements of the shape and placement of this frontier can be made. These problems are especially likely when the number of individual utilities included is small (implying the influence of outliers), when the number of inputs and/or outputs is relatively large (thereby providing poor discrimination in indentifying benchmark utilities), or when non-discretionary ‘environmental’ factors (factors outside management control) influence efficiency. In view of erroneous or misleading data, some critics of DEA have questioned the validity and stability of these measures of efficiency.

However, there a number of benefits implicit in the mathematical programming approach that makes it attractive on a theoretical level. Given its non-parametric basis, substantial freedom is given on the specification of inputs and outputs, the formulation of the production correspondence relating inputs to outputs, and so on. Thus, in cases where the usual axioms of production activity breakdown (i.e. profit maximization) then the programming approach may still offer useful insights into efficiency—some assumptions regarding the production technology are still made regardless, such as that relating to convexity. Similarly, it is entirely possible that the types of data necessary for the statistical approaches are neither available nor desirable, and therefore the imposition of as few as possible restrictions on the data is likely to be most attractive. Simulation studies have also indicated that the piecewise linear production frontier formulated by DEA is generally more flexible in approximating the true production frontier than even the most flexible parametric functional form. Nonetheless, very recent theoretical developments have been made in an attempt to synthesise the best features of stochastic frontier analysis and DEA in the estimation of production efficiency: namely, allowance for statistical noise and outliers (as in stochastic frontiers) and the modelling of multiple inputs, multiple output technologies without the imposition of parametric assumptions on the production relationship (as in DEA). Unfortunately, as these are presently unapplied to urban water utilities they are beyond the scope of this survey.

These theoretical and empirical considerations explain part of the dominance of DEA in water utility efficiency measurement studies, comprising some 59 per cent of the studies included in this survey. The obvious desirability of quantifying multiple inputs and outputs in different units of measurement is one consideration. For example, many water utility studies define inputs as the amount of or expenditures on labour, energy or materials. In turn, outputs are often defined as the number of households connected, the amount of potable water produced, and the length of the mains. Finally, and once again in a context where the usual axioms of production activity breakdown [i.e. the replacement of strict profit maximisation with bounded cost minimisation], there is the ability to define inputs and outputs depending on the conceptualization of water utility performance thought most appropriate.

Problematically, the inability of conventional DEA modelling to take account of statistical error is also likely to cause complications in very many urban water contexts. For example, most urban water sectors comprise both large (regional) and small (local) utilities, with a least some likely to be candidates for outliers (especially given the small number of individual entities in any particular milieu) and hence a source of bias in the results. Further, many sectors include a mix of both public and private entities, such that competing behavioural assumptions governing the determination of inputs and outputs for superficially similar entities, may mis-specify the actual or intended behaviour of the utilities included.

3.5 Scope and outcomes of past studies

Within the broad scope of urban water, frontier efficiency measurement techniques have been applied to a number of different types of utilities. As shown in Table 3.1, these include both water-only companies (Norman and Stoker, 1991; Thanassoulis, 2000; Woodbury and Dollery, 2004) and water and sewerage companies (Thanassoulis, 2002; Tupper and Resende, 2004; Erbetta and Cave, 2006) and both public and private utilities (Lambert et al., 1993; Kirkpatrick et al., 2006; da Silva e Souza et al., 2007; Munisamy, 2010). As discussed, past studies principally concern urban water utilities in the UK, but also in the US, Australia, Italy, Mexico, Germany, Brazil, Malaysia, Canada, Spain, Slovenia, and Mexico. The only known international studies are Estache and Rossi's (2002) analysis of water companies in 29 Asia-Pacific countries and Kirkpatrick's et al. (2006) study of 110 water utilities across 13 countries in Africa.

In contrast to the general frontier efficiency literature (financial services, education, and health) focus on the US, UK studies dominate the urban water utility efficiency literature (Cubbin and Tzanidakis, 1998; Erbetta and Cave, 2006; Saal et al., 2007) and, to a lesser extent, Spain (Garcia-Sánchez, 2006; Picazo-Tadeo et al., 2008) and Australia (Woodbury and Dollery, 2004; Coelli and Walding, 2006). The reason is not hard to find in the former, with OfWat (the regulator of water services in the UK) being both an early provider (since 1994) of comparative information on urban water utilities and an enthusiastic user [see Cubbin (2004) for a critique] of both stochastic frontier analysis and DEA. One key application has been RPI–X price cap regulation where the allowable price increases for water services reflect the rate of inflation, as measured by the retail price index (RPI), less the ability of the operator to gain efficiencies (X) (OfWat 2010a, 2010b, 2010c). However, several other countries have subsequently employed efficiency analysis, especially DEA, for the regulation of urban water utilities, including Italy, Columbia and the Netherlands (Walter et al., 2009). Reasons for policy interest are also not hard to find in the latter, with Spain being the driest country in the European Union and Australia recently suffering its longest drought on record.

The measures of efficiency obtained by these studies have varied widely. In Australia, Woodbury and Dollery's (2004) analysis of 73 water supply authorities in NSW found mean technical efficiencies between 73.7 and 79.8 per cent using data from the Australian Water Association and the NSW Departments of Local Government and Land and Water Conservation. Alternatively, Byrnes et al. (2010) calculated technical efficiencies of 45.6–48.2 per cent in urban water utilities in regional NSW and Victoria using data from the Department of Energy, Utilities and Sustainability and VicWater. In the US, Aubert and Reynaud (2005) estimated cost inefficiencies of up to 12.5 per cent in Wisconsin water utilities, while Bhattacharyya et al. (1995) used a similar approach to obtain cost inefficiencies of close to zero (0.32 per cent) in private utilities and 5.09 per cent in publicly-owned firms.

More interestingly, in the UK, Erbetta and Cave (2007) and Saal et al. (2007) used almost identical data from OfWat to calculate respective mean technical efficiencies of 90.9 per cent over the period 1993–2005 in the first instance and 92.7–96.4 per cent over the period 1985–2000 in the second. There is also wide and somewhat startling variability elsewhere. For example, respective analyses of Australian water utilities by Woodbury and Dollery (2004) and Coelli and Walding (2006) both employed the Malmquist index approach to efficiency and productivity measurement. Over the period 1997–2000, Woodbury and Dollery (2004) concluded that TFP increased only slightly (0.20 per cent), primarily because of technological gain (2.2 per cent) combined with a decrease in technical efficiency (2.1 per cent). Conversely, Coelli and Walding (2006) observed that over the period 1995–2003, TFP fell by 1.2 per cent, comprising an efficiency improvement of 1.1 per cent and a technological loss of 2.2 per cent. Unfortunately, only limited comparison is between the alternative frontier efficiency techniques and their impact on efficiency measurement and estimation. For the exceptions, see Kirkpatrick et al. (2006) and Saal and Parker (2006)

3.6 Specification of inputs and outputs

The only conceptualisation used in past studies in defining the input-output relationship in urban water utility behaviour follows a production approach. This approach views urban water utilities as producers of physical water outputs, typically the volume of potable water (Norman and Stoker, 1991; Thannassoulis, 2000; Andwandter and Ozuna, 2002; Tupper and Resende, 2004; Coelli and Walding, 2006; Byrnes et al., 2010) and/or the number of properties supplied with water (Coelli and Walding, 2006; Saal and Parker, 2006; García-Valiñas and Muñiz, 2007). However, the outputs can also include the length of mains supplied or the service area (Thanassoulis, 2002; Munisamy, 2010), the proportion of non-households supplied with water and/or the average pumping head (Guder et al., 2009), and indexes of water quality assessments, service outages, and customer complaints (Woodbury and Dollery, 2004; Byrnes et al., 2010). Table 3.1 provides details.

Of course, the arguments supporting the use of the alternative outputs vary markedly. For example, Byrnes et al. (2010) argue that non-residential (industrial and commercial) customers place fewer input demands on utilities because of their smaller number, are usually not subject to water restrictions, and have more predictable patterns of demand. However, these users may also require water of a higher quality (typically pressure) and this imposes additional costs/input requirements on water utilities. Similarly, other studies have specified the proportion of water supply from surface or groundwater supplies to proxy for the variation in capital costs associated with different sources of water (Bhatttacharyya et al., 1995; Aubert and Reynaud, 2005; Filippini et al., 2008). Yet other studies have used water losses as a proxy for the age of the capital stock (Thanassoulis, 2000; Andwandter and Ozuna, 2002; Estache and Rossi, 2002).

While there is obviously substantial variation in the specification of outputs across studies, the use of the number of properties connected and/or the volume of water supplied is common in network industries, including water, electricity and gas, and is largely an attempt to take account of the scale of operations. Further, most dedicated studies of economies of scale in water utilities have not employed frontier efficiency measurement techniques. For instance, Garcia et al. (2007) in the US and Filippini et al. (2008) in Slovenia found economies of scale prevailed up to 2.30 million m^3 using translog functions while Fabbri and Fraquelli (2000) concluded they held up to 18.86 million m^3 depending on the chosen functional form (Cobb–Douglas or translog) using least squares regression. Nevertheless, most frontier studies employ at least some output measures, principally as a means of allowing for scale economies, even if this is not their focus.

There is also often an attempt to reflect that the inputs required (and costs) of providing services to geographically dispersed customers are relatively higher, so many studies include a measure of ‘network density’ by dividing the number of properties served or the population by the network length (Bottasso and Conti, 2003; Fraquelli and Moiso, 2005). In effect, these measure the input savings available from increasing the number of customers and total output, holding all other variables constant. In general, the empirical evidence is that urban water utilities are heavily characterised by economies of density. One basic argument is that water collection and connections require fewer inputs than capital-intensive pipe laying and dam building (Walter et al. 2009). Of course, as in all network industries, there is also the suggestion of diseconomies of density (congestion) as the number of customers increases further relative to the length of mains, causing falls in pumping pressure, higher frequencies of bursts and greater infrastructure investment.

Closely related to the concepts of economies of scale and density in urban water utilities studies is the notion of economies of scope—where a single utility can produce different products at lower cost than several specialised utilities—of which there are three main potential sources, all of which impact upon the specification of outputs. The first potential source of economies of scope concerns those that may exist with the provision of water outputs of varying characteristics to different customers, say, households and non-households (industrial and commercial users). For example, while industrial and commercial consumers may have different demands for water quality and/or pressures than households, a single utility (as against a specialised provider) is generally able to service both types of user more cheaply, thereby lowering input requirements and improving efficiency.

The second potential source of economies of scope is where some water providers are also providers of sewerage services. This is especially common in the UK where larger regional water-only companies and smaller local water and sewerage companies are often included in a single analysis [see, for example, Thanassoulis (2000), Bottaso and Conti (2003) and Saal and Parker (2006)]. Certainly, the jointness argument for water and sewerage services is compelling—environmental improvements, water quality and the avoidance of some treatment costs, the reuse of recycled water, the attainment of a larger organisational scale for administrative and other fixed costs, and the sharing of pipe laying and pumping technology, access and infrastructure. The fundamental problem is, however, that specifying water-only and water and sewerage utilities in a single analysis is likely to result in misspecification as they do not share a common production frontier and at least some of the utilities included will have zero sewerage outputs (Saal and Parker 2006).

In the UK, Ofwat (2010c) partly addresses this by separately assessing different aspects of water and sewerage services using only partial performance measures given the non-separability of water and sewerage operations in the one firm. Nonetheless, it would generally be better to include only those utilities in a single analysis where some degree of certainty exists that they share a common conceptualisation of performance (and a common frontier). A final source of economies of scope concerns cost economies from conventionally unrelated network utility services provided to households and other users. In terms of the economies of scope existing alongside water utilities, this is known only by a single (albeit non-frontier) analysis by Fraquelli et al. (2004) of the joint provision of water, gas and electricity.

As discussed, the specification of outputs in urban water utilities is primarily to control for the largely exogenously determined factors that impact upon the use and costs of inputs. That is, there is often no suggestion that utilities would intentionally seek to increase the volume of water supplied or the number of properties serviced. In some cases, this would not be possible as the existing network limits utilities (and any feasible competition) to a specific area. In other cases, such as increasing the volume of water provided, this may lie counter to efforts aimed at demand management and the avoidance of future investment in supply infrastructure. This lies well with the underlying assumption that the principal role of these utilities is the production of quality water services for their existing customers and given the usual input-orientation in DEA, focus is placed on the reduction of inputs relative to some level of outputs. Nevertheless, the utility may seek to maximise some outputs, such as service quality, and as this likely reflects discretionary actions taken by management: if suitable data were available, it should be included in the efficiency measurement process.

Turning now to inputs, with cost frontiers in the stochastic frontier approach these are reflected in both the dependent variable as average variable or total costs and in the independent variables as the price and quantities of the separate inputs. In terms of the left-hand side of the cost function, it is conventionally desirable to include as many of the costs of provision that can be gathered, including management, maintenance and operation, energy and chemical and capital replacement costs. In practice, capital replacement costs especially are sometimes difficult to obtain, so many studies use the length of mains or equivalent to proxy the utility’s commitments to dams, treatment works, pump stations and reservoirs along with the costs associated with the reticulation system included in maintenance and operation costs.

Other studies, such as Byrnes et al. (2010), instead argue that only operating expenses (including network maintenance, treatment, wages and salaries, and administration and energy consumption) are relevant given the sunk cost nature of water infrastructure and the fact that while additions to capital over time are likely through renewal, the opposite (implying the decommissioning of infrastructure) is not. Coelli and Walding (2005) and Bhatttacharyya et al. (1994) also exclude the costs of fixed capital. As for the input prices and quantities on the right-hand side of the cost function, these also vary by study. For example, Aubert and Reynaud (2005) and da Silva e Souza et al. (2007) specify the input prices and quantities of labour and electricity; Filippini et al. (2008) adds materials; and Fraquelli and Moiso (2005) further include the price and quantities of services and capital. The obvious advantage of a fuller specification is that the estimated results can elaborate most fully on allocative efficiency and its source(s).

By its nature, DEA is unconstrained by the actual specification of inputs. This means that inputs can be specified in, say, money and/or quantity and/or quality terms in a single analysis. For example, Lambert et al. (1993) specify inputs as the amounts of labour, energy and materials used, while Garcia-Sanchez (2006) includes the number of staff and the number of treatment works. For the most part, however, many DEA studies restrict themselves to a single input (likely because of data availability) in the form of operating expenditure (Cubbin and Tzanidikas, 1998; Thanassoulis, 2000; Kirkpatrick et al., 2006; Garcia-Valinas and Muniz, 2007; Byrnes et al., 2010), though there are also some attempts to divide expenditures more finely into operating and capital costs (Saal and Parker, 2006), labour and nonlabour operating and capital costs (Tupper and Resende, 2004), operating and maintenance costs (Kirkpatrick et al., 2006), or even personnel, electricity, materials, chemicals, outside services and wastewater treatment costs (Andwandter and Ozuna, 2002). In an unusual alternative, Guder et al. (2009) specify revenue as the single input in their study of German water utilities. Typically, revenue efficiency focuses on errors in the choice of output mix, such as having too little output. By specifying revenue as an input, Guder et al. (2009) may instead be attempting to proxy for costs by assuming zero profits.

Somewhat confusingly, a number of DEA studies also specify variables as inputs that elsewhere serve as outputs. For example, in their analysis of water and sewerage companies in England and Wales, Erbetta and Cave (2006) specify the number of household and nonhousehold connections as inputs, while Munisamy (2010) includes network length and the volume of non-revenue water in his study of Malaysian water supply authorities. This is primarily a reflection of alternative means for controlling for non-discretionary inputs and outputs, that is, inputs and outputs beyond the direct control of management, either at all (e.g. water quality standards and environmental and structural factors) or during the sample period (i.e. an input that cannot be changed in the short run but can in the long run). There are two main approaches available for dealing with non-discretionary inputs and outputs.

The first approach, now common in many DEA software programs, is where the input (or output) orientated envelope program is modified so that only non-discretionary inputs (outputs) are considered in deciding the efficiency improvements possible relative to benchmark. The second approach combines DEA and regression in two stages. In the first stage, DEA is used to obtain efficiencies without including non-discretionary inputs (or outputs). The resulting efficiencies are then regressed on the non-discretionary factors to filter their effects on the efficiency scores and the regression residuals provide the final regression scores (Ramanathan, 2004). As shown in Table 3.1, this approach is substantially more common in the urban water utility literature, including applications by Tupper and Resende (2004), Woodbury and Dollery (2004), Erbetta and Cave (2006), Garcia-Sanchez (2006), Guder et al. (2009), Reznetti and Dupont (2009) and Byrnes et al. (2010).

3.7 Ownership and regulation

Alongside the empirical research into the measurement of efficiency in urban water utilities, an equal amount of attention has been logically directed to the factors that influence efficiency. Very often these involve the use of descriptive statistics and parametric and non-parametric tests of efficiency differences between different types or attributes of water utilities. The other equally common approach is the specification of the estimated or calculated efficiencies as dependent variables in regression models. Part of this work has already been discussed in the attempt to purge efficiency scores of confounding factors or at least better appreciate the possible efficiency effects of non-discretionary inputs/outputs, especially those concerning the structure of the sector and the role of environmental factors.

For the most part, however, the key purpose of many urban water utility studies of efficiency has been to examine the role of ownership and regulation. Obviously, this well serves the policy purposes of water utility regulators in deciding among other things the preferred mix of private and public ownership and the impact of regulation, including standards and pricing. In terms of the first area, much of the literature has examined the argument that privately-owned water utilities are relatively more efficient than publicly-owned water utilities [see, for example, Lynk (1993), Lambert et al. (1993), Bhattacharyya et al. (1995), Estache and Ross (2002), Kirkpatrick et al. (2006), da Silva e Souza et al. (2007), and Munisamy (2010)]. This fittingly parallels an equally sizeable literature examining efficiency differences using non-frontier techniques [see, for instance, da Silva e Souza et al. (2008) and Faria et al. (2005)].

Unfortunately, the results arising from both the frontier and non-frontier approaches are somewhat mixed, with no clear consensus emerging on the relative efficiency of private over public water utilities. For example, in the US Bhattacharyya et al. (1995) find that publicly-owned water utilities are more efficient, while Garcia-Sanchez (2006) concludes there is no significant difference between publicly and privately-owned utilities in Spain. A similar pattern appears to hold in the developing world. For instance, in a cost frontier analysis of 50 water utilities across 19 Asia-Pacific countries, Estache and Rossi (2001) found no strong evidence that private providers were more efficient than public operators (in fact, county-level corruption and governance were found to be more important in explaining the efficiency of individual utilities).

Likewise, Kirkpatrick et al. (2006) considered 110 water utilities across 13 African countries and employed both DEA and stochastic frontier analysis to study whether state-owned utilities in Africa outperformed those involving at least some private capital. The results were very weak: while DEA pointed tentatively to the superiority of the private sector and the stochastic frontier analysis provided some evidence that state-owned utilities were more cost efficient, none of the efficiency differences were statistically significant. Lastly, in Malaysia, Munisamy (2010) concluded that while privately-owned utilities were slightly less efficient in terms of overall technical efficiency, after scale effects were taken into account there was no difference in the level of pure technical efficiency.

Instead of comparing public and private water utilities operating at the same point of time, a second but rather narrowly focused body of work considers the impact of privatisation on the efficiency and productivity of the sector, mostly in the UK. Following the privatisation of water utilities in England and Wales in 1989, Saal and Parker (2000; 2001) cite arguments in early (non-frontier) work that privatisation should improve efficiency on the premise that privatisation removes soft-budget constraints and any political or special interest group interference associated with public ownership, exposes utilities to the market for corporate control, and incentivises management and employees with performance pay structures and the market for managerial talent.

Using cost function and TFP measures, Saal and Parker (2000; 2001) concluded that there was no statistically significant reduction in the trend growth rate of total costs following privatisation using the former and that privatisation had no impact on TFP in the latter. Estache and Trujillo (2003) employed a similar approach to examine Argentinean water and sewerage utilities and concluded TFP improvements, albeit with rather poor quality data, following privatisation. Later, Saal et al. (2007) used a cost frontier to re-examine English and Welsh water and sewerage utilities, arguing that this technique allowed more careful consideration of the productivity gains associated with privatisation. Importantly, while Saal et al. (2007) found that technological change improved after privatisation, productivity growth did not, and they attributed this to efficiency losses as firms struggled to come to terms with the new regulatory regime.

One challenge with these studies is the appropriate recognition of the differences in the underlying production technology. Consider a comparison of the efficiency of privately and publicly-owned urban water utilities. While there are clear similarities in the specification of inputs and outputs for a water utility regardless of ownership, we can reasonably expect (and trust) that profit maximisation especially will play at least some role (even in a stakeholder model) in privately-owned utilities. As a result, at the least the weights (or emphasis) these utilities place on particular inputs and outputs, and possibly the inclusion or exclusion of certain inputs and outputs, will differ from publicly-owned firms and vice versa. This is not a trivial exercise and may mean that the production correspondence relating inputs and outputs in some firms will be misspecified, thereby rendering the measures of efficiency obtained invalid. This is especially likely in non-stochastic approaches, including DEA.

Now consider changes in efficiency or productivity arising from the privatisation of the entire sector, as in the UK. Here there may not only be problems in comparing the productive behaviour of utilities before and after privatisation but also the data gathered in the previous regime for public providers (even where commercialised) may be inconsistent with the data gathering process in even a heavily regulated sector. In fact, the quality and quantity of data gathered on urban water utilities has generally improved in all institutional milieus over time, and the policy desirability of comparing utility efficiency and productivity over time may lead researchers to mistakenly reengineer past data drawn in different contexts and for different purposes to meet current data requirements. Some studies are more careful than others. For example, Saal et al. (2007) go to some effort when comparing the productivity of UK water and sewerage companies that the outputs of water, river and bathing quality are consistent in both the transitional/pre-privatisation (1985–90) and post-privatisation (1991–99) periods by using the quality-adjusted output measures in Saal and Parker (2000; 2001).

A final area applying frontier efficiency techniques focuses on the impact of regulation, primarily in public, though often commercialised, water utilities. For example, Andwandter amd Ozuna (2002) measure the impact of public sector reforms as an alternative to privatisation in Mexico. Using DEA, they find that neither decentralisation to the municipal level nor that the establishment of an autonomous regulator had a positive impact on efficiency. Lastly, again in their 2001 non-frontier analysis, Saal and Parker (2001) hypothesise that a regulatory change of the price cap in 1995 led to a statistically significant change in performance at the industry and individual level for UK water and sewerage companies. Upon finding that the price cap review was not effective in generating efficiency gains, Saal and Parker (2001) conjectured this may have been because of diminishing returns to legally mandated environmental investment taking place at the same time, rather than regulatory failure per se.

3.8 Concluding remarks

This chapter has provided useful insights into efficiency in urban water utility sector. A common theme that runs through these various dimensions of urban water services is that the discretionary (controllable) and non-discretionary (non-controllable) resources available to a particular utility have an important influence on its relative performance if other utilities are operating in different environments. These environmental (or contextual) factors may encompass both physical environmental circumstances, as well as constraints arising from organisational, managerial and regulatory policy. Ignoring these imposed factors may lead to disingenuous efficiency measures. For example, the socioeconomic profile and topography of a water utility is beyond its control, yet directly affects the ability of the utility to provide water-related services, however defined. Similarly, contextual information in the form of statutory and professional standards or norms may dictate the quantity and/or quality of output. Numerous examples exist in the form of mandated water quality and water efficiency standards. These factors should be clearly in mind when surveying the past literature.

This research could be extended in several ways. First, there are few studies including urban water utilities from different countries. One difficulty with such an exercise is that the mixing of utilities from different contexts may entail some problems in specifying a set of common behavioural objectives, even though the central purposes of water utilities are ubiquitous. However, once addressed, the results may offer useful insights into the varying impact of regulation, particularly quality standards and price capping. A related extension would be to take advantage of the increasing availability of panel data to assess efficiency both within and across time, especially as so many existing studies rely on a single cross section.

Second, a more fundamental step would be to consult with industry and regulators on the precise nature of the behavioural objectives in urban water utilities. That is, a clear and unambiguous weighting of the multiple and often conflicting goals and objectives—including profitability, water quality and security of supply, network expansion and maintenance, customer service, sustainability and environmental impact—urban water utilities pursue or have imposed on them through regulation. This would better inform all future studies of efficiency and productivity. Nevertheless, researchers are commonly restricted in specifying inputs and outputs by the availability of comparative data often gathered by changing regulators and other bodies that may not be fully appropriate for efficiency and productivity measurement.

A particular limitation in many contexts is that the input data especially are often poorly available and do not provide the fine detail required for useful quantitative analysis. Nevertheless, most outputs in past efficiency studies also serve only as (non-discretionary) controls. That is, they serve to scale the inputs used by the utilities, such as the amount of water supplied or the number of properties, rather than being an output over which the utility has any meaningful control, such as the level of customer service or the responsiveness to interruptions in the supply of water. As a result, future researchers need to address realistic and valuable qualitative outputs amenable to managerial control, including levels of customer satisfaction, water quality, the prevention of loss of supply, etc.

A final area of research would be to compare the efficiency measures obtained for the same set of urban water utilities from alternative approaches with different assumptions on the specification of inputs and outputs. As discussed, the underlying assumptions of the main efficiency techniques vary markedly, as potentially do the results obtained. Likewise, research elsewhere indicates some efficiency measurement techniques (especially DEA) are very sensitive to variable specification, further complicated by the naturally small number of water utilities in any one sector. Rigorous comparison of the techniques themselves and their outcomes may also help facilitate their dissemination and acceptance by regulators, utilities, the public at large, and other stakeholders concerned with achieving efficient, reliable and sustainable urban water supplies in the 21st century.

4 Non-parametric measures of productivity, efficiency change and technological progress in urban water utilities

4.1 Introduction

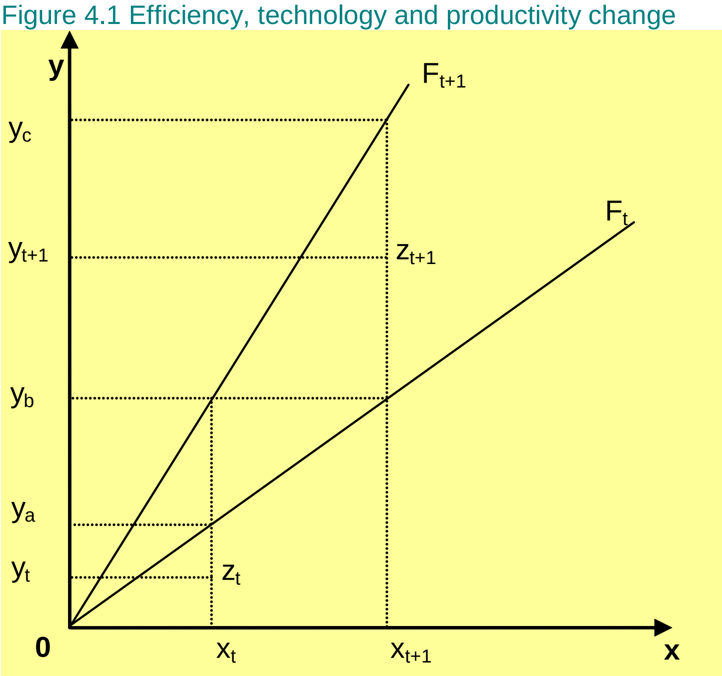
As discussed in Chapter 3, one method for assessing the changes in efficiency and productivity over time in urban water utilities is the Malmquist productivity index, as derived from DEA-like linear programs. The purpose of this chapter is to apply this empirical approach to a sample of large urban water utilities over a recent period. This will allow the evaluation of total factor productivity (TFP) changes net of efficiency improvements as well as providing some indication of any technological changes found in the sector.

The chapter comprises four sections. Section 4.2 focuses on the specification used to measure productivity, efficiency and technological change in Australian urban water utilities. Section 4.3 deals with the specification of inputs and outputs. Section 4.4 presents the results. The section ends with some concluding remarks in Section 4.5.

4.2 Indexes of productivity and technical change

The methodology employed to calculate productivity change and decompose it into its technical efficiency and technological component is the non-parametric Malmquist index. Past applications of this approach cover a range of service industries, including healthcare, financial services and education, along with water services.

Figure 4.1 Efficiency, technology and productivity change



Following Coelli et al. (1998) Figure 4.1 depicts the framework. In this diagram, a production frontier representing the efficient level of output (*y*) that can be produced from a given level of input (*x*) is constructed, and the assumption made that this frontier can shift over time. The frontiers (*F*) thus obtained in the current (*t*) and future (*t*+1) time periods are labelled accordingly. When inefficiency exists, the relative movement of any given water utility over time will therefore depend on both its position relative to the corresponding frontier (technical efficiency) and the position of the frontier itself (technical change). If we ignore inefficiency, then productivity growth over time will be unable to distinguish between improvements that derive from a water utility 'catching up' to the frontier, or those that result from the frontier itself shifting up over time.

Now, for any given water utility in period *t*, say, represented by the output/input bundle z_t, the inputs used are x_t and the output is y_t. However, this is technically inefficient as the water utility lies below the production frontier: with the available technology and the same level of inputs, the utility should be able to produce output y_a. In the next period, there is a technology increase such that more outputs can be produced for any given level of inputs: the frontier moves upward to F_{t+1}. This technology increase potentially relates to a large range of changes in engineering and work practices, management, governance.

The only requirement is that it alters the way utilities transform their inputs into outputs and that this technology ultimately becomes available to the entire sector. Assume the output/input bundle is now represented by z_{t+1} with input x_{t+1} and output y_{t+1}. Once again the utility is inefficient, but in reference to the new technology, and should be producing output y_c if it were efficient. The challenge for productivity assessment is to sort these increases in output relative to the level of inputs into that associated with the change in efficiency and that associated with the change in technology.

It is possible using the Malmquist input-orientated productivity index to decompose this total productivity change between two periods into technological (or technical) change and technical efficiency change. Input-orientation refers to the emphasis on the equi-proportionate reduction of inputs, within the context of a given level of outputs. There are several reasons for selecting this orientation. To start with, as show in Table 1 and discussed in the literature review, the overwhelming majority of past research into efficiency in urban water utilities employs an input orientation.

As discussed in Chapter 3, we assume that the outputs we later specify are not amenable to change in the short run. Further, even if they are able to be changed, there are limits to the ability of the utility to augment these outputs, either because of natural limits to behaviour (i.e. maximum water quality and compliance with chemical and microbiological standards) or limits imposed by regulation and the environment (such as increasing the number of households using the existing infrastructure). Following Coelli et al. (1998), the input-based Malmquist productivity change index is:

$$M_I^{t+1}(y_t, x_t, y_{t+1}, x_{t+1}) = \left[\frac{D_I^t(y_{t+1}, x_{t+1})}{D_I^t(y_t, x_t)} \times \frac{D_I^{t+1}(y_{t+1}, x_{t+1})}{D_I^{t+1}(y_t, x_t)} \right]^{1/2} \quad (4.1)$$

where the subscript *I* indicates an input-orientation, *M* is the productivity of the most recent production point (x_{t+1}, y_{t+1}) (using period *t* + 1 technology) relative to the earlier production point (x_t, y_t) (using period *t* technology), *D* are input distance functions (the distance an input is from the frontier), and all other variables are as previously defined. Values greater than unity indicate positive total factor productivity growth between the two periods. An equivalent way of writing this index is:

$$M_I^{t+1}(y_t, x_t, y_{t+1}, x_{t+1}) = \frac{D_I^{t+1}(y_{t+1}, x_{t+1})}{D_I^t(y_t, x_t)} \left[\frac{D_I^t(y_{t+1}, x_{t+1})}{D_I^{t+1}(y_{t+1}, x_{t+1})} \times \frac{D_I^t(y_t, x_t)}{D_I^{t+1}(y_t, x_t)} \right]^{1/2} \quad (4.2)$$

or $M = E \cdot P$ where *M* (Malmquist total factor productivity) is the product of a measure of technical progress *P* as measured by shifts in the frontier measured at period *t* + 1 and period *t* (the geometric mean of the two ratios in the square bracket corresponding to y_c/y_b and y_b/y_a in Figure 4.1) and a change in efficiency *E* over the same period (the term outside the square bracket corresponding to $(y_{t+1}/y_c)/(y_t/y_a)$ in Figure 4.1).

Using this approach, four efficiency/productivity indices are provided for each water utility along with a measure of technical progress over time. These are:

technical efficiency change (i.e. relative to a constant returns-to-scale technology). This is the change over time in the ability of the utility to best combine inputs and outputs (i.e. using fewer inputs to provide the same level of outputs) without altering its scale (or size) of operations.

technological change. This is the increase in the ability of the industry as a whole to better combine inputs and outputs. It flows from improvements in technologies and practices or the removal of impediments to production (such as regulation and other restrictions).

pure technical efficiency change (i.e. relative to a variable returns-to-scale technology). This is the change over time in the ability of the utility to best combine inputs and outputs were it is able to alter its scale of operations.

scale efficiency change. This is the change over time in efficiency from a utility being able to alter its scale. It is the efficiency benefit that only results from being a utility of a different scale without any other change in current behaviour.

total factor productivity change is the gain in the use of inputs that results from improvements in efficiency of all kinds (utilities catching up to existing best practice) and from any technological changes that enable potential improvement in industry best practice.

Coelli et al. (1998) discuss the linear programs necessary to calculate these indices and the DEAP 2.1 software used in this analysis.

4.3 Specification of outputs and inputs

The data consist of annual observations of 55 major Australian urban utilities over the period 2005–06 (NWC 2007) (the year of the first National Performance Report) to 2008–09 (NWC 2010a). Unfortunately, the data for 2009–10 (NWC 2011) was not available at the time of the technical preparation of this report (released in April 2011). This is longest period where the Water Services Association of Australia (WSAA), in conjunction with the NWC and the parties to the National Water Initiative (the Commonwealth of Australia and the governments of NSW, Victoria, Queensland, South Australia, ACT, Northern Territory, Tasmania and Western Australia), has provided consistent utility-level data.

In the 2008–09 report, 73 utilities from across Australia supplying approximately 17.2 million Australians with their water services provided the some 117 indicators used in the report, compared to 56 water utilities in 2007–08. These indicators cover a wide range of critical performance areas, including safety (health), customer service, asset management, environmental, finance and pricing. As it was not feasible to examine in specific detail the service coverage of all the utilities, we assumed that all of the information given in the urban water performance reports related to urban water services.

In terms of sampling, we first removed all utilities where data was unavailable for each year over the four-year period. We then removed an additional eighteen reporting water utilities from the sample.

To start with, we excluded the seven bulk water suppliers (Fish River Water, Goldenfields Water, Rous Water, Sydney Catchment Authority, Seqwater, Hobart Water, and Melbourne Water) because their productive behaviour differs substantially from the utilities that are the focus of this study. Bulk utilities are utilities that do not have end-use customers of their own; instead, they provide services to other water utilities. These services potentially include the harvesting and storage of water in reservoirs, treating and transferring water from storage to other reticulation networks, and the treating and disposing of (or recycling) of sewage collected from other customers.

Then, given there is a range of behaviour with most utilities providing both potable water and wastewater services and a few providing only either service, we removed institutions that offered wastewater services only (including Wagga Wagga Council, Riverina Water, City of Kalgoorlie–Boulder, and Water Corporation–Bunbury). Fortunately, as the indicators in the report split according to water and wastewater services, we were able to retain utilities offering water services only and use only the water-related indicators for utilities offering both water and wastewater services.

Finally, we removed seven other utilities with substantial amounts of missing data that we were unable to extrapolate, reconstruct or approximate from the data available. One indicator of the scale of missing data is that in the 2006–07 report, the amount of available data was about 60 per cent of the total potential dataset, rising to 80 per cent in 2007–08 and 85 per cent in 2008–09. This has necessarily determined both the sample composition and the specification of inputs and outputs with a view of maximising the sample size.

Table 4.1 lists the 55 utilities remaining in the sample along with their location by jurisdiction (state) and the categorisation in the report by the number of connected properties. The utility names correspond to the abbreviations in the 2008–09 report (NWC 2010a). The inputs and outputs employed follow a production approach to modelling water utility behaviour, that is, utilities combine factors of production and produce outputs in the form of water-related services. In terms of previous work in Table 3.1, the approach selected is most consistent with Guder et al. (2009), Garcia-Valina and Muniz (2007), Picazo-Tadeo et al. (2009), Byrnes et al. (2010) and Munisamy (2010). Ideally, it should be possible to identify several different inputs and outputs so that the production process can reflect the different flexibilities utilities may have in using a range of potentially substitutable inputs to produce a variety of outputs. For instance, efficient usage of a particular input will vary by its degree of factor substitutability and price, whereas production of a particular output will be determined by, among other things, the price paid or the weighting assigned by the utility's customers. Unfortunately, the inputs in the NWC reports are not finely specified (into, say, expenditure on energy, labour, materials, chemicals, machinery, etc.) and so we are unable to identify even capital and labour inputs separately, let alone their prices [as in, say, Filipini et al. (2008) and Reznetti and Dupont (2009)].

Table 4.1 Sampled urban water utilities

Code	Utility	Jurisdiction	Type
ACW	ACTEW	ACT	ML
ALB	Albury City Council	NSW	NML
AQW	Aqwest - Bunbury Water Board	WA	NMO
BAL	Ballina Shire Council	NSW	NMO
BAR	Barwon Water	VIC	ML
BAT	Bathurst Regional Council	NSW	NMO
BEG	Bega Valley Shire Council	NSW	NMO
BRI	Brisbane Water	QLD	ML
BYR	Byron Shire Council	NSW	NMO
CGW	Central Gippsland Water	VIC	MO
CHW	Central Highlands Water	VIC	MO
CIT	City West Water	VIC	ML
CLA	Clarence Valley Council	NSW	NMO
COF	Coffs Harbour City Council	NSW	NML
COL	Coliban Water	VIC	MO
DUB	Dubbo City Council	NSW	NMO
EGW	East Gippsland Water	VIC	NML
GCW	Gold Coast Water	QLD	ML
GFW	Goldenfields Water	NSW	NMO
GOS	Gosford City Council	NSW	MO
GOU	Goulburn Valley Water	VIC	MO
GWM	GWM Water	VIC	NML
HWC	Hunter Water Corporation	NSW	ML
IPS	Ipswich Water	QLD	MO
KMP	Kempsey Shire Council	NSW	NMO
LIS	Lismore City Council	NSW	NMO
LOG	Logan Water	QLD	MO
LOW	Lower Murray Water	VIC	NML
MCW	MidCoast Water	NSW	NML
NEW	North East Water	VIC	NML
ORC	Orange City Council	NSW	NMO
PAD	Power and Water - Darwin	NT	NML
PAS	Power and Water - Alice Springs	NT	NMO
PMQ	Port Macquarie Hastings Council	NSW	NML
QUE	Queanbeyan City Council	NSW	NMO
RIV	Riverina Water	NSW	NML
SAW	SA Water - Adelaide	SA	ML
SEW	South East Water Ltd	VIC	ML
SGW	South Gippsland Water	VIC	NMO
SHL	Shoalhaven City Council	NSW	NML
SWC	Sydney Water Corporation	NSW	ML
TAM	Tamworth Regional Council	NSW	NMO
TWE	Tweed Shire Council	NSW	NML
WAN	Wannon Water	VIC	NML
WAY	Water and Waste Services (Mackay Regional Council)	QLD	NML
WCA	Water Corporation - Albany	WA	NMO

Code	Utility	Jurisdiction	Type
WCG	Water Corporation - Geraldton	WA	NMO
WKB	Water Corporation - Kalgoorlie-Boulder	WA	NMO
WMN	Water Corporation - Mandurah	WA	NML
WPT	Water Corporation - Perth	WA	ML
WSA	Western Water	VIC	NML
WSP	Westernport Water	VIC	NMO
WSR	Wingecarribee Shire Council	NSW	NMO
WYS	Wyong Shire Council	NSW	MO
YAR	Yarra Valley Water	VIC	ML

Notes: ACT Australian Capital Territory, NSW New South Wales, NT Northern Territory, QLD Queensland, SA South Australia, VIC Victoria, WA Western Australia, ML Metropolitan Large 100 000+ connected properties, MO Metropolitan Other 50–100 000 connected properties, NML Non-metropolitan Large 20–50 000 connected properties, NMO Non-metropolitan Other 10–20 000 connected properties.

Accordingly, our sole input is total operating cost (in $000s). The NWC (2009) defines operating costs as comprising a range of expenditure water utilities incur on a range of activities, including labour and technology costs, fees for legal and other professional services, and corporate or head office expenditure. Operating expenditure also includes operations and maintenance expenditure on water infrastructure, water and sewage treatment costs, including chemicals and processes to treat water, licence fees paid to entities such as regulators and government departments, and water conservation expenditure including public education, costs associated with the advertisement and enforcement of water restrictions.

Unfortunately, only the two most-recent performance reports (NWC, 2010a, 2011) provide information (corresponding to 2008–09 and 2009–10, respectively) on the written down replacement cost of fixed water supply assets. Without this information, it is not possible to scale the level of capital expenditure made by each utility. Moreover, as discussed earlier, the performance reports for 2009–10 (NWC, 2011) were unavailable at the time of the technical preparation of this report. Finally, NWC (2010b) makes the following point that supports both the focus on operating expenditure as an input and the input orientation of this analysis:

Operating expenditure is usually directly recovered from customers through prices, in the year it is incurred. Therefore, increases in operating expenditure are passed on to customers relatively quickly. This is because without the necessary revenue to recover the day-to-day operating expenditure of the business, utilities would be unable to operate their systems.

Equally importantly, this input makes no allowance for the non-discretionary or non-controllable structural and environmental factors that also impact upon the observed behaviour of water utilities, including its size, density, location, and principal sources of water and infrastructure requirements. This is because in this part of the analysis, we employ the method of first estimating the efficiencies using only the set of controllable factors and then gauging the effects on these efficiencies using the set of non-controllable factors.

The six non-controllable factors are:

PMN, the number of properties served per km of water main (n)

WTR, total urban water supplied (ML)

BLK, the percentage of water sourced from bulk suppliers (per cent)

GRD, the percentage of water sourced from groundwater (per cent)

REC the percentage of water sourced from recycling (per cent), and

SUR, the percentage of water sourced from surface water (per cent).

We should note that the number of connections is commonly considered as one of the main drivers of operating costs in urban water utilities. We also note that apart from the number of properties served and the volume of water supplied, at least some utilities will have zero values for some of these factors. For example, relatively few utilities source recycled water as an input. However, this is not a theoretical concern, as the purpose of these factors is merely to condition the input environment in which utilities operate, and the positive or negative effects of this imposed environment on operating costs. It is also not an empirical concern in the second-stage regression analysis.

Table 4.2 Selected descriptive statistics of controllable and non-controllable inputs and controllable outputs by year

		Controllable input	Controllable outputs					Non-controllable inputs						
		OXT	CHC	MBC	LSI	WQI	WMI	PRP	WTR	PMN	BLK	GRD	REC	SUR
2005–06 to 2008–09 n=220	Mean	35189.770	89.705	95.578	1.607	25.827	8.637	127.532	37396.340	40.309	28.616	14.413	3.404	53.388
	Maximum	601724.600	100.000	100.000	12.500	263.158	92.593	1755.000	528260.000	84.000	100.000	100.000	43.428	100.000
	Minimum	1920.000	0.000	0.000	0.260	0.010	1.075	9.990	1426.000	5.000	0.000	0.000	0.000	0.000
	Std. Dev.	74903.750	21.218	13.805	1.230	39.318	9.446	274.849	79052.580	16.629	42.320	28.407	6.289	41.631
	CV	2.129	0.237	0.144	0.766	1.522	1.094	2.155	2.114	0.413	1.479	1.971	1.848	0.780
	Skewness	4.968	-2.857	-4.427	4.290	2.948	4.441	4.063	4.216	0.780	0.907	2.046	3.677	-0.220
	Kurtosis	32.095	11.391	25.785	33.258	13.351	33.244	22.081	23.343	3.229	1.913	5.788	20.256	1.287
2005–06 n=55	Mean	30862.070	89.089	92.104	1.468	21.914	9.486	124.425	40069.560	39.992	26.856	13.141	3.027	56.943
	Maximum	407983.100	100.000	100.000	4.762	111.111	50.000	1706.000	528260.000	82.000	100.000	100.000	36.351	100.000
	Minimum	3475.296	0.000	0.000	0.287	0.010	1.818	10.000	1983.000	5.000	0.000	0.000	0.000	0.000
	Std. Dev.	61669.760	23.189	18.945	0.892	26.010	8.842	271.919	83590.430	16.731	42.387	29.333	5.785	43.311
	CV	1.998	0.260	0.206	0.608	1.187	0.932	2.185	2.086	0.418	1.578	2.232	1.911	0.761
	Skewness	4.522	-2.687	-3.096	1.621	1.543	2.388	4.100	4.135	0.709	1.018	2.163	3.828	-0.364
	Kurtosis	26.802	9.689	13.136	5.535	4.660	9.975	22.429	22.804	3.114	2.104	6.053	21.292	1.298
2006–07 n=55	Mean	33835.540	89.087	95.991	1.524	23.975	7.316	126.446	38189.950	40.272	28.802	15.027	3.452	52.524
	Maximum	476992.400	100.000	100.000	3.846	200.000	33.333	1721.000	509930.000	83.000	100.000	100.000	33.891	100.000
	Minimum	3543.384	0.000	0.000	0.336	0.010	1.075	11.000	1426.000	6.000	0.000	0.000	0.000	0.000
	Std. Dev.	70892.260	21.826	15.218	0.900	35.694	6.570	275.073	80717.740	16.732	42.134	29.222	6.018	41.715
	CV	2.095	0.245	0.159	0.591	1.489	0.898	2.175	2.114	0.415	1.463	1.945	1.743	0.794
	Skewness	4.776	-2.761	-5.129	0.989	2.839	1.994	4.072	4.180	0.821	0.892	2.022	2.899	-0.158
	Kurtosis	29.153	10.985	30.928	3.110	12.679	7.207	22.164	23.028	3.246	1.922	5.656	13.414	1.289
2007–08 n=55	Mean	37116.060	90.888	96.403	1.751	27.156	8.373	128.563	35320.610	40.422	28.025	14.963	3.470	53.318
	Maximum	601724.600	100.000	100.000	12.500	200.000	50.000	1737.000	481701.000	83.000	100.000	100.000	41.308	100.000
	Minimum	3608.500	0.000	50.000	0.429	1.060	1.471	11.000	1535.000	6.000	0.000	0.000	0.000	0.000

		Controllable input	Controllable outputs					Non-controllable inputs					
		OXT	CHC	MBC	LSI	WQI	WMI	PRP	WTR	PMN	BLK	GRD	REC	SUR
	Std. Dev.	86699.410	18.686	10.095	1.713	42.329	8.012	278.293	76253.390	16.692	42.486	28.588	6.660	41.281
	CV	2.336	0.206	0.105	0.978	1.559	0.957	2.165	2.159	0.413	1.516	1.911	1.919	0.774
	Skewness	5.294	-2.971	-3.210	4.698	2.645	2.977	4.046	4.237	0.799	0.943	1.959	3.756	-0.230
	Kurtosis	34.129	12.920	12.855	29.473	9.883	14.726	21.928	23.353	3.269	1.969	5.479	20.369	1.309
2008–09 n=55	Mean	38945.390	89.755	97.815	1.685	30.263	9.373	130.695	36005.260	40.550	30.783	14.520	3.664	50.769
	Maximum	524745.000	100.000	100.000	8.333	263.158	92.593	1755.000	491968.000	84.000	100.000	100.000	43.428	100.000
	Minimum	1920.000	0.000	50.000	0.260	0.937	1.248	9.990	2061.000	5.460	0.000	0.000	0.000	0.000
	Std. Dev.	79807.490	21.459	7.883	1.243	49.861	13.161	281.586	77542.600	16.815	43.337	27.180	6.792	41.087
	CV	2.049	0.239	0.081	0.738	1.648	1.404	2.155	2.154	0.415	1.408	1.872	1.853	0.809
	Skewness	4.462	-2.963	-4.661	3.148	2.819	4.904	4.032	4.297	0.792	0.782	2.033	3.956	-0.136
	Kurtosis	26.309	12.087	26.617	16.282	11.391	30.591	21.786	23.826	3.278	1.698	5.968	22.608	1.290

Notes: OXT Total operating cost ($000s), CHC Percentage of zones where chemical compliance was achieved (per cent), MBC Percentage of zones where microbiological compliance was achieved (per cent), LSI Inverse of real losses (L/service connection/d), WQI Inverse of water quality and service complaints (per 1000 properties), WMI Inverse water main breaks (per 100 km of water main), PRP Total connected properties - water supply (000s), WTR Total urban water supplied (ML), PMN Properties served per km of water main (n), BLK Percentage of water sourced from bulk supplier (per cent), GRD Percentage of water sourced from groundwater (per cent), REC Percentage of water sourced from recycling (per cent), SUR Percentage of water sourced from surface water (per cent). CV Coefficient of variation.

Table 4.3 Selected descriptive statistics of controllable and non-controllable inputs and controllable outputs by jurisdiction and type

		Controllable input	Controllable outputs						Non-controllable inputs					
		OXT	CHC	MBC	LSI	WQI	WMI	PRP	WTR	PMN	BLK	GRD	REC	SUR
ACT n=1	Mean	43033.960	100.000	100.000	2.008	33.839	2.883	141.000	45678.750	46.769	0.000	0.000	6.072	93.928
	Maximum	50019.980	100.000	100.000	2.857	52.632	3.429	144.000	52470.000	47.074	0.000	0.000	8.558	96.209
	Minimum	35833.510	100.000	100.000	1.603	7.246	2.083	139.000	40749.000	46.000	0.000	0.000	3.791	91.442
	Std. Dev.	5839.995	0.000	0.000	0.581	19.635	0.647	2.160	5464.214	0.514	0.000	0.000	2.549	2.549
	CV	0.136	0.000	0.000	0.289	0.580	0.224	0.015	0.120	0.011	0.000	0.000	0.420	0.027
NSW n=24	Mean	29850.330	87.929	91.501	1.425	21.680	12.851	103.470	30843.180	38.040	28.540	10.612	3.037	57.811
	Maximum	601724.600	100.000	100.000	4.082	263.158	92.593	1755.000	528260.000	84.000	100.000	98.224	43.428	100.000
	Minimum	3475.296	0.000	0.000	0.336	0.010	2.237	9.990	2851.000	5.000	0.000	0.000	0.000	0.000
	Std. Dev.	100558.100	22.824	18.904	0.845	42.986	12.442	343.430	99842.630	16.699	41.949	23.049	7.902	40.645
	CV	3.369	0.260	0.207	0.593	1.983	0.968	3.319	3.237	0.439	0.000	0.000	2.602	0.703
VIC n=16	Mean	36425.700	92.780	99.028	2.051	36.730	4.559	138.281	36408.730	37.891	29.738	5.963	3.873	60.352
	Maximum	148070.000	100.000	100.000	12.500	200.000	14.286	670.000	172797.000	80.000	100.000	39.020	17.079	100.000
	Minimum	1920.000	62.857	84.091	0.287	5.587	1.075	13.000	1426.000	22.000	0.000	0.000	0.000	0.000
	Std. Dev.	42629.710	9.950	2.600	1.793	34.183	2.743	204.466	47728.040	18.346	42.078	10.439	4.971	38.751
	CV	1.170	0.107	0.026	0.874	0.931	0.602	1.479	1.311	0.484	0.000	0.000	1.283	0.642
SA n=1	Mean	113925.200	87.500	100.000	1.495	138.491	4.172	507.173	150776.600	56.341	0.000	0.000	13.789	86.129
	Maximum	141056.400	100.000	100.000	1.613	166.667	4.762	516.690	163577.000	57.365	0.000	0.000	15.522	89.671
	Minimum	97788.770	83.333	100.000	1.287	111.111	3.704	498.000	139129.400	55.000	0.000	0.000	10.329	84.330
	Std. Dev.	18777.100	8.333	0.000	0.148	31.623	0.447	8.016	12547.200	1.064	0.000	0.000	2.439	2.500
	CV	0.165	0.095	0.000	0.099	0.228	0.107	0.016	0.083	0.019	0.000	0.000	0.177	0.029
QLD n=5	Mean	53325.570	96.132	98.599	1.702	21.092	6.135	166.175	43283.560	55.115	62.662	1.115	3.858	32.170
	Maximum	154411.800	100.000	100.000	4.348	76.923	11.111	446.950	140458.000	75.000	100.000	12.344	12.247	100.000
	Minimum	14932.520	78.788	87.879	0.709	0.010	2.012	30.000	10374.000	37.000	0.000	0.000	0.000	0.000
	Std. Dev.	48309.440	6.439	3.083	0.893	22.154	2.326	156.897	42582.550	14.553	46.155	3.237	4.372	44.398
	CV	0.906	0.067	0.031	0.524	1.050	0.379	0.944	0.984	0.264	0.000	0.000	1.133	1.380

		Controllable input	Controllable outputs					Non-controllable inputs						
		OXT	CHC	MBC	LSI	WQI	WMI	PRP	WTR	PMN	BLK	GRD	REC	SUR
NT n=2	Mean	14075.220	35.417	91.667	0.549	1.572	2.492	29.924	22701.270	33.839	0.000	52.105	3.962	43.919
	Maximum	23285.530	100.000	100.000	0.926	3.003	6.495	50.731	37504.070	38.474	0.000	94.955	10.417	89.656
	Minimum	7397.071	0.000	33.333	0.260	0.821	1.248	11.000	8802.000	30.000	0.000	9.402	0.914	0.000
	Std. Dev.	6140.925	44.040	23.570	0.214	0.783	1.665	19.571	14620.930	4.070	0.000	43.815	3.566	46.960
	CV	0.436	1.243	0.257	0.391	0.498	0.668	0.654	0.644	0.120	0.000	0.000	0.900	1.069
WA n=6	Mean	30746.780	100.000	100.000	1.376	5.259	8.493	129.934	45957.850	41.906	16.639	55.474	0.877	25.752
	Maximum	166108.200	100.000	100.000	3.333	15.152	23.743	707.000	249756.000	54.972	99.963	100.000	3.146	100.000
	Minimum	3532.340	100.000	100.000	0.556	0.010	1.923	12.000	3362.000	29.884	0.000	0.000	0.000	0.000
	Std. Dev.	54902.770	0.000	0.000	0.879	3.619	5.998	254.368	88834.180	9.023	38.006	43.123	1.254	36.825
	CV	1.786	0.000	0.000	0.639	0.688	0.706	1.958	1.933	0.215	0.000	0.000	1.430	1.430
ML n=11	Mean	132781.800	98.490	99.260	1.505	48.656	3.779	517.106	146531.300	62.860	46.545	8.373	4.161	40.129
	Maximum	601724.600	100.000	100.000	3.333	166.667	7.692	1755.000	528260.000	84.000	100.000	57.333	15.522	96.209
	Minimum	34007.000	83.333	80.000	0.709	3.215	1.163	125.000	31868.000	37.000	0.000	0.000	0.000	0.000
	Std. Dev.	127335.400	4.398	3.190	0.508	40.930	1.683	435.034	128130.800	14.595	48.849	17.031	4.524	40.985
	CV	0.959	0.045	0.032	0.337	0.841	0.445	0.841	0.874	0.232	0.000	0.000	1.087	1.021
MO n=8	Mean	21205.380	90.688	99.675	2.168	14.848	6.548	61.380	16361.810	41.526	37.547	2.387	2.520	57.421
	Maximum	38127.950	100.000	100.000	4.348	41.667	25.000	93.000	28170.000	73.000	100.000	23.643	8.151	99.352
	Minimum	15000.380	70.270	97.222	0.287	0.010	2.326	51.000	11334.000	26.000	0.000	0.000	0.000	0.000
	Std. Dev.	4413.357	9.595	0.875	1.138	11.847	5.964	7.950	4616.332	14.803	40.604	4.560	2.660	40.323
	CV	0.208	0.106	0.009	0.525	0.798	0.911	0.130	0.282	0.356	0.000	0.000	1.056	0.702
NML =16	Mean	11519.870	89.739	95.418	1.881	25.571	10.288	33.835	12452.300	32.947	12.872	8.377	2.706	76.038
	Maximum	23285.530	100.000	100.000	8.333	200.000	50.000	50.731	37504.070	47.000	99.963	77.585	17.079	100.000
	Minimum	5370.912	33.333	50.000	0.260	0.010	1.587	20.000	5108.000	17.000	0.000	0.000	0.000	0.000
	Std. Dev.	4502.625	17.890	10.608	1.247	34.635	8.498	8.770	7296.858	8.391	32.090	17.782	4.716	33.441
	CV	0.391	0.199	0.111	0.663	1.354	0.826	0.259	0.586	0.255	0.000	0.000	1.742	0.440

		Controllable input	Controllable outputs					Non-controllable inputs					
		OXT	CHC	MBC	LSI	WQI	WMI	PRP	WTR	PMN	BLK	GRD	REC	SUR
NMO n=20	Mean	6043.803	84.453	92.043	1.220	17.867	10.824	14.685	5741.148	33.310	27.779	27.374	3.898	40.948
	Maximum	16456.000	100.000	100.000	12.500	263.158	92.593	21.000	10435.000	57.582	100.000	100.000	43.428	100.000
	Minimum	1920.000	0.000	0.000	0.336	0.010	1.075	9.990	1426.000	5.000	0.000	0.000	0.000	0.000
	Std. Dev.	2465.574	29.578	20.141	1.400	44.255	12.341	2.630	2326.698	11.449	42.249	39.247	8.758	41.031
	CV	0.408	0.350	0.219	1.148	2.477	1.140	0.179	0.405	0.344	1.521	1.434	2.247	1.002

In contrast, we are able to use the reports to specify five categories of discretionary (or controllable) output. The key focus here is on the provision of high-quality water services to the utility's customers, encompassing requirements for clean, potable water reliably delivered with a minimum of waste and interruption. These are:

CHC, the percentage of zones where chemical compliance was achieved (per cent),

MBC, the percentage of zones where microbiological compliance was achieved (per cent),

LSI, the inverse of real losses (litres/service connection/day);

WQI, the inverse of water quality and service complaints (per 1000 properties, and

WMI, the inverse of water main breaks (per 100 km of water main).

Key points to note are that we normalise microbiological and chemical compliance by the number of zones (originally in terms of the number of compliant zones) because the number of zones vary by utility. Of course, the size of these zones varies across utilities and so a utility with generally smaller zones may appear to perform relatively better than one with only a few larger zones if there is a failure to chemically or microbiological comply in one or two zones. Unfortunately, the NWC data does not include information on the size of the zones in each utility. That said, the level of chemical and microbiological compliance is not very variable across the sample utilities and we expect that the structural and environmental factors may adequately account for this possible source of misspecification. Note also that inverses are used for real losses, water quality and service complaints and water main breaks to ensure that an increase in an output is associated with an improvement in services (i.e. less water wastage and fewer service complaints and main breaks).

Table 4.2 includes selected descriptive statistics by year and for the entire sample period. As shown, the distributional properties of the panel data for most of the thirteen variables included appear non-normal. Given that the sampling distribution of skewness is normal with mean 0 and standard deviation of $\sqrt{6/n}$ where *n* is the sample size (0.323 for the panel, 0.647 for each year) OXT, LSI, WQI, WMI, PRP, WTR, PMN, BLK, GRD and REC are significantly positively skewed at the .05 level (one-tailed), suggesting the greater likelihood of higher than lower values. CHC and MBC are negatively skewed indicating the greater probability of lower than higher values.

The kurtosis or degree of excess, for all variables is also large, thereby indicating leptokurtic or fat-tailed distributions (relatively many extreme values). Given the sampling distribution of kurtosis is normal with mean 0 and standard deviation of $\sqrt{24/n}$ where n is the sample size, then all estimates are once again statistically significant at any conventional level (0.647 for the panel, 1.294 for each year). Finally, the calculated Jarque-Bera statistics and corresponding p-values (not shown) are used to test the null hypotheses that the variables are normally distributed. All *p*-values are smaller than the .01 level of significance suggesting the null hypothesis can be rejected. None of these controllable and non-controllable inputs and controllable outputs is then well approximated by the normal distribution.

That said, the non-parametric, non-stochastic methodology employed in this analysis does not rely upon conventional asymptotic distributional assumptions, and it is only in the case of extreme outliers that a particular utility would be excluded. Drawing on the coefficient of variation (CV), it is clear that the most variable inputs and outputs for major water utilities are operating expenditure (OXT), the number of connected properties (PRP) and the amount of water supplied (WTR). In contrast, the least variable inputs or outputs are chemical and microbiological compliance (CHC and MBC) and the number of properties served per km of water main (PMN)

Table 4.3 provides similar descriptive statistics for the 55 major urban water utilities by justification (state) and type (size and location). As shown, relatively more of the sample utilities are located in NSW (44 per cent), followed by VIC (29 per cent) and then WA (11 per cent). In terms of other characteristics, mean operating expenditures are higher in SA ($113 925) and QLD ($53 325) and lower in NT ($14 075) and NSW ($29 850). The coefficients of variation suggest that NSW and WA have the most variable water utility sectors in terms of expenditure patterns, while ACT and SA (each with only one utility in the sample) have the least variable. This primarily relates, of course, to the sector structure imposed in each state and does not imply any difference in efficiency or productivity.

There is also substantial variation in the types of urban water utility included in the sample. The typical metropolitan large (ML) utility, for instance, incurs operating expenditures of about $132 million in delivering nearly 146 thousand ML of treated water to its more than half a million densely clustered customers, with water almost equally supplied by bulk providers and surface water. In stark contrast, the average non-metropolitan other (NMO) water utility incurs expenditures of just $6 million in providing approximately 5 thousand ML of treated water to its 14 thousand relatively dispersed customers, principally relying on surface water, followed by bulk and groundwater almost equally.

4.4 Results

Table 4.4 presents the geometric mean changes in efficiency, technology and productivity growth by urban water utility. Using this information, three primary issues are addressed in the computation of Malmquist indices of productivity growth over the sample period. The first is the measurement of productivity growth over the period. The second is to decompose changes in productivity growth into what are generally referred to as a ‘catching-up’ effect (technical efficiency change) and a ‘frontier shift’ effect (technological change). The third is that the ‘catching-up’ effect is decomposed to identify the main source of improvement, through enhancements in pure technical efficiency or increases in scale efficiency.

Three points should be emphasised concerning the efficiency, technology and productivity growth indexes before proceeding. First, the indexes (and any resulting percentage changes) are relative. Put differently, a water utility may be more or less efficient, or more or less productive, but only in reference to the other utilities included in the sample, not the population.

Productivity growth is also a relative concept: a larger water utility may be more productive (producing more outputs), but its productivity growth may still be low (when related to inputs). Second, the technique employed places no emphasis on particular inputs and outputs. On one level, this means that if a water utility chooses to focus, say, on avoiding water losses as against ensuring chemical or microbiological compliance, or minimising customer complaints as against water main breaks, its efficiency is only assessed relative to best-practice water utilities making similar sorts of decisions.

As shown in column 10 in the last row of Table 4.4, there was an annual mean growth in TFP of just 1.04 per cent over the period 2005–06 to 2008–09 across the urban water utility sector. Given that productivity growth is the sum of technical efficiency and technological change, we can ascertain the major cause of productivity growth by comparing the values of the efficiency change and technological change. Put differently, the productivity growth can be the result of efficiency gains, technological improvements, or both. In the case of urban water utilities, the overall improvement in productivity over the period is composed of an average efficiency increase (movement towards the frontier) of 4.73 per cent, and average technological progress (upward shift of the frontier) of 0.22 per cent annually. We can further decompose the technical efficiency into pure technical efficiency and scale efficiency and this indicates a 2.11 per cent increase in the former and a 2.23 per cent improvement in the latter.

Table 4.4 Geometric mean changes in efficiency, technology and productivity by utility

Utility	Efficiency change	Rank	Technological change	Rank	Pure efficiency change	Rank	Scale efficiency change	Rank	TFP change	Rank
ACW	3.150	48	0.232	15	0.885	49	3.560	22	0.731	46
ALB	7.298	11	0.225	19	7.298	6	1.000	35	1.640	13
AQW	0.537	54	0.251	5	0.537	54	1.000	35	0.135	53
BAL	5.421	29	0.223	22	5.421	15	1.000	35	1.207	24
BAR	4.239	40	0.209	37	1.516	29	2.797	27	0.888	40
BAT	9.839	6	0.258	4	9.839	3	1.000	35	2.542	3
BEG	6.343	16	0.229	18	6.343	12	1.000	35	1.455	16
BRI	7.982	10	0.236	12	7.982	5	1.000	35	1.886	7
BYR	3.158	47	0.223	22	0.797	50	3.964	18	0.705	48
CGW	6.771	13	0.225	19	6.771	10	1.000	35	1.526	14
CHW	9.791	7	0.239	11	9.791	4	1.000	35	2.338	5
CIT	4.772	35	0.223	22	1.724	27	2.768	28	1.066	32
CLA	6.796	12	0.275	3	6.937	9	0.980	46	1.869	8
COF	8.315	9	0.221	25	2.173	24	3.827	20	1.834	9
COL	5.936	20	0.212	34	6.112	13	0.971	48	1.258	23
DUB	5.734	24	0.287	2	5.895	14	0.973	47	1.645	12
EGW	3.603	45	0.205	44	1.153	33	3.125	24	0.739	45
GCW	4.098	41	0.232	15	2.622	22	1.563	33	0.951	38
GFW	5.816	23	0.241	9	3.362	20	1.730	30	1.400	19
GOS	3.907	42	0.200	48	1.000	39	3.907	19	0.783	44
GOU	3.633	44	0.242	8	3.771	18	0.963	49	0.880	42
GWM	10.006	5	0.176	55	1.000	39	10.006	1	1.764	11
HWC	3.118	49	0.233	14	1.226	31	2.542	29	0.726	47
IPS	0.545	53	0.209	37	0.573	53	0.951	50	0.114	54
KMP	1.951	51	0.250	6	1.966	25	0.993	45	0.487	51
LIS	12.761	1	0.234	13	3.417	19	3.734	21	2.985	1
LOG	6.425	15	0.179	54	2.243	23	2.864	26	1.148	28
LOW	3.273	46	0.194	51	0.721	51	4.537	16	0.636	49
MCW	3.650	43	0.241	9	1.217	32	2.999	25	0.879	43
NEW	4.342	39	0.218	27	2.701	21	1.608	32	0.947	39
ORC	6.499	14	0.231	17	7.173	7	0.906	54	1.499	15
PAD	5.826	22	0.246	7	4.030	17	1.446	34	1.432	17
PAS	4.346	38	0.290	1	4.346	16	1.000	35	1.262	22
PMQ	8.890	8	0.200	48	1.932	26	4.600	14	1.780	10
QUE	0.435	55	0.218	27	0.462	55	0.942	51	0.095	55
RIV	12.414	2	0.218	27	13.966	1	0.889	55	2.710	2
SAW	4.819	33	0.217	30	1.034	37	4.660	13	1.046	33
SEW	6.099	19	0.208	41	1.281	30	4.760	11	1.268	21
SGW	4.694	37	0.219	26	1.064	36	4.410	17	1.029	35
SHL	5.638	26	0.211	35	1.635	28	3.448	23	1.192	26
SWC	5.365	31	0.214	31	1.139	34	4.709	12	1.146	29
TAM	6.272	17	0.225	19	6.708	11	0.935	52	1.412	18
TWE	11.749	3	0.214	31	7.111	8	1.652	31	2.515	4
WAN	10.034	4	0.214	31	10.768	2	0.932	53	2.149	6
WAY	1.000	52	0.210	36	1.000	39	1.000	35	0.210	52

Utility	Efficiency change	Rank	Technological change	Rank	Pure efficiency change	Rank	Scale efficiency change	Rank	TFP change	Rank
WCA	6.180	18	0.209	37	1.122	35	5.508	5	1.293	20
WCG	4.958	32	0.209	37	0.977	45	5.075	10	1.036	34
WKB	5.830	21	0.206	43	1.018	38	5.726	3	1.203	25
WMN	4.792	34	0.185	53	0.900	48	5.326	8	0.888	40
WPT	5.699	25	0.204	45	1.000	39	5.699	4	1.163	27
WSA	5.443	28	0.202	46	0.950	46	5.731	2	1.100	30
WSP	2.965	50	0.197	50	0.645	52	4.595	15	0.583	50
WSR	4.762	36	0.207	42	0.901	47	5.284	9	0.988	37
WYS	5.481	27	0.187	52	1.000	39	5.481	6	1.025	36
YAR	5.419	30	0.201	47	1.000	39	5.419	7	1.087	31
Mean	4.727		0.220		2.116		2.234		1.040	

Notes: Utility changes are geometric means. Mean is arithmetic mean of utility geometric means. Utility names in Table 4.1.

Clearly, across all of the urban water utilities in the sample, the improvement in productivity over the period is the result of improvements in efficiency rather than any expansion in the frontier relating inputs to outputs. Put differently, the best-practice frontier has not expanded over time, such that changes in practices, technology and regulation have enabled utilities as a whole to produce more with less. Instead, efficiency improvements in individual utilities have improved overall productivity in the sector as they have caught up with their best-practice counterparts.

Further, the efficiency improvements are roughly equal between improvements in the ability to combine inputs and outputs in optimal proportions without altering the scale of operations and the benefits from increasing the scale or size of operations. Unfortunately, because the technique used in this section provides relative, not absolute measures of efficiency, it is invalid to compare these findings directly with the results of other studies. However, in some respects it would appear that the efficiency and productivity outcomes have changed markedly in the sector. For example, in a study of Australia's 18 largest water utilities over the period 1995–06 to 2002–03, Coelli and Walding (2006) calculated a mean total factor productivity decrease of –1.2 per cent in the sector, including a technical efficiency gain but with technological regress.

However, these figures obscure very different results across a number of urban water utilities as ranked in the column to the right of their scores. Lismore City Council (LIS), for example, had a mean productivity growth of 2.98 per cent (first-ranked) which was composed of a 12.76 per cent improvement in efficiency (moving towards the efficient frontier) and, like the other utilities, a relatively small 0.23 per cent technological gain (movement in the frontier) (i.e. TFP change = Efficiency change x Technological change).

In turn, the technical efficiency gain almost equally resulted from improvement in pure technical efficiency (3.42 per cent) (optimising the relationships between inputs and outputs without increasing the scale of operation) and through scale efficiency (3.73 per cent) (i.e. Efficiency change = Pure efficiency change x Scale efficiency change) (the gains solely attributable to increasing the scale of operations). That is, LIS improvised its technical efficiency by better combining its inputs and producing outputs and by getting larger (more inputs and outputs) and taking advantage of the increasing returns-to-scale found in this sector. By way of comparison, Riverina Water (RIV) was ranked second in terms of productivity growth (2.71 per cent), again mostly as result of an improvement in technical efficiency (12.41 per cent).

However, whereas LIS improved its technical efficiency almost equally through the increase in pure technical and scale efficiency, RIV increased its efficiency almost wholly based on pure technical efficiency (13.9 per cent) with little improvement in efficiency from the change in scale (0.89 per cent). Put differently, RIV got better at using its existing inputs to produce outputs but did not grow larger in terms of its scale of operations. Lastly, Bathurst Regional Council (BAT) was third-ranked with productivity growth of 2.54 per cent, again mostly attributable to improvements in technical (mostly pure technical) efficiency but with a relatively larger component attributable to technological progress (0.26 per cent).

Together, these results appear to confirm what we know about firm-level productivity growth: impressive rates of growth can occur from a low base as utilities eliminate inefficiency, but productivity growth is more difficult to sustain as utilities make efforts to remove inefficiencies and reliance is placed on the technological improvements potentially available to the entire sector. As the engineering relationships prevailing in the sector have likely changed little in the past few years, utilities must then place emphasis on areas like workplace and reporting practices, financial coordination, and so on.

Table 4.5 Regression analysis of efficiency, technology and productivity

Dependent variable	Efficiency change			Technological change			Pure efficiency change			Scale efficiency change			TFP change		
	Coef.	Std. error	p-value	Coef.	Std. error	p-value	Coef.	Std. error	p-value	Coef.	Std. error	p-value	Coef.	Std. error	p-value
PRP	0.0069	0.0076	0.36	–0.0001	0.0001	0.32	0.0035	0.0062	0.5756	0.0048	0.0082	0.5649	0.0012	0.0016	0.4784
WTR	0.0000	0.0000	0.46	0.0000	0.0000	0.28	0.0000	0.0000	0.6711	0.0000	0.0000	0.6843	0.0000	0.0000	0.6027
PMN	–0.0486	0.0257	0.06	–0.0002	0.0003	0.51	–0.0656	0.0325	0.0487	0.0071	0.0233	0.7620	–0.0117	0.0056	0.0426
BLK	0.0727	0.0143	<0.01	0.0022	0.0001	0.00	0.0520	0.0151	0.0012	0.0251	0.0117	0.0373	0.0163	0.0032	0.0000
GRD	0.0631	0.0172	<0.01	0.0024	0.0001	0.00	0.0552	0.0218	0.0147	0.0229	0.0117	0.0556	0.0145	0.0037	0.0003
REC	0.0431	0.0453	0.34	0.0021	0.0004	0.00	0.0774	0.0629	0.2247	0.0236	0.0453	0.6047	0.0088	0.0114	0.4423
SUR	0.0789	0.0109	<0.01	0.0023	0.0001	0.00	0.0609	0.0147	0.0001	0.0245	0.0099	0.0172	0.0180	0.0024	0.0000
R-squared	0.065			0.143			0.116			0.065			0.076		
Wald F-statistic	21.864		<0.001	352.085		0.01	8.305		0.006	4.814		0.033	17.493		0.000
Ramsay F-statistic	0.725		0.390	1.429		0.23	2.937		0.093	1.283		0.263	0.031		0.861

Notes: White heteroskedasticity-consistent standard errors.

At the other end of the scale are urban water utilities with a low rate of TFP growth over the period. For example, while TFP fell in no utility over the period, the three lowest-ranked, Ipswich Water (IPS), Queanbeyan City Council (QUE) and Aqwest - Bunbury Water Board (AQW), all made only small efficiency gains (largely through scale efficiency) combined with only modest improvements in technology (as in the rest of the sector). However, rather than suggesting overall poor performance, this instead indicates that these utilities were generally operating close to the best-practice frontier and so with limited efficiency improvement potential, and that their opportunities for gain were therefore limited to the small technological gains available to the sector. We gain further insights by examining the changes in pure technical and scale efficiency for these utilities.

Consider pure technical efficiency: some water utilities have clearly improved by moving towards their best practice frontier—increasing outputs relative to inputs subject to the available technology and scale— and this helped improve TFP growth, including Power and Water - Alice Springs (PAS), Dubbo City Council (DUB) and Clarence Valley Council (CLA). Others have moved towards the frontier largely through an increase in the scale of operations, including GWM Water (GWM), Western Water (WSA) and Water Corporation - Kalgoorlie–Boulder (WKB). Together, these findings indicate the diversity of practices and behaviour that urban water utilities have implemented to improve their efficiency during the sample period.

The second part of the analysis employs a second-stage regression approach where the efficiency, technology and productivity scores from the first part are regressed against the non-controllable environmental factors thought to impact upon the measured results. Potentially, this indicates how these factors impact upon efficiency outcomes. It also suggests whether we make any allowance when considering these measures. As shown in Table 4.5, the environmental factors only account for a small percentage of the variation in efficiency technology and productivity; between 6.5 per cent (scale efficiency change) and 14.3 per cent (technological change).

In terms of technical efficiency change and its significant determinants, efficiency improvements are generally lower in utilities with a greater number of properties served per km of water main (PMN), a possible indicator of congestion effects, and in utilities sourcing a relatively higher proportion of water from surface (SUR) followed by bulk (BLK) water. With technological change, the significant determinants are not the characteristics of the utility—the number of connected properties (PRP), the volume of water supplied (WTR), or the properties served per length of main (PMN), rather the sources of water, this time, groundwater (GRD) followed by surface water (SUR).

Though the magnitude of these influences are small, we use the estimated models in Table 4.5 to predict efficiency, technology and productivity change in these utilities 'washed' of the inclusion of non-controllable inputs. More specifically, we insert the values of the explanatory variables for each utility into the model estimates in Table 4.5 and evaluate the residual of the actual and predicted efficiency. If the residual is negative (positive), the utility has performed relatively poorly (better) than what we would expect based on its environmental context.

Unsurprisingly, urban water utilities that performed relatively better (poorly) in Table 4.4 also perform relatively better (poorly) in Table 4.6, largely because of the small amount of variance in performance attributable to uncontrollable inputs. That is, the results in Tables 4.4 and 4.6 are consistent. However, consideration of the average adjusted performance ranking across the five measures particularly helps identify utilities that may be deserving of more attention.

Table 4.6 Efficiency, technology and productivity scores adjusted for influence of non-controllable inputs

	Efficiency change		Technological change		Pure efficiency change		Scale efficiency change		TFP change		Overall rank
	Resid.	Rank	Resid.	Rank	Resid.	Rank	Resid.	Rank	Resid.	Rank	
ACW	–2.424	45	0.011	17	–2.336	43	0.641	21	–0.504	44	40
ALB	1.378	14	0.004	23	3.891	6	–1.760	49	0.320	13	16
AQW	–3.899	52	0.014	13	–2.460	45	–1.558	38	–0.866	52	49
BAL	0.237	23	0.009	19	2.787	8	–1.815	51	0.082	23	20
BAR	–1.600	40	–0.017	43	–2.126	39	–0.084	25	–0.413	41	47
BAT	3.968	4	0.037	4	6.467	3	–1.736	46	1.232	4	2
BEG	0.435	18	–0.003	29	2.122	14	–1.555	37	0.120	21	19
BRI	3.264	8	0.027	5	6.683	2	–2.729	55	0.904	6	3
BYR	–1.720	41	0.009	19	–1.769	35	1.137	15	–0.346	39	32
CGW	0.303	21	0.001	24	2.618	10	–1.725	45	0.073	24	20
CHW	3.421	7	0.016	12	5.528	5	–1.748	47	0.918	5	3
CIT	0.809	16	0.013	15	1.398	16	–0.725	28	0.240	15	7
CLA	–0.274	30	0.050	3	1.874	15	–1.591	39	0.271	14	12
COF	2.197	10	0.000	26	–1.472	31	1.067	16	0.469	8	9
COL	–0.064	26	–0.007	35	2.301	12	–1.808	50	–0.069	30	33
DUB	–0.075	27	0.061	1	2.236	13	–1.663	42	0.339	12	10
EGW	–3.148	50	–0.019	44	–3.390	54	0.477	22	–0.780	51	53
GCW	–0.231	29	0.021	6	1.086	17	–1.823	52	0.044	25	26
GFW	–1.152	38	0.019	7	–1.458	30	–0.802	29	–0.161	33	29
GOS	–0.685	35	–0.013	39	–0.476	26	0.778	19	–0.200	35	34
GOU	–2.655	48	0.017	9	–0.287	23	–1.652	40	–0.543	46	39
GWM	3.769	5	–0.048	55	–3.467	55	7.356	1	0.371	11	24
HWC	–2.527	46	0.010	18	–1.961	37	–0.469	27	–0.530	45	42
IPS	–4.836	55	–0.003	29	–2.229	40	–1.916	53	–1.053	54	54
KMP	–3.559	51	0.014	13	–2.265	41	–1.494	35	–0.762	50	48
LIS	7.430	1	0.019	7	0.857	18	0.913	18	1.823	1	1
LOG	1.468	12	–0.033	54	0.359	21	–0.189	26	0.088	22	28
LOW	–2.349	44	–0.028	50	–3.334	53	1.901	10	–0.615	48	50
MCW	–2.763	49	0.017	9	–2.919	50	0.290	24	–0.559	47	44
NEW	–1.808	43	–0.005	32	–1.668	33	–1.058	31	–0.427	43	46
ORC	1.630	11	0.013	15	2.608	11	–1.716	44	0.447	9	7
PAD	0.278	22	0.017	9	0.602	20	–1.060	32	0.165	19	14
PAS	–0.289	32	0.052	2	0.681	19	–1.459	34	0.213	16	15
PMQ	2.778	9	–0.021	47	–1.749	34	1.822	12	0.419	10	18
QUE	–4.092	53	0.006	22	–1.009	27	–1.996	54	–0.872	53	52
RIV	6.565	2	–0.020	46	9.459	1	–1.515	36	1.370	2	6
SAW	–0.683	34	–0.002	27	–2.058	38	1.151	14	–0.155	32	31
SEW	0.677	17	0.008	21	–0.102	22	0.425	23	0.167	18	12
SGW	–1.782	42	–0.005	32	–3.226	52	1.759	13	–0.426	42	45
SHL	–0.784	36	–0.012	37	–2.485	46	0.731	20	–0.248	38	43
SWC	–0.914	37	–0.003	29	–0.383	24	–0.814	30	–0.191	34	34
TAM	0.061	25	0.001	24	2.748	9	–1.714	43	0.015	26	24
TWE	6.095	3	–0.006	34	3.854	7	–1.142	33	1.262	3	5
WAN	3.768	6	–0.014	40	6.202	4	–1.655	41	0.736	7	11

	Efficiency change		Technological change		Pure efficiency change		Scale efficiency change		TFP change		Overall rank
	Resid.	Rank	Resid.	Rank	Resid.	Rank	Resid.	Rank	Resid.	Rank	
WAY	–4.793	54	–0.012	37	–2.323	42	–1.755	48	–1.083	55	55
WCA	1.141	15	–0.026	49	–2.399	44	2.938	3	0.157	20	27
WCG	0.226	24	–0.029	51	–2.585	48	2.579	6	–0.035	28	37
WKB	0.380	20	–0.014	40	–1.819	36	2.960	2	–0.009	27	22
WMN	–0.274	30	–0.029	51	–1.278	29	2.430	9	–0.208	36	36
WPT	1.419	13	–0.019	44	–1.141	28	2.640	5	0.170	17	17
WSA	–0.595	33	–0.015	42	–2.513	47	2.938	3	–0.229	37	38
WSP	–2.635	47	–0.022	48	–3.096	51	1.847	11	–0.650	49	51
WSR	–1.318	39	–0.011	36	–2.707	49	2.564	7	–0.356	40	41
WYS	0.431	19	–0.029	51	–1.555	32	2.522	8	–0.070	31	30
YAR	–0.137	28	–0.002	27	–0.427	25	1.045	17	–0.049	29	23

Notes: Utility names in Table 4.1. Overall rank is rank average.

For example, utilities that performed relatively better than suggested by their environment across the five efficiency measures are Lismore City Council (LIS), Bathurst Regional Council (BAT), Brisbane Water (BRI) and Central Highlands Water (CHW). Those that performed relatively poorly relative to their imposed environment are Water and Waste Services–Mackay Regional Council (WAY), Ipswich Water (IPS), East Gippsland Water (EGW) and Queanbeyan City Council (QUE). Of course, we should take care in interpreting these results as they are from only one of a number of ways for adjusting for imposed contextual factors. Further, they result directly from our specification of controllable and non-controllable inputs and outputs. In particular, the non-controllable inputs may not accurately reflect the particularly disadvantageous contexts in which utilities sometimes operate.

4.5 Concluding remarks

This section examined the productivity growth of major Australian urban water utilities over the period 2005–06 to 2008–09. Using Malmquist indices, productivity growth was decomposed into technical efficiency and technological change. The results indicate that annual productivity growth averaged 1.04 per cent across all utilities, with a range of 0.09–2.98 per cent, and was largely attributable to efficiency gains (that is reducing inputs relative to outputs based on observed industry best practice). There appears to have been very little gain from technological improvements (0.17–0.29 per cent) and this is suggestive of a slow pace of best-practice improvement in the sector. Unfortunately, it is not possible using this analysis to identify the impediments to these technological changes.

One possibility is that it is increasingly difficult to improve the quantity and quality of water services beyond some physical engineering limit, which the sector has perhaps already met. Another possibility is that the demands for capital expenditure for expanding and modifying expensive infrastructure are having adverse impacts on utility operations. For instance, diverting funding, attention and effort away from operations to fund and build up capital works implies fewer financial, intellectual and managerial resources are available for innovation in water utility operations and so the efficient frontier will not expand as rapidly as it might otherwise.

A somewhat likely prospect in a sector as highly regulated as urban water is also that the costs associated with regulation in the sector, including compliance costs, costs associated with price distortions and resulting production loses, and costs associated with delayed or deferred investment have an adverse effect. Nevertheless, one possible empirical factor is the focus in this report on potable water where there has been arguably less technological progress in recent years or at least over the short run. This contrasts with wastewater treatment processes where there are perhaps more opportunities for technological improvements to play a role. It would then be necessary to specify both potable water and wastewater in a single study to full account for the different sorts of technological advances the urban water sector has made.

Nonetheless, apart from identifying the slow pace of technological progress in the sector and the moderate but steady growth in sector efficiency, there are a number of useful lessons here for the utilities themselves. Clearly, this technique helps identify other utilities to which they can benchmark. In this regard, it would be most useful for utilities to investigate practices in those utilities that perform relatively better than their operating environment would suggest. Further, it would be useful for those utilities that generally perform worse than their environment to investigate practices in both similar urban water utilities and the sector as a whole.

5 Stochastic estimates of economies of scale and scope in urban water utilities

5.1 Introduction

As discussed in Chapter 2 and evidenced in the survey of the literature in Chapter 3, one of the recurrent themes in efficiency analyses of urban water utilities has been the estimation of economies of scale and scope. This is important as the presence of economies of scale has implications for industry structure through horizontal (dis)aggregation while the presence of economies of scope has implications for the assignment of functions and thereby the extent of vertical integration. Unfortunately, there is currently very little quantitative evidence concerning scale economies in urban water utilities, in Australia or elsewhere.

Accordingly, the purpose of this chapter is to estimate economies of scale and scope in Australian urban water utilities. To the author's best knowledge, this is the only study of its type to address these important issues in water utilities, in either Australia or elsewhere. The section comprises four subsections. Section 5.2 briefly discusses the nature of economies and scope in urban water utilities. Section 5.3 deals with the specification of costs, inputs and outputs. Section 5.4 specifies the models used and Section 5.5 presents the results. The section ends with some concluding remarks in Section 5.5.

5.2 The nature of economies of scale and scope in urban water utilities

In general, we can divide the overall costs (or expenditure) required to operate an urban water utility into two areas: operating costs and capital costs. We broadly define operating expenditure as the day-to-day expenditure incurred by the water utility in managing its business while capital expenditure relates to those amounts typically invested in long-lived assets and depreciated over time. Using the NWC's (2010) indicators and definitions handbook, operating costs (operation, maintenance and administration) include the following: water resource access charge or resource rent tax, purchases of raw, treated or recycled water, salaries and wages, overheads on salaries and wages, materials/chemicals/energy, contracts, accommodation.

They also include items expensed from work in progress (capitalised expense items) and community service obligations (CSOs) and competitive neutrality adjustments, they may include but not be limited to, land tax, debits tax, stamp duties and council rates. In contrast, and again using the NWC's own definitions, capital expenditure includes all capital expenditure for new works, renewals or replacements, other expenditure that would otherwise be referred to as capital, and recycling water assets.

Importantly, as in most other businesses, external parties will almost universally handle some of the services associated with these expenditures whereas others lie along a spectrum of in-house and external third-party providers. For example, NWC (2010) highlights the 'alliance' contracts used to deliver operations and maintenance work, customer service, or capital expenditure activities as one feature of water utility operations in Australia that is increasingly prevalent. While individual alliance contracts differ, they typically involve: an agreement between the water utility and an alliance partner(s), the reimbursement by the utility of the alliance partners' direct and indirect expenses, usually including an agreed upon profit margin, forecast expenditure on capital or operating programs, to be agreed upon in advance, and transparent performance measures. Alliance arrangements also include reporting from the alliance partners to the utility once programs are underway, along with the sharing of any cost savings or overruns between the utility and alliance partners (NWC, 2010).

The actual behavioural stance water utilities take to these expenditures, both operating and capital, is potentially difficult to conceptualise. As discussed, Australia's urban water utilities are in the main commercialised public sector entities operating in highly regulated quasi-markets. That said, there is often an expectation of profitability, with the anticipation of dividends being paid. As argued by the NWC (2010b), the level of dividend payable will reflect government dividend policy, pricing policies, the profitability of the utility and its future cash requirements. Nevertheless, government generally sets dividend policy and it is often outside of the control of the individual utility.

In addition, we generally observe a stable dividend policy in only the largest water utilities, often with very high (but volatile) payout ratios, while in practice few of the smaller water utilities pay dividends. Clearly, we cannot blindly apply a profit-maximising objective across the sector. However, one acceptable long-run cost objective for water utilities is to be in a position to produce the desired output (or outputs) either stipulated by regulation and/or required by customers at the lowest possible cost (or cost minimisation). This minimal performance criterion should apply to any economic enterprise desiring the efficient use of resources.

Based on earlier discussion, the principal outputs for most urban water utilities would appear to be the quantity and quality of water produced and distributed and the number of customers served in the distribution network. Efficient production would then entail, among other things, adjusting the scale of production to the most appropriate size for the outputs produced. Sometimes dividing the production process into smaller more specialised production units can result in economies, as evidenced by division of most urban water utilities into separate departments responsible for water and sewerage services, sometimes into entirely different entities with not necessarily corresponding networks.

On other occasions, enlarging the scale of production can achieve lower unit costs. This can proceed over time through a continuum ranging from the internal provision of services through to full contracting out. Through this process, water utilities overcome indivisibilities in factor inputs, avoid the costs of a lack of capacity, and gain access to economies in the fixed costs of production including purchasing, marketing and administration (including human resources and information technology). Unfortunately, this can be difficult in the context of an urban water utility as it is not always possible to adjust scale smoothly. For example, increasing scale may require 'lumpy' investment in dams, pipelines and treatment plants such that utilities will not be operating their infrastructure optimally (through under or over-investment). However, it could also be relatively easy for, say, retail water utilities sourcing water from a bulk water supplier.

The production process for a specific output (say, the amount of potable water supplied or the number of customers served) is then said to exhibit economies of scale when average cost (AC) (i.e. cost per unit of output) declines over some range, where:

$$AC = TC/Q \qquad (5.1)$$

For long-run average cost (LRAC) to decline, the marginal cost (MC) (i.e. the cost of the last unit produced) must be less than overall average costs, where:

$$MC = \Delta TC/\Delta Q \qquad (5.2)$$

If average cost is increasing, then marginal cost must exceed average cost and production exhibits diseconomies of scale. It is thought that diseconomies of scale arise from a number of sources. These include the increase in input prices as industry constraints on factor availability apply (for example, the bidding up of the price of specialised labour) and the reduction of incentives and effective coordination through the growth of bureaucracy and organisational complexity in large organisations. From a pure engineering viewpoint, there are additional complexities in urban water utilities relating to the often less than proportional increase in production from larger plants and in distribution from larger pipes and pumping stations.

Figure 5.1 Operating expenditure per connected property and number of connected properties, 2008–09

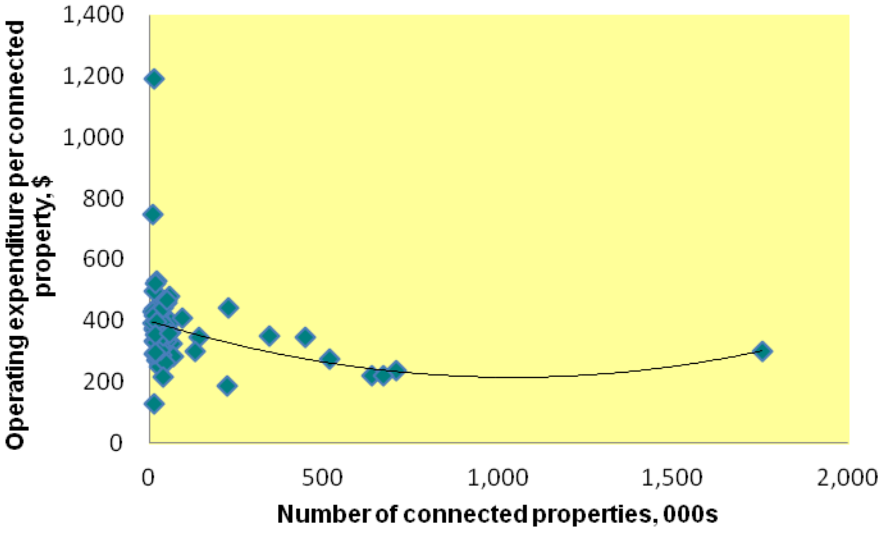
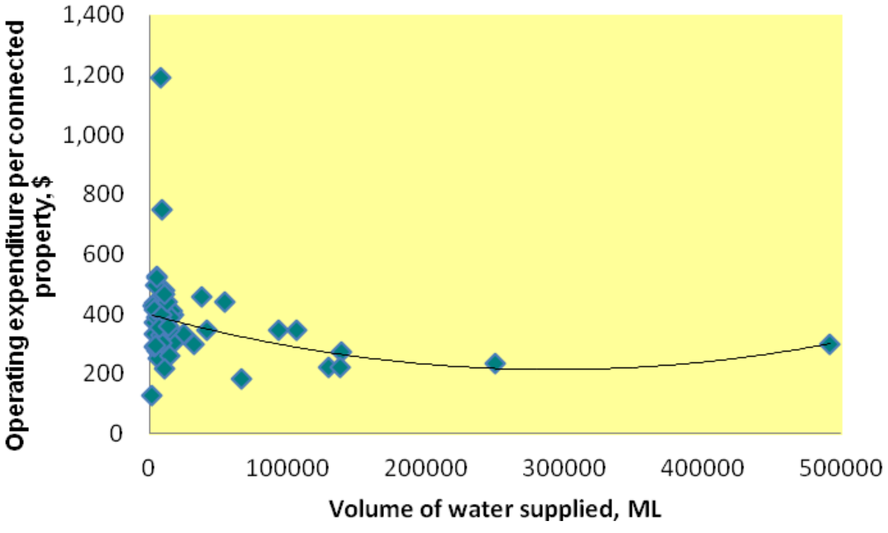


Figure 5.2 Operating expenditure per connected property and volume of water supplied, 2008–09



In most industries, average costs are U-shaped in cost–output space, so that the smallest and largest utilities would have equally high costs relative to medium-sized utilities. That is, on either side of the minimum efficient scale (MES) of production, costs are rising so output less than or more than the MES is inefficient from a cost perspective. This would appear to match the simple analysis in Figures 5.1 and 5.2 where a quadratic function is fitted to a scatter plot of observations using the data to be employed in this analysis. As shown, both operating costs per connected property to the number of properties and the volume of water supplied display a somewhat U-shaped pattern, but with apparently little difference in costs as we increase output, but a substantial variation in costs at relatively low levels of output.

Figure 5.3 Capital expenditure per connected property and number of connected properties, 2008–09

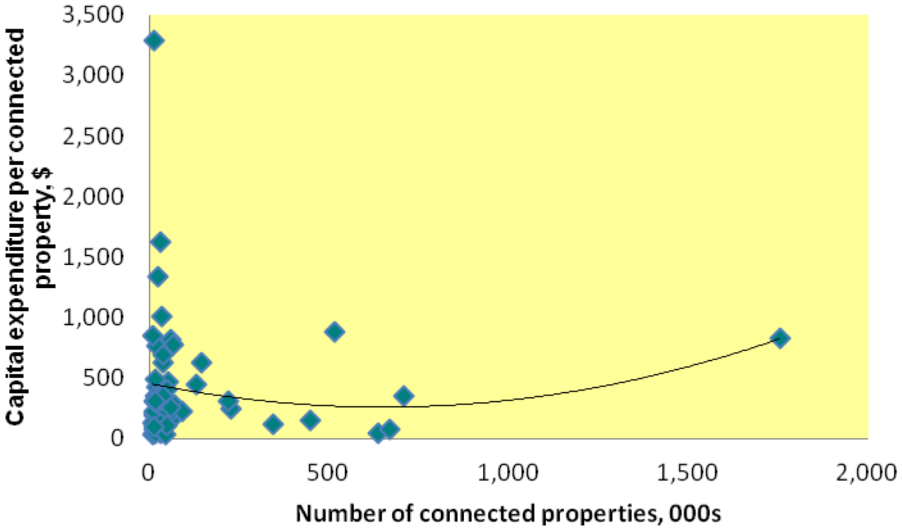
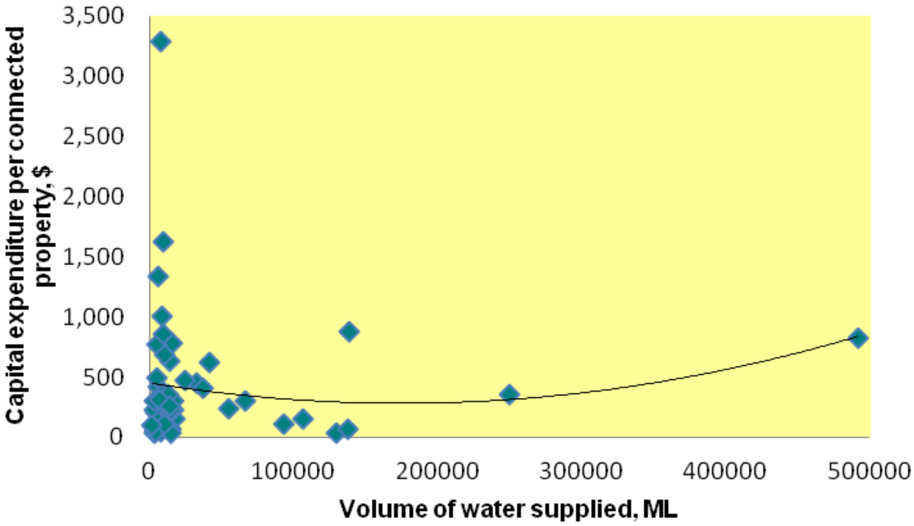


Figure 5.4 Capital expenditure per connected property and volume of water supplied, 2008–09



Of course, the pattern is not as distinct as one may well find in other industries because of the distribution pattern of Australian urban water utilities, with very many small utilities and only a few larger utilities distributed along a wide range of output (Sydney Water Corporation is the utility located on the extreme right-hand side in all four figures). In practice, there is much variation in the shape of LRAC across industries. One possibility is that economies of scale are negligible and diseconomies dominate at relatively low levels of output. Elsewhere, economies of scale may be extremely important and decline continuously over a wide range until output diseconomies are experienced. This results in cost efficient outputs for output levels equal to and exceeding the MES.

In yet other contexts, the LRAC may be virtually horizontal over a wide range of output: economies of scale are quickly exhausted though diseconomies are not encountered until very large levels of output are produced. These L-shaped cost curves are indicative that small, medium, and large-sized water utilities could operate with an approximately equal level of cost efficiency beyond the point of MES where average costs are either flat or only slightly increasing. This would seem to be the case in Figures 5.1 and 5.2. As shown, operating costs per connection and urban water supplied decrease at relatively low levels of production over a short range and then increase only slightly with output over a very long range. This contrasts sharply with Figures 5.3 and 5.4 where capital costs appear to be declining over a large range of output and then increase relatively sharply over a short range. Of course, while these figures are suggestive, they are only partial indicators of the true shape of the LRAC and highly sensitive to the observations included (especially the outliers).

The presence of economies (diseconomies) of scale then rests on the functional relationship between the costs of production and the rate of output per period. In other words, costs = f(output). However, the rate of output is, in turn, a function of the rate of usage of the resource inputs: that is, output = f(inputs). As the production function displays the relationship between input and output flows, once the prices of the inputs (or factor prices) are known, the costs of a specific quantity of output can be calculated. Consequently, the level and behaviour of costs as a utility's rate of output changes (as evidenced by the LRAC) depends on two important factors:

the character of the underlying production function, and

the prices the utility must pay for its resource inputs.

Generally, the first factor determines the shape of the cost function while the second determines the level of costs.

Consider now a water utility using L units of labour (say, management, administrative and operational labour) in combination with K units of capital (both financial and physical) to obtain an output of Q units such that $L + K \rightarrow Q$. Now assume that the amounts of labour and capital are increased by some arbitrary proportion a with the expected proportional increase in output given by b such that $aL + aK \rightarrow bQ$. When the change in output is more than proportional to the change in input ($b > a$), increasing returns-to-scale are found. For example if the inputs of labour and capital increase by 20 per cent, output rises by 30 per cent. Alternatively, when the change is less than proportional to the change in inputs ($b < a$), the firm experiences decreasing returns-to-scale. An example here would be the labour and capital inputs increase by 20 per cent but outputs only rise by 10 per cent. Finally, where the change in output is proportional to the change in inputs ($b = a$) constant returns-to-scale are present. In this case, increasing inputs by 20 per cent would also result in output increasing by 20 per cent.

It is often tempting to use the terms economies (diseconomies) of scale (a cost concept) and increasing (decreasing) returns-to-scale (a production concept) interchangeably. While strictly incorrect, to yield economies of scale the production function must have some region of increasing returns-to-scale, and to yield diseconomies of scale it must have a region where there are decreasing returns-to-scale. In fact, the levels of output where economies (diseconomies) of scale and increasing (decreasing) returns-to-scale occur will exactly correspond when the firm faces constant input prices as output expands. This is most likely to occur for a relatively small entity in a competitive industry where the input demand by one firm is likely to be small relative to total market demand. In other cases, however, where the firm's demand for inputs is large relative to total industry demand, situations may arise where economies of scale occur at the same time that the firm experiences constant (or even decreasing) returns-to-scale.

Consider, for example, a water utility with constant returns-to-scale in a decreasing cost industry. If the inputs (L, K) increase by a given proportion (a), output (Q) will expand by the same proportion (b) such that $b = a$ (i.e. constant returns-to-scale). However, if input prices decline as Q rises, it follows that the average costs of producing aQ must be less than the average cost of producing Q, and long-run average costs must fall (i.e. economies of scale). Similar arguments show that production can even exhibit decreasing returns-to-scale and we can still attain economies of scale so long as the impact on average costs by the decline in factor prices sufficiently offsets the increased use of inputs and vice versa.

In the above discussion, a single output (connected properties and water supplied) is considered. Once multiple product production arises, the presence or absence of complementarity between outputs in production (joint production) in a firm becomes important. This diversity of products (goods or services) within a single entity, known as 'scope', may provide cost advantages in that a single water utility producing a given level of output for product may spend less than a combination of several specialised utility. That is, economies of scope arise when it is cheaper in terms of total cost (*TC*) to produce some level of output (*Q*) of a particular type of output *A* in conjunction with some level of another particular type of output (*B*), rather than each separately, $TC(QA, QB) < TC(QA, 0) + TC(0, QB)$.

Among firms, this process often manifests itself in the jargon as leveraging core competences, competing on capabilities, mobilising invisible assets, diversification into related products, and umbrella branding. In the case of production in water utilities, the production process typically comprises multiproduct attributes because it produces multiple products (qualities and quantities of water, water and sewerage services) through the sharing and joint utilisation of inputs including management and administrative labour, information technology, human resources, piping networks and access, technical knowledge, and so on.

We can see this especially clearly in Table 3.1 where outputs typically include the volume of water (Norman and Stoker, 1991; Thannassoulis, 2000; Andwandter and Ozuna, 2002; Tupper and Resende, 2004; Coelli and Walding, 2006; Byrnes et al., 2010) and the number of connected properties (Coelli and Walding, 2006; Saal and Parker, 2006; García-Valiñas and Muñiz, 2007). However, they also can include the length of mains or the service area (Thanassoulis, 2002; Munisamy, 2010), the proportion of non-households supplied with water and/or the average pumping head (Guder et al., 2009), and indexes of water quality assessments, service outages, and customer complaints (Woodbury and Dollery, 2004; Byrnes et al., 2010).

Of course, in many cases we simply cannot envisage the situation separate specialised utilities could provide these outputs. This is easy enough with water and sewerage services (the latter not considered in this report) where most studies assume sizeable economies of scope exist through joint production in the sharing of the various types of labour, pipe-laying machinery, and recycling technology and so on. However, given the network nature of urban water utilities we can have some difficulty imagining separate firms delivering the quantity of water and another quality. We could more readily accept one producing water (as in a bulk supplier) and another distributing it, or separate responsibilities for wholesale, commercial and retail distribution, or for operation and maintenance of the network. However, in any estimation we would usually wish to include several dimensions of output, if only to ensure that we have fully specified the nature and qualities of an output to avoid any misspecification bias.

5.3 Specification of outputs and costs

The data sampling in this chapter corresponds to that described in Chapter 4. Stochastic cost functions typically regress costs (here separated into operating and capital expenditure) on the quantity and price of the factor inputs used in production (typically capital and labour) and the outputs produced. Unfortunately, the data do not permit full specification of the prices and quantities of the factor inputs. For example, a water utility cost function would typically specify the quantity of labour employed (where price is the average wage) along with the amount of energy and chemicals used (where the price is the average price paid). It would also include some measure of physical capital (say, the dollar value of physical assets, where the price could be the rate of depreciation). See, for example, Norman and Stoker (1991), Bhattacharya et al. (1995), Bottasso and Conti (2003), Aubert and Reynaud (2005), Kirkpatrick et al. (2006) and Da Silva e Souza et al. (2007)].

Table 5.1 Selected descriptive statistics of cost function variables

	Variable	Mean	Max.	Min.	Std. dev.	Skew.	Kurt.
2005–06 to 2008–09 (n = 220)	OXT	35189.770	601724.600	1920.000	74903.750	4.968	32.095
	CXT						
	CHC	89.705	100.000	0.000	21.218	-2.857	11.391
	MBC	95.578	100.000	0.000	13.805	-4.427	25.785
	LSI	1.607	12.500	0.260	1.230	4.290	33.258
	WQI	25.827	263.158	0.010	39.318	2.948	13.351
	WMI	8.637	92.593	1.075	9.446	4.441	33.244
	PRP	127.532	1755.000	9.990	274.849	4.063	22.081
	WTR	37396.340	528260.000	1426.000	79052.580	4.216	23.343
	PMN	40.309	84.000	5.000	16.629	0.780	3.229
	CAP						
	BLK	28.616	100.000	0.000	42.320	0.907	1.913
	GRD	14.413	100.000	0.000	28.407	2.046	5.788
	REC	3.404	43.428	0.000	6.289	3.677	20.256
	SUR	53.388	100.000	0.000	41.631	-0.220	1.287
2008–09 (n = 55)	OXT	38945.390	524745.000	1920.000	79807.490	4.462	26.309
	CXT	32143.725	454445.389	410.132	69802.258	4.914	27.156
	CHC	89.755	100.000	0.000	21.459	-2.963	12.087
	MBC	97.815	100.000	50.000	7.883	-4.661	26.617
	LSI	1.685	8.333	0.260	1.243	3.148	16.282
	WQI	30.263	263.158	0.937	49.861	2.819	11.391
	WMI	9.373	92.593	1.248	13.161	4.904	30.591
	PRP	130.695	1755.000	9.990	281.586	4.032	21.786
	WTR	36005.260	491968.000	2061.000	77542.600	4.297	23.826
	PMN	40.550	84.000	5.460	16.815	0.792	3.278
	CAP	689623.891	10433975.000	29256.000	1582023.599	4.979	17.001
	BLK	30.783	100.000	0.000	43.337	0.782	1.698
	GRD	14.520	100.000	0.000	27.180	2.033	5.968
	REC	3.664	43.428	0.000	6.792	3.956	22.608
	SUR	50.769	100.000	0.000	41.087	-0.136	1.290

Notes: CAP Written down replacement cost of fixed water supply assets ($000s). All other variables as previously defined.

As this data is not available, it amounts to the assumption that input prices are constant across the urban water utility industry and so the quantity of factor inputs employed in production is proportional to the quantity of operating and capital expenses. Fortunately, Australian urban utilities are arguably price-takers operating in competitive factor markets, at least in terms of labour and financial capital. However, we do include a number of non-price variables that help determine input prices in our specification to account for variation across water utilities.

Moreover, while we should attempt to model the determination of operating and capital costs separately, not least because they are a function of different parameters, information on capital expenditure and the written down replacement cost of fixed water supply assets is only available for the most recent report (2008–09). For this reason, we estimate three separate cost functions. The first specifies total operating cost ($000) as the dependent variable as a function of seven outputs:

the percentage of zones where chemical compliance was achieved (per cent) (CHC)

the percentage of zones where microbiological compliance was achieved (per cent) (MBC) the inverse of real losses (L/service connection/d) (LSI)

the inverse of water quality and service complaints (per 1000 properties) (WQI)

the inverse of water main breaks (per 100 km of water main) (WMI)

total connected properties (000s) (PRP) and

total urban water supplied (ML) (WTR).

This is similar to the specification in Chapter 4 with the exception that PRP and WTR are included directly in the cost function. This is reasonable in that the literature generally accepts these parameters are drivers of water utility costs and that the focus of this section is not on individual level technical efficiencies rather sector wide economies of scale and scope. We also specify five input variables that help determine water utility costs:

properties served per km of water main (n) (PMN)

the percentage of water from bulk suppliers (per cent) (BLK)

the percentage of water from groundwater (per cent) (GRD)

the percentage of water from recycling (per cent) (REC) and

the percentage of water from surface water (per cent) (SUR).

Because of the unavailability of data, we specify this operating cost function over the period 2005–06 to 2008–09. The upper panel in Table 5.1 provides selected descriptive statistics.

The second and third cost functions only use data from 2008–09 when information on capital expenditure and the amount of physical capital is available. Accordingly, an attempt is made to more finely specify those parameters that determine operating costs from those that determine capital costs. The first model specifies total operating expenses ($000) (OXT) as a function of four outputs (CHC, MBC, WQI and PRP) and five input variables (PMN, BLK, GRD, REC and SUR). The second model specifies total capital cost ($000s) (CXT) as a function of four outputs (LSI, WMI, WTR and PRP) and five input variables (CAP, BLK, GRD, REC and SUR). The lower panel of Table 5.1 provides descriptive statistics for the data used in these specifications.

In general, the first model regards operating costs as a function of water quality, the number of supplied properties, the sources of water the utility employs and the associated requirements for treatment, and the density characteristics of its service area. The focus is short-run, day-to-day operating demands of customers. The second model instead focus on capital expenditure and the efforts the utility takes to expand and maintain a network that minimise water losses and breaks relative to the amount of water supplied and the size of the utility, the amount of capital already invested, and the infrastructure needs of its water resources. The focus is then the long-run asset demands of the network.

5.4 Model specification

We commonly employ a quadratic (a polynomial equation of the second degree) cost function to estimate the stochastic cost functions. This has the advantage of a flexible specification applicable to multifactor production. The cost function is also an appropriate form to take account of the linear, quadratic and cross-product terms found with more than one output. A cost function that allows the economies of scale to vary with different levels of input, x_i and output, y_i is specified as:

$$C = \alpha_0 + \sum_{i=1}^{m} \alpha_i y_i + 1/2 \sum_{i=1}^{m} \beta_i (y_i)^2 + \sum_{\substack{i,j=1 \\ i \neq j}}^{m} \delta_{ij} y_i y_j + \sum_{i=1}^{n} \gamma_i x_i + \varepsilon_i \qquad (5.3)$$

where α_0 is the fixed cost term, α_i (i = 1, 2, 3… m) are the slope coefficients of the linear term for all outputs y_i (i = 1, 2, 3... m), β_i (i = 1, 2, 3… m) are the slope coefficients of the quadratic terms, δ_{ij} (i = 1, 2, 3… m, j = 1, 2, 3… m and $i \neq j$) are the slope coefficients of the cross-product terms, γ_i(i = 1, 2, 3… n) are the coefficients of the linear term for all inputs x_i (i = 1, 2, 3… n) and C is either the total operating (OXT) or capital (CXT) costs for each water utility.

The cost function in (5.3) allows the estimation of economies of scale and scope. These are:

ray economies of scale

product-specific economies of scale

global economies of scope and

product-specific economies of scope.

With ray economies of scale (i), we assume the composition of each water utility's output remains fixed while the aggregate size of output varies. That is, the water utility provides more outputs but in the same proportions as its existing outputs (it does not choose to focus on expanding a particular output). This provides a measure of scale analogous to the single output case where ray economies (diseconomies) of scale exist if the measure is greater (less) than unity.

Product specific economies of scale (ii), however, allow one output to vary, while all other outputs are held constant. This could be the case if the utility focuses on increasing only a single particular output. Product-specific economies (diseconomies) of scale exist if the measure is greater (less) than unity.

With global economies of scope (iii), the composition of each water utility's output is again assumed to remain fixed while the aggregate size of output varies. That is, outputs are increased in their existing proportions. Finally, product-specific economies of scope (iv) measure whether the cost of producing the outputs jointly is less than the costs of producing them separately. A value greater than or equal to zero thus indicates that cost advantages accrue through the joint production of outputs.

The method for calculating these measures is as follows. First, the average incremental cost, $AIC(y_i)$) for producing output y_i is defined as:

$$AIC(y_i) = \frac{C(y) - C(y_{N-i})}{y_i} \qquad i = 1, 2, 3, \ldots \text{m} \tag{5.4}$$

where $C(y)$ is the total cost of producing the four outputs and $C(y_{N-1})$ is the total cost of producing zero units of the ith output. In the case of a single product, the economies of scale are measured by the average incremental cost divided by the marginal cost. The product-specific economies of scale for y_i, $E(y_i)$ are specified as:

$$E(y_i) = \frac{AIC(y_i)}{MC(y_i)} \tag{5.5}$$

where $MC(y_i) = \partial C / \partial y_i$ is the marginal cost of producing y_i units of output. Ray economies of scale exist when the quantities of the product are increased proportionately and are presented as:

$$E(RAY) = \frac{C(y)}{\sum_{i=1}^{m} y_i \times MC(y_i)} \tag{5.6}$$

If $E(y_i)$ or $E(RAY)$ is greater than one (less) than one then economies of scale (diseconomies of scale) exists for output y_i. Second, economies of scope can be divided into global economies of scope (*GES*) and product-specific economies of scope (*S*) and these are defined as:

$$GES(y_i) = \frac{\sum_{i=1}^{m} C(y_i) - C(y)}{C(y)} \quad (5.7)$$

The product-specific economies of scope are calculated as:

$$S(y_i) = \frac{C(y_i) + C(y_{N-i}) - C(y)}{C(y)} \quad (5.8)$$

5.5 Results

Table 5.2 presents the estimated coefficients, standard errors and p-values of the three quadratic cost functions: namely, operating expenditure for 2005–06 to 2008–09 in columns 2–4, operating expenditure for 2008–09 in columns 5–7, and capital expenditure for 2008–09 in columns 8–10. The table also include R^2 as a measure of goodness-of-fit and the F-statistic of the null hypothesis that the slope coefficients are jointly zero. To start with, it is obvious that the models will inevitably include multi-collinearity as the explanatory variables contain a linear combination of outputs together with squared and cross-product terms. Accordingly, it is generally difficult to interpret the estimated slopes for the individual coefficients.

Table 5.2 Estimated cost functions

	Operating expenditure 2005–06 to 2008–09 (4 years)			Operating expenditure 2008–09 (1 year)			Capital expenditure 2008–09 (1 year)		
Variable	Coef.	Std. error	p-val.	Coef.	Std. error	p-val.	Coef.	Std. error	p-val.
CONS.	2.85E+05	7.85E+04	0.000	–6.10E+04	3.66E+05	0.868	9.20E+06	4.46E+06	0.047
CHC	–75.008	151.898	0.622	397.240	2504.130	0.875	–	–	–
MBC	579.137	270.384	0.034	1138.092	3550.244	0.750	–	–	–
LSI	11804.460	9272.236	0.205	–	–	–	36145.080	16628.240	0.037
WQI	–273.638	183.248	0.137	–119.665	966.062	0.902	–	–	–
WMI	828.060	484.660	0.089	–	–	–	1045.508	1326.943	0.436
PRP	–497.313	903.460	0.583	–546.242	705.028	0.444	–2687.601	1041.254	0.014
WTR	1.379	2.510	0.584	–	–	–	9.026	3.750	0.022
$.5\times CHC^2$	–0.610	2.043	0.766	–7.785	5.227	0.145	–	–	–
$.5\times MBC^2$	–8.699	3.570	0.016	–16.259	17.872	0.369	–	–	–
$.5\times LSI^2$	–517.658	288.620	0.075	–	–	–	–6022.853	2298.697	0.013
$.5\times WQI^2$	–1.323	0.708	0.063	–1.150	1.605	0.479			
$.5\times WMI^2$	7.595	4.445	0.089	–	–	–	–12.590	18.538	0.502
$.5\times PRP^2$	–2.435	1.119	0.031	0.032	0.111	0.778	–30.266	11.621	0.013
$.5\times WTR^2$	0.000	0.000	0.002	–	–	–	–0.001	0.000	0.013
CHC×MBC	1.265	1.098	0.251	–0.211	23.956	0.993	–	–	–
CHC×LSI	1.077	24.058	0.964	–	–	–	–	–	–
CHC×WQI	5.933	2.048	0.004	5.530	11.671	0.639	–	–	–
CHC×WMI	–2.367	4.568	0.605	–	–	–	–	–	–
CHC×PRP	–4.091	3.847	0.289	1.744	6.636	0.794	–	–	–
CHC×WTR	0.003	0.009	0.704	–	–	–	–	–	–
MBC×LSI	–66.832	95.938	0.487	–	–	–	–	–	–
MBC×WQI	0.255	2.760	0.927	–3.118	20.583	0.881	–	–	–
MBC×WMI	–8.597	4.653	0.066	–	–	–	–	–	–
MBC×PRP	9.621	8.287	0.247	5.794	2.577	0.031	–	–	–
MBC×WTR	–0.010	0.023	0.671	–	–	–	–	–	–
LSI×WQI	–46.699	30.984	0.134	–	–	–	–	–	–
LSI×WMI	–118.633	125.545	0.346	–	–	–	–1249.505	646.443	0.061
LSI×PRP	–26.709	63.612	0.675	–	–	–	501.954	251.346	0.054
LSI×WTR	–0.130	0.198	0.512	–	–	–	–2.600	1.400	0.072
WQI×WMI	–9.288	5.009	0.065	–	–	–	–	–	–
WQI×PRP	0.638	1.091	0.559	0.470	0.627	0.458	–	–	–
WQI×WTR	–0.004	0.004	0.320	–	–	–	–	–	–
WMI×PRP	10.369	18.299	0.572	–	–	–	83.019	76.173	0.283
WMI×WTR	–0.022	0.052	0.678	–	–	–	–0.132	0.222	0.556
PRP×WTR	0.010	0.004	0.008	–	–	–	0.137	0.052	0.012
CAP	–	–	–	–	–	–	0.115	0.041	0.009
PMN	271.688	83.320	0.001	286.587	207.650	0.176	–	–	–
BLK	–3097.165	760.069	0.000	250.072	2668.655	0.926	–92452.080	44718.650	0.046
GRD	–3106.105	756.327	0.000	245.928	2673.185	0.927	–92420.640	44733.180	0.046
REC	–3200.504	745.960	0.000	415.026	2748.360	0.881	–92678.890	44795.400	0.046
SUR	–3128.429	754.924	0.000	206.572	2683.464	0.939	–92504.950	44751.500	0.046
R-squared	0.986	–	–	0.986	–	–	0.990	–	–

	Operating expenditure 2005–06 to 2008–09 (4 years)			Operating expenditure 2008–09 (1 year)			Capital expenditure 2008–09 (1 year)		
Variable	Coef.	Std. error	p-val.	Coef.	Std. error	p-val.	Coef.	Std. error	p-val.
F-statistic	317.342	–	0.000	131.297	–	0.000	173.727	–	0.000

Notes: CONS. Constant. All other variables as previously defined.

The values of R^2 in Table 5.2 generally indicate that the models explain a significant proportion of the operating and/or capital expenditure in the sampled water utilities, ranging from 98.6 to 99.0 per cent. The null hypotheses of no output effects are jointly tested in addition with various tests of no linear, quadratic and output cross-product effects with Chi-squared test statistics (statistics not shown). We reject all hypotheses at the 1 per cent level of significance, thus indicating that all of the explanatory variables (including their squares and cross-products) should be included when estimating operating and capital cost functions for Australian urban water utilities.

The estimated quadratic cost functions in Table 5.2 are used to estimate the marginal costs (MC) (Table 5.3) and average incremental costs (AIC) (Table 5.4) for each of the water utility outputs for levels of mean output from 50 per cent to 300 per cent (i.e. 100 per cent is the mean output in the sample data). For instance, over the period 2005–06 to 2008–09, the mean water utility has chemical compliance (CHC) of 89.70 per cent, microbiological compliance (MBC) of 95.58 per cent, inverse water losses per connection per day (LSI) of 1.607 (87.7 litres per connection per day), inverse water quality and service complaints (per 1000 properties) (WQI) of 25.83 (17.5 complaints per 1000 properties), inverse water main breaks (per 100 km of water main) (WMI) of 8.64 (21.5 breaks per 100 km of water main), and 127.53 thousand total connected properties.

Consider the marginal costs of operations over 2005–06 to 2008–09 in the upper panel of Table 5.3. As shown, the marginal costs of microbiological compliance decline from 50 to 75 per cent of mean output and range from 50 to 300 per cent for both water quality and service complaints and the number of connected properties. Interestingly, the marginal cost of an additional connected property for a utility three times larger than the mean ($67.53) is twelve times smaller than a utility with only 50 per cent of the mean number of connected properties ($843.33). The results for 2008–09 are similar.

In general, there are decreasing marginal costs in water quality and services complaints, chemical compliance and the volume of water delivered at relatively low levels of output, declining marginal costs at a wide range of output for the number of connected properties, and the number of water main breaks, and declining capital costs up to 150 per cent of mean output.

The negative values for marginal costs in Table 5.3 are potentially confusing. In theory, if all inputs are normal and their prices positive, then total variable cost necessarily increases with output, i.e. marginal cost is everywhere positive. One obvious problem with our analysis is that we were unable to specify individual factors and factor prices due to a lack of data. Accordingly, the assumption of constant cost over the sector may not hold and this could account for negative marginal costs (i.e. larger water utilities may have substantially lower factor prices than smaller utilities). Putting this aside, there are several other reasons why we may observe negative marginal costs.

First, consider the production of treated water. Even if we can design the treatment plant to operate optimally at any level of output, it is unlikely that we can design it to operate optimally at all levels at the same time. In particular, it may well be that the plant requires additional maintenance when operated at less than its ideal level. The maintenance cost saved could then outweigh the increased cost of the other variable factors required to produce closer to the plant's ideal level, resulting in a negative marginal cost.

Table 5.3 Marginal costs (MC)

	Level	MC(CHC)	MC(MBC)	MC(LSI)	MC(WQI)	MC(WMI)	MC(PRP)	MC(WTR)
Operating expenditure 2005–06 to 2008–09	50%	–166.935	378.188	–17214.407	331.933	–917.584	843.833	–0.579
	75%	–180.616	170.341	–17422.390	323.390	–901.184	766.203	–0.956
	100%	–194.298	–37.507	–17630.374	314.846	–884.783	688.572	–1.333
	125%	–207.979	–245.354	–17838.357	306.303	–868.383	610.942	–1.710
	150%	–221.660	–453.201	–18046.340	297.759	–851.983	533.311	–2.086
	175%	–235.342	–661.048	–18254.323	289.216	–835.582	455.681	–2.463
	200%	–249.023	–868.896	–18462.306	280.672	–819.182	378.051	–2.840
	225%	–262.705	–1076.743	–18670.289	272.129	–802.782	300.420	–3.217
	250%	–276.386	–1284.590	–18878.272	263.585	–786.382	222.790	–3.593
	300%	–303.749	–1700.285	–19294.238	246.498	–753.581	67.529	–4.347
Operating expenditure 2008–09	50%	25.230	–151.200		235.389		739.542	
	75%	–149.458	–548.792		226.690		740.573	
	100%	–324.146	–946.384		217.990		741.604	
	125%	–498.834	–1343.976		209.290		742.634	
	150%	–673.522	–1741.568		200.590		743.665	
	175%	–848.210	–2139.160		191.891		744.696	
	200%	–1022.898	–2536.752		183.191		745.727	
	225%	–1197.586	–2934.344		174.491		746.758	
	250%	–1372.274	–3331.936		165.792		747.789	
	300%	–1721.650	–4127.121		148.392		749.850	
Capital expenditure 2008–09	50%			–44807.463		3929.703	4580.587	1.741
	75%			–47345.328		3900.201	3591.677	–3.534
	100%			–49883.192		3870.698	2602.768	–8.809
	125%			–52421.057		3841.195	1613.858	–14.084
	150%			–54958.922		3811.693	624.949	–19.359
	175%			–57496.786		3782.190	–363.961	–24.633
	200%			–60034.651		3752.688	–1352.870	–29.908
	225%			–62572.515		3723.185	–2341.780	–35.183
	250%			–65110.380		3693.683	–3330.689	–40.458
	300%			–70186.109		3634.677	–5308.508	–51.007

Notes: Level is per cent of sample mean output.

Table 5.4 Average incremental costs (AIC)

	Level	AIC(CHC)	AIC(MBC)	AIC(LSI)	AIC(WQI)	AIC(WMI)	AIC(PRP)	AIC(WTR)
Operating expenditure 2005–06–2008–09	50%	–158.476	768.231	3197.256	–107.671	369.268	–554.055	1.089
	75%	–200.209	862.778	–1106.346	–24.688	139.872	–337.240	0.944
	100%	–241.943	957.325	–5409.947	58.296	–89.524	–120.426	0.799
	125%	–283.677	1051.872	–9713.549	141.279	–318.920	96.388	0.655
	150%	–325.410	1146.419	–14017.151	224.262	–548.316	313.203	0.510
	175%	–367.144	1240.966	–18320.753	307.246	–777.712	530.017	0.365
	200%	–408.878	1335.513	–22624.355	390.229	–1007.108	746.831	0.220
	225%	–450.611	1430.060	–26927.957	473.212	–1236.504	963.646	0.075
	250%	–492.345	1524.607	–31231.558	556.196	–1465.900	1180.460	–0.070
	300%	–575.813	1713.701	–39838.762	722.162	–1924.692	1614.089	–0.359
Operating expenditure 2008–09	50%	409.855	1062.492		–1.970		–176.471	
	75%	416.162	1024.692		56.877		8.415	
	100%	422.470	986.892		115.724		193.300	
	125%	428.777	949.092		174.571		378.186	
	150%	435.085	911.292		233.419		563.071	
	175%	441.392	873.492		292.266		747.957	
	200%	447.699	835.693		351.113		932.842	
	225%	454.007	797.893		409.961		1117.728	
	250%	460.314	760.093		468.808		1302.613	
	300%	472.929	684.493		586.503		1672.384	
Capital expenditure 2008–09	50%			13741.348		3010.360	–397.308	9.896
	75%			2539.483		3992.785	747.839	10.331
	100%			–8662.383		4975.211	1892.986	10.766
	125%			–19864.249		5957.637	3038.133	11.201
	150%			–31066.115		6940.063	4183.279	11.637
	175%			–42267.980		7922.489	5328.426	12.072
	200%			–53469.846		8904.914	6473.573	12.507
	225%			–64671.712		9887.340	7618.719	12.942
	250%			–75873.578		10869.766	8763.866	10.465
	300%			–98277.309		12834.618	11054.159	14.247

Second, input prices may be negative, especially in the presence of joint production. This is particularly pertinent when we consider the specification of outputs in this analysis. For example, by decreasing water main breaks (an increase in WMI) water utilities will also jointly produce lower water losses (an increase in LSI) and potentially fewer water service complaints (an increase in WQI). Similarly, production aimed at improving chemical (CHC) and microbiological (MBC) compliance will surely also lower the number of complaints relating to water quality (an increase in WQI). Accordingly, the specific factors of production underlying our operating and capital costs (not specified) may have a negative price, thereby also accounting for the estimated negative marginal costs.

The product-specific (E) and ray (RAY) economies of scale for operating and capital costs are in Table 5.5. As defined earlier, the estimates represent the degrees of ray economies (diseconomies) of scale: if the estimate is greater than one, then ray economies of scale exist, less than one, no economies or diseconomies of scale exist. As shown by the shaded cells, ray economies (the proportional augmentation of output holding composition constant) exist from 50 to 75 per cent of the mean output over the sample period for operating expenses in the period 2005–06 to 2008–09 and for capital costs in 2008–09. This suggests that much of the sector as a whole is currently experiencing economies of scale and there is a clear incentive to expand the production of all outputs at low levels to exploit existing potential scale economies. However, at some level between 75 and 100 per cent of current mean output, diseconomies of scale affect operating and capital costs in Australia's urban water utilities if we hold the composition of output constant.

Table 5.5 also includes the product-specific economies of scale. These are the scale economies that exist were an output increased in isolation. As shown for operating costs in the period 2005–06 to 2008–09, for CHC these are from 75–300 per cent of mean output, 50–75 per cent for MBC, 175–300 per cent for LSI, WQI and PRP and 200–300 per cent for WMI. These indicate that water utilities can obtain economies of scale (lower average costs) by increasing individual outputs up to very high levels (calculated up to 300 per cent of mean output, which is far in excess of any realistic average scale for urban water utilities in Australia). For capital costs in 2008–09, the evidence suggests that there are product-specific economies of scale for LSI from 225-300 per cent, from 75–300 per cent for LSI and at 50 per cent for WTR. Of course, we must treat the results using the 2008–09 data with care, for although the models better reflect the separate cost drivers of operating and capital expenditure, we have only a single cross section of data to draw upon.

Table 5.6 includes the product-specific and global economies of scope at levels of mean output from 50–300 per cent. In Table 5.6, a value greater than one indicates economies of scope at that level (shaded to assist readability). As shown in the upper panel, global economies of scope increase (though at a diminishing rate) from 50–300 per cent of current mean output. This indicates that there are cost advantages of providing the outputs as specified at all conceivable levels of output. However, the clearer separation of operating and capital costs in the middle and lower panel in Table 5.6, respectively, suggest product-specific and global economies of scope and scale increase quite dramatically in operating costs at relatively low levels (50 to 75 per cent).

The suggestion is that water utilities do not have to be very large at all before it makes cost sense to produce these outputs in a single entity (even if it were possible to disentangle, say, treatment from system maintenance and customer service). In contrast, there are global economies of scope in capital costs for all conceivable levels of outputs, but only product-specific economies of scope (again for all conceivable levels of output) in LSI. One implication is that by increasing in size, water utilities can lower the average costs associated with water losses at all levels of output. Otherwise, they can increase the economies of scope in capital costs by increasing output in its current composition, again at all levels.

Table 5.5 Product-specific (E) and ray (RAY) economies of scale

	Level	E(CHC)	E(MBC)	E(LSI)	E(WQI)	E(WMI)	E(PRP)	E(WTR)	E(RAY)
Operating expenditure 2005–06 to 2008–09	50%	0.949	2.031	–0.186	–0.324	–0.402	–0.657	–1.880	7.476
	75%	1.108	5.065	0.064	–0.076	–0.155	–0.440	–0.988	12.007
	100%	1.245	–25.524	0.307	0.185	0.101	–0.175	–0.600	–29.701
	125%	1.364	–4.287	0.545	0.461	0.367	0.158	–0.383	–4.741
	150%	1.468	–2.530	0.777	0.753	0.644	0.587	–0.244	–2.253
	175%	1.560	–1.877	1.004	1.062	0.931	1.163	–0.148	–1.372
	200%	1.642	–1.537	1.225	1.390	1.229	1.975	–0.078	–0.940
	225%	1.715	–1.328	1.442	1.739	1.540	3.208	–0.023	–0.692
	250%	1.781	–1.187	1.654	2.110	1.864	5.299	0.019	–0.533
	300%	1.896	–1.008	2.065	2.930	2.554	23.902	0.083	–0.348
Operating expenditure 2008–09	50%	16.245	–7.027		–0.008		–0.239		–0.568
	75%	–2.784	–1.867		0.251		0.011		–0.393
	100%	–1.303	–1.043		0.531		0.261		–0.179
	125%	–0.860	–0.706		0.834		0.509		–0.177
	150%	–0.646	–0.523		1.164		0.757		–0.146
	175%	–0.520	–0.408		1.523		1.004		–0.121
	200%	–0.438	–0.329		1.917		1.251		–0.101
	225%	–0.379	–0.272		2.349		1.497		–0.086
	250%	–0.335	–0.228		2.828		1.742		–0.073
	300%	–0.275	–0.166		3.952		2.230		–0.055
Capital expenditure 2008–09	50%			–0.307		0.766	–0.087	5.686	28.427
	75%			–0.054		1.024	0.208	–2.923	39.507
	100%			0.174		1.285	0.727	–1.222	–
	125%			0.379		1.551	1.883	–0.795	–20.354
	150%			0.565		1.821	6.694	–0.601	–8.796
	175%			0.735		2.095	–	–0.490	–5.089
	200%			0.891		2.373	–4.785	–0.418	–3.361
	225%			1.034		2.656	–3.253	–0.368	–2.398
	250%			1.165		2.943	–2.631	–0.259	–1.803
	300%			1.400		3.531	–2.082	–0.279	–1.129

Table 5.6 Product-specific (S) and global (GES) economies of scope

	Level	S(CHC)	S(MBC)	S(LSI)	S(WQI)	S(WMI)	S(PRP)	S(WTR)	GES
Operating expenditure 2005–06–2008–09	50%	0.922	0.848	0.934	0.904	0.918	0.805	0.906	5.397
	75%	0.898	0.739	0.924	0.859	0.890	0.646	0.864	5.099
	100%	0.883	0.609	0.928	0.816	0.870	0.450	0.824	4.800
	125%	0.875	0.462	0.943	0.775	0.855	0.221	0.786	4.500
	150%	0.874	0.297	0.969	0.734	0.846	–0.040	0.750	4.196
	175%	0.879	0.114	1.005	0.693	0.842	–0.332	0.715	3.886
	200%	0.890	–0.084	1.050	0.653	0.843	–0.653	0.680	3.570
	225%	0.907	–0.300	1.104	0.613	0.848	–1.003	0.647	3.247
	250%	0.928	–0.532	1.167	0.572	0.857	–1.383	0.614	2.914
	300%	0.985	–1.048	1.318	0.490	0.886	–2.233	0.547	2.216
Operating expenditure 2008–09	50%	2.625	2.908		2.374		3.230		7.868
	75%	7.293	8.827		5.937		10.570		21.850
	100%	–28.689	–37.723		–20.700		–47.996		–85.900
	125%	–6.951	–9.794		–4.436		–13.027		–20.799
	150%	–4.850	–7.219		–2.755		–9.913		–14.507
	175%	–4.222	–6.557		–2.157		–9.213		–12.623
	200%	–4.044	–6.492		–1.880		–9.275		–12.088
	225%	–4.079	–6.717		–1.746		–9.717		–12.188
	250%	–4.244	–7.131		–1.690		–10.414		–12.678
	300%	–4.855	–8.398		–1.722		–12.427		–14.501
Capital expenditure 2008–09	50%			1.000		0.997	0.974	0.985	2.976
	75%			1.001		0.995	0.943	0.969	2.951
	100%			1.004		0.992	0.900	0.946	2.918
	125%			1.008		0.989	0.845	0.918	2.876
	150%			1.013		0.986	0.778	0.883	2.826
	175%			1.019		0.983	0.700	0.843	2.767
	200%			1.026		0.979	0.609	0.796	2.700
	225%			1.034		0.974	0.506	0.743	2.625
	250%			1.043		0.970	0.392	0.714	2.541
	300%			1.066		0.960	0.126	0.548	2.347

5.6 Concluding remarks

This section employed stochastic functions of operating and capital costs to calculate product-specific economies of scale and scope and ray and global economies of scale and scope, respectively for 55 major urban water utilities over the four-year period 2005–06 to 2008–09.

The section comprised two separate but complementary analyses. The first focused only on scale and scope economies in operating expenditure over the full four-year period 2005–06 to 2008–09. The second analysis considered scale and scope economies in both operating and capital expenditures, but because the written down replacement cost of capital was only available for 2008–09, it was not possible to accurately specify separate operating and capital cost equations for the full four-year period. Accordingly, the results for economies of scale and scope in operating expenditure over the whole four-year period are relatively more robust than the single cross section used to evaluate scale and scope economies in operating and capital expenditure for 2008–09 only. Nevertheless, the technique employed incorporates allowance for stochastic variation (mismeasurement, misspecification, unexpected outcomes, etc.) that could potentially arise when using a single year of data.

First, in terms of economies of scale, the evidence suggests that there are strong economies of scale at relatively low levels of output (up to 75 per cent of mean output or about 90 000 connected properties). One implication is that horizontal aggregation will provide efficiency gains, especially if the composite utilities are located in close proximity and if the increase in scale is without significant investment in network costs. In the sample, 11 utilities are currently too large (experiencing diseconomies of scale) with connected properties in excess of 125 000 properties while 44 utilities have less than 65 000 connected properties of which 25 have less than 30 000 connected properties (both experiencing economies of scale). It is, of course, important to recall that the sample only includes utilities with at least ten thousand connected properties, and so it is likely that increasing economies of scale also prevail for the several hundred smaller water utilities in the Australian population, but not included in this analysis.

In terms of product-specific economies of scale (increasing an output in isolation), there is evidence that there are scale economies in chemical compliance, water quality and service complaints, and the number of connected properties. That is, the average costs of each of these outputs become lower as production increases. Further, there are product-specific economies of scale in capital costs for water losses and water main breaks. That is, the average costs of reducing water losses and water main breaks also become lower as production increases. However, it would appear that these only come about at relatively high levels of output (125 per cent and higher) and so are unobtainable for all but the very largest utilities in the sample.

Second, in terms of economies of scope it is clear that there are substantial cost benefits from the joint production of the outputs included in this analysis. The presence of scope economies typically provide some support for vertical integration as here where wholesale water storage and acquisition, treatment, delivery and retail services are included in single entities. Nevertheless, we should remember that the focus of this report is on potable water, so we have not considered the economies of scope that potentially exist between water and wastewater services.

Of course, the analysis does have a number of limitations and these both qualify the findings in this report and suggest future directions for research. First, the sample only includes the largest urban water utilities in Australia, and while these service the majority of Australian households, the results are not directly reflective of the many hundreds of smaller urban water utilities. Unfortunately, there is no nationally consistent dataset readily available for these smaller entities. An equally important consideration is that the evidence for economies of scale and scope in capital expenditure is less robust than that for operating expenditure as the former is only able to employ a single year of data (2008–09). This qualifies the interpretation of the relevant results.

Second, the focus in this analysis is on water services not water and wastewater services, even though the majority of water utilities provide both. While it is possible to separate the services provided by water utilities in water and sewerage services at least as far as correctly specifying their respective cost functions using the available data, it is likely that utilities benefit from the economies of scope between water and sewerage. For example, both are network services and have similar input requirements. There is also the real potential for the production of one type of output to affect the other.

For example, improving the treatment of sewage will have benefits for water quality drawn from surface sources, while treated sewage can also provide an input into water services in the form of recycled water. Fortunately, there is an emerging body of literature applying efficiency measurement techniques to wasterwater services from which direction can be obtained [see, for example, Estache and Trujillo (2003), Tupper and Resende (2004), Erbetta and Cave (2006) and Nauges and van den Berg (2008)].

6 Non-parametric measures of technical efficiency in urban water utilities

6.1 Introduction

The earlier analyses in this report have focused on the use of panel data (pooled time-series, cross-sectional data) to comment on efficiency change over time and the impact of the scale and scope of urban water utilities on measured and estimated efficiency. In this section, we focus on a single cross section of recent data from the National Performance Reports to highlight how water utilities could use efficiency measures from a current year to identify best-practice benchmark utilities upon which they can more closely focus. This provides, among other things, both an alternative way in which the industry can employ commonly available performance metrics and as a direction where regulators can timely identify where problems concerning the sustainability of individual utilities may arise. We should exercise caution, of course, as one-off or unexpected events may adversely affect measured efficiency and the non-stochastic technique employed here is unable to take account of any such variation.

The purpose of this chapter is to estimate cross-sectional technical efficiency assuming constant and variable returns-to-scale for Australian water utilities for the second-most recent year of data available. The chapter comprises four sections. Section 6.2 outlines the frontier approaches to efficiency measurement. Section 6.3 addresses the methodology employed. Section 6.4 deals with the specification of inputs and outputs. Section 6.5 presents the results. The section ends with some concluding remarks in Section 6.6.

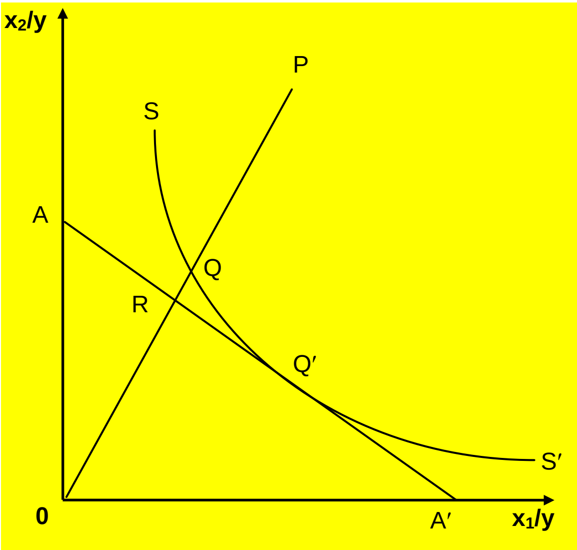
6.2 Frontier approaches to efficiency measurement

The recent history of microeconomic efficiency measurement begins with Farrell (1957) who defined a simple measure of firm efficiency that could account for multiple inputs. In his approach, Farrell (1957) proposed that the efficiency of any given firm (here, an urban water utility) consisted of two components: technical efficiency, or the ability of a utility to maximise output from a given set of inputs, and allocative efficiency, or the ability of a utility to use these inputs in optimal proportions, given their respective prices. Combining the two measures provides a measure of cost or productive efficiency. It is Farrell's (1957) suggestion that we could measure efficiency in reference to an idealised frontier isoquant – or equivalently, disturbances in an econometric model – which forms the basis of all subsequent analysis.

The essence of Farrell's (1957) argument is contained in Figure 6.1. Here two inputs, x_1 and x_2 (say, capital and labour) are utilised to produce a single output, y (say, treated water), under an assumption of constant returns-to-scale. The isoquant of the fully efficient utility *SS′* (showing the alternative combinations of inputs used to produce a given level of output) permits the measurement of technical efficiency. For a given utility using quantities of inputs defined by point *P* to produce a unit of output, the level of technical efficiency is the ratio *OQ*/*OP*. This is the proportional reduction in all inputs (i.e. by movement onto the efficient isoquant) we could theoretically achieve without any reduction in output. The technical efficiency ratio for the utility at point *P* will then be less than unity.

Point *Q*, on the other hand, is technically efficient as it already lies on the efficient isoquant. The technical efficiency ratio of the utility at *Q* is *OQ*/*OQ* or unity, thereby implying absolute or relative efficiency (depending upon the manner in which the efficient isoquant is constructed). If the input price ratio *AA′* is known (showing the different combinations of inputs that can be purchased with a given cost outlay), then allocative efficiency at point *P* is the ratio *OR/OQ*. The distance *RQ* is then the reduction in production costs which would occur if production occurred at *Q′*—the allocatively and technically efficient point, rather than *Q*—the technically efficient, but allocatively inefficient point. Hence, total economic (cost) efficiency is the ratio *OR/OP*, with the cost reduction achievable being the distance *RP*. Note that the cost efficiency ratio *OR*/*OP* is the product of the technical efficiency ratio *OQ*/*OP* and the allocative efficiency ratio *OR*/*OQ*.

Figure 6.1 Technical, allocative and cost efficiencies



The approach employed in this chapter to construct empirical measures of technical efficiency is the DEA approach. One obvious problem with DEA is that in contrast to the econometric approaches to efficiency measurement it is both non-parametric and non-stochastic. Thus, no accommodation is made for the types of biases resulting from some environmental heterogeneity, external shocks, measurement error, and omitted variables. Consequently, the entire deviation from the frontier is assessed as being the result of inefficiency. This may lead to either an under or overstatement of the level of inefficiency.

However, there a number of benefits implicit in the mathematical programming approach that makes it attractive on a theoretical level. First, given its non-parametric basis, it is relatively easy to alter the specification of inputs and outputs and thereby the formulation of the production correspondence relating inputs to outputs. Thus, in cases where the usual axioms of production activity breakdown (i.e. profit maximisation) then the programming approach may offer useful insights into the efficiency of these types of industries. This is especially the case with urban water utilities.

Second, we impose considerable structure upon the data when using the econometric approach from stringent parametric form and distributional assumptions regarding inefficiency. These considerations, and the natural emphasis of DEA on the notion of ‘best-practice’ performance, make it an attractive choice from these two separate, though conceptually similar, approaches to the assessment of technical efficiency

6.3 Empirical methodology

The computational procedure used to implement the DEA (input-orientated) approach to technical efficiency measurement is as follows. Consider *N* urban water utilities each producing *M* outputs using *K* inputs. The $K \times N$ input matrix, *X*, and the $M \times N$ output matrix, *Y*, represent the data of all *N* utilities, while for the individual utility these are represented by the vectors x_i and y_i.

The purpose of DEA is to construct a non-parametric envelopment frontier over the data points such that all observed points lie on or below the production frontier. The relative efficiency of each utility in ratio form (where we obtain a ratio of all outputs over all inputs) is specified as follows:

$$\begin{aligned} &\max_{u,v}(u'y_i / v'x_i) \\ &\text{s.t. } u'y_j / v'x_j \le 1 \\ &u,v \ge 0 \end{aligned} \qquad (6.1)$$

where y_i is the vector of outputs produced by the *i*th water utility, x_i is the vector of inputs used by the *i*th water utility, *u* is a $M\times1$ vector of output weights and *v* is a $K\times1$ vector of input weights (the prime denotes a transposed vector), *i* runs from 1 to *N*, and *j* equals 1, 2, ..., *N*.

The first inequality ensures that the efficiency ratios for all utilities cannot exceed one, while the second ensures that the weights are non-negative. The weights are determined such that each utility maximises its own efficiency ratio (that is, is in the best possible light). A problem with this particular ratio formulation is that it has an infinite number of solutions. To avoid this the constraint $v'x_i = 1$ is imposed. This fractional linear program (6.1) can then be transformed into the following equivalent linear programming problem:

$$\begin{aligned} &\max_{\mu,v}(\mu'y_i) \\ &\text{s.t. } \nu'x_i = 1 \\ &\mu'y_j - \nu'x_j \le 0 \\ &\mu,\nu \ge 0 \end{aligned} \qquad (6.2)$$

where the notation change from *u* and *v* to μ and ν reflects the transformation. Using the duality of linear programming, we use this multiplier form to derive an equivalent envelopment form of the problem:

$$\begin{aligned} &\min_{\theta,\lambda} \theta \\ &\text{subject to } -y_i + Y\lambda \ge 0 \\ &\theta x_i \quad X\lambda \ge 0 \\ &\lambda \ge 0 \end{aligned} \qquad (6.3)$$

where θ is a scalar and λ is a $N\times1$ vector of constants. The value of θ will be the technical efficiency score for a particular utility. It will satisfy $\theta \le 1$, with a value of 1 indicating a point on the frontier, and hence a technically efficient utility. The value of $\theta \le 1$ identifies the amount of any inefficiencies that may be present.

The model specified in (6.3) has an assumption of constant returns-to-scale and is only appropriate where all utilities are operating at an optimal scale. In other words, we compare the performance of an individual utility against both utilities of a similar size (or scale) and all other utilities. Where this assumption does not hold, scale effects will confound the measures of technical efficiency. Generally, regulatory, geographical and institutional constraints imply that most utilities are not operating at an optimal scale, so it is inappropriate to compare utilities against other utilities that may be benefiting from scale economies and are operating at a scale that a particular may never conceivable attain.

Accordingly, we modify the linear programming problem to account for variable returns-to-scale (that is, measures of technical efficiency without scale efficiency effects) by adding the convexity constraint $N1'\lambda = 1$ to (6.3). As a result, no utility will obtain a lower efficiency score under variable returns-to-scale than it achieves with constant returns-to-scale and some utilities are likely to improve their scores under variable returns-to-scale. The number of 100 per cent efficient utilities is also likely to be higher under variable returns-to-scale. Despite, this, the assumption of constant returns-to-scale is usually reasonable in most contexts.

DEA models can be either input (as above) or output orientated. In the input orientation, the efficiency scores relate to the largest feasible proportional reduction in inputs for fixed outputs, while in the output orientation it corresponds to the largest feasible proportional expansion in outputs for fixed inputs. It is common to use an input orientation in analyses of network utilities because the firms are generally required to supply services to a fixed geographical area, and hence the output vector (or most of it) is essentially fixed or at least not amenable to change in the short run. Of the DEA studies in Table 3.1, the only known exceptions are Tupper and Resende (2004) and Picazo-Tadeo et al. (2008).

In this analysis, however, we take a different approach, as we are able to split the available data on inputs and outputs into operations and capital. With operating inputs and outputs, utilities are committed to providing certain qualities and quantifies of water to their customers, at least in the short run. Consequently, we use an input orientation so the natural focus is on producing a given level of outputs with the least possible inputs. This also corresponds with the orientation used in earlier DEA studies.

As for capital-related inputs and outputs, we apply an output orientation. Conventionally, this should fit better with the longer-run objective of water utilities expanding and maintaining long-lived assets to ensure the sustainability and security of water supply. Unfortunately, at the time of preparation of this report, data on the written down replacement cost of capital was only available for 2008–09, so this part of the analysis is necessarily restricted to a single year. Consequently, the technical assumption of a long-run output orientation does not perfectly align with the availability of data (a single year) and this potentially affects the validity of the results.

The final adjustment we make is that in our model we divide the inputs into controllable and uncontrollable inputs. This is because many of the factors that influence the observed performance of water utilities derive from their inherent geographical, competitive and regulatory characteristics. For instance, a utility is largely unable to alter substantially the sources of water it draws upon and the number of connected properties to which it provides water, even if it wished.

The technique we use to reflect this is to incorporate the contextual information directly into the DEA calculation. In the case of input-orientated (output-orientated) models, it is then not relevant to maximise (minimise) the proportional decrease (increase) in the entire input (output) vector, rather maximisation (minimisation) should only be determined with respect to the sub-vector that is composed of discretionary inputs (outputs). Thus, the contextual information contributes to the constraints placed upon decision-making units, but not the posited efficiency improvements.

6.4 Specification of inputs and outputs

The data sampling in this section corresponds to that previously described in Chapters 4 and 5 except we use only the data from 2008–09. In this chapter, we specify two sets of inputs and outputs reflecting the different models of operating and capital behaviour in Table 6.1. The first (input-orientated) specification specifies total operating expenditure ($000) as the input along with four outputs:

the percentage of zones where chemical compliance was achieved (per cent) (CHC)

the percentage of zones where microbiological compliance was achieved (per cent) (MBC)

the inverse of water quality and service complaints (per 1000 properties) (WQI) and

total urban water supplied (ML) (WTR).

Table 6.1 Selected descriptive statistics

	Variable	Operating specification	Capital specification	Mean	Std. dev.	Skew.	Kurt.
2008–09 (n = 55)	OXT	CI		38945.390	79807.490	4.462	26.309
	CXT		CI	32143.725	69802.258	4.914	27.156
	CHC	CO		89.755	21.459	–2.963	12.087
	MBC	CO		97.815	7.883	–4.661	26.617
	LSI		CO	1.685	1.243	3.148	16.282
	WQI	CO		30.263	49.861	2.819	11.391
	WMI		CO	9.373	13.161	4.904	30.591
	PRP	NCI	CO	130.695	281.586	4.032	21.786
	WTR	CO	CO	36005.260	77542.600	4.297	23.826
	PMN		NCI	40.550	16.815	0.792	3.278
	CAP		NCI	689623.891	1582023.599	4.979	17.001
	BLK	NCI	NCI	30.783	43.337	0.782	1.698
	GRD	NCI	NCI	14.520	27.180	2.033	5.968
	REC	NCI	NCI	3.664	6.792	3.956	22.608
	SUR	NCI	NCI	50.769	41.087	–0.136	1.290

The inputs also include five uncontrollable (or non-discretionary) contextual factors:

total connected properties (000s) (PRP)

the percentage of water from bulk suppliers (per cent) (BLK)

the percentage of water from groundwater (per cent) (GRD)

the percentage of water from recycling (per cent) (REC) and

the percentage of water from surface water (per cent) (SUR).

The second (output-orientated) specification specifies total capital expenditure ($000s) as the input with three controllable outputs:

the inverse of real losses (L/service connection/d) (LSI)

the inverse of water main breaks (per 100 km of water main) (WMI)

total connected properties – water supply (000s) (PRP), and

total urban water supplied (ML) (WTR).

Six uncontrollable (or non-discretionary) contextual input factors are also included:

properties served per km of water main (n) (PMN)

the written down replacement cost of fixed water supply assets ($000s) (CAP)

the percentage of water from bulk suppliers (per cent) (BLK)

the percentage of water from groundwater (per cent) (GRD)

the percentage of water from recycling (per cent) (REC), and

the percentage of water from surface water (per cent) (SUR).

In using this specification, we assume the utility aims to ensure a sustainable supply of networked water at the given level of capital expenditure after accounting for network density, the level of existing assets and the sources of water. Our expectation is that by including PRP and WTR we will be able to identify surplus productive capacity that could allow for future growth and expanded delivery opportunities.

6.5 Results

Table 6.2 provides the technical efficiency scores for the 55 urban water utilities in 2008–09. The scores from four separate models are included: input-orientated technical operating efficiency assuming constant and variable returns-to-scale and output-oriented technical capital efficiency also assuming constant and variable returns-to-scale. An efficiency score of 100 per cent indicate an efficient utility (one located on the best-practice frontier) while a score less than 100 per cent indicates a technically inefficient utility.

To start with, an input-orientation is used for operating efficient measurement so a score less than 100 per cent indicates the extent to which inputs could be reduced while maintaining the same level of output. For example, Barwon Water (BAR) has an constant returns-to-scale efficiency score of 87.71 per cent, suggesting that based on observable best practice it could reduce its inputs to 87.71 per cent of their current level (a 12.29 per cent decrease) and still maintain its output at the current level (thereby moving it on to the best-practice frontier and becoming fully efficient).

Conversely, we use an output orientation for the measurement of capital efficiency. This measure thus indicates the level to which outputs must be augmented holding inputs constant to move the utility onto the efficient frontier. Consider the constant returns-to-scale efficiency score of 78.15 per cent for Coliban Water (COL). This means that outputs are only 78.15 per cent of their feasible level based on observable best practice, and that increasing outputs by 21.5 per cent (= 100.00 per cent – 78.15 per cent) holding inputs constant would likewise place COL on the efficient frontier alongside its best-practice peers.

As shown in Table 6.2, the mean urban water utility in Australia is relatively efficient in terms of both operating and capital efficiency, with mean constant returns-to-scale operating and capital efficiencies of 94.93 and 92.58 per cent, respectively. This suggests that across the sector we could reduce operating inputs to 94.93 per cent of their current level while capital outputs are only 92.58 per cent of their feasible level, both based on observable best practice.

Table 6.2 2008-09Technical efficiency scores by utility

Utility	Operating efficiency		Capital efficiency		Utility	Operating efficiency		Capital efficiency		Utility	Operating efficiency		Capital efficiency	
	CRS	VRS	CRS	VRS		CRS	VRS	CRS	VRS		CRS	VRS	CRS	VRS
ACW	100.00	100.00	100.00	100.00	GOS	80.20	80.35	92.70	92.73	SGW	100.00	100.00	100.00	100.00
ALB	100.00	100.00	100.00	100.00	GOU	100.00	100.00	100.00	100.00	SHL	100.00	100.00	100.00	100.00
AQW	100.00	100.00	100.00	100.00	GWM	62.92	62.94	100.00	100.00	SWC	100.00	100.00	100.00	100.00
BAL	100.00	100.00	95.83	100.00	HWC	100.00	100.00	100.00	100.00	TAM	100.00	100.00	100.00	100.00
BAR	87.71	87.71	100.00	100.00	IPS	100.00	100.00	97.50	100.00	TWE	100.00	100.00	81.75	82.29
BAT	100.00	100.00	100.00	100.00	KMP	100.00	100.00	81.43	100.00	WAN	93.13	93.53	80.94	84.50
BEG	100.00	100.00	100.00	100.00	LIS	93.81	100.00	100.00	100.00	WAY	100.00	100.00	100.00	100.00
BRI	100.00	100.00	87.00	100.00	LOG	100.00	100.00	100.00	100.00	WCA	100.00	100.00	92.52	100.00
BYR	100.00	100.00	100.00	100.00	LOW	100.00	100.00	100.00	100.00	WCG	100.00	100.00	100.00	100.00
CGW	100.00	100.00	100.00	100.00	MCW	100.00	100.00	100.00	100.00	WKB	100.00	100.00	100.00	100.00
CHW	44.46	44.46	41.14	43.24	NEW	100.00	100.00	100.00	100.00	WMN	100.00	100.00	100.00	100.00
CIT	100.00	100.00	100.00	100.00	ORC	100.00	100.00	97.71	100.00	WPT	100.00	100.00	100.00	100.00
CLA	100.00	100.00	100.00	100.00	PAD	100.00	100.00	100.00	100.00	WSA	100.00	100.00	100.00	100.00
COF	100.00	100.00	100.00	100.00	PAS	100.00	100.00	100.00	100.00	WSP	100.00	100.00	100.00	100.00
COL	71.46	71.68	78.15	82.27	PMQ	100.00	100.00	100.00	100.00	WSR	99.20	99.20	50.76	51.06
DUB	100.00	100.00	100.00	100.00	QUE	100.00	100.00	100.00	100.00	WYS	64.16	64.28	100.00	100.00
EGW	100.00	100.00	100.00	100.00	RIV	100.00	100.00	100.00	100.00	YAR	100.00	100.00	100.00	100.00
GCW	100.00	100.00	56.91	100.00	SAW	100.00	100.00	100.00	100.00	Mean	94.93	94.94	92.58	96.08
GFW	100.00	100.00	100.00	100.00	SEW	100.00	100.00	100.00	100.00	Std. dev.	14.07	14.05	16.56	13.42

Notes: Data for 2008–09 only. CRS Constant returns-to-scale, VRS Variable returns-to-scale. Utility names in Table 4.1.

Table 6.3 2008-09 Best-practice reference utilities

Utility	Operating efficiency		Capital efficiency		Total	Utility	Operating efficiency		Capital efficiency		Total	Utility	Operating efficiency		Capital efficiency		Total
	CRS	VRS	CRS	VRS			CRS	VRS	CRS	VRS			CRS	VRS	CRS	VRS	
SEW	6	5	10	6	27	NEW	2	2	2	2	8	TAM	1	1	1	1	4
GFW	7	6	5	4	22	CGW	1	1	4	1	7	WCG	1	1	1	1	4
WMN	6	6	3	2	17	QUE	1	1	4	1	7	WKB	1	1	1	1	4
EGW	3	3	6	3	15	SAW	1	1	2	3	7	WSA	1	1	1	1	4
ORC	6	6		3	15	WCA	3	3		1	7	YAR	1	1	1	1	4
PMQ	4	2	6	3	15	GOU	1	1	3	1	6	BAL	1	1		1	3
WPT	4	5	4	2	15	GWM			3	3	6	BRI	1	1		1	3
WSP	6	6	1	1	14	PAD	1	1	3	1	6	GCW	1	1		1	3
ALB	4	4	2	2	12	COF	2	1	1	1	5	IPS	1	1		1	3
BYR	3	3	4	2	12	KMP	2	2		1	5	WSR		3			3
LOG	2	1	6	3	12	LIS		1	2	2	5	BAR			1	1	2
SWC	1	1	6	4	12	WAY	1	1	2	1	5	TWE	1	1			2
AQW	2	2	6	1	11	ACW	1	1	1	1	4	WYS			1	1	2
HWC	6	3	1	1	11	BAT	1	1	1	1	4	CHW					0
LOW	1	1	5	4	11	CIT	1	1	1	1	4	COL					0
RIV	3	3	2	3	11	DUB	1	1	1	1	4	GOS					0
SHL	4	4	2	1	11	MCW	1	1	1	1	4	WAN					0
BEG	1	1	4	3	9	PAS	1	1	1	1	4	Mean	3.79	3.37	4.11	2.68	13.74
CLA	3	2	1	3	9	SGW	1	1	1	1	4	Std.dev.	1.93	1.86	2.40	1.29	4.45

Notes: Data for 2008–09 only. CRS Constant returns-to-scale, VRS Variable returns-to-scale. Utility names in Table 4.1.

Of course, we should recall that DEA scores are relative measures; the data determines the best practice frontier, not some absolute theoretical standard. Putting this aside, most utilities in the sample are 100 per cent efficient. One of the three factors that may assist this achievement is the relatively large number of outputs specified in both models. All other things being equal, more outputs increase the likelihood that a utility lies on the frontier in at least one dimension, and as we have not applied a weighting to the outputs, relatively good performance in one area may effectively outweigh relatively poor performance in another.

A second consideration is that we have made substantive allowance for the contextual factors that impact upon observed efficiency. These contextual factors are included as part of the constraints placed on utilities, but are not included in calculating the efficiency score. A final consideration is that the outputs specified may not do a very good job at distinguishing between good and bad performance. For example, chemical and microbiological compliance are enforced by regulation and most of the utilities in the sample have performed relatively highly, if not perfectly, in terms of these outputs.

It is also noteworthy that the constant and variable returns-to-scale measures are generally the same, suggesting that the utilities included perform equally well (or poorly) regardless of whether we compare their observed behaviour with utilities of a similar scale (variable returns-to-scale) or all other scales (constant returns-to-scale). Consider, for example, the capital efficiency scores for Ballina Shire Council (BAL). As shown, BAL has a constant returns-to-scale score of 95.83 per cent but this improves to 100 per cent when we compare BAL only with best-practice utilities of the same scale.

The implication is that the difference in efficiency is attributable to the scale at which BAL operates (i.e. scale inefficient). Now consider the constant returns-to-scale and variable returns-to-scale operating efficiency of Gosford City Council (GOS) and GWM Water (GWM). As shown, the constant and variable returns-to-scale measures for each are almost identical, indicating inefficient behaviour irrespective of whether we compare their performance with utilities of all scales or only those of a similar scale.

Table 6.3 provides details of the water utilities that define the best-practice frontier. Generally, but not necessarily, these utilities will be fully efficient. The values indicate the number of times that the utility serves as a best-practice performer for some other utility. Conventionally, advocates of DEA analysis would then suggest that practices in these peer organisations be looked at more closely in order to ascertain the particular source(s) of efficient behaviour. As shown, the best practice utilities are led by South East Water Ltd (SEW) with 27 references (compared to a mean of 13.74), followed by Goldenfields Water (GFW) with 22 references, Water Corporation - Mandurah (WMN) with 17 and East Gippsland Water (EGW), Orange City Council (ORC), Port Macquarie Hastings Council (PMQ) and Water Corporation - Perth (WPT), all with 15 references.

As noted, utilities serving least frequently (if at all) as best-practice references for their peers are usually inefficient, and include Water and Waste Services (WAN), Gosford City Council (GOS), Coliban Water (COL) and Central Highlands Water (CHW). The bulk of the remaining utilities only occasionally serve as reference peers and this may indicate that only one or two aspects of their performance serve as a reference for another utility, sometimes the same one, and sometimes only because it is of a similar scale. In sum, were we interested in identifying best-practice water utilities to provide possible benchmarks of behaviour in the sector, we may look no further than utilities providing relatively many reference points for their peers.

Table 6.4 focuses more closely on the inefficient utilities and the efforts needed to bring them onto the operating efficient frontier. The upper panel includes the results from the constant returns-to-scale analysis, where we compare a given utility against all other utilities, whereas the lower panel includes a variable returns-to-scale assumption such that we only compare utilities with those of a similar scale. As discussed, under variable returns-to-scale, generally fewer utilities will be inefficient and the efficiency scores are generally lower (as they exclude the effects of scale). Now consider Barwon Water (BAR) in the constant returns-to-scale analysis. As shown, BAR has an operating efficiency score of 87.71 per cent indicating that we could reduce operating inputs by 12.29 per cent and still theoretically maintain the same level of output as determined by observable best practice. In this instance, we could attain this by reducing OXT by the entire amount.

The other main influence on BAR in terms of its efficiency gap is the fact that it is not producing enough water relative to its peers. We must tale care here because we would not reasonably expect a utility to increase supply where demand does not exist or where water restrictions effectively constrain demand. However, it does suggest that one reason why BAR appears operationally inefficient is that it is producing less water than best-practice reference peers of a similar scale, context and operations (AQW, EGW, NEW, WCA and WPT). This may warrant a closer look.

Now consider Wannon Water (WAN) with a constant returns-to-scale operating efficiency score of 93.13 per cent. As shown, in order to make WAN as efficient as its best practice peers (CLA, EGW, GFW, ORC, RIV, SHL and WPT), we would need to cut operating expenditure (OXT) by 6.9 per cent, improve its chemical compliance (CHC) by 6.2 per cent, and decrease the number of water quality and service complaints (WQI) by 50 per cent. As with BAR, WAN is also not producing enough water relative to its peers, and though not easy to change in a highly-regulated networked sector (possibly through water trading with nearby jurisdictions or the easing of water restrictions) an increase in supply of 14 per cent would help move WAN on to the efficient frontier, or alternatively, more severe cuts in operating expenditure as the key controllable input.

Finally, when we consider the lower panel in Table 6.4 we can see that LIS is no longer included. This is because the efficiency scores and target improvements are under an assumption of variable returns-to-scale, meaning that the main reason LIS is included among the inefficient utilities is its scale and that this inefficiency would improve, were we to adjust its scale to the optimal level. The utilities of COF, GFW and LOG provide some indication of where these scale changes may possible lie.

Table 6.5 provides a comparable analysis for capital efficiency. Consider Brisbane Water (BRI). As shown, when assuming constant returns-to-scale, BRI is 87 per cent efficient and in order to improve its efficiency to the level of its best-practice peers (AQW, LOG, SEW and SWC) we would need to cut capital expenditure by 64 per cent, and reduce water losses by 14.9 per cent and water main breaks by 32.4 per cent. However, we would also need to increase the number of connected properties by 34.8 per cent and the amount of delivered water by 14.9 per cent. Once again, the last two variables are not easily changed and are potentially indicative of surplus capacity and the effects of water restrictions, etc. In fact, when we assume variable returns-to-scale in the lower panel in Table 18, BRI is no longer inefficient, suggesting the observed capital inefficiency results from non-optimal scale.

Now consider Gosford City Council (GOS). Here no decrease in capital expenditure is indicated, rather GOS needs to reduce the number of water main breaks and losses to a level comparable to its peers in EGW, LOG, LOW, PMQ, SEW and SWC. Clearly, once again the number of properties and the amount of water supplied are a major factor in determining the efficiency gap, even after allowance for contextual factors, suggesting that many utilities in the upper panel are operating at an inefficient scale given their circumstances. If we examine the lower panel in Table 6.5, we can thus see far fewer utilities are inefficient.

Table 6.4 CRS and VRS operating inefficient utilities and actual and target inputs and outputs

Utility	Score	Actual OXT	Target OXT	% OXT	Actual CHC	Target CHC	% CHC	Actual WQI	Target WQI	% WQI	Actual WTR	Target WTR	% WTR	Reference peers
BAR	87.71	40033	35114	–12.3	100.00	100.00	0	43.48	43.48	0.0	32493	45912	41.30	AQW EGW NEW WCA WPT
CHW	44.46	28202	12538	–55.5	75.68	98.96	30.8	6.62	12.85	94.1	11334	16470	45.30	GFW HWC PMQ SEW WCA WMN WSP
COL	71.46	21318	15232	–28.5	90.91	100.11	10.1	25.64	25.64	0.0	16106	16106	0.00	BYR GFW HWC ORC SEW SHL WMN WPT WSP
GOS	80.20	19909	15968	–19.8	100.00	100.00	0	3.96	12.24	209.5	12619	16269	28.90	ALB HWC ORC PMQ SEW WMN WSP
GWM	62.92	12555	7899	–37.1	62.86	97.52	55.1	22.22	22.22	0.0	7525	11651	54.80	CLA GFW HWC KMP ORC RIV SHL WSP
LIS	93.81	5799	5439	–6.2	0.00	100.00	100	1.35	3.64	170.4	3522	6006	70.60	COF GFW LOG
WAN	93.13	13572	12639	–6.9	91.18	96.81	6.2	10.20	20.66	102.5	14374	16389	14.00	CLA EGW GFW ORC RIV SHL WPT
WSR	99.20	5342	5299	–0.8	50.00	100.00	100	20.00	41.28	106.4	4825	6482	34.30	ALB BYR GFW SEW WMN
WYS	64.16	21396	13728	–35.8	100.00	100.00	0	10.89	12.04	10.5	13785	14100	2.30	ALB HWC ORC PMQ SEW WMN WSP
BAR	87.71	40033	35114	–12.3	100.00	100.00	0	43.48	43.48	0.0	32493	45912	41.30	AQW EGW NEW WCA WPT
CHW	44.46	28202	12538	–55.5	75.68	98.90	30.7	6.62	12.17	83.8	11334	16476	45.40	GFW HWC PMQ SEW WCA WMN WSP YAR
COL	71.68	21318	15281	–28.3	90.91	99.78	9.8	25.64	25.64	0.0	16106	16106	0.00	BYR GFW ORC SHL WMN WPT WSP YAR
GOS	80.35	19909	15997	–19.6	100.00	100.00	0	3.96	12.31	211.2	12619	16155	28.00	ALB ORC SEW WMN WSP
GWM	62.94	12555	7901	–37.1	62.86	97.52	55.1	22.22	22.22	0.0	7525	11651	54.80	CLA GFW HWC KMP ORC RIV SHL WPT WSP
WAN	93.53	13572	12693	–6.5	91.18	96.58	5.9	10.20	21.11	106.9	14374	16360	13.80	EGW GFW ORC RIV SHL WPT
WSR	99.20	5342	5299	–0.8	50.00	100.00	100	20.00	41.28	106.4	4825	6482	34.30	ALB BYR GFW SEW WMN
WYS	64.28	21396	13753	–35.7	100.00	100.00	0	10.89	12.10	11.1	13785	14002	1.60	ALB ORC SEW WMN WSP

Notes: Data for 2008–09 only. CRS Constant returns-to-scale, VRS Variable returns-to-scale. Utility names in Table 4.1.

Table 6.5 CRS and VRS capital inefficient utilities and actual and target inputs and outputs

Utility	Score	Actual CXT	Target CXT	% CXT	Actual LSI	Targe t LSI	% LSI	Actual WMI	Target WMI	% WMI	Actual PRP	Target PRP	% PRP	Actual WTR	Target WTR	% WTR	Reference peers
BAL	95.83	631	631	0	0.82	0.86	4.3	11.76	57.02	384.7	14.02	14.70	4.9	3568	3723	4.3	BYR QUE SEW SHL
BRI	87.00	67460	24290	–64.0	1.35	1.55	14.9	3.60	4.77	32.4	446.95	602.65	34.8	106331	122223	14.9	AQW LOG SEW SWC
CHW	41.14	48321	33505	–30.7	1.49	3.63	143.1	4.17	10.13	143.1	59.00	143.40	143.1	11334	33110	192.1	GFW GWM QUE SEW SWC
COL	78.15	51348	23771	–53.7	2.38	3.05	28	3.07	9.07	195.8	66.00	94.43	43.1	16106	20608	28.0	EGW GFW GWM LOG SEW SWC
GCW	56.91	54466	21027	–61.4	0.98	1.72	75.7	6.37	11.19	75.7	226.00	474.54	110.0	54661	96052	75.7	AQW LOG QUE SEW SWC
GOS	92.70	19499	19499	0	3.12	3.37	7.9	3.69	16.54	348.6	70.07	75.59	7.9	12619	16715	32.5	EGW LOG LOW PMQ SEW SWC
IPS	97.50	12755	12755	0	2.12	2.17	2.6	6.59	15.31	132.3	60.60	62.15	2.6	13317	14575	9.4	AQW BYR GFW LOG SEW WMN
KMP	81.43	2728	2728	0	1.24	1.53	22.8	4.18	17.20	311.0	12.29	15.09	22.8	3633	4461	22.8	AQW BEG CGW LOW PAD PMQ WPT
ORC	97.71	5635	4032	–28.4	1.68	1.72	2.3	5.42	5.54	2.3	15.89	19.58	23.3	8353	8549	2.3	EGW GOU LOW NEW PAD PMQ
TWE	81.75	51355	11042	–78.5	1.27	2.73	114.4	19.12	23.39	22.3	31.66	38.73	22.3	9205	11650	26.6	GOU LOW PMQ SAW
WAN	80.94	24492	10901	–55.5	0.83	1.60	94	6.67	8.24	23.5	39.00	48.18	23.5	14374	17758	23.5	BEG CGW PMQ RIV SEW WPT
WCA	92.52	4459	4040	–9.4	0.86	0.93	8.1	8.27	8.94	8.1	14.64	15.83	8.1	3384	5751	70.0	AQW BEG CGW EGW WAY WPT
WSR	50.76	8796	8796	0	0.89	1.75	97	5.42	15.47	185.5	18.00	35.46	97.0	4825	9720	101.5	ALB BYR EGW GFW LIS SEW WMN
CHW	43.24	48321	31490	–34.8	1.49	3.45	131.3	4.17	9.64	131.3	59.00	136.44	131.3	11334	32089	183.1	BEG CLA GFW GWM ORC RIV SEW SWC
COL	82.27	51348	21852	–57.4	2.38	2.89	21.5	3.07	9.08	195.9	66.00	81.89	24.1	16106	19576	21.5	GFW GWM LOG LOW ORC SEW SWC
GOS	92.73	19499	19499	0	3.12	3.37	7.8	3.69	16.52	348.0	70.07	75.56	7.8	12619	16710	32.4	EGW LOG LOW PMQ SEW SWC
TWE	82.29	51355	11116	–78.4	1.27	2.73	114.7	19.12	23.24	21.5	31.66	38.84	22.7	9205	11720	27.3	LOW PMQ SAW

Utility	Score	Actual CXT	Target CXT	% CXT	Actual LSI	Targe t LSI	% LSI	Actual WMI	Target WMI	% WMI	Actual PRP	Target PRP	% PRP	Actual WTR	Target WTR	% WTR	Reference peers
WAN	84.50	24492	24492	0	0.83	2.47	199.3	6.67	7.89	18.3	39.00	46.15	18.3	14374	17175	19.5	BEG CLA EGW NEW RIV SAW SEW WPT
WSR	51.06	8796	7855	–10.7	0.89	1.74	95.9	5.42	15.51	186.4	18.00	35.25	95.9	4825	9819	103.5	ALB BYR GFW LIS SEW WMN

Notes: Data for 2008–09 only. CRS Constant returns-to-scale, VRS Variable returns-to-scale. Utility names in Table 4.1.

However, because of the assumption of variable returns-to-scale in this panel, it is more difficult to explain away observed inefficiencies because we have already taken account of scale (and contextual factors). Accordingly, we need to look more closely at the actual and target improvement. Here, the capital efficiency of GOS and WAN could be improved by augmenting their outputs in taking greater efforts to reduce water losses and preventing main breaks. In others (CHW, COL and TWE), capital expenditures a very high relative to best-practice peers in the sector, and we would need to look at what is specifically going on in each utility to help explain this expenditure. We would then evaluate whether it is only temporary or more permanent, and judge the possible long-run impacts on the sustainable and secure supply or urban water in these areas.

6.6 Concluding remarks

This section examined the technical operating and capital efficiency of major Australian urban water utilities in 2008–09 using data envelopment analysis. Different inputs and outputs were specified for each aspect of efficiency and allowance made for the direction inclusion of uncontrollable contextual inputs thought to impact upon the observed efficiency of utilities but largely outside their control. Efforts were also made to distinguish between factors that determine inefficiency and those that affect the gap in efficiency.

The results indicate that a relatively high level of relative operating and capital efficiency prevails across the sector, at least in the context of the single year of data used in this part of the analysis. Efficiency improves further when allowance is made for the scale of operations. However, a number of utilities exhibit inefficient behaviour in operations and, to a lesser extent, in capital activities, and we are able to provide target inputs, outputs, and sets of best-practice peers that these utilities can focus on when seeking to improve their performance.

Of course, not all inputs and outputs are amenable to change. While this analysis took clear account of the differences in non-controllable inputs, it also found that a major determinant of observed inefficiency is the influence of these factors, particularly the number of properties served and the amount of water supplied. This is perhaps because at least some utilities are obliged to operate at a more or less than optimal scale. One possibility is ‘lumpy’ investment in infrastructure (pipelines, dams, treatment plants). As a physical network industry, it is difficult for these utilities to trade surplus capacity with any but geographically proximate utilities. At the same time, the heavy reliance on water restrictions and costly water conservation measures may be obligating urban water utilities to supply less than what is optimal given their circumstances.

One major limitation of this particular analysis is the relatively limited number of inputs able to be specified (operating and capital expenditure) and the restrictive range of possible outputs (mostly concerning regulated chemical and microbiological compliance and water quality). This acts against the ability to distinguish finely between efficient and inefficient water utilities.

7 Conclusion

The objectives of this report were as follows. First, examine existing empirical research on efficiency and productivity measurement in urban water utilities. Second, provide quantitative measures of efficiency, productivity and technological change and the impact of various factors on efficient and productive outcomes in the sector. Third, assay the scope and source of productivity and technological improvements that have taken place in recent years and identify key productivity drivers and impediments to productivity growth in urban water utilities and help identify best-practice behaviour. Finally, help feed any newly developed multidimensional metrics into future developments in the National Performance Reports as a means of further improving stakeholders' understanding of Australia's urban water utilities and assisting utilities to improve their performance.

7.1 Summary of findings

Chapter 2— An overview of the Australian urban water utility sector

There have been recent substantial increases in capital expenditure and to a lesser extent operating expenditure accompanied by declining profitability in the urban water utility sector. Generally, the increases in expenditure have been greatest in the very largest utilities while the decline in profitability has been least in the very smallest and very largest utilities.

There is considerable variance in the primary sources of water, industry structure and ownership across the various jurisdictions (states).

Regulation relating to the provision of services, affordability, public health and the environment has a major impact on outcomes in the urban water utility sector. Of these, pricing control is potentially the most important.

Chapter 3—A review of efficiency and productivity measurement in urban water utilities

There is an ever-increasing literature concerning the application of efficiency measurement techniques to urban water utilities worldwide. Reasons for this growth in the literature include common global challenges facing the sustainability of urban water resources and water utilities and the improved availability of institutional level data to allow better comparisons of productive behaviour. There is good evidence that the results of these techniques are finding application in guiding regulatory policy and industry practice.

A common global theme is that the discretionary (controllable) and non-discretionary (non-controllable) resources available to a particular utility have an important influence on relative performance in diverse contexts. These potentially encompass both physical environmental circumstances, as well as constraints arising from organisational, managerial and regulatory policy. Ignoring these imposed factors may lead to disingenuous efficiency measures.

The most common conceptualisation used in defining the input-output relationship in urban water utility behaviour follows a production approach. This principally views water utilities as producers of physical water outputs, typically the volume of potable water and the number of properties supplied with water as a function of operating expenditure. Past studies generally include little allowance for qualitative outputs such as customer satisfaction and water quality. Problematically, this specification is often the result of limited data availability and the inability of some methodologies to reflect the regulatory obligations of water utilities to provide water to households in their services areas. It also seldom reflects the capital-intensiveness of water utilities or the fullest range of input factors upon which they draw in the production process.

Section 4—Non-parametric measures of productivity, efficiency change and technological progress

This analysis examined the productivity growth of major Australian urban water utilities over the period 2005–06 to 2008–09 using non-parametric methods. The inputs included in the analysis were total operating expenditure and the outputs were chemical and microbiological compliance, real losses (litres/service connection/day), water quality and service complaints (per 1000 properties), and the inverse of water main breaks.

The results indicated that annual productivity growth averaged 1.04 per cent across all utilities, with a range of 0.09–2.98 per cent, and was largely attributable to efficiency gains. There appears to have been very little gain from technological improvements (0.17–0.29 per cent) and this is suggestive of a slow pace of best-practice improvement in the sector.

The suggestion is that it is becoming increasingly difficult to improve the quantity and quality of water services beyond some physical engineering limit, which the sector has perhaps already met. Another possibility is that the demands for capital expenditure are directing funding, attention and effort away from operations implying fewer financial, intellectual and managerial resources are available for innovation in this area.

Also likely is that the costs associated with regulation in the sector, including compliance costs, costs associated with price distortions and resulting production loses, and costs associated with delayed or deferred investment are have an adverse effect. However, regulation can also exert a positive effect in encouraging innovation. This suggests the need for further investigation into the opportunities for structural and regulatory reform.

One likely empirical factor that comprises the results in this part of the analysis is the focus on potable water, where there has been arguably less technological progress in recent years or at least over the short run and the corresponding neglect of wastewater treatment processes where there are perhaps greater opportunities for technological improvements to play a role.

Section 5—Stochastic estimates of economies of scale and scope in urban water utilities

This analysis employed stochastic functions to calculate product-specific and overall economies of scale and scope over the period 2005–06 to 2008–09 for operating costs and 2008–09 for operating and capital costs.

In terms of economies of scale, the evidence suggests that economies of scale prevail up to 75 per cent of mean sample output (about 90 000 connected properties). The sample only includes utilities with at least ten thousand connected properties, but it is likely that increasing economies of scale also prevail for smaller out-of-sample water utilities in the population.

Horizontal aggregation should provide efficiency gains up to this point, especially if the composite utilities are located in close proximity and if the increase in scale is without significant investment in network costs. Horizontal disaggregation down to this level should also provide scale economies. However, opportunities are more limited for disaggregation with very few utilities having in excess of 125 000 connected properties.

The analysis also indicates very strong and ongoing economies of scope. This infers the appropriateness of vertical integration in the urban water utility sector, though we should note that the analysis excludes bulk water suppliers from the supply chain.

Section 6—Non-parametric measures of technical efficiency in urban water utilities

This section examined technical operating and capital efficiency in 2008–09 using data envelopment analysis. Different inputs and outputs were specified for each aspect of efficiency and allowance made for the direction inclusion of uncontrollable contextual inputs thought to impact upon the observed efficiency of utilities but largely outside their control. Efforts were also made to distinguish between factors that determine inefficiency and those that affect the gap in efficiency.

The results indicate a relatively high level of relative operating and capital efficiency, at least in the single year included in this part of the report. Efficiency improves further when allowance is made for the scale of operations. However, a number of utilities exhibit inefficient behaviour in operations and, to a lesser extent, in capital activities, and we are able to provide target inputs, outputs, and sets of best-practice peers that these utilities can focus on when seeking to improve their performance.

A major determinant of observed inefficiency is the influence of the number of properties served and the amount of water supplied. This is perhaps because at least some utilities are obliged to operate at a more or less optimal scale. One possibility is 'lumpy' investment in infrastructure (pipelines, dams, treatment plants). For instance, capital requirements may incorporate excess capacity to cover anticipated change over the lifetime of an asset. Further, as a physical network industry, it is difficult for these utilities to trade surplus capacity with any but geographically proximate utilities. At the same time, the heavy reliance on water restrictions and costly water conservation measures may be obligating urban water utilities to supply less than what is optimal given their circumstances.

One major limitation of this particular analysis is the relatively limited number of inputs able to be specified (operating and capital expenditure) and the restrictive range of possible outputs (mostly concerning regulated chemical and microbiological compliance and water quality). This acts against the ability to distinguish finely between efficient and inefficient water utilities.

7.2 Limitations and related policy and research recommendations

Despite the conceptualisation of water utility behaviour being consistent with the established literature in Australia and elsewhere, it remains difficult to model quantitatively the multi-dimensional objectives and constraints within which water utilities operate. For instance, it is necessary to specify the amount of potable water supplied and/or the number of properties served as outputs, even though there is no suggestion a given utility would wish to increase either. The alternative would be to include only scale-independent variables like water quality and compliance and security of supply, but this would ignore the size of the water utilities and the potential impact this has on quality.

There is a need for additional conceptual work to understand better the actual decision-making framework urban water utilities use when deciding upon inputs and outputs and thereby determining key performance indicators. Further investigation is also required to explore alternative modelling and specification techniques consistent with practice in this industry.

Unfortunately, only very limited input factors are available in the NWC's performance reports, especially for operating expenditure, and to a lesser extent, capital expenditure (for instance, data on the written down replacement cost of capital is only available from 2008–09 onwards). This contrasts sharply with the many output indicators already available. Importantly, this limits the ability of the analysis to explain the sources and influence of technical and allocative efficiency. In terms of recommendations, for operating factors it would be useful for the NWC to gather fuller information on the factors employed by utilities (in dollar costs and/or quantity), including personnel, material, energy and chemical use, the use of outside services, and plant characteristics. Similarly, for capital factors, it would be useful to have some assessment made of the condition of the existing infrastructure and the amounts spent on maintaining this and providing for new infrastructure. This is especially important given the capital intensiveness of the urban water utility sector.

The NWC should expand data collection in the National Performance Reports to include a fuller set of input information, particularly that relating to individual items in operating and capital, such as expenditure on energy, chemical, maintenance, labour, advertising, water education programs, etc.

The primary limitation is that there has been a focus on potable water and no attempt to incorporate the wastewater services offered by many urban water utilities. While the NWC performance reports clearly separate the two different areas of operation in the performance indicators, this is likely to ignore an additional and important dimension of operational behaviour for most utilities. It is also likely to understate the economies of scope that exist in the sector, particularly those relating to the use and re-use of recycled water.

Future empirical work on economies of scale and scope in urban water utilities should include existing data contained in the National Performance Reports to enable the consideration of potable water and wastewater services in the same study.

It is clear from this analysis and related work that the constraints placed upon urban water utilities significantly constrain their activities and therefore have significant efficiency impacts. These constraints potentially include the socioeconomic and environmental contextual factors considered in this report but also some neglected areas including price-setting regulation and mandated water quality and other guidelines, the impact of existing and alternative governance arrangements, and the interrelationship between the financing and investment decisions of urban water utilities.

There should be further investigation into the nature of the constraints placed on productive behaviour in urban water utilities and their efficiency impacts as a means of informing regulatory, institutional and governance reform.

References

Abbott M and Cohen B 2009, ‘Productivity and efficiency in the water industry’, Utilities Policy 17(3-4):233–44.

Abbot M and Cohen B 2009, ‘Industry structure issues in the water and waste water services sectors in Australia’, Economic Papers 29(1):48–63.

Antonioli B and Filippini M 2001, ‘The use of variable cost function in the regulation of the Italian water industry’, Utilities Policy 10(3-4):181–187.

Anwandter L and Ozuna T 2002, ‘Can public sector reforms improve the efficiency of public water utilities’, Environment and Development Economics 7(4):687–700.

Aubert C and Reynaud A 2005, The impact of regulation on cost efficiency: An empirical analysis of Wisconsin water utilities’, Journal of Productivity Analysis 23(3):383–409.

Bhattacharyya A, Harris T, Narayanan R and Raffie K 1995, ‘Specification and estimation of the effect of ownership on the economic efficiency of the water utilities’, Regional Science and Urban Economics 25:759–784.

Bhattacharyya A, Parker E and Raffie K 1994, ‘An examination of the effect of ownership on the relative efficiency of public and private water utilities’, Land Economics 70:197–209.

Bottasso A and Conti M 2003, ‘Cost inefficiency in the English and Welsh water industry: An heteroskedastic stochastic cost frontier approach, DIEM, University di Genova.

Bottasso A and Conti M 2009, ‘Scale economies, technology and technical change in the water industry: Evidence from the English water only sector’, Regional Science and Urban Economics 39(2):138–147

Byrnes J, Crase L, Dollery BE and Villano R 2010, ‘The relative economic efficiency of urban water utilities in regional New South Wales and Victoria’, Resource and Energy Economics 32(3): 439–455

Coelli T and Walding S 2006, ‘Performance measurement in the Australian water supply industry: A preliminary analysis’, in Coelli T and Lawrence D (Eds), Performance Measurement and Regulation of Network Utilities, Edward Elgar, Cheltenham, 29–62.

Coelli TJ, Rao DSP, O’Donnell CJ and Battese GE 2005, An Introduction to Efficiency and Productivity Analysis, 2nd ed. Springer, New York.

Cooper WW, Seiford LM and Tone K 2006, Introduction to Data Envelopment Analysis and its Uses: With DEA-Solver Software and References, Springer, New York.

Council of Australian Governments (COAG) 1994, Council of Australian Governments' Communiqué 25 February 1994—Water Resource Policy, available at http://www.coag.gov.au/, accessed April 2011.

Council of Australian Governments (COAG) 1995, Agreement to Implement the National Competition Policy and Related Reforms, Attachment A of Council of Australian Governments Meeting 11 April 1995, available at http://www.coag.gov.au/, accessed April 2011.

Council of Australian Governments (COAG) 2004, Intergovernmental Agreement on a National Water Initiative between the Commonwealth of Australia and the Governments of New South Wales, Victoria, Queensland, South Australia, the Australian Capital Territory and the Northern Territory, available at http://www.coag.gov.au/, accessed April 2011.

Council of Australian Governments (COAG) 2008, Council of Australian Governments’ Meeting 29 November 2008—Climate Change and Water, available at http://www.coag.gov.au/, accessed April 2011.

Cubbin J 2004, ‘Assessing Ofwat’s efficiency econometrics: A report for water UK’, available at http://www.staff.city.ac.uk/, accessed May 2010.

Cubbin J 2005, ‘Efficiency in the water industry’, Utilities Policy 13(4): 289–293.

Cubbin J and Tzanidakis G 1998, ‘Regression versus data envelopment analysis for efficiency measurement: An application to the England and Wales regulated water industry’, Utilities Policy 7(2): 75–85.

da Silva e Souza G, Coelho de Faria R, Belchiar S and Moreira T 2007, ‘Estimating the relative efficiency of Brazilian publicly and privately owned water utilities: A stochastic cost frontier approach’, Journal of the American Water Resources Association 43(5): 1237–1244.

da Silva e Souza G, Coelho de Faria R, Belchior T and Moreira S 2008, ‘Efficiency of Brazilian public and private water utilities’, Estudos Economicos 38(4): 905–917

Erbetta F and Cave M 2006, ‘Regulation and efficiency incentives: Evidence from the England and Wales water and sewerage industry’, Review of Network Economics 6(2): 425–452.

Estache A and Rossi M 2002, ‘How different is the efficiency of public and private water companies in Asia?’, World Bank Economic Review 16(1): 139–148.

Estache A and Trujillo L 2003, ‘Efficiency effects of ‘privatization’ in Argentina’s water and sanitation services’, Water Policy 5(4): 369–380.

Fabbri P and Fraquelli G 2000, ‘Costs and structure of technology in the Italian water industry’, Empirica 27(1): 65–82.

Färe R, Grosskopf S, Norris M and Zhang Z 1994, ‘Productivity growth, technical progress, and efficiency change in industrialised countries’, American Economic Review 84(1): 66–83.

Färe R, Grosskopf S, Lindgren B and Roos P 1992, ‘Productivity changes in Swedish pharmacies 1980–1989: A non-parametric Malmquist approach’, Journal of Productivity Analysis 3(1-2): 85–101.

Faria CR, Souza G and Moreira T 2005, ‘Public versus private water utilities: Empirical evidence for Brazilian companies’, Economics Bulletin 8(2): 1–7

Farrell, MJ 1957, ‘The measurement of productive efficiency’, Journal of the Royal Statistical Society, 120: 253–289.

Filippini M, Hrovatin N and Zoric J 2008, ‘Cost efficiency of Slovenian water distribution utilities: An application of stochastic frontier methods’, Journal of Productivity Analysis 29(2): 169–182.

Fraquelli G and Moiso V 2005, ‘Cost efficiency and economies of scale in the Italian water industry, Società Italiana di Economia Pubblica (SIEP), Dipartimento di Economia Pubblica e Territoriale–Università di Pavia, available at http://www-3.unipv.it/, accessed May 2010.

Fraquelli G, Piacenza M and Vannoni D 2004, ‘Scope and scale economies in multiutilities: Evidence from gas, water and electricity combinations’, Applied Economics 36(18): 2045–2057.

Frontier Economics 2008, ‘Urban water markets: A final report prepared for the Joint Steering Committee for Water Sensitive Cities (JSCWSC)’, Frontier Economics, Melbourne.

Garcia S, Moreaux M and Reynaud A 2007, ‘Measuring economies of vertical integration in network industries: An application to the water sector’, International Journal of Industrial Organisation 25: 791–820.

García-Sánchez IM 2006, ‘Efficiency measurement in Spanish local government: The case of municipal water services’, Review of Policy Research 23(2): 355–371.

García-Valinas MA and Muniz MA 2007, ‘Is DEA useful in the regulation of water utilities? A dynamic efficiency evaluation’, Applied Economics 39(2): 245–252.

Guder J, Kittlau B, Moll R, Walter M and Zschille M 2009, ‘The performance of German water utilities: A first non-parametric analysis’, DIW Berlin (German Institute for Economic Research) and Dresden University of Technology Efficiency Analysis Working Papers. WP-EA-20, available at http://tu-dresden.de/, accessed May 2010.

Industry Commission (IC) 1992, Water Resources and Waste Water Disposal, Report No. 26, Canberra, July.

Kirkpatrick C, Parker D and Zhang YF 2006, ‘State versus private sector provision of water services in Africa: An empirical analysis’, World Bank Economic Review 20(1): 143–163.

Lambert D, Dichev D and Raffiee K 1993, ‘Ownership and sources of inefficiency in the provision of water services’, Water Resources Research 29(6): 1573–1578.

Lynk EL 1993, ‘Privatisation, joint production and the comparative efficiencies of private and public ownership: The UK water industry case’, Fiscal Studies 14(2): 98–116.

Mosheim R 2006, ‘A shadow cost function model of the US water industry incorporating water quality and ownership effects’, in Coelli T and Lawrence D (Eds), Performance Measurement and Regulation of Network Utilities, Edward Elgar, Cheltenham, 243–267.

Munisamy S 2010, ‘Efficiency and ownership in water supply: Evidence from Malaysia’, Proceedings of the 12th International Business Research Conference, 8–9 April, Dubai, United Arab Emirates, available at http://www.wbiconpro.com/, accessed May 2010.

Nauges C and van den Berg C 2008, ‘Economies of density, scale and scope in the water supply and sewerage sector: A study of four developing and transition economies’, Journal of Regulatory Economics 34(2): 144–163.

National Water Commission 2007, National Performance Report 2005–06—Urban Water Utilities, available at http://www.nwc.gov.au/, accessed April 2011.

National Water Commission 2008, National Performance Report 2006–07—Urban Water Utilities, available at http://www.nwc.gov.au/, accessed April 2011.

National Water Commission 2009, National Performance Report 2007–08—Urban Water Utilities, available at http://www.nwc.gov.au/, accessed April 2011.

National Water Commission 2010a, National Performance Report 2008–09—Urban Water Utilities, available at http://www.nwc.gov.au/, accessed April 2011.

National Water Commission 2010b, National Performance Framework 2009–10—Urban Water Performance Report Indicators and Definitions Handbook, available at http://www.nwc.gov.au/, accessed April 2011.

National Water Commission 2011, National Performance Report 2009–10—Urban Water Utilities, available at http://www.nwc.gov.au/, accessed April 2011.

Norman M and Stoker B 1991, Data Envelopment Analysis: The Assessment of Performance, John Wiley, Chichester NY.

Ofwat (2010a) Relative efficiency assessment 2007–08—Supporting information, available at http://www.ofwat.gov.uk/, accessed May 2010.

Ofwat (2010b) Relative efficiency assessment 2007–08—Water operating expenditure model data, available at http://www.ofwat.gov.uk/, accessed May 2010.

Ofwat (2010c) Water and sewerage relative efficiency assessments, available at http://www.ofwat.gov.uk/, accessed May 2010.

Picazo-Tadeo AJ, Sáez-Fernández FJ and González-Gómez F 2008, ‘Does service quality matter in measuring the performance of water utilities?’, Utilities Policy 16: 30–38.

Productivity Commission 2011, Australia’s Urban Water Sector, Draft Report, April, Canberra.

Ramanathan R 2003, An Introduction to Data Envelopment Analysis: A Tool for Performance Measurement, Sage, Thousand Oaks, CA.

Ray SC 2004, Data Envelopment Analysis: Theory and Techniques for Economics and Operations Research, Cambridge University Press, Cambridge.

Renzetti S and Dupont DP 2009, ‘Measuring the technical efficiency of municipal water suppliers: The role of environmental factors’, Land Economics 85(4): 627–36.

Saal DS and Parker D 2000, ‘The impact of privatization and regulation on the water and sewerage industry in England and Wales: A translog cost function model’, Managerial and Decision Economics 21(6): 253–268.

Saal DS and Parker D 2001, Productivity and price performance in the privatised water and sewerage companies of England and Wales’, Journal of Regulatory Economics 20(1): 61–90.

Saal DS and Parker D 2006, ‘Assessing the performance of water operations in the English and Welsh water industry: A lesson in the implications of inappropriately assuming a common frontier’, in Coelli T and Lawrence D (Eds), Performance Measurement and Regulation of Network Utilities, Edward Elgar, Cheltenham, 297–328.

Saal DS, Parker D and Weyman-Jones T 2007, ‘Determining the contribution of technical change, efficiency change and scale change to productivity growth in the privatised English and Welsh water and sewerage industry: 1985–2000’, Journal of Productivity Analysis 28(1): 127–139.

Thanassoulis E 2001, Introduction to the Theory and Application of Data Envelopment Analysis: A Foundation Text with Integrated Software, Kluwer, Norwell, MA.

Thanassoulis E 2000, ‘The use of data envelopment analysis in the regulation of UK water utilities: Water distribution’, European Journal of Operational Research 126: 436–453.

Thanassoulis E 2002, ‘Comparative performance measurement in regulation: The case of English and Welsh sewerage services’, Journal of Operational Research Society 53: 292–302.

Torres M and Morrison Paul CJ 2006, ‘Driving forces for consolidation or fragmentation of the US water utility industry: A cost function approach with endogenous output’, Journal of Urban Economics 59(1): 104–120.

Tupper HC and Resende M 2004, ‘Efficiency and regulatory issues in the Brazilian water and sewage sector: An empirical study’, Utilities Policy 12(1): 29–40.

Walter M, Cullmann A, von Hirschhausen C, Wand R and Zschille M 2009, ‘Quo vadis efficiency analysis of water distribution? A comparative literature review’, Utilities Policy 17: 225–232.

Woodbury K and Dollery BE 2004, ‘Efficiency measurement in Australian local government: The case of New South Wales municipal water services’, Review of Policy Research 21(5): 615–636.