Marginal Cost Water Pricing: Welfare Effects and Policy Implications using Minimum Cost and Benchmarking Models, with Case Studies from Australia and Asia

Thesis

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by

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for Marcella

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ABBREVIATIONS

2SLS	Two-Stage Least Squares
ADB	Asian Development Bank
ADERASA	Association of Water and Sanitation Regulatory Entities of the Americas
ADR	Appropriate Discount Rate (Phil.[1])
AEPA	Accelerated Extraordinary Price Adjustment (Phil.)
AWWA	American Water Works Association
AUD	Australian Dollar
BEA	Bureau of Economic Analysis (USA)
BOOT	Build Own Operate Transfer (Vic.[2])
CAPEX	Capital Expenditure
CERA	Currency Exchange Rate Adjustment (Phil.)
CES	Constant Elasticity of Substitution
CPI	Consumer Price Index
CRS	Constant Returns to Scale
DCRA	Debt Capital and Restructuring Agreement (Phil.)
DEA	Data Envelopment Analysis
EEPSEA	Economy and Environment Program for Southeast Asia (Canada)
ESC	Essential Services Commission (Vic.)
FCDA	Foreign Currency Devaluation Adjustment (Phil.)

[1] Philippines
[2] Victoria, Australia

FIES	Family Income and Expenditure Survey (Phil.)
FTE	Full Time Equivalent
HPE	Heterogeneous Preferences Error
IBRD	International Bank for Reconstruction and Development
IBRT	Increasing Block Rate Tariff
IDA	International Development Agency
IFC	International Finance Corporation
IPART	Independent Pricing and Regulatory Tribunal (NSW)
KL	Kilolitres
KLM	Kilolitres per Month
LIBOR	London Interbank Overnight Rate
ML	Megalitres
MLD	Megalitres per Day
MLE	Maximum Likelihood Estimation
MWCI	Manila Water Company Inc. (Phil.)
MWSI	Maynilad Water Supply Inc. (Phil.)
MWSS	Metropolitan Water and Sewerage Service (Phil.)
MWSS−RO	Metropolitan Water and Sewerage Service - Regulatory Office
NCR	National Capital Region (Phil.)
NGO	Non-Government Organisation
NRW	Non-Revenue Water
NSO	National Survey Office (Phil.)
NWC	National Water Commission (Australia)
OECD	Organisation for Economic Cooperation and Development
OFWAT	Office of Water Services (UK)
OLS	Ordinary Least Squares

PAWS	Public Assessment of Water Services (Phil.)
PhP	Philippine Peso
PPE	Property Plant and Equipment
RESET	Regression Specification Error Test
RTS	Returns to Scale
SEAWUN	Southeast Asian Water Utilities Network
SFA	Stochastic Cost Frontier
SPR	Service Performance Report (Phil.)
SUR	Seemingly Unrelated Regressions
UATP	Umiray Angat Transbasin Project (Phil.)
USD	US. Dollar
VAT	Value Added Tax (Phil.)
VRS	Variable Returns to Scale
WACC	Weighted Average Cost of Capital
WIRO	Water Industry Regulatory Order (Vic.)
WUP	Water Utility Partnership (Africa)

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ABSTRACT

Recent studies in water management policy point to insufficient recognition of water as a scarce commodity and the failure of pricing policies to account for the full economic costs of its production and supply. These costs include opportunity costs related to alternative uses of water; user costs associated with managing a scarce resource; and costs of externalities such as ground water depletion, pollution of waterways, and greenhouse gas emissions. Existing cost recovery based pricing policies may lead to inefficiencies such as excess consumption, under-investment in water infrastructure, and unnecessary subsidisation.

Water scarcity can be managed in several ways. We can increase supply by investment in additional harvesting capabilities or new technologies such as desalination; we can constrain consumption so that existing supplies last longer; or we can use water in more efficient ways. As a short term measure, most countries adopt water restrictions when supplies are at critical levels. In the future, as urban population growth continues, harvesting of storm water and reuse of grey water may become part of a sustainable water management strategy. Water trading can be used to move water to where the marginal benefits are highest. Considerable water savings are possible through the use of more efficient industrial and domestic appliances. There is evidence in some countries that higher water tariffs have reduced consumption and promoted awareness of conservation. If we accept that water is an economic good, then we need to understand the costs related to its production, the patterns of its use, and the benefits received by different users.

This thesis is an examination of theoretical and applied aspects of urban water pricing based on analysis of cost, demand, and welfare. We present theoretical models of cost that include economies of scale as a parameter, and a model of water demand by households with heterogeneous preferences. We determine marginal cost at the efficient level of output based on a partial equilibrium of supply and demand. We also show that when water is produced with increasing returns to scale, the efficient price will be insufficient to recover all costs, and therefore a form of second best pricing is required. We contrast conventional notions about water suppliers being cost minimisers with an alternative frontier model of cost efficiency. Two case studies examine the provision of water services under different forms of ownership. The first case study examines the provision of water to domestic households in the state of Victoria, Australia. The second case study examines the supply of water to the residents of Manila, one of the world's largest cities that privatised its water service in 1997 under a form of concession agreement. A third case study derives an efficient cost frontier for a sample of water utilities from Asia and Australia and proposes a form of best practice pricing. The thesis concludes with a summary of the main results and policy conclusions, and ideas for future research.

THESIS DECLARATION

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being made available in all forms of media, now or hereafter known.

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CHAPTER 1

Introduction

The sustainable use of water is one of most important challenges of our time. Urban water supplies are under considerable pressure in a number of the world's major cities as a result of ageing infrastructure, a decline in investment, increased demand from population growth, and the migration of rural workers to cities. The drought in Australia has placed severe stress on water supplies, for both agriculture and urban dwellers. Storage dams in our major cities are at record low levels. Warragamba dam, Sydney's main supply, is at 33.9% of capacity; the Thomson reservoir in Melbourne is at 18.2% of capacity[1]. Queensland is operating under level five water restrictions, the highest ever applied, where residential users can be fined for excess consumption. The Murray Darling Basin, upon which Adelaide relies for most of its water, has received inflows in the past year that are only 60% of the previous low level set in 1983 (Australian Broadcasting Commission, 2007). The problems are not limited to Australia. Of the world's total population, an estimated twenty percent do not have access to potable water (United Nations, 2006). Between 2000 and 2030, most population growth is expected to occur within the urban areas of less developed countries. This is expected to place urban supplies under even greater pressure. In response to the crisis, water management and use have moved to the forefront of policy debate, water is becoming more valued, and innovative solutions are being sought and evaluated.

[1]First quarter 2007 figures supplied by Sydney Catchment Authority and Melbourne Water respectively.

Supply augmentation, construction of new infrastructure to increase harvest and storage resources, has been the usual approach employed to manage growth in water consumption. Governments have become reluctant to adopt this approach in the recent past because it requires debt funding of large capital investments, and suitably located sites have been given over to urban or agricultural development. When the need to carry out new investment is unavoidable however, because of population growth, reduced inflows, or ageing infrastructure; it is likely to result in considerably higher marginal costs than the existing supply. If marginal costs increase, either the level of subsidisation needs to increase, or long run prices and allocations will adjust so that the marginal benefit for different classes of users are equal. Potentially, urban and agricultural users of water will compete for the same resource (Saleth and Dinar, 1997).

Demand management is acknowledged as an important part of a mix of strategies that will be required to achieve sustainability in water resource management. This can take several forms. Firstly, in Australia, we have experienced demand management in the form of water restrictions over many years. In the past, these were seasonal, however, restrictions have now become permanent in a number of states due to drought conditions. Given the considerable penalties for failure to comply, water restrictions do reduce consumption when brought into force. Secondly, innovative pricing mechanisms such as block rate pricing are becoming increasingly common. An increasing block rate will reduce overall consumption of water, because once basic household needs are satisfied, consumption becomes more sensitive to price. In the presence of a well designed block rate pricing tariff, consumers are less willing to pay for high water use activities such as watering of gardens or car washing. Thirdly, demand management may take the form of seasonal adjustments to price, for example to cope with the increase in demand in summer. This approach has yet to be adopted in Australia.

Recognition that water is an economic good is a precondition for implementation of sustainable strategies such as demand management. This means that water prices need to be determined in accordance with economic principles rather than those that focus on cost recovery. Accounting for the costs of water supply should include opportunity and environmental costs, in addition to operational and investment costs. Market based marginal cost pricing needs to be considered as a replacement for the established practice of *rate of return* pricing whereby a utility prices its service according to average cost plus a minimum rate of return on capital.

The need for change is already accepted by many water utilities and their owners. Government owners are more aware of the need for an economic return from water supply investment that accounts for the long run marginal costs. Market based mechanisms are already in place that allow water to move between and across sectors, from rural to rural and rural to urban, to those users that value the resource more. This promotes conservation among users and establishes clear market driven pricing signals. With more transparent data about prices and demand, governments and the private sector can be better informed about long term investment opportunities.

The changes in thinking about water, coupled with the knowledge that governments have in many cases been unsuccessful in managing the resource, have acquired large debt burdens, and often have been unable to move beyond least cost recovery pricing mechanisms, has led to privatisation of water supply operations in many countries. The reaction to the price increases that invariably follow, or the lack of service improvement, has been negative, indeed sometimes violent (Forero, 2005). Opinions regarding the success of private sector management of water service are polarised, as are the outcomes. Some countries have been successful, in others renationalisation appears imminent (Quiggin, 2002).

This thesis is a microeconomic analysis of the provision of water services in an urban context. Our primary research objective is to examine marginal cost water pricing by asking the following questions. How is the marginal cost of water determined? How is the price of water established using marginal cost as the basis? How do current water prices compare with estimated price based on marginal cost? What is the welfare impact of current water pricing relative to a proposed marginal cost based price? What are the main policy issues that we need to address in a debate on water pricing - particularly one based on marginal cost? In trying to provide answers, we will use the tools of applied microeconomic and econometric analysis and focus only on the provision of urban water services; including harvesting, production, and distribution. We hope that this work will contribute to our understanding of the variables and the relationships that are significant, the policy directions that will maximise benefits for society, and where our future efforts in research and understanding ought to be focused.

The novelty of the approach rests with three key features of this work. The first is extensive use of functional forms to describe the key variables: cost, demand, and welfare. This is in contrast to industry practice which relies on present value techniques to derive scalar quantities of the key variables. The second is the recognition that water utilities often operate with increasing returns to scale and therefore the efficient economic solution based on marginal cost pricing means that the utility does not recoup its costs. We therefore consider the use of Ramsey pricing. The third feature is an acceptance that utilities may not behave as cost minimisers in all cases, particularly if operating under rate of return regulation. Therefore we have proposed an alternate pricing mechanism based on use of efficiency frontiers. These areas have been dealt with independently but seldom in a unified manner. A fuller discussion of the original aspects of this work will be reserved until the thesis conclusion.

This thesis consists of thirteen chapters. Chapter 1 is this introduction that sets out the motivation for this research and an outline of the document structure. Chapter 2 is a description of existing water pricing practices and the regulatory contexts that determine water prices in many parts of the world. In this chapter we examine rate of return regulation, the dominant method used to price water. We also examine marginal cost pricing, price caps and other forms of regulation such as yardstick regulation that are applicable to water utilities. Chapters 3, 4, and 5 are devoted to theory and empirical issues. Chapter 3 is primarily devoted to description of a cost function that includes a parameter for economies of scale and that can be used to accommodate increasing, decreasing or constant marginal cost. We also outline the use of translog cost functions under assumptions of constant returns to scale production technology. Chapter 4 presents two alternative models for estimation of domestic water demand: the linear almost ideal demand system, and a two error heterogeneous preferences model for use in block rate water pricing. This chapter discusses empirical issues surrounding use of the two error model and the use of maximum likelihood estimation for estimation of the parameters of the demand function. In Chapter 5, we consider different ways of determining the marginal cost including an efficient allocation that maximises total net benefit for consumers and producers. We examine the welfare outcomes related to pricing at below marginal cost based on whether marginal costs are increasing, decreasing or constant. We also discuss issues of subsidisation and equity under second best (Ramsey) prices and the determination of a partial equilibrium when demand elasticity is known but the parameters of the complete demand function are not known.

Chapters 6 to 10 constitute the main body of applied work and are centered around two empirical case studies. The theoretical and methodological material of Chapters 3 to 5 are applied to the supply of urban water in one state of Australia and the capital city of the Philippines.

Chapters 6 and 7 contain a case study based on cost and demand data from the seventeen water businesses that supply water to domestic households across the state of Victoria. These businesses are owned by the state government but operate as corporations. Based on an unbalanced panel data set of accounting data, we estimate cost functions including constant returns to scale cost, variable returns to scale (scale economies), and constant returns translog cost function. The econometric techniques used include ordinary least squares and seemingly unrelated regression estimation. We determine the marginal cost based on a partial equilibrium and estimate the welfare losses associated with current prices, and estimate the subsidy still required under marginal cost pricing.

Chapters 8 to 10 contain a case study that focuses on the recently privatised supply of water to residential users in Manila in the Philippines. We examine the historical events surrounding the privatisation that occurred in 1997 when responsibility for operation and maintenance of the water supply was passed to two private companies under a 25 year concession agreement. Following this we carry out a cost and demand analysis similar to the preceding case study. In this case study we estimate the demand function based on data from a national household expenditure survey and, using this demand function, we estimate the welfare losses associated with current prices.

Although this work is not a comparative study, in Chapter 11 we identify and explain some common and contrasting results based on the two case studies. From this analysis we identify weaknesses in the marginal cost approach particularly in respect of the use of cost minimisation as the basic theoretical assumption. We then present an alternative approach based on the use of a stochastic cost frontier to model firms. This approach is gaining recognition in benchmarking and performance based utility pricing. Chapter 12 is a third case study that presents an application of performance modelling using a stochastic frontier model and a benchmarking data set originating from the World Bank. This case study suggests various ways in which price might be determined using this kind of performance based approach.

Chapter 12 concludes the thesis with a summary of the main results and presents a number of areas in which policy might be focused based on the evidence from the case studies and some stylised facts that have emerged from the study. Finally, we identify some new research questions and the proposed direction of future research in this area. A bibliography of cited references appears at the very end of the document.

CHAPTER 2

Urban Water Pricing

2.1 Introduction

The objective of this chapter is to review theoretical and conventional urban water pricing practice, and to establish both the motivation for use of marginal cost pricing and an understanding of the limitations of its use. We start with an overview of theoretical developments in utility pricing in general and water pricing in particular, before discussing the role of regulation, and the relationship between the form of regulation and the determination of price. We next review two alternative approaches to water pricing: rate of return pricing and marginal cost pricing. We will outline the case in support of marginal cost pricing and examine some of the limitations of its use. The following three chapters will then focus on development of cost, demand, and welfare models applicable to marginal cost pricing of water services.

2.2 Theoretical Foundations of Utility Pricing - First and Second Best Solutions

The economic basis of water pricing is that the supplier must be able to recover all of its costs including operations and maintenance, investment, and social costs including externalities. The economically efficient basis for pricing would be to set the price at the level of long run marginal cost so that net surplus is maximised. We will review some of the practical difficulties of this approach later in this chapter, but for now we concentrate only on the theoretical approaches that evolved during the twentieth century. At the heart of the problem of utility pricing (or of any network industry that exhibits increasing returns to scale) is that marginal cost pricing will result in a unit price that is less than average cost, therefore the utility will not generate sufficient revenue to cover costs. First and Second Best solutions differ mainly in how this shortfall is recouped (Harris, Tate, and Renzetti, 2002).

First Best pricing solutions rely on some form of lump sum transfer to make up the loss. Hotelling (1938) proposed the use of subsidies and taxation. This approach was criticised by Coase (1946) who considered subsidies to be distortionary. For example, a small community that is able to supply its own needs will most likely switch to a lower cost subsidised public utility despite the full cost of provision being higher than if they continued to self supply. The solution proposed by Coase entailed the use of a fixed charge covering the cost of network connection and a volumetric charge. The volumetric charge would be set at the marginal cost of supply, while the fixed charge would be set to make up the revenue shortfall. Subsequently, Vickrey (1955) pointed out that volume and distribution were two complementary goods - both with variable costs (volume decreasing marginal cost, while distribution was increasing moving to the network extremities). Residual costs could be recouped as fixed *network access* charges. Vickrey also argued that where consumers had the option of opting out of the supply, or not connecting at all, there was a degree of cross-price elasticity between volume and distribution.

Second Best or Quasi-Optimal Solutions are characterised by the use of price discrimination to recover costs. Of these Ramsey pricing and Pareto Superior Non-Linear Outlay Schedules are the most common. A Ramsey price is set at the welfare maximising level of output using price discrimination based on the demand elasticity of different user classes. This is calculated as a markup from the marginal cost - the Ramsey *number* (R). In the simplest case where there is only one good produced and the cross price elasticity of demand among user classes is zero, the Ramsey number is the percentage deviation from marginal cost weighted by the demand elasticity:

$$R_i = \left(\frac{p_i - m_i}{p_i}\right) * \eta_i$$

where for the i^{th} class of user, p_i is the volumetric charge for the good, m_i is its marginal cost, and η_i is the price elasticity of demand. Ramsey numbers are constrained to the interval $0 < R < 1$, with 1 corresponding to a price discriminating monopolist who recovers all costs, while 0 is perfect competition.

Ramsey pricing of water presents a difficulty in terms of equity because lower income consumers with inelastic demands will pay a higher unit price relative to those whose demand is more elastic such as higher income residential or industrial consumers. Pareto Superior Non-Linear Outlay Schedules (more simply declining block rate tariffs or volume discounts) were developed as a means of overcoming these problems. The introduction of one or more blocks with declining unit price results in an increase in both firm profit and consumer surplus, hence of net welfare. Willig (1978) showed that for any case where average cost was greater than the marginal cost, there exists a declining block rate structure that Pareto dominates the average cost price. The Pareto Superior solution stands in contrast to the case of increasing marginal cost of production caused, for example, by water scarcity. In this case the efficient solution is to apply an increasing block rate tariff that approximates the marginal cost curve where marginal cost is in excess of average cost (where there are decreasing returns to scale) and revert to the cost recovery methods where this is not the case. At higher levels of consumption, demand is more elastic so that the use of increasing block rates can be effective in conserving water.

In summary, from a theoretical viewpoint, the problem of utility pricing and water pricing in particular arise because the network structure leads to a form of monopolistic production characterised by increasing returns to scale. Under these conditions, if price is set at marginal cost, some form of transfer is required to make up the shortfall. Otherwise the problem becomes one of determining the optimum price level that is Pareto efficient for different classes of user. In the next section we discuss the regulatory environment within which this price setting occurs.

2.3 The Regulatory Environment

Natural monopolies arise in network industries such as water supply because high capital requirements create barriers to entry and the entrenched owner can produce under conditions of economies of scale and scope - therefore at a lower cost than the cost of multiple individual firms (sub-additivity). Regulation evolved in the nineteenth century to protect consumers from the potential abuse of monopoly powers while preserving the interests of investors. Utilities initially operated under private ownership, but where the interests of consumers and owners was in conflict, nationalisation took place (Newbery, 1998). Gas and water industries were renationalised in the United Kingdom in 1949 and 1973 respectively following excessive rent seeking by the private operators of those services. Similar events took place in Australia after the Second World War; for example, the South Australian Electricity Trust was nationalised in 1946, and the airline Qantas in 1947. The return of nationalised assets to private ownership in the latter part of the twentieth century (in the UK this occurred over a period 1984-1994, and in Australia in the 1990s) was in response to a widely held perception that years of public ownership had distorted prices and created inefficiencies, often as a result of repeated political interference (Saal and Parker, 2004). Private industry was considered a better vehicle to deliver cost efficiencies, service improvements and investment. In the developing parts of the world, the IMF and World Bank have been strong advocates of privatisation as a means of debt reduction and increasing access to capital markets for funding new infrastructure projects (Magdahl, Sørreimd, Christensen, Preston, Kronen, and Berg, 2006). Corresponding with the wave of privatisation that commenced over two decades ago, a considerable body of literature has evolved in the area of regulation and pricing of utilities, including water supply. This work was driven by the need for an expanded regulatory role in those countries where major privatisations had occurred, in particular the United Kingdom and the United States. Applied research focused on the impact of ownership on productivity and efficiency, and the extent to which consumers have benefited from changes in ownership. The studies of urban water supply undertaken since this period including, for example, Bhattacharyya, Parker, and Raffiee (1994); Bruggink (1982); Feigenbaum and Teeples (1983); Renzetti (1999); Saal and Parker (2004) aim to determine differences, if any, in cost efficiency or productivity by firms under private or public ownership. Often the applied results are inconclusive and sensitive to specification. A consensus is emerging from the empirical literature however, that it is the presence of competition that leads to cost efficiencies, rather than ownership *per se*. This debate is by no means over and remains an active area of research - nor is it the central theme of this study, but it has produced a great amount of useful applied research in the area of cost models and efficiency measurement.

One could argue that, using some form of Ramsey pricing, price determination is a mechanical process once long run marginal costs are understood and quantified. However, regulators have been reluctant to adopt this method because long run marginal costs are by definition forward looking and it is simpler to base price on historical data, adjusted for projected growth in demand and costs. Furthermore long run marginal costs should include costs that are related to scarcity, negative externalities such as greenhouse emissions, and the positive externalities arising from quality potable water. Much of the research in this area ignores these factors because data limitations mean these costs can not be estimated at the same accuracy of operating and investment costs. Increasingly regulators are under pressure to quantify these costs and provide for their recovery in the price.

The literature on utility price regulation appears to have evolved separately to that focused only on Pareto efficient pricing[1]; and tends to treat the regulatory environment as imposing a degree of incentive on a firm to manage costs and profitability. There are several forms of price regulation that we will review in the following sections.

2.3.1 Cost of Service Regulation

Direct price and rate of return regulation are collectively termed *cost of service* regulation. Direct price regulation affords the least incentive to the firm to operate efficiently, and has been the most criticised on economic grounds (Harris, Tate, and Renzetti, 2002).

Rate of Return price regulation allows the supplier to earn an agreed rate of return on its capital assets. Assuming a single period, and if fixed overhead costs are covered equally by fixed revenues (this might be achieved by a fixed charge applied to each account holder during each billing period), then we only have to consider the variable components of revenue and cost:

$$px = C(x, \mathbf{w}) + rK$$

where p is the unit price, x is the unit consumption, r is the agreed rate of

[1]Studies that tackle these issues together are uncommon.

return on K units of capital. $C()$ is a variable cost function that depends on consumption and a vector of input prices $\mathbf{w}$. The price is therefore:

$$p = AVC + r\frac{K}{x}$$

The capital output ratio K/x can be assumed constant for constant technology, and so the price is simply the average variable cost plus a constant markup. When the markup is implicitly included in the variable cost, the unit price is simply the average variable cost. This corresponds to a Ramsey number of one.

In practice the required rate of return is decided by the utility and built into its costs as presented to the regulator. The regulator sets the price such that the present value of future cash flows is equal to the present value of historical cash flows. The only decision variable is then the discount rate (often called the *appropriate discount rate* - ADR) used to discount future cash flows.

Rate of return regulation gives a degree of comfort to investors because of the guaranteed return and low risk. This can lower the cost of capital for the owners of the utility and ultimately benefit consumers. On the other hand there are a number of problems associated with this form of pricing. Rate of return regulation limits the firm's incentive to reduce costs because allowable costs are always recoverable. Firms have been known to engage in *cost padding* in their submissions, and deciding on allowable costs is problematic. There is also potential for *regulatory capture* (Laffont and Tirole, 1991). Firms regulated under rate of return tend to invest in excess of the efficient level if their cost of capital is lower than the rate of return - the Averch-Johnson Effect (Averch and Johnson, 1962). Rate of return regulation has also been criticised for the monitoring and reporting burden it places on both regulator and utility. Where different firms service different areas, there may also be significant discrepancies in prices.

2.3.2 Price Cap Regulation

Price cap regulation (Littlechild, 1988) is mainly intended to increase cost efficiency and promote investment. The firm manages its cost and pricing and is permitted to keep its profits for the period that the cap is in place. The cost reporting requirements are less; although the determination of the initial price cap is reliant on firms' historical and projected costs. The need to determine allowable costs and the rate of return is removed, as is the need for monitoring the firm's profits.

Price cap regulation is prevalent in the telecoms and electricity markets of Australia, where it operates under a form of allowable price adjustment known as CPI-X. In the UK it is called RPI+X and covers the telecoms, gas, airports, water, and electricity sectors. Under this regime, prices follow the CPI plus or minus a constant rate (X) that is determined by the regulator. The value of X is set so as to reflect cost efficiencies and technological improvements that are expected to occur over time, promoting efficiency and investment by the firm. In the next period, the base price is progressively lowered so that these benefits are passed on to consumers without diminishing the profit incentive for the firm. Successful implementation of price cap schemes depends on correctly setting the initial price base and the level of X. In some instances incorrect settings of these values may lead to problems. A price cap that is set too low may discourage investment; it may be uneconomic for the firm to employ all its capital, creating a problem of *stranded assets* and placing the regulatory agreement under strain (Newbery, 1998). On the other hand, firms that become too profitable may face a windfall profits tax.

Price caps appear to work well when competing firms offer different services using a monopoly network as is the case with the Australian mobile phone network.

The cap is set to an average for a basket of services and the firms are free to set prices within the basket as long as the average price is below the cap. Recently the NSW Independent Pricing and Regulatory Tribunal (IPART) has canvased the idea that the monopoly Sydney metropolitan supplier, Sydney Water, should allow third party access to the trunk network to supply competitive services (Keating, 2006).

2.3.3 Performance and Yardstick Based Approaches

Other forms of regulation including performance and yardstick regulation, have a light handed regulatory approach. Instead, targets are set - normally based on observation of firms regarded as industry leaders. These may relate to cost efficiency; but may also focus on quality, management and staffing, or some other measure of performance. In practice a hybrid form of regulation may be adopted. These methods place more emphasis on statistical and econometric approaches to benchmark setting. This is in contrast to cost of service and price caps which rely on historical and future cost estimates, and use averaging or present value methods to aggregate. Two methods that have received attention are Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA). Chapter 11 will present the motivation for using and theory behind stochastic frontier analysis, while Chapter 12 will give a case study application of this method.

2.3.4 Incentive Regulation Theory

The foregoing discussion indicates that regulation imparts some degree of incentive to a monopoly supplier to act as if it faces a competitive market, while the regulator is faced with imperfect information about the supplier's operation. Work in incentive theory views the regulator as facing an optimisation problem that requires maximisation of expected social welfare subject to a constraint of asymmetrical information. This situation involves a welfare loss compared to one of perfect information as, for example, when the firm engages in cost padding.

The extent to which a regulator observes utilities' true costs has been the subject of a number of studies. Baron and Myerson (1982) assumed that the regulator is unable to observe costs and therefore the firm has no need for overstatement. Laffont and Tirole (1986) present a model in which the regulator observes noisy cost and output of the firm. The firm can adjust its efficiency (proxied by marginal cost) according to an effort parameter; neither of which are observed by the regulator.

The problem of asymmetric information has been the subject of work related to cost of service regulation of water utilities. In Wolak (1994) a procedure for estimating the parameters of a regulated firm's production function under asymmetric information is presented based on a sample of California Class A water utilities. The model assumes that the firm holds private information that it can exploit to increase profit while revealing only the minimum requirement of information to the regulator. In a recent paper, Bougheas and Worrall (2006) model cost padding by observing differences in real and total (padded) costs in the contracting and the post-contractual stages.

The standard incentive regulation model of Laffont and Tirole (1986) is a Bayesian optimising problem which there is a trade-off between cost reduction and rent transfer to consumers:

$$R = b\bar{R} + (1 - b)C$$

where b is the *power* of the regulatory incentive scheme, $\bar{R}$ is a base revenue and C are costs. The lowest regulatory power, $(b = 0)$, corresponding to rate of return pricing, creates an opportunity for the firm to engage in *cost padding.* At the highest power, ($b = 1$), the utility receives all the benefit of its cost reduction and does not need to inflate its costs.

2.4 Practical Approaches to Urban Water Pricing

The practical basis of water pricing in a regulated environment is primarily *cost recovery* based and reliant on the use of historical and forecast cost and consumption data. The requirement for economic efficiency in water supply and criticism of rate of return regulatory approaches has focused attention on marginal cost approaches in price determination. Mann (1993) discusses the advantages of marginal cost pricing in an American context. In this section we consider the implications of a strict marginal cost approach before reviewing three different industry approaches to urban water pricing: Turvey long run marginal cost, average incremental cost, and base extra method. Each of these are departures from strict marginal cost but retain some of the desirable efficiency characteristics of that approach.

Strict marginal cost pricing of water entails the use of two marginal cost regimes (Warford, 2003). The price of water is its short run marginal operating cost as long as capacity is in excess of demand, and distribution requirements are met. Marginal capacity cost is zero when existing supply is at a safe level in excess of short term demand. The applicable marginal costs occur only in operating and distribution. Once demand increases to the level where capacity constraints are evident, prices increase (short run marginal cost becomes vertical) until either demand is reduced or consumers reveal their willingness to pay for the required investment in new capacity. If the latter is the case then the price follows the long run marginal cost curve. Once the capital investment has been carried out, there is again excess capacity and the relevant price is again the short run marginal cost curve. Expansion of the distribution network can be treated similarly, with marginal costs becoming zero once expansion is completed.

A variant of strict marginal cost pricing is based on the observation that demand varies seasonally and therefore capacity constraints are more likely to be evident at these times. In a study by Renzetti (1992), the welfare effects of adoption of a peak load pricing scheme were analysed and found to be positive. This entailed pricing according to the short run marginal cost in off peak demand periods and the long run marginal cost in peak demand periods (typically summer months). Peak demand prices were also proposed to be increased further in the event that capacity constraints would be met. Grafton and Kompas (2006) propose a modification to peak pricing that increases prices according to dam storage levels - implicitly weighting the marginal supply cost by a scarcity factor. Again, this would be subject to ensuring that the predicted aggregate demand at the new price level was safely within existing capacity. When dams were at or close to full storage levels, prices would revert to their short run marginal cost.

One feature of marginal cost approach to water pricing is the inclusion of a fixed charge or connection fee. This is justified for two reasons. First, as a means of recovery of fixed costs such as administration, meter reading, and other overheads. Second, as a form of Ramsey pricing, to recover the variable cost losses that arise when marginal operating costs are below average costs. Sibly (2006) argues that equity considerations in the use of a fixed charge can be overcome by relating it to property values - in the sense that these are a proxy for the consumer's ability to pay, or by use of a discount or concessional scheme based on need.

Although theoretically desirable, in practice strict marginal cost pricing is difficult to achieve for a number of reasons. Firstly it would lead to price fluctuations that may be unpopular with consumers and hold political risks for government. Secondly funds for investment in additional capacity may become available at a time when a comfortable buffer of capacity is still available; causing consumers to question the need for price increases. Thirdly there are risks involved with managing supply at or near its demand level. Unforeseen pressures on the supply such as increases in domestic demand, firefighting, or drought could lead to a critical water shortage. The approach prefered by utilities and governments is to leave a safe buffer of capacity.

To overcome these problems the utility industry has adopted several different approaches which we outline in the next three sections. Primarily these aim to recover costs, allowing for the *lumpy* nature of capital investment in water supply and the desirability of non-volatile rates.

2.4.1 Turvey Long Run Marginal Cost

Early work by Turvey (1976) set out to define the long run marginal cost of water supply as the sum of marginal capacity costs, marginal operating costs, marginal distribution costs and per connection overhead costs. Turvey claimed that marginal capacity costs need to be considered in a different light to conventional economic theory. Because commitments to capacity expansion are made years in advance to their implementation, the decision variable is not the actual incremental system expenditure, but rather the timing of implementation. Turvey shows that a one year change in commissioning new capacity can have a significant marginal cost, based on different capital recovery factors (discount rates) and consumption. This, he argued, is the actual marginal capacity cost. The UK Office of Water (OFWAT) (Price, 1993) and the Essential Services Commission in Victoria (Victorian State Government, 2005) have both employed this concept of marginal capacity cost to estimate long run marginal costs.

2.4.2 Average Incremental Cost Pricing

A second approach common among North American water suppliers is the Average Incremental Cost (AIC). This is defined as the additional cost per unit of additional consumption when both additional annual costs and consumption are expressed as the present value of their flows (Warford, 2003). If price is equated to cost of supply, the applicable volumetric price at the start of the period is:

$$p = \mathrm{AIC} = \frac{\mathrm{PV}\left(I_t + C_t - C_0\right)}{\mathrm{PV}\left(x_t - x_0\right)}$$

where for year t, I_t is investment, C_t is operating cost, and x_t is consumption, and the base year is $t = 0$.

Whilst theoretically less attractive than strict marginal cost approaches, the AIC approach has the desirable property of producing a constant price over for the period (possibly adjusted annually for inflation). The difficulties of this approach for the regulator are that the discount rate remains to be determined, and there is a possibility of a price discontinuity arising from a period in which no major investments are undertaken.

2.4.3 Base Extra Method

The Base Extra Method, used by the American Water Works Association (AWWA), is an allocation of historical costs and demands by user class and cost category. The user classes are residential, industrial, and commercial; and the cost categories are base, extra capacity, customer service, and fire protection. Base and extra capacity refer to marginal costs of production and investment under normal and peak consumption, while customer service are billing and metering overheads. Fire protection is related to cost of hydrants. A formula is used to determine the ratio of base to extra capacity costs. Each cost category for each user class is assigned a *rate method class cost* which is the average unit cost of providing that service to that user class. For example, the rate method class cost of base demand for the residential class is the average cost of one cubic meter of demand under base demand. The rate method class costs are summed to determine the tariff rate for each class of user.

There are two points to note in respect of the Base Extra Method. Firstly, it results in unit prices that are higher for residential users (compared to industrial and commercial) as that class are more likely to be assigned extra capacity costs. Secondly the price schedules will need modification if a block rate tariff is required or if the regulator disallows certain costs.

2.5 A Functional Approach to Water Pricing

The foregoing has demonstrated that regulation of utility industries requires the quantification of many variables including tariff price, input factor prices, allowable costs, social and private discount rates, industry rates of return, performance and quality standards, social and environmental costs and externalities, and mechanisms for their recovery. The utility must be able to predict population growth to determine capital investment requirements for the rate setting period. These capital investments must be ready well in advance of the time that predicted increases in demand occur. The sources and timing of finance are important factors also. These may not be directly controlled by the utility, and therefore short term adjustments in the form of price increases or restrictions may be required to cope with delays in investment. The regulator must ensure the presence of equity in pricing - so that low income groups receive a basic quantity of water at an affordable price. The regulator must also ensure that the supplier remains financially viable and is able to recover costs and repay creditors.

From an economic perspective the problem of water pricing requires an understanding of the opportunity costs of production, and, in the absence of competitive markets, determining how costs and benefits are allocated among consumers, producers and the environment. Current industry approaches have several deficiencies from an economic viewpoint. Firstly, there is an emphasis on average cost instead of marginal cost approaches to water pricing. While the average cost approach means that costs are recovered, it is also a less efficient solution as price signals are incorrect. This is particularly important when scarcity needs to be considered. Secondly, there is a dependence on historical costs in price determination. From an economic perspective these are sunk costs and do not enter into the decision mix because they cannot be controlled. Thirdly, existing methods based on second best solutions, may result in higher prices for users whose demand is inelastic because they have no substitutes.

One could argue that a market based approach to urban water supply may resolve some of these problems. Indeed, Littlechild (1988) sees regulation as a stop gap measure until competitive markets are in place. It is difficult to see how this might become completely possible given that most urban water is delivered over a network. Instead, competition, when it is introduced is likely to appear in other areas that can be dissociated from the network itself, such as meter reading and billing, maintenance, competitive tendering for capital works, and public-private partnerships. Importantly, as we will see in Chapters 11 and 12, the increased use of performance based benchmarking means that competition will not be within a network area but across different networks - municipalities, regions and indeed countries.

In the chapters that follow we depart from current industry and regulatory approaches to water pricing to examine the problem from a purely functional stance. We develop cost and demand functional specifications and, in case studies that follow, we test these against a number of data sets. This will allow us to characterise the parameters of production, cost and demand such as economies of scale and elasticities; and to demonstrate the utility of this approach to pricing.

CHAPTER 3

Production and Costs

3.1 Introduction

The objective of this chapter is to introduce production and cost models suitable for analysis of urban water service providers. Apart from their use in determining the marginal cost function, these models will enable us to measure the economic parameters of production and cost including output elasticities, cost shares, returns to scale and economies of scale. This introduction contains an overview of some of the work that has been carried out in this area, with emphasis on the various models employed. This is followed by a presentation of the theoretical basis of production and cost models. We then develop a minimum cost model for both constant returns to scale production technology and one for variable returns to scale production. This is followed by an examination of issues in estimation and the transformations required to express the models in a form suitable for estimation. Actual estimation of cost functions will be presented in two *case studies* that commence in Chapter 6. We conclude this chapter with a brief discussion.

3.2 Production and Costs in Urban Water Supply

An urban water supply can be broken down into several components. The raw water is extracted from a source such as a reservoir, aquifer, river or the sea.

It is then treated in various ways including filtration, chemically treated to meet public health standards for potable water, possibly treated for taste, and in some countries fluoridated. The water is distributed via a network of pipes to consumers including residential, commercial, and industrial users. For the purposes of this study, the extent of this network defines the boundaries of *urban* - in contrast to a rural supply which services outlying communities and relies on other forms of distribution such as channels, or where consumers source their own water.

Wastewater is collected via the sewerage network to treatment plants where it is treated to a standard suitable for discharge to the sea or some other water source. Stormwater is runoff collected by sewers or a separate drainage network and enters the wastewater treatment system or is dispersed directly to the sea or other water source. Leakages occur throughout water networks which result in *unaccounted for water*. Wastewater and stormwater networks may also record losses. Network infiltration is not uncommon also, and this can be a major problem if the potable supply is infiltrated.

Production is generally measured in terms of the amount of water delivered to customers, that is, the output of treatment plants. Generally this is not the same as the amount of water extracted from its sources as losses occur in the extraction and production. Similarly, wastewater volumes do not generally match consumption because of losses. Costs are the costs of management, operating, and investment in the various components of supply. These include the facilities where the water is harvested, treatment plants, pumping facilities, distribution networks, storage facilities, service connections, meters and fire hydrants. For wastewater the components include the distribution network, treatment plants, and may also include facilities for solid waste/effluent disposal. Costs can be classified as centralised or distribution costs. The distinguishing feature is that centralised costs are shared by a greater number of users compared to distribution costs which are incurred for fewer users as network density decreases. This explains why marginal costs are greater as network density decreases, and also why costs for network expansion, in for example, residential developments, are often born by the users.

The environment contributes to and is impacted by urban water supply. River basins act as collectors for reservoirs, and pollution of rivers by agricultural, industrial, or human activity can contribute to treatment costs. For supplies that rely on groundwater, poor quality and over extraction can also have an impact on treatment costs. Urban water and wastewater treatment are both energy intensive and therefore contribute to greenhouse emissions. Wastewater treatment itself is an industrial process that requires large amounts of water inputs. Wastewater is returned to the sea or river systems, while solid waste residues go to land fill. Environmental costs are difficult to quantify and applied work in this area is uncommon. In a number of countries water authorities now include levies in consumer tariffs which are returned to government to fund environmental initiatives.

3.3 Functional Modelling of Production and Cost

The estimation of production and cost functions of particular industries or sectors either nationally or regionally holds considerable interest for researchers. Work undertaken in this area has focused on the impacts of model specification, elasticity of substitution, and the dynamics of capital adjustment. Based on a US manufacturing data set, Kim (1992) used a translog production function to show that assumptions about homotheticity, homogeneity, and constant returns to scale in production were incorrect. In a study of industrial factor demand across six OECD countries, Kolstad and Lee (1993) also used a translog cost functional form to examine the variability of results under different model dynamics. The models specified include long run cost (full static equilibrium), short run restricted cost (partial static equilibrium), and short run restricted cost with a Euler equation (partial dynamic equilibrium) governing the change in capital stock. In a similar study, Bregman, Fuss, and Regev (1995) estimated production and cost functions for a panel data set of Israeli industry for the period 1979 to 1983. In each case short and long run estimates were obtained under assumptions of cost minimising choice of inputs. In Balistreri, McDaniel, and Wong (2003) the authors estimate the short and long run elasticity of substitution for different industry sectors based on U.S. Bureau of Economic Analysis (BEA) data and suggest that the true relationship between capital and labour is indeed most likely to be Cobb-Douglas. The study employed time series aggregates of production and inputs and compared results based on AR(1), first differences, and single error correction models.

For studies that are focused on the provision of utility services, including water, major areas of interest are model specification, long run marginal cost, returns to scale, and application of Ramsey pricing principles. We reviewed the major developments in this area in the previous chapter. As was discussed, one feature of current water pricing practice is the use of discounting to aggregate historical cost and future cost estimates - in contrast to the use of statistical modelling of cost functions. This approach is characterised by the two main approaches to cost determination used in the UK, USA and Australia: the Turvey method and the Average Incremental Cost method.

A functional approach to cost modelling has been a feature of the research literature since work by Nerlove (1963), considered to be among the earliest major application of statistical cost analysis (Greene, 2003, p. 125). Hines (1969) studied the relationship between cost and utility size in water production by regressing average fixed, variable and total costs on plant capacity utilisation and adjusted plant investment. These latter two terms are engineering measurements of utilisation and capital inputs. Bruggink (1982), in the context of the debate concerning public vs private ownership, modelled the effect of ownership on technical efficiency of municipal water companies in the USA. He used a linear model to regress operating costs on production and a set of variables related to inputs and input costs, treatment methods, distribution, regulation, and ownership. Feigenbaum and Teeples (1983), also contributing to the ownership debate, criticised the use of single output models and instead applied a hedonic model in translog form that included a multiple output variable containing volume produced and a vector of service attributes. Bhattacharyya, Parker, and Raffiee (1994) used a translog form for the cost equation to estimate technical, price, and scale efficiencies based on a cross section of American water utilities to conclude that public utilities were on average more efficient. Wolak (1994) uses a Cobb-Douglas production form to derive a two factor variable cost function in a study of regulator-utility information asymmetry. More recently, Saal and Parker (2004) examine the impact of privatisation of regional water authorities in England and Wales by measuring changes in productivity growth using a time dependent translog cost function.

There appear to be relatively few studies that directly address issues of welfare and tariff design. In a departure from other cost studies, Renzetti (1999) examines the welfare loss brought about by consumption at current prices compared to consumption at marginal cost for a cross section of municipal water and wastewater utilities in Ontario, Canada. He firstly estimated a system of cost and cost share equations for water and wastewater using a translog cost specification, and then estimated aggregate demand for residential and non-residential consumers using an OLS specification. The study found evidence of increasing returns to scale in both water and wastewater operations. Welfare loss due to mispricing was found to be around 78% of the existing unit price and around 29% of the efficient marginal cost for residential consumers. In another study (Pushpangadan and Murugan, 1998), the authors aim to address the problem of equity in Ramsey pricing of water supply under increasing returns to scale. They estimate a partial equilibrium to determine an optimal tariff for Kerala State in India that allows for subsidisation of low income (inelastic demand) users by high income (elastic demand) users.

3.4 Theory of the Firm

3.4.1 The Constant Elasticity of Substitution Production Function

The purpose of this section is to review the major results related to the theory of the firm. We will initially restrict ourselves to a class of production functions having those properties that permit analytical solution of the profit maximisation problem:

- homogeneous of degree one in factor inputs (ie. production exhibits constant returns to scale)
- quasiconcave
- twice differentiable

Within this class of functions, the Constant Elasticity of Substitution (CES) (Layard and Walters, 1987, p. 272) production function exhibits the required properties and has been widely used in economic analysis. The CES production function expresses a firm's output x as a function of its inputs, capital K and labour L:

$$x = \gamma \left[\delta K^{-\rho} + (1 - \delta) L^{-\rho}\right]^{-1/\rho}$$

where γ is an efficiency parameter, ρ a substitutional parameter, and δ is a distributional parameter.

The implicit form of the CES function is:

$$F(x, K, L) = x^{-\rho} - \gamma^{-\rho}\delta K^{-\rho} - \gamma^{-\rho}(1-\delta)L^{-\rho} = 0$$

By the Implicit Function Theorem (Klein, 1998, p. 240) we get the marginal products of labour and capital:

$$x_L = -\frac{F_L}{F_x} = \gamma^{-\rho}(1-\delta)\left(\frac{x}{L}\right)^{1+\rho}$$

$$x_K = -\frac{F_K}{F_x} = \gamma^{-\rho}\delta\left(\frac{x}{K}\right)^{1+\rho}$$

The ratio of these two is:

$$\frac{x_L}{x_K} = \frac{(1-\delta)}{\delta}\left(\frac{K}{L}\right)^{1+\rho} \tag{3.1}$$

The elasticity of substitution measures the change in the input ratio as the ratio of marginal products changes:

$$S_{KL} = \frac{\partial log(K/L)}{\partial log(x_L/x_K)} = \frac{1}{1+\rho}$$

Production *technology* is determined by the limiting value of ρ. When this is ∞, the technology is Marx-Leontief, when it is -1, it is linear or perfect substitution. As $\rho \to 0$, $S_{KL} \to 1$, and the technology is Cobb-Douglas production.

Totally differentiating the implicit CES form:

$$(-\rho)x^{-\rho-1}dx - \gamma^{-\rho}\delta(-\rho)K^{-\rho-1}dK - \gamma^{-\rho}(1-\delta)(-\rho)L^{-\rho-1}dL = 0$$

we set $\rho \to 0$ and integrate:

$$\begin{aligned} \frac{dx}{x} &= \delta\frac{dK}{K} + (1-\delta)\frac{dL}{L} \\ log\, x &= \beta + \delta log\, K + (1-\delta) log\, L \end{aligned}$$

to obtain the Cobb-Douglas production function:

$$x = \alpha K^{\delta} L^{(1-\delta)} \tag{3.2}$$

This function satisfies all our required properties. Moreover, the homogeneity requirement means that this class of production technology exhibits *constant returns to scale*, a linear increase in both inputs results in the same increase in output.

Under Cobb-Douglas, equation (1.1) above becomes

$$\frac{x_L}{x_K} = \frac{(1-\delta)}{\delta}\left(\frac{K}{L}\right)$$

This equation reveals two important properties of Cobb-Douglas technology. Firstly, the slope of all isoquants are the same for constant capital labour ratio. Secondly, moving along an isoquant (increasing capital labour ratio) the ratio of marginal product of labour to marginal product of capital is increasing. The same level of output is achieved with less labour so its marginal product must be increasing. By the same argument, the marginal product of capital must be decreasing.

3.4.2 The Constant Returns to Scale Minimum Cost Function

In the following treatment we assume that in water supply, input and output prices are determined exogenously and the firm has decided on a short term level of production output. Therefore the firm can only adjust input levels and will seek to maximise profits by cost minimisation. To simplify notation, we adopt a Cobb-Douglas production function with all inputs variable.

The firm's cost minimisation problem is to minimise:

$$C(w, r, L, K) = wL + rK$$

subject to the Cobb-Douglas production constraint:

$$x = \alpha K^{\delta} L^{(1-\delta)}$$

where w, r are the factor prices. The first order conditions are:

$$\begin{aligned} w &= -\lambda\alpha(1-\delta)\left(\frac{K}{L}\right)^{\delta} \\ r &= -\lambda\alpha\delta\left(\frac{K}{L}\right)^{\delta-1} \end{aligned}$$

The input price ratio is proportional to the input factor ratio, and also equal to the ratio of marginal products:

$$\frac{w}{r} = \left(\frac{1-\delta}{\delta}\right)\left(\frac{K}{L}\right) = \frac{x_L}{x_K}$$

Rearranging the first equality and solving for rK and wL in the cost equation, we can see that δ determines the cost shares of each input:

$$\begin{aligned} rK &= \delta C \\ wL &= (1-\delta)C \end{aligned}$$

We express the production constraint in terms of the capital labour ratio and replace this with the price ratio:

$$x = \alpha L \left[\left(\frac{w}{r} \right) \left(\frac{\delta}{1-\delta} \right) \right]^{\delta}$$

which can be rearranged to get the conditional labour demand function $L(x, w, r)$.

Transforming the cost objective function:

$$C = L \left[w + r \left(\frac{K}{L} \right) \right]$$

and inserting the expressions for labour demand and capital labour ratio delivers the minimum cost function for Cobb Douglas technology:

$$C(w, r, x) = \left[\alpha \delta^{\delta} (1-\delta)^{1-\delta} \right]^{-1} r^{\delta} w^{(1-\delta)} x \tag{3.3}$$

This function has the following properties (Luenberger, 1995, p. 42):

1. Homogeneous of degree one in factor prices
2. Homogeneous of degree one in output
3. Nondecreasing in factor prices
4. Concave in factor prices

3.4.3 Nonconstant Returns to Scale Minimum Cost Function

Despite the strong empirical evidence that production in many industries exhibit constant returns to scale in the long run, there are reasons for relaxing this assumption and seeking a more flexible technology. Utilities and other network industries have barriers to entry that promote economies of scale and therefore formation of natural monopolies (Luenberger, 1995, p. 64). Regulators of essential services require utilities to retain spare capacity. In the case of water supply this is to ensure they can cope with peak demands and emergencies such as water shortages or firefighting. This reserve capacity results in decreasing marginal costs and therefore increasing returns to scale. In the short run, utilities may be in a period of short term adjustment, they may be operating with an excess of capacity that creates a decreasing marginal cost, or alternately, capacity may be insufficient to meet demand, forcing marginal costs to increase.

In this section we present the derivation of the minimum cost function subject to a production constraint in a similar manner to the CRS formulation above but without the assumption about constant returns. We include three factors; capital, labour, and energy. These models are sometimes termed *KLE* production models.

The firm's cost minimisation problem is to minimise:

$$C(w, r, s, L, K, P) = wL + rK + sP$$

subject to the Cobb-Douglas production constraint:

$$x = AL^{\alpha}K^{\beta}P^{\delta}$$

where w, r, s are the factor prices. The sum of the exponents is the scale economies parameter: $\mathcal{Q} = \alpha + \beta + \delta$; $0 \leq \alpha \leq 1$, $0 \leq \beta \leq 1$, and $0 \leq \delta \leq 1$. Note that $\mathcal{Q} = 1$ implies CRS technology and $\mathcal{Q} < 1$ is decreasing returns to scale.

The first order conditions yield three price ratios:

$$
\begin{aligned}
\frac{w}{r} &= \frac{\alpha}{\beta}\frac{K}{L} \\
\frac{w}{s} &= \frac{\alpha}{\delta}\frac{P}{L} \\
\frac{r}{s} &= \frac{\beta}{\delta}\frac{P}{K}
\end{aligned}
$$

We use these to decompose the variable cost function into its shares, for example:

$$
\begin{aligned}
C &= L\left[w + r\left(\frac{K}{L}\right) + s\left(\frac{P}{L}\right)\right] \\
&= \frac{\mathcal{Q}}{\alpha} wL
\end{aligned}
$$

The cost shares are: $wL = \frac{\alpha}{\mathcal{Q}}C$, $rK = \frac{\beta}{\mathcal{Q}}C$, $sP = \frac{\delta}{\mathcal{Q}}C$.

We use the production function to derive the conditional factor demand for labour:

$$
L = \left[A^{-1}x\left(\frac{w}{r}\frac{\beta}{\alpha}\right)^{-\beta}\left(\frac{w}{s}\frac{\delta}{\alpha}\right)^{-\delta}\right]^{\frac{1}{\mathcal{Q}}}
$$

Finally we substitute this expression into the labour cost share to get the unrestricted cost function:

$$
C = \mathcal{Q}\frac{w}{\alpha}\left[A^{-1}x\left(\frac{w}{r}\frac{\beta}{\alpha}\right)^{-\beta}\left(\frac{w}{s}\frac{\delta}{\alpha}\right)^{-\delta}\right]^{\frac{1}{\mathcal{Q}}}
$$

$$
C(w,r,s,x) = \mathcal{Q}\left(\frac{1}{A}\right)^{\frac{1}{\mathcal{Q}}}\left(\frac{\alpha}{w}\right)^{-\frac{\alpha}{\mathcal{Q}}}\left(\frac{\beta}{r}\right)^{-\frac{\beta}{\mathcal{Q}}}\left(\frac{\delta}{s}\right)^{-\frac{\delta}{\mathcal{Q}}}(x)^{\frac{1}{\mathcal{Q}}} \tag{3.4}
$$

This function has the following properties, which are verified in Appendix A:

1. Homogeneous of degree one in factor prices
2. Homogeneous of degree $(1/\mathcal{Q})$ in output
3. Nondecreasing in factor prices
4. Nondecreasing in output
5. Concave in factor prices

3.5 The Translog Cost Functional Form

The preceding two cost models are either constant in output or exponential functions that are decreasing or increasing in output. In each case economies of scale are independent of factor prices. The function will indicate increasing, constant or decreasing returns to scale over the full range of output. In the case that economies of scale changes with output from increasing to decreasing returns, for example because average cost is quadratic in output (the cost function is a cubic polynomial), or that cost factor price elasticity is not constant, the CES functional forms may be too restrictive.

There are several approaches to this. The first is the direct use of a linear cost model that includes higher order terms as regressors. Although text books often use this form to show the parabolic shape of cost functions, in empirical work, this approach is not popular because the analytic form of cost elasticity also involves quadratic terms. The second is to employ a log-linear form that includes a squared log output term. Cost elasticity is a linear function of $\log x$, but there is still the question as to how prices enter the quadratic model.

A third approach involves the use of a more flexible cost function. The translog (*transcendental logarithmic*) function is widely used in the estimation of production and cost functions in empirical economics. It can be used to estimate any arbitrary polynomial function, however in practice only second or third order functions are used.

A translog function is a Taylor series expansion about some value of its arguments. As an example, Bhattacharyya, Parker, and Raffiee (1994) used a translog cost function to estimate the parameters of a variable cost function for a sample of US water utilities. The authors used a function with one input and output variable and three price variables $\mathbf{Z} = (X, \mathbf{p})$, $|\mathbf{Z}| = k$. The second order Taylor series was expanded around $\log(\mathbf{Z}) = \mathbf{0}$:

$$\log C = \sum_{i=1}^{k} \beta_i \log \mathbf{Z}_i + \frac{1}{2} \sum_{i=1}^{k} \sum_{j=1}^{k} \beta_{ij} \log \mathbf{Z}_i \log \mathbf{Z}_j$$

Translog cost functions are usually estimated as a system of equations. We will discuss issues related to their estimation in the next section.

3.6 Estimation of the Production and Cost Functions

3.6.1 Issues in Estimation

Before estimating these models there are several issues that we need to consider.

Firstly, the theoretical models based on CES production are static models that implicitly assume use of a cross-sectional data set. If multiple observations over time are available we would like to make use of these. The use of time series data introduces problems of autocorrelation of the error term and nonstationarity of time series. Autocorrelation can be tested for by use of the Durbin-Watson statistic and estimation can proceed using a technique such as Cochrane-Orcutt estimation (Pindyck and Rubinfeld, 1991, p. 141). We can test for nonstationarity of time series using Dickey Fuller tests. Estimation in the presence of nonstationarity of time series can proceed if the series for the dependent variable is cointegrated with a linear combination of the series for the independent variables. Otherwise an OLS model runs a risk of spurious regression and the model specification must be altered.

Secondly, a problem often encountered in applied work is omitted variables bias. The occurs when an unobserved independent variable is correlated with other independent variables. Varian (1984, p. 175) gives an example of this in relation to agricultural production. Suppose there is a factor *land quality* that is related to both output and to choice of capital inputs. If this is unobserved it becomes part of the error term. However under the OLS assumptions the error term must not be correlated with the regressors and so estimates will be biased. Wooldridge (2001, p. 248) mentions three methods for overcoming omitted variables bias in cross sectional data: OLS with a proxy for the omitted variable; instrumental variables method such as 2SLS; and a multiple indicator instrumental variables procedure.

Omitted variables is one instance of a more general problem of specification error. The generally accepted approach to determining the presence of specification error is by use of various tests, for example the Regression Specification Error Test (RESET) test (Hill, Griffiths, and Judge, 2001, p. 187). The use of panel data, if available, is another method for overcoming the omitted variables problem.

Panel data studies can be characterised by the presence of some heterogeneity among cross-sectional units that does not alter over time but that may not be directly measurable. This heterogeneity or *unobserved effect* causes bias in OLS estimation if it is correlated with any of the explanatory variables, including lags of those variables. With a two period panel data set, for example, a time-constant unobservable variable can be eliminated by use of first differencing. If the OLS conditions of orthogonality and full rank based on difference variables still hold then OLS will produce unbiased results. A key requirement for maintenance of the orthogonality condition is *strict exogeneity*. This is the requirement that the regressors in any time period are not correlated with the error term in any other time period. That is, unobserved effects that are absorbed into the error term may not influence explanatory variables in another time period.

For utility industries, estimation of the minimum cost function and use of duality to derive the parameters of the production function has an important advantage over the direct use of the production function. If factor prices are exogenous then any omitted endogenous factor (*unobserved effect*) will be uncorrelated with prices (Varian, 1984, p. 178). In the cost model presented earlier, output is also an explanatory variable. It is reasonable to assume that water output is driven by exogenous demand and so will be uncorrelated with the error term.

A third issue that has hampered progress in empirical work is difficulty in the measurement of capital stock. Most water infrastructure assets in the major cities of the world were commissioned many decades ago. Accounting book values may differ from replacement value. The outstanding debt on assets might be used as a capital stock measure but this also may not reflect replacement value. This provides further motivation for use of duality in estimation.

3.6.2 Specification of the Constant Returns to Scale Minimum Cost Function

The Cobb-Douglas production function is:

$$x = \alpha K^{\delta} L^{(1-\delta)}$$

By confining ourselves to a restricted model, and with cross sectional data, a log-linear form may be expressed in terms of a single regressor:

$$log\left(\frac{x_i}{L_i}\right) = \beta_0 + \beta_1 log\left(\frac{K_i}{L_i}\right) + u_i$$

where u_i is an independently and identically distributed error term with zero mean.

The minimum cost function corresponding to this production function is:

$$C = Ar^{\delta}w^{1-\delta}x$$

In restricted CRS log linear model form with cross sectional data this becomes:

$$log\left(\frac{C_i}{w_i x_i}\right) = \gamma_0 + \delta log\left(\frac{r_i}{w_i}\right) + u_i$$

Note that the parameters of the production function based on estimation of the minimum cost function will in general not be the same as those derived by direct estimation.

3.6.3 Specification of the Variable Returns to Scale Minimum Cost Function

The three factor unrestricted minimum cost function is:

$$C = \mathcal{Q}\left(\frac{1}{A}\right)^{\frac{1}{\mathcal{Q}}}\left(\frac{\alpha}{w}\right)^{-\frac{\alpha}{\mathcal{Q}}}\left(\frac{\beta}{r}\right)^{-\frac{\beta}{\mathcal{Q}}}\left(\frac{\delta}{s}\right)^{-\frac{\delta}{\mathcal{Q}}}(x)^{\frac{1}{\mathcal{Q}}}$$

The log linear form requires factoring out the coefficients and forming price ratios. Using cross sectional data:

$$log\left(\frac{C_i}{r_i}\right) = \gamma_0 + \frac{\alpha}{\mathcal{Q}} log\left(\frac{w_i}{r_i}\right) + \frac{\delta}{\mathcal{Q}} log\left(\frac{s_i}{r_i}\right) + \frac{1}{\mathcal{Q}} log\left(x_i\right) + u_i$$

In this form the variable coefficients form a system of three equations with three unknowns and hence a unique solution for the estimates exists. The choice of which variable to form the ratio is arbitrary.

3.6.4 Translog Cost Function

We assume cost is a product of two separable output and price functions, then:

$$\log C(X, \mathbf{p}) = \log f(X) + \log g(\mathbf{p})$$

In the case that there are constant returns to scale, then $g(\mathbf{p})$ is the average cost function.

Shephard's lemma states that if $C(X, \mathbf{p})$ is a minimum cost function, then the cost shares that produce the minimum cost for some level of output are:

$$s_i = \frac{\partial \log C(X, \mathbf{p})}{\partial \log p_i} = \frac{\partial \log g(\mathbf{p})}{\partial \log p_i}$$

The second order Taylor series expansion of $\log g(\mathbf{p})$ about $\log \mathbf{p} = \mathbf{0}$ is:

$$\log g = \beta_0 + \sum_{i=1}^{k} \frac{\partial \log g}{\partial \log p_i} \log p_i + \frac{1}{2} \sum_{i=1}^{k} \sum_{j=1}^{k} \left(\frac{\partial^2 \log g}{\partial \log p_i \partial \log p_j} \right) \log p_i \log p_j$$

The derivatives in this expression become constants when evaluated at the expansion point. Let

$$\beta_i = \frac{\partial \log g}{\partial \log p_i}, \quad \text{and} \quad \delta_{ij} = \delta_{ji} = \frac{\partial^2 \log g}{\partial \log p_i \partial \log p_j}$$

then we have:

$$\log g = \beta_0 + \beta_1 \log p_1 + \cdots + \beta_k p_k + \delta_{11} \frac{1}{2} \log^2 p_1 + \cdots + \delta_{kk} \frac{1}{2} \log^2 p_k + \delta_{12} \log p_1 \log p_2 + \ldots$$

We derive the i^{th} share equation by differentiating this with respect to the i^{th}

price:

$$s_i = \frac{\partial \log g(\mathbf{p})}{\partial \log p_i} = \beta_i + \delta_{i1} \log p_1 + \delta_{i2} \log p_2 + \cdots + \delta_{ik} \log p_k$$

In the share equation form, the elasticities of substitution (Greene, 2003, p. 368) are $\theta_{ij} = (\delta_{ij} + s_i s_j)/(s_i s_j)$ and $\theta_{ii} = (\delta_{ii} + s_i s_i - s_i)/(s_i^2)$.

The share equations form a system of k equations that can be estimated by a multiple equation method such as Seemingly Unrelated Regression (SUR) estimation (Greene, 2003, p. 366).

3.6.5 Panel Data Estimation

The basic linear regression model used in panel data estimation is:

$$y_{it} = \mathbf{x}_{it}'\boldsymbol{\beta} + \mathbf{z}_i'\boldsymbol{\alpha} + \varepsilon_{it}$$

where $\mathbf{x}_{it}$ is a vector of explanatory variables for the i^{th} cross sectional unit, and $\mathbf{z}_i$ is a vector of time constant individual effects for the i^{th} cross sectional unit. An example (Greene, 2003, p.284) of the presence of time constant individual effects in short and wide panel data analysis occurs when different firms exhibit different economies of scale.

We consider three different techniques that may be used to estimate the parameters of the equation above depending on the form of $\mathbf{z}_i$.

1. Pooled regression. When $\mathbf{z}_i$ is a constant then OLS will yield consistent and efficient estimates of the parameters $\boldsymbol{\beta}$ and the constant term α.

2. Fixed effects. This entails capturing the mean group specific behaviour in a single variable that is constant for each cross sectional unit. This means that we are replacing the unobserved linear combination of individual effects

with a single value, ie. $\alpha_i = \mathbf{z}_i'\boldsymbol{\alpha}$.

3. Random effects. In the random effects approach we split the individual effect into a term that is constant mean value for the whole panel (as in the pooled case) and a disturbance term distributed around this mean but with only one random drawing for each cross sectional unit. The regression model appears now as:

$$y_{it} = \mathbf{x}_{it}'\boldsymbol{\beta} + \alpha + u_i + \varepsilon_{it}$$

with α the constant term capturing mean behaviour for all units and u_i the time constant cross sectional disturbance term.

3.7 Chapter Discussion

One of the objectives of this thesis is to establish an economic basis for urban water pricing based on marginal cost. This chapter has presented several production and cost models that appear promising for this application. Much of the applied literature has focused on the use of cost models in applications other than price determination. These include measurement of economies of scale and scope, elasticity and substitution effects, and cost drivers. Duality can be used to derive the parameters of production and factor demands. Cost modelling is important for identification of endogenous and exogenous cost drivers. Shadow pricing can be used to price non-market factors, in particular those that are associated with user costs. The theory underlying these cost models assumes that firms aim to minimise costs. In the case of water utilities, this is reasonable given that there are few other controllable parameters. Later in the thesis we will contrast this with another approach that relaxes this assumption.

CHAPTER 4

Household Demand

4.1 Introduction

In this chapter we present the theoretical basis for determination of the urban water demand function. Determination of price and income elasticity of demand is generally the primary aim of empirical demand analysis (Deaton and Muellbauer, 1983, p. 17). For the purposes of this study, an estimate of household demand will help determine the efficient price, where net benefits are maximised. For water authorities, it is important to know how households will respond to changes in prices. In the short run, demand can be expected to decrease with an increase in price. The change in revenue may be positive or negative depending on demand elasticity. For a scarce resource such as water, these changes need to be balanced with the benefits of reduced demand. Changes in demand can also be expected as incomes increase. A high income family may eat out more often, and reduce their domestic water consumption, compared to a lower income family. Alternatively, they may build a bigger house with more bathrooms and consume more water.

We present two complementary models, both have gained considerable acceptance in empirical work over more than two decades. The first is the *Almost Ideal Demand System* of Deaton and Muellbauer (1980) that builds on early work in linear expenditure systems. The second is a model of household demand in the context of block rate pricing - a form of pricing common in utility industries. This model was proposed initially by Burtless and Hausman (1978). We describe estimation of this model by use of a Maximum Likelihood Estimator (MLE), based primarily on work by Moffitt (1986). This modelling and estimation framework has been applied in a working paper from Rietveld, Rouwendal, and Zwart (1997) based on a household consumption data set from Central Java in Indonesia. A derivation of the MLE likelihood function used in estimation of the block rate demand function is included in Appendix B.

4.2 Consumer Optimisation Problems

A consumer derives an amount of well-being or satisfaction through consumption of a market basket, the cost of which does not exceed the available income in the same period. This is measured by a utility function that permits different baskets to be ranked numerically so that higher ranked baskets are preferable to lower ranked ones. Utility, in its simplest form, can be expressed as a function of consumption:

$$U = u(\mathbf{x})$$

where $\mathbf{x}$ is a consumption vector of goods in the market basket, or *bundle*. Existence of a utility function is predicated on the *axioms of choice*: reflexivity, completeness, transitivity, continuity, monotonicity, nonsatiation, and convexity[1]. These dictate a consistent ordering of preferences over bundles of goods (Varian, 1984, p. 113). In applied work, utility is usually not observable. If we assume the existence of a utility function, we can use a constant unspecified level of utility, represented by an *indifference curve*, to solve consumer optimisation problems in terms of the variables that can be observed: prices, quantities and expenditures.

[1]Formally, nonsatiation and convexity are not required for existence of a utility function.

There are two constrained optimisation problems that are the basis of demand theory. First, the utility maximisation problem is:

$$\text{maximise } u(\mathbf{x}), \text{ subject to } (\mathbf{p} \cdot \mathbf{x}) \leq m$$

where $\mathbf{p}$ and $\mathbf{x}$ are vectors of prices and quantities for goods in the bundle, and m is income. In this problem all points on the indifference curve that are above the budget line are infeasible, those below the budget line are suboptimal as there is a feasible indifference curve with a higher level of utility. The solution to this problem is the *indirect utility* function $v(\mathbf{p}, m)$, the locus of maximal utility obtained over the domain of prices and incomes.

Second, the expenditure minimisation problem is:

$$\text{minimise } (\mathbf{p} \cdot \mathbf{x}), \text{ subject to } u(\mathbf{x}) \geq u^*$$

where u^* is the minimum required utility. In this problem all points on the indifference curve that are above the budget line are suboptimal as they have higher expenditure, those below the budget are infeasible, as they are below the required level of utility. The solution to this problem is the *expenditure* function $e(\mathbf{p}, u^*)$, the locus of minimal expenditure (or cost) obtained over the domain of prices and utility.

4.2.1 Demand Functions

Demand functions determine the response in the quantity of a good demanded when prices, income, and utility are variable. The *Marshallian* demand curve plots the change in consumption of the good as its price, or the price of any other good changes - holding income at some constant level m^*. For any vector of prices $\mathbf{p}$, the utility maximisation problem produces an optimal level of consumption:

$$x_i(\mathbf{p}, m^*) = \arg\max_{x_i} \; u(\mathbf{x}) \quad \text{, subject to } (\mathbf{p} \cdot \mathbf{x}) \leq m^*$$

More generally we allow incomes to vary also, and the Marshallian demand function defines a family of demand curves $x(\mathbf{p}, m)$. When attention is focused on one particular good, and the consumer's response to its *own price*, the remainder of the market basket can be aggregated into one good (the *numeraire*) with price normalised to one. The price of the good being studied is expressed as a relative price and analysis is reduced to two dimensions.

The *Hicksian* or *compensated* demand curve, in contrast, plots the change in consumption as prices change, for the expenditure minimising consumer - holding utility constant. At each new price point, the consumer is *compensated* with more or less income so that she remains at the same utility level u^*. Formally, Hicksian demand is stated as:

$$h_i(\mathbf{p}, u^*) = \arg\min_{x_i} \; e(\mathbf{p}, u^*) \quad \text{, subject to } u(\mathbf{x}) \geq u^*$$

More generally, allowing utility to vary also, the Hicksian demand function defines a family of demand curves: $h(\mathbf{p}, u)$.

4.2.2 Applied Demand Analysis and the Almost Ideal Demand System

Indirect utility, Marshallian and Hicksian demand are functions that describe consumer demand subject to different variables being held constant and under different optimisation objectives[2]. Applied analysis generally involves the search for a functional form for demand that performs well in empirical work and satisfies desirable theoretical properties. One such demand function is the Almost Ideal Demand System of Deaton and Muellbauer (1980) and a modified version of it

[2] These functions are related by a set of identities see: Varian (1984, p. 126).

that has proven popular in empirical work, the Linear Approximate Almost Ideal Demand System. These are based on early work in linear expenditure systems, for example, Pollack and Wales (1978).

The Almost Ideal expenditure function determines the least amount of money required to reach utility level u^* when prices are $\mathbf{p}$. It is a function of prices and utility that is non-linear in its parameters, α, β, γ:

$$\ln e(\mathbf{p}, u^*) = \alpha_0 + \sum_k \alpha_k \ln p_k + \frac{1}{2} \sum_k \sum_j \gamma_{kj} \ln p_k \ln p_j + u^* \beta_0 \prod_k p_k^{\beta_k} \tag{4.1}$$

In the following steps we eliminate the (assumed unobservable) utility u^* to produce a form suitable for estimation. We begin by differentiating the expenditure function with respect to the log price of good i:

$$\frac{\partial \ln e(\mathbf{p}, u)}{\partial \ln p_i} = \alpha_i + \frac{1}{2} \sum_k (\gamma_{ki} + \gamma_{ik}) \ln p_k + u^* \beta_0 \beta_i \prod_k p_k^{\beta_k} \tag{4.2}$$

Shephard's lemma (Jehle and Reny, 2001, p. 36) states that the Hicksian demand for the i^{th} good is equal to the change in expenditure for a unit change in its price:

$$\frac{\partial e(\mathbf{p}, u)}{\partial p_i} = x_i$$

The left hand side of equation 4.2 is the price elasticity of expenditure. We can show that this is equivalent to the share of expenditure for the i^{th} good by removing the logs and applying Shephard's lemma:

$$\frac{\partial \ln e(\mathbf{p}, u)}{\partial \ln p_i} = \frac{\partial e(\mathbf{p}, u)}{\partial p_i} \frac{p_i}{e(\mathbf{p}, u)} = \frac{x_i \ p_i}{e(\mathbf{p}, u)}$$

Now we express expenditure in terms of the desired level of utility u^*, and assume that the minimum expenditure at this level is equal to income m. The share equation can then be expressed in terms of prices and income:

$$
\begin{aligned}
\frac{x_i \; p_i}{e(\mathbf{p}, u)} &= \alpha_i + \frac{1}{2}\sum_k (\gamma_{ki} + \gamma_{ik}) \ln p_k + u^* \beta_0 \beta_i \prod_k p_k^{\beta_k} \\
s_i &= \alpha_i + \frac{1}{2}\sum_k (\gamma_{ki} + \gamma_{ik}) \ln p_k + \\
& \quad \beta_i \left(\ln m - \alpha_0 + \sum_k \alpha_k \ln p_k + \frac{1}{2} \sum_k \sum_j \gamma_{kj} \ln p_k \ln p_j \right)
\end{aligned}
$$

The share equation is therefore:

$$
s_i = \alpha_i + \frac{1}{2}\sum_k (\gamma_{ki} + \gamma_{ik}) \ln p_k + \beta_i \ln \left(\frac{m}{P^*} \right) \tag{4.3}
$$

where P^* is a price index of the form:

$$
\ln P^* = \alpha_0 + \sum_k \alpha_k \ln p_k + \frac{1}{2} \sum_k \sum_j \gamma_{kj} \ln p_k \ln p_j
$$

A simplified form of Equation 4.3 that has gained some popularity in empirical work involves the use of Stone's price index; a share weighted average price:

$$
\ln P^* = \sum_k s_k \ln p_k
$$

The model that uses this price index is known as the Linear Approximate Almost Ideal Demand System. The uncompensated demand elasticities (Green and Alston, 1990) are:

$$
\eta_{ij} = -\delta_{ij} + \frac{1}{w_i} \left(\gamma_{ij} - \beta_i \frac{\partial \ln P^*}{\partial \ln p_j} \right)
$$

where $\delta_{ij} = 1$ for $i = j$ otherwise $\delta_{ij} = 0$, and P^* is the chosen price index.

The main advantage of the Linear Almost Ideal model appears to be data related. Household expenditure surveys often record expenditure and prices, but not consumption on different goods. Official price indices for commodity groups can be used in preference to household surveyed prices. Use of this model in applied work continues to be quite popular for example, Blanciforti and Green (1983); Nelson (1994).

4.3 Modelling Demand subject to a Block Rate Tariff

Commonly, utilities such as water, power, and gas, are sold using a *block rate tariff*, where the volumetric price varies with consumption, usually in non-linear steps. Utility tariffs may also include a fixed service or connection charge, which may contain a basic quota of the commodity, beyond which volumetric pricing starts. Volumetric prices under a block rate tariff are either all increasing or all decreasing. Decreasing block rates are commonly used when there are increasing returns to scale and average costs are decreasing. Increasing block rate tariffs (IBRT) are employed to reduce consumption when there are decreasing returns to scale and average costs are increasing. When there are short run increasing returns to scale, an increasing block rate tariff prices the commodity according to its long run marginal cost so that investment in expanded capacity can occur.

In many parts of North America, domestic water was in the past priced using a flat fee (decreasing average rate) or a declining block rate. This was a result of the utility using average costs to price water and an abundant supply (Tietenberg, 1992, p. 241). Australia and the UK have progressively moved to volumetric pricing with one or two block rates. As metering becomes more widespread, and as the economic costs of water supply are better understood, use of IBRT pricing is becoming more common.

The microeconomic theory of demand subject to a block rate tariff involves representation of the budget constraint in a piecewise linear form that consists of *segments* of constant marginal price and *kinks* where the price changes. Utility maximisation subject to this kind of constraint induces a nonlinear form of demand function that, as observed in empirical work, causes demand to cluster around the kinks. There has been a considerable effort over more than thirty years in theory development and model estimation in a variety of applications where price is endogenous because it varies with the dependent variable. Early studies commenced with the work of Burtless and Hausman (1978) in the context of taxation and transfer programs, consumer surplus (Hausman, 1981), and later in model specification and estimation by Moffitt (1986, 1990). Outside of the labour supply and welfare literature, utility pricing using block rate tariffs is an area of active research that has received much attention including Hewitt and Hanemann (1995), Dalhuisen, Florax, de Groot, and Nijkamp (2003), Chicoince and Ramamurthy (1986), Billings (1987), Taylor, McKean, and Young (2004), Gaudin, Griffin, and Sickles (2001), and Nieswiadomy and Molina (1989).

4.3.1 The IBRT Demand Function

In the following we consider a household as the sample unit and confine ourselves to a two good consumption basket where the second good is the numeraire, normalised to have unit price. A linear budget constraint defines the set of feasible consumption bundles whose cost does not exceed the available income[3]. On the constraint, income and expenditure are equal:

$$m_i = px_i + y_i$$

In this expression m_i is household i's income, p is the relative price of the first

[3]We will assume that all income is spent.

good, x_i is consumption of the first good, and y_i is the expenditure on the second good. Now consider the case when the unit price of the first good changes at some threshold level of consumption, x^*. The household budget constraint now consists of two segments:

$$m_i = \begin{cases} p_1 x_i + y_i & \text{if } x_i \leq x^* \\ p_1 x^* + p_2(x_i - x^*) + y_i & \text{if } x_i > x^* \end{cases}$$

where p_1 is the price in the first block of consumption and p_2 is the price in the second block. The second block constraint can be simplified by substituting $\hat{m}_i = m_i + (p_2 - p_1)x^*$, so that it becomes $\hat{m}_i = p_2 x_i + y_i$ for $x_i > x^*$. Graphically, $\hat{m}_i$ occurs at the intersection of the extended second segment with the y axis. In the literature this is known as the *virtual* or *imputed income*. As price and income are constant over each segment of the constraint each must also have constant indirect utility value, $v(p_1, m_i)$, and $v(p_2, \hat{m}_i)$.

The demand function is derived by initially finding the segment with the highest indirect utility, for which Marshallian demand is feasible. The household choice is:

$$\begin{array}{lll} \text{segment 1:} & \text{if } v(p_1, m_i) > max\,(v(p_2, \hat{m}_i), u(x^*, y^*)) & \text{and} \quad x(p_1, m_i) < x^* \\ \text{segment 2:} & \text{if } v(p_2, \hat{m}) > max\,(v(p_1, m_i), u(x^*, y^*)) & \text{and} \quad x(p_2, \hat{m}_i) > x^* \\ \text{kink:} & \text{if } u(x^*, y^*) > max\,(v(p_1, m_i), v(p_2, \hat{m}_i)) & \end{array}$$

where y^* is the level of consumption of the numeraire that corresponds with x^*, and $x(p, m)$ is Marshallian demand. For example, segment 1 is chosen if it has an indirect utility that is greater than that of both the other segment and the kink, *and* the point of utility maximisation lies on segment 1.

Note that in the case that the budget set is nonconvex, it is possible to construct a situation where there are two solutions - the utility maximising points lie on the same indifference curve but within different segments. This can be seen in

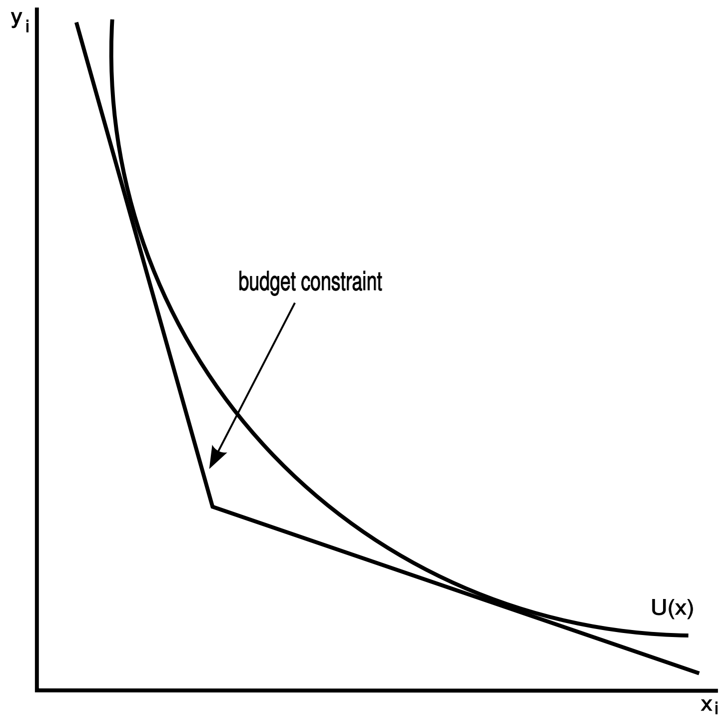

Figure 4.1. Nonconvex Budget Constraint

Figure 4.1. In this case some additional criterion must be applied to identify a unique choice. A solution for the nonconvex case is given by Moffitt (1986). As we are only concerned with increasing block tariffs we confine the analysis to a convex budget set.

With a convex budget set, the existence of a utility maximising point somewhere along a budget segment is sufficient to guarantee that segment will be chosen. For example, consider a situation where there is a utility maximising point ω strictly located on the first segment, ie. $x(p_1, m_i) < x^*$. As preferences are strongly monotonic (alternately as utility is quasiconcave), and the budget set is convex; both the kink and all points on the second segment must be less

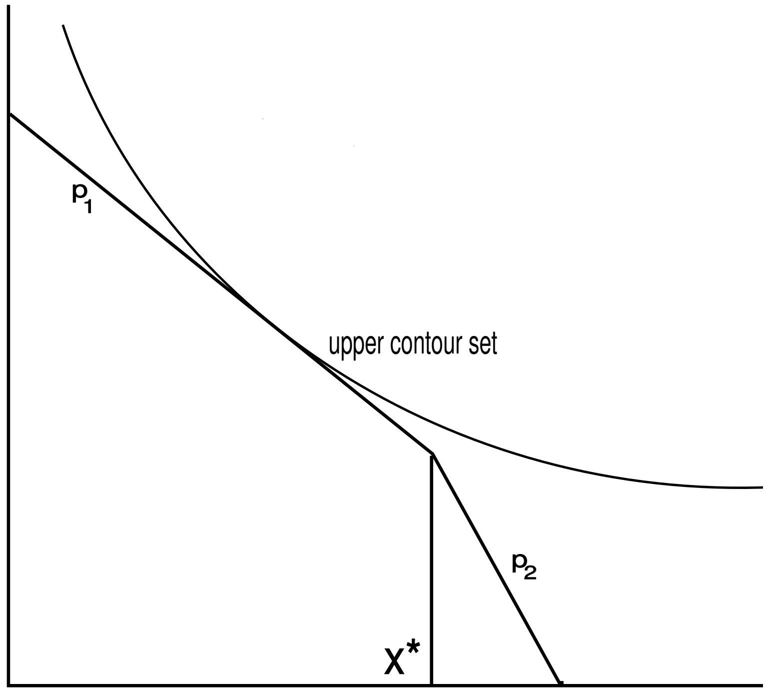

Figure 4.2. Convex Budget Constraint

preferable than $x(p_1, m_i)$. In other words, there is an upper contour set that includes ω but that excludes the kink and all points on the other segment. By the same argument, $x(p_2, \hat{m}_i) > x^*$ implies that no other point on the first segment or the kink will be preferred. If there is no optimal point on either segment, then consumption must occur on the kink. None of this precludes the possibility of a corner solution when one of the segments is chosen.

This is shown in figure 4.2 for the two segment case.

The demand function for household i can therefore be expressed in conditional terms as:

$$x_i = \begin{cases} x(p_1, m_i) & \text{if } x(p_1, m_i) < x^* \\ x(p_2, \hat{m}_i) & \text{if } x(p_2, \hat{m}_i) > x^* \\ x^* & \text{otherwise} \end{cases}$$

An equivalent compact form of demand function using indicators is given by Moffitt (1986) as:

$$x_i = d_1(x(p_1, m_i)) + d_2(x(p_2, \hat{m}_i)) + (1 - d_1 - d_2)x^* \tag{4.4}$$

where:

$$d_1 = 1 \quad \text{if } x(p_1, m_i) < x^* \quad \text{otherwise, } d_1 = 0$$
$$d_2 = 1 \quad \text{if } x(p_2, \hat{m}_i) > x^* \quad \text{otherwise, } d_2 = 0$$

4.3.2 Estimation of the IBRT Demand Function

4.3.2.1 Least Squares

The application of OLS to this model can result in biased results due to correlation between the explanatory variables and the error term. In this case, the model in 4.4 is specified with a measurement error term:

$$x_i = d_1(x(p_1, m_i)) + d_2(x(p_2, \hat{m}_i)) + (1 - d_1 - d_2)x^* + \varepsilon_i$$

As the error term increases in magnitude, the likelihood that we will observe demand in a block adjacent to the block in which *true* demand occurs will also increase. Therefore there will be positive correlation between the explanatory variables and the error term. As noted by Moffitt (1986), the problem with the use of OLS to estimate the demand function is caused by the incorrect assumption that all unexplained variance in consumption is measurement error, including the possibility of omitted variables. Although these assumptions hold for a large class of problems, in the case of piecewise linear budget constraints, a more sophisticated form of error specification is required. This lead to development of a two error model by Burtless and Hausman (1978) for study of the effects of taxation on labour supply, and upon which many subsequent studies have been based.

4.3.2.2 The Two Error Specification

The two error specification aims to explain all of the unexplained variation in terms of both measurement error and heterogeneity of preferences error (HPE). These errors have different effects. Measurement error is spread out evenly over the budget constraint because the random component is uncorrelated with the explanatory variables and across households. Heterogeneity of preferences generates clusters around the expected points of utility maximisation. For example, given perfect measurement of two households with identical characteristics (incomes, size, etc.), the model would predict that utility maximisation would occur at the same point and that consumption would be the same. The fact that it does not is due to the inability of the model to fully account for different preferences or tastes across households. Although this appears to be a kind of omitted variables problem, combining both measurement and heterogeneity of preferences errors leads to biased results as just discussed. Therefore we would expect that a specification containing two error terms with different and independent distributions will produce substantially better estimation results.

We will consider the model with only heterogeneity of preferences error initially, before incorporating the measurement error term. A generic form of demand function with HPE included is:

$$x_i = x(p_i, m_i, z_i, \beta, \alpha_i)$$

where x_i is household $i's$ monthly consumption of water, p_i is the marginal price paid by household i, m_i is the household's budget, z_i is a vector of covariates, β is a vector of coefficients of the regressors (including a constant), and α_i is the HPE error, assumed to have distribution: $\alpha \sim N(0, \sigma_\alpha^2)$.

We will confine ourselves to a specification of HPE as an added disturbance so the complete demand specification can be expressed as:

$$x_i = d_1 \left(x(p_1, m_i) + \alpha_i\right) + d_2 \left(x(p_2, \hat{m}_i) + \alpha_i\right) + (1 - d_1 - d_2)x^* \tag{4.5}$$

where:

$$d_1 = 1 \quad \text{if } x(p_1, m_i) + \alpha_i < x^* \quad \text{otherwise, } d_1 = 0$$
$$d_2 = 1 \quad \text{if } x(p_2, \hat{m}_i) + \alpha_i > x^* \quad \text{otherwise, } d_2 = 0$$

The household choice conditions in 4.5 allow us to identify the dichotomous parameters of the assumed distribution of α. Segment 1 is chosen for $\alpha_i < x^* - x(p_1, m_i)$, segment 2 is chosen for $\alpha_i > x^* - x(p_2, \hat{m}_i)$, and the kink for all points between. Therefore under the assumption of normality and zero mean, these inequalities identify two critical points (α', α''), that define the boundaries of choice. The amount of probability assigned to the segments and kink determines the degree of clustering that will be evident. The distribution of α_i is depicted in Figure 4.3.

The empirical evidence that observations of demand subject to piecewise linear budget constraints tend to cluster around the kinks is supported by the theoretical model with the assumption of normality. We can see that the support for the kink lies between α_i' and α_i'' and these two extremes are on either side of the mean of the distribution. Despite the empirical evidence of clustering around the kinks, and the two error model's support for this, we note that it is possible

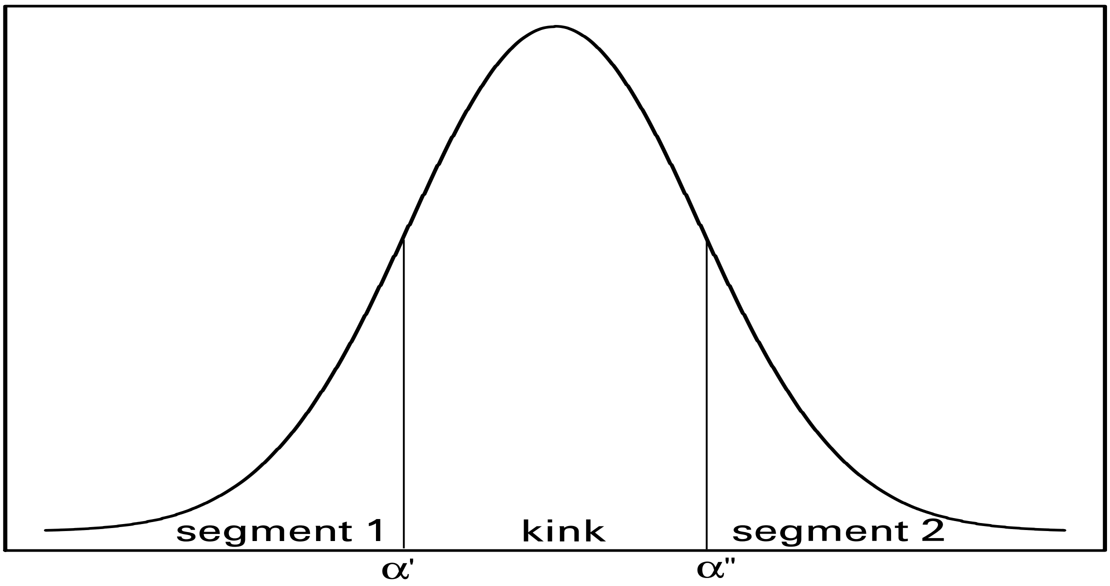

Figure 4.3. Distribution of α

to construct a piecewise linear budget constraint in which the expected point of utility maximisation does not occur at a kink. The model can also handle this situation. The critical points in the distribution of α would be set so that the segment probability was large and the kink probability was small.

4.3.2.3 Measurement Error

We can now reincorporate a measurement error term into the model. The approach is to assume that measurement is normally distributed: $\varepsilon \sim N(0, \sigma_{\varepsilon}^2)$, and the error term is simply added to the expected demand. Furthermore we assume that both errors are uncorrelated, ie. $cov(\alpha, \varepsilon) = 0$, and, in general $\sigma_{\alpha}^2 \neq \sigma_{\varepsilon}^2$.

The model now becomes:

$$x_i = d_1(x(p_1, m_i) + \alpha_i) + d_2(x(p_2, \hat{m}_i) + \alpha_i) + (1 - d_1 - d_2)x^* + \varepsilon_i \tag{4.6}$$

where:

$$d_1 = 1 \quad \text{if } x(p_1, m_i) + \alpha_i < x^* \quad \text{otherwise, } d_1 = 0$$

$$d_2 = 1 \quad \text{if } x(p_2, \hat{m}_i) + \alpha_i > x^* \quad \text{otherwise, } d_2 = 0$$

4.4 Maximum Likelihood Estimation of the Two Error Model

Maximum Likelihood Estimation (MLE) involves maximisation of a likelihood function that is a function of the known sample values, the unknown coefficients of the demand function, and the unknown parameters of the distributions of the error terms. Maximisation is performed by an iterative computer algorithm that varies the unknown coefficients and parameters in such a way as to converge to the maxima of the likelihood function. Most econometric or statistical software packages provide some capability in this area. With a highly nonlinear demand function, programming the maximum likelihood procedure is generally required.

The development of the likelihood function starts with determination of the likelihood for a single unit. Assuming that all units are independent, then the sample likelihood is the product of the unit likelihoods, or the sum of the unit log-likelihoods. Log-likelihood conversion is more accurate because probabilities can be summed reducing the risk of numeric underflow.

We will initially develop a likelihood function for the two error model with a two segment, one kink tariff. This will be followed by two proposals for adaptation to a tariff with more than two blocks. The likelihood of a single unit is determined by reference to a bivariate density function of the errors, for a particular value of expected demand. The bivariate density has zero mean and contours of equal probability that are elliptical in shape as determined by the variances of the errors. For the two error demand model, maximum likelihood estimation requires finding the set of demand coefficients that determine the errors of the data set, and the parameters of a bivariate normal distribution that most closely fits the distribution of these errors.

4.4.1 The Likelihood Function

The MLE approach is to reform the specification given by 4.6 in terms of the stochastic errors whose distributions we wish to estimate. For the ith household, the observed demand in segment 1 is given by:

$$x_i = x(p_1, m_i) + \alpha_i + \varepsilon_i$$

The probability of the occurrence of this observation in segment 1 is:

$$\Pr\left[(\alpha_i + \varepsilon_i = x_i - x(p_1, m_i)) \wedge (\alpha_i < x^* - x(p_1, m_i))\right]$$

where $\wedge$ is logical *and.*

If we define the total error as $v_i = \alpha_i + \varepsilon_i$, then the contribution to the likelihood function of an observation in the first segment is an integral over the bivariate distribution of v_i and α_i, that is:

$$\Pr[\text{segment } 1] = \int_{-\infty}^{x^* - x(p_1, m_i)} h(v_i, \alpha_i) d\alpha_i \tag{4.7}$$

where h is the bivariate normal distribution. Similarly, the joint probability for segment 2 is:

$$\Pr\left[(\alpha_i + \varepsilon_i = x_i - x(p_2, \hat{m}_i)) \wedge (\alpha_i > x^* - x(p_2, \hat{m}_i))\right]$$

and so the contribution to the likelihood function of an observation in the second segment is:

$$\Pr[\text{segment } 2] = \int_{x^* - x(p_2, \hat{m}_i)}^{\infty} h(v_i, \alpha_i) d\alpha_i \tag{4.8}$$

For the kink, observed demand is only subject to measurement error as the expected demand is x^*:

$$x_i = x^* + \varepsilon_i$$

Maximisation on the kink occurs over an interval $[\alpha_i', \alpha_i'']$ of α centred around its mean value. Therefore the joint probability for a kink observation is:

$$\Pr\left[(\varepsilon_i = x_i - x^*) \wedge (x^* - x(p_1, m_i) < \alpha_i < x^* - x(p_2, \hat{m}_i))\right]$$

This may be expressed as a joint probability integrated over $[\alpha_i^{'}, \alpha_i^{''}]$,

$$\Pr[\text{kink}] = \int_{x^* - x(p_1, m_i)}^{x^* - x(p_2, \hat{m}_i)} f(\varepsilon_i) f(\alpha_i) d\alpha_i \tag{4.9}$$

The likelihood of a single observation $\Pr[x_i]$ is therefore the sum of expressions 4.7, 4.8, and 4.9:

$$\Pr[x_i] = \int_{-\infty}^{x^* - x(p_1, m_i)} h(v_i, \alpha_i) d\alpha_i + \int_{x^* - x(p_2, \hat{m}_i)}^{\infty} h(v_i, \alpha_i) d\alpha_i + \int_{x^* - x(p_1, m_i)}^{x^* - x(p_2, \hat{m}_i)} f(\varepsilon_i) f(\alpha_i) d\alpha_i \tag{4.10}$$

This expression may be transformed so that it contains only standard normal density and probability functions:

$$\Pr[x_i] = \frac{1}{\sigma_v} f(z_{1i}) F(r_{1i}) + \frac{1}{\sigma_v} f(z_{2i})[1 - F(r_{2i})] + \frac{1}{\sigma_\varepsilon} f(s_i)[F(t_{2i}) - F(t_{1i})] \quad (4.11)$$

where z, r, s, t are standardised forms of the errors and integration limits that appear in 4.10 above. The complete derivation and explanation of terms is presented in the Appendix B.

Finally, the sample likelihood and the function that we wish to maximise is:

$$L(\beta, \sigma_\alpha, \sigma_\varepsilon) = \prod_i \Pr[x_i]$$

4.4.2 Extending the Model with more than Two Blocks

In this section we formulate two different methods for extending the model to accommodate more than two blocks. The first follows directly from the two error model presented in Section 4.3.2.2. The second method alters the consumer choice decision in the face of multiple blocks to a binary decision that is carried out multiple times. Therefore preference sets will be different in both methods as will the computed sample likelihoods.

4.4.2.1 Multiple Choice Method

We begin by extending the conditions under which the indicator variables are set in the original model 4.6:

$$
\begin{array}{lll}
d_1 = 1 & \text{if } (x(p_1, m_{i,1}) + \alpha_i < x_1^*) & \text{otherwise, } d_1 = 0 \\
d_2 = 1 & \text{if } (x(p_2, m_{i,2}) + \alpha_i > x_1^*) \wedge (x(p_2, m_{i,2}) + \alpha_i < x_2^*) & \text{otherwise, } d_2 = 0 \\
d_3 = 1 & \text{if } (x(p_3, m_{i,3}) + \alpha_i > x_2^*) \wedge (x(p_3, m_{i,3}) + \alpha_i < x_3^*) & \text{otherwise, } d_3 = 0 \\
\ldots & &
\end{array}
$$

where x_k^* is the k^{th} kink and $m_{i,k}$ is the virtual income in block k for household i. These expressions can be simplified further; for example, the logical expression in the second block becomes:

$$x_1^* < x(p_2, m_{i,2}) + \alpha_i < x_2^*$$

$$x_1^* - x(p_2, m_{i,2}) < \alpha_i < x_2^* - x(p_2, m_{i,2})$$

The kinks occupy a range of density between the segments. For example, the second kink is between the second and third segment. Therefore the integration limits are given by:

$$x_2^* - x(p_2, m_{i,2}) < \alpha_i < x_2^* - x(p_3, m_{i,3})$$

We can now express the likelihood function for a single observation as the sum of all s segments and $s-1$ kinks:

$$
\begin{aligned}
\Pr[x_i] \quad = \quad & \int_{-\infty}^{x_1^* - x(p_1, m_i)} h(v_i, \alpha_i) d\alpha_i + \sum_{j=2}^{s-1} \int_{x_{j-1}^* - x(p_j, m_{i,j})}^{x_j^* - x(p_j, m_{i,j})} h(v_i, \alpha_i) d\alpha_i + \\
& \int_{x_{s-1}^* - x(p_s, m_{i,s})}^{\infty} h(v_i, \alpha_i) d\alpha_i + \sum_{j=1}^{s-1} \int_{x_j^* - x(p_j, m_{i,j})}^{x_j^* - x(p_{j+1}, m_{i,j+1})} f(\varepsilon_i) f(\alpha_i) d\alpha_i
\end{aligned}
$$

The modifications to 4.11 follow directly from this.

4.4.2.2 Binary Choice Method

We generalise to the n-block tariff case by considering an arbitrary kink x_j^*. Define $LEFT_j$ to mean *all segments and kinks to the left of* x_j^* and $RIGHT_j$ to mean *all segments and kinks to the right of* x_j^*. Following from the two segment case in 4.7 and 4.8, the likelihood of each is:

$$\Pr[LEFT_j] = \int_{-\infty}^{x_j^* - x(p_j, m_{i,j})} h(v_i, \alpha_i) d\alpha_i \tag{4.12}$$

and:

$$\Pr[RIGHT_j] = \int_{x_j^* - x(p_j, m_{i,j})}^{\infty} h(v_i, \alpha_i) d\alpha_i \tag{4.13}$$

Therefore the probability of the j^{th} segment is:

$$\Pr[\text{segment } j] = \Pr[RIGHT_{j-1}] * \Pr[LEFT_j] \tag{4.14}$$

The kink probability is:

$$\Pr[\text{kink } j] = 1 - \Pr[RIGHT_j] - \Pr[LEFT_j] \tag{4.15}$$

The likelihood function for a single observation is now expressed as the sum of the first and last segments, $s-2$ segment product terms, and $s-1$ kinks:

$$
\begin{aligned}
\Pr[x_i] \quad = \quad & \int_{-\infty}^{x_1^*-x(p_1,m_i)} h(v_i,\alpha_i)d\alpha_i + \int_{x_{s-1}^*-x(p_s,m_{i,s})}^{\infty} h(v_i,\alpha_i)d\alpha_i + \\
& \sum_{j=2}^{s-1}\left[\left(\int_{x_{j-1}^*-x(p_{j-1},m_{i,j-1})}^{\infty} h(v_i,\alpha_i)d\alpha_i\right) * \left(\int_{-\infty}^{x_j^*-x(p_j,m_i)} h(v_i,\alpha_i)d\alpha_i\right)\right] + \\
& \sum_{j=1}^{s-1}\int_{x_j^*-x(p_j,m_{i,j})}^{x_j^*-x(p_{j+1},m_{i,j+1})} f(\varepsilon_i)f(\alpha_i)d\alpha_i
\end{aligned}
$$

4.5 Chapter Discussion

In this chapter we have presented theoretical and econometric models suitable for applied analysis of urban water consumption. The consumer problem is one where a budget must be allocated among different goods in an optimal way. Linear expenditure systems allows us to determine the elasticity of demand using budget shares and price indices. The two error model is used to model the non-linear demand that occurs when consumers are faced with an increasing block rate tariff, an increasingly common form of urban water pricing.

CHAPTER 5

Welfare and Optimal Pricing

5.1 Introduction

This chapter examines the role of welfare in water price determination. We discuss the measurement and maximisation of welfare using conventional cost benefit approaches. We examine the relationship between marginal cost, average cost and economies of scale in production. Then we assess marginal cost and second best water pricing in terms of the level of subsidy required. Second best or Ramsey pricing has been criticised for adverse equity effects. We examine a model of welfare maximisation that allows regulator to weight different classes of users to achieve a more equitable outcome under Ramsey pricing. Finally we examine some issues related to estimation of welfare using the cost and demand models presented in the preceding two chapters. Note that in the following treatment we assume that demand curves are formed by the horizontal summation (quantities summed according to prices) of the household demand curves, and that the marginal cost curve is that of a representative single utility that supplies all households.

5.2 Measurement of Welfare

The use of total net benefit as a measure of static welfare has origins dating from the eighteenth century, but became widespread when an executive order of the US President in 1981 mandated that regulatory arms of government adopt this approach. In this section we will present a brief outline of the main result of maximisation of total net benefit - more detail is available in texts such as Tietenberg (1992) and Boardman, Greenberg, Vining, and Weimer (2006).

An allocation x^* of some good is *statically efficient* if its total net benefit is maximised at a single point in time:

$$x^* = \arg\max_x \left(CS(x) + PS(x) \right)$$

where consumer surplus is the excess of benefit over cost:

$$CS(x^*) = \int_0^{x^*} MB(x,m)dx - p^* x^*$$

and producer surplus is the excess of revenues over cost:

$$PS(x^*) = p^* x^* - \int_0^{x^*} MC(x)dx$$

In this notation the inverse demand or marginal benefit function is $MB(x,m)$, while the inverse supply or marginal cost function is $MC(x)$, where x and m are quantity and income respectively.

Letting $\omega(x) = CS(x) + PS(x)$, the maximum occurs where $\partial\omega/\partial x = 0$, that is:

$$MB(x) - \left[MB(x) + x\frac{\partial MB(x)}{\partial x} \right] + \left[MB(x) + x\frac{\partial MB(x)}{\partial x} \right] - MC(x) = 0$$

therefore:

$$MB(x^*) = MC(x^*)$$

The partial equilibrium (x^*, p^*), where marginal benefit is equal to marginal

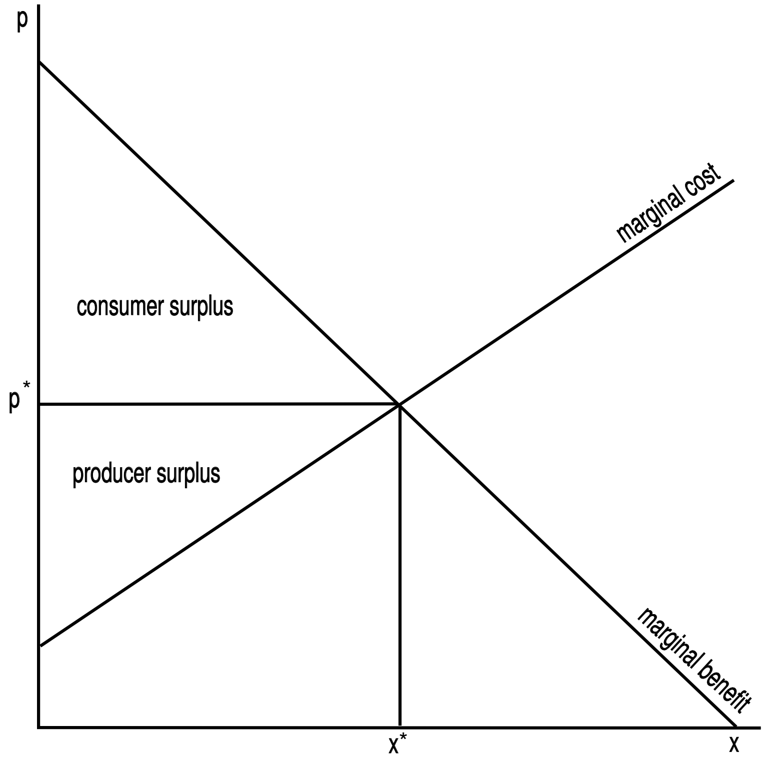

Figure 5.1. Maximisation of Total Net Benefit

cost, is the point where total net benefit is maximised. This is shown in Figure 5.1.

In practice this equilibrium changes over time. If the good is a renewable scarce resource such as water then a series of statically efficient allocations may deplete the resource faster than it can be renewed. This form of scarcity can be modelled as a constrained maximisation problem. A stream of allocations $x_t,\ \ t = 1 \ldots T$ is dynamically efficient if the sum of the net present values of the net benefit of each allocation is maximised. We can determine the optimal allocations by maximising the objective function:

$$\sum_{t=1}^{T}\left[(1+r)^{1-t}\left(\int_0^{x_t} MB(x)dx - \int_0^{x_t} MC(x)dx\right)\right]$$

subject to the constraint:

$$\sum_{t=0}^{T} q_t < Q$$

5.3 Measurement of Welfare Change

Often it is the change (or in the simplest case the sign of the change) in welfare that is the principal object of interest. In this section we consider the loss of welfare arising from pricing water below marginal cost using *deadweight loss* as our measure.

Deadweight loss is the loss of net benefit caused by the inefficient price. This is:

$$DWL(x^0) = \int_{x^*}^{x^0} (MC(x) - MB(x, m))\ dx$$

where x^0 is the inefficient level of output, and $x^0 > x^*$. This situation is depicted in Figure 5.2 where the deadweight loss is area C and the marginal cost is increasing.

The contrasting cases of constant marginal cost and decreasing marginal cost are shown in Figures 5.3 and 5.4. The dead-weight loss in both cases is area C. These correspond respectively to constant returns to scale and increasing returns to scale.

In Renzetti (1999) two normalised measures of inefficiency are presented. The first is the proportional deviation from the optimal quantity of water supplied:

$$DEV(x^0) = \frac{x^0 - x^*}{x^0}$$

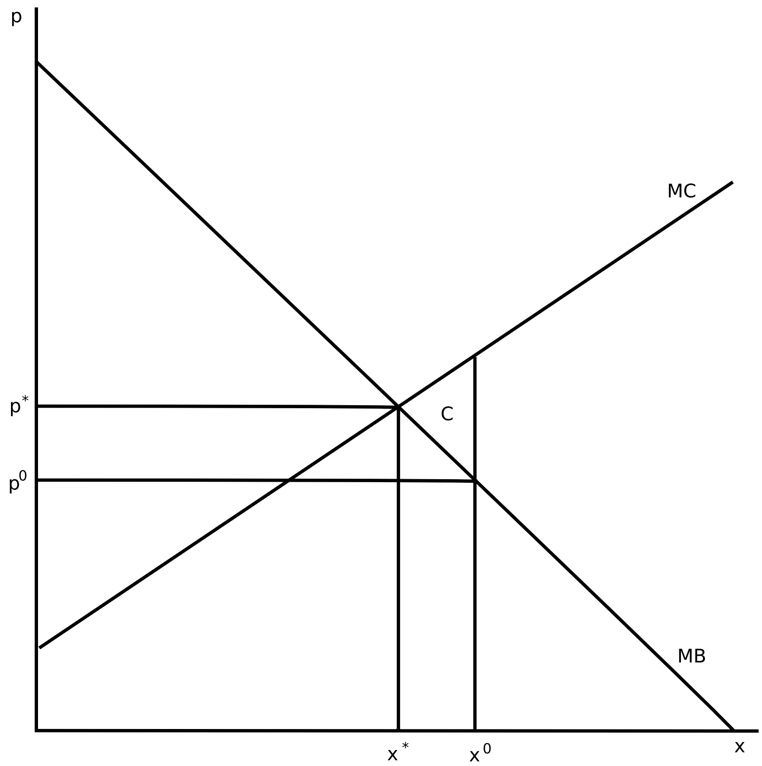

Figure 5.2. Deadweight Loss from Inefficient Pricing

The second is deadweight loss per unit of output:

$$waste(x^0) = DWL(x^0)/x^0$$

An alternative measurement of welfare change when firms supply with constant marginal cost is *compensating variation*(CV) (Jehle and Reny, 2001, p. 167). This is the change in income that is required to keep a consumer's utility constant when the price changes. Graphically, it is the area to the left of the Hicksian or compensated demand curve bounded by the original and the new price. The CV

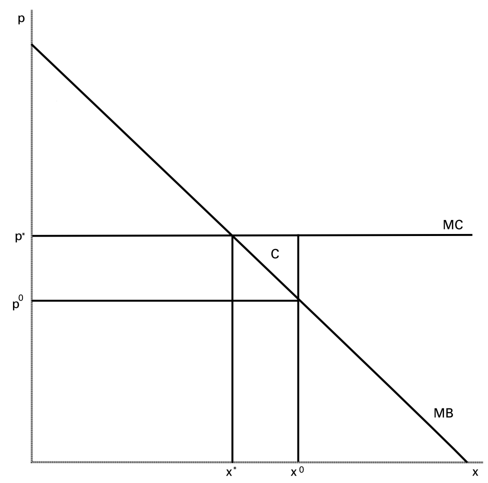

Figure 5.3. Deadweight Loss under Constant Marginal Cost

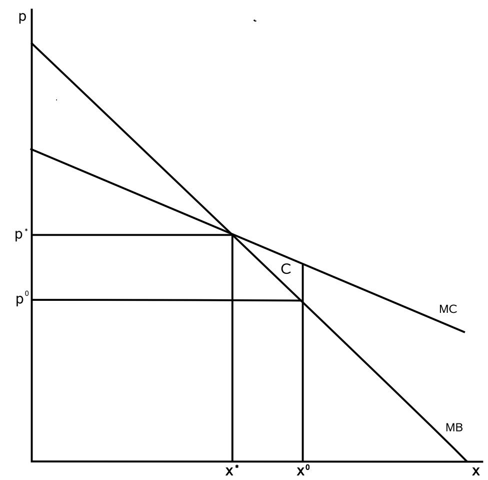

Figure 5.4. Deadweight Loss under Decreasing Marginal Cost

is formulated as:

$$CV = \int_{p_0}^{p_1} x_h(p, m)dp$$

Generally Hicksian demand is not observable. In empirical work, under conditions of small price changes, and when the good constitutes only a small proportion of total expenditure, compensating variation can be approximated by the change in consumer surplus, ΔCS.

5.4 Welfare and Economies of Scale

We have seen that in the supply of urban water, and other regulated industries, firms generally operate under increasing returns to scale. Therefore Figure 5.4 is the more applicable to the case of water supply. In this case, setting the volumetric price at marginal cost means that price is below average cost and therefore either the price is set at marginal cost and the utility receives a subsidy to cover the shortfall, or a Ramsey (second best) pricing scheme is adopted so the firm can recover its costs. When the utility serves different classes of consumer, use of a Ramsey pricing scheme creates a potential problem of equity. This is because the markup will be higher for the class of consumers with less elastic demand, for example low income households, compared to those with more elastic demand.

In the following three sections we discuss the relationship between economies of scale and marginal and average cost, determine the amount of subsidy required for strict marginal cost pricing, and lastly address the problem of equity in allocations.

5.4.1 Marginal Cost, Average Cost, and Economies of Scale

Consider a generalised cost function with m outputs and k factor prices:

$$C = C(x_1, x_2, \ldots, x_m, w_1, w_2, \ldots, w_k)$$

The cost elasticity of the i^{th} output is:

$$\xi_{Cx_i} = \frac{\partial C / \partial x_i}{C / x_i}$$

For a multiproduct firm, the measure of scale economies is defined as the reciprocal of the sum of the cost elasticities (Kim, 1995):

$$\mathcal{Q} = \frac{1}{\sum \xi_{Cx_i}} \tag{5.1}$$

where $\mathcal{Q}$ is the returns to scale parameter. If outputs are priced at their marginal cost, then:

$$\mathcal{Q} = \frac{C}{\sum p_i x_i} = \frac{C}{R} \tag{5.2}$$

Therefore the overall measure of scale economies is the ratio of cost to revenue. If this is greater than one, then there are economies of scale and the utility does not recover all its costs if marginal cost pricing is adopted.

We can also examine the relationship of economies of scale with marginal and average cost. In the case where there is only one output we have:

$$AC = \mathcal{Q}MC$$

Therefore:

$$\begin{aligned}
\mathcal{Q} > 1 \quad &\Leftrightarrow \text{increasing returns to scale,} \quad \text{AC} > \text{MC} \\
\mathcal{Q} = 1 \quad &\Leftrightarrow \text{constant returns to scale,} \quad \text{AC} = \text{MC} = \text{constant} \\
\mathcal{Q} < 1 \quad &\Leftrightarrow \text{decreasing returns to scale,} \quad \text{AC} < \text{MC}
\end{aligned}$$

In the case of multiple outputs we need to recognise that the portion of variable cost devoted to production of each output is not the same as C/x_i and therefore returning to equation 5.2,

$$\begin{aligned}
\mathcal{Q} &= \frac{1}{\sum\left(MC_i\ x_i\right)} \\
&= \frac{AC}{\sum\left(MC_i\ \frac{x_i}{x}\right)} \\
AC &= \mathcal{Q}\sum\left(\frac{x_i}{x}\ MC_i\right)
\end{aligned}$$

Therefore average cost is the economies of scale multiplied by the weighted sum of the marginal cost of each output where the weights are the share of outputs

5.4.2 Cost Recovery under Marginal Cost Pricing

Consider the amount of subsidy required if all outputs are priced at marginal cost. This will be $C - R$. From equation 5.2 the subsidy will be:

$$S = C\left(1 - \frac{1}{\mathcal{Q}}\right)$$

For increasing returns to scale, the amount of subsidy as a proportion of cost increases with the degree of scale economies $\mathcal{Q}$. No subsidy is required when returns to scale are constant or decreasing.

5.4.3 Equity in Ramsey Pricing

We consider now the use of a Ramsey (above marginal cost) pricing scheme for a regulated water utility. In the case of a single output, the tradeoff for the regulator is between decreasing consumer surplus and increasing profitability (decreased subsidisation) of the utility. When there are multiple outputs and distinct user classes for each output, problems of equity emerge as Ramsey prices will be higher for those user classes with inelastic demand. In this section we illustrate this with a model originally presented by Ross (1984) where the regulated utility produces two goods that have distinct user classes, demand and prices, and zero cross price elasticity. For a water utility, if the goods are residential and non-residential water, then the production mix and input prices are the same and a single marginal cost function is applicable.

The welfare problem is to maximise total consumer welfare so that the loss does not exceed some predetermined value. In the following notation, the consumer surplus function for good i is $z(p_i)$, the profit function is $\pi(p_1, p_2)$ and the regulator implicitly weights the welfare of group i by α_i. The problem can be expressed as:

Maximise: $\Theta = \alpha_1 z(p_1) + \alpha_2 z(p_2)$ subject to: $\pi \geqslant \pi^*$.

The Lagrangian is:

$$\mathcal{L} = \alpha_1 z(p_1) + \alpha_2 z(p_2) - \lambda(\pi - \pi^*)$$

The first order condition is:

$$\alpha_i \frac{\partial z(p_i)}{\partial p_i} = \lambda \frac{\partial \pi(p)}{\partial p_i}$$

By the definition of consumer surplus, the instantaneous rate of change in surplus as price increases is current consumption:

$$\frac{\partial z(p_i)}{\partial p_i} = -x_i$$

The rate of change in profit can be determined by differentiation of the revenue and cost components R, C as follows:

$$\begin{aligned}
\pi &= R\left(x(p)\right) - C\left(x(p)\right) \\
\frac{\partial \pi}{\partial p_i} &= \frac{\partial R}{\partial x}\frac{dx}{dp_i} - \frac{\partial C}{\partial x}\frac{dx}{dp_i} \\
&= \left(p_i + x_i\frac{dp_i}{dx} - MC\right)\frac{dx}{dp_i}
\end{aligned}$$

Substituting these results into the first order condition we have:

$$\begin{aligned}
\lambda\left(p_i + x_i\frac{dp_i}{dp} - MC\right)\frac{dx}{dp_i} &= -\alpha_i x_i \\
\left(\frac{p_i - MC}{p_i}\right)\frac{dx/dp_i}{x_i/p_i} &= -\frac{\lambda + \alpha}{\lambda}
\end{aligned}$$

Therefore, expressing the own price elasticity of demand η as an absolute value:

$$\left(\frac{p_i - MC}{p_i}\right)\eta_i = \frac{\lambda + \alpha}{\lambda}$$

The left hand side of this last expression is the Ramsey number, the term $(p_i - MC)/p_i$ is the markup and ranges from 0 (MC pricing) to 1. The quantity λ is the shadow price of net consumer surplus - a unit increase in profit results in a loss of net surplus of λ. As the Ramsey price is increased, the shadow price of net consumer surplus decreases. As demand becomes more elastic, holding the Ramsey price constant, the shadow price of surplus also decreases. Furthermore, as Ramsey prices increase, the weights must be increased if elasticity and shadow prices are held constant. These relationships suggest that the effect of Ramsey pricing on consumer surplus and utility profit is greatest for small markups over marginal cost but diminishes as the markup increases.

In a two good production model the ratio of weights is:

$$\frac{\alpha_1}{\alpha_2} = \frac{1 - M_1\eta_1}{1 - M_2\eta_2}$$

Using data from other studies Resende (1997) showed that this ratio was close to unity in the case of a sample of North American water utilities using residential and non-residential water use to differentiate outputs. This implies that there is no cross subsidisation of water between these groups despite non-residential users having more elastic demand.

5.5 Estimation Issues related to Welfare Models

The figures presented in this chapter have represented marginal cost and marginal benefit curves as linear functions of output. This implies variable economies of scale and price elasticity over the range of output. For empirical work the use of log-linear functional forms means that these parameters will be constant over the range of output. This simplifies analysis considerably.

There are a variety of data deficient situations that we might encounter in applied work when welfare measurement is the primary objective. In this section we propose two solutions that may help overcome these problems. The first starts with a single output unrestricted returns to scale cost function similar to the one presented in Chapter 3. Restating this in log-linear form:

$$\log C = \log A + \frac{1}{\mathcal{Q}} \log x$$

where $\mathcal{Q}$ is the returns to scale parameter. Differentiating this expression with respect to the output price:

$$\frac{\partial C}{\partial p}\frac{p}{C} = \frac{\eta}{\mathcal{Q}}$$

This suggests a functional form:

$$\log C = \log A + \frac{\eta}{\mathcal{Q}} \log p$$

that might be useful when cost and price are observed but output is unobservable and one of η or $\mathcal{Q}$ is unknown.

The second situation might occur when the parameters of the consumer demand function cannot be estimated because consumption data was not recorded. This can occur, for example when households who previously used water supplied by informal means[1], become connected to a water supply. In this case it is unlikely that estimates of consumption under the previous system are available. However, if prices and an estimate of elasticity are available, then an estimate of the increase in welfare from connection to the water supply can be derived. We start with the specification of household demand:

$$\ln x = \ln A + \eta \ln p$$

where A is an aggregate of covariates that is independent of price and consumption and all variables are household measurements, subscripts are omitted for clarity. Inverting and integrating this we have the Marshallian demand function:

$$x(p) = Ap^{\eta}$$

By definition, the increase in consumer surplus when prices are decreased from p_0 to p_1 is:

[1]These may include water trucks, carters, tanks, and wells.

$$
\begin{aligned}
\Delta CS &= \int_{p_1}^{p_0} A p^{\eta} dp \\
&= \frac{A}{1+\eta}\left[p_0^{1+\eta} - p_1^{1+\eta}\right]
\end{aligned}
$$

Here the original water price p_0 is assumed constant for all households, while the new utility price varies across households. Substituting for the covariates from the demand function under the new price we have:

$$
\begin{aligned}
\Delta CS &= \frac{x p_1^{-\eta}}{1+\eta}\left[p_0^{1+\eta} - p_1^{1+\eta}\right] \\
&= \frac{x p_1}{1+\eta}\left[\left(\frac{p_0}{p_1}\right)^{1+\eta} - 1\right] \\
&= \frac{E}{1+\eta}\left[\left(\frac{p_0}{p_1}\right)^{1+\eta} - 1\right]
\end{aligned}
$$

where E is household expenditure on water. This approach appears in Basani, Isham, and Reilly (2005) in the context of measurement of welfare change for households receiving a new water connection, and in Pushpangadan and Murugan (1998) in a study of Ramsey pricing when data limitations prevented estimation of the demand function.

CHAPTER 6

First Case Study

Urban Water Services in Victoria

Part A - Cost

6.1 The Supply of Urban Water in Victoria

Urban water in the State of Victoria is supplied by thirteen regional water businesses and three metropolitan businesses. Each water business is operated as a state owned company constituted by ministerial order under the Water Act 1989. The single shareholder is the Victorian State Government. Businesses operate under a board of directors appointed by the State Government with overall reporting responsibility to the Minister for Water. The board of directors is responsible for setting and overseeing the policies, objectives, and strategies of the business. While they are not listed entities, water businesses have adopted the Australian Stock Exchange *Principles of Good Corporate Governance and Best Practice Recommendations*, and generally follow management and reporting guidelines that are similar to those of a listed company. Water businesses are required to pay a dividend to the State Government based on a prescribed percentage of their annual profit.

There are two main contractual arrangements with government. The first is a Water Service Agreement with the Minister for Water that sets out the business' customer service obligations and quarterly reporting obligations to government. The second is a regulatory framework termed the Water Industry Regulatory

Order (WIRO) established in January 2004, that sets out new regulatory arrangements for water businesses. Under this framework the Essential Services Commission (ESC) assumes an economic regulation role for the Victorian water sector. Prices and service standards are now regulated, while each business was required to establish a Water Plan detailing the services to be provided and proposed prices for delivery of those services for the three year period commencing July 2005.

This new regulatory regime has been introduced as a means of ensuring the long-term sustainability of water resources. The objectives of the WIRO include promoting the economic valuation of water rather than valuation purely on cost of service delivery; ensuring that prices increase to reflect scarcity and user cost of service; providing incentives for long-term investment; preventing the misuse of monopoly power; promoting competitive market conduct; and ensuring that consumers benefit from the gains of competition and efficiency.

The Water Plans therefore form the basis for ESC's approval of the business's proposed prices. Following submission of Water Plans, the ESC undertook a detailed review of pricing and conducted a number of public forums seeking feedback on the Water Plans prior to making its determinations. On 15 June 2005 the ESC released its final decision on pricing for the years 2005/06 to 2007/08. As part of the price review, most water businesses have now introduced a block rate tariff. For example, the three suppliers for Melbourne are now operating under a rising three block tariff structure.

In accordance with the need to include user costs in water services, each business has, since 2004, collected an environmental contribution from consumers. This is paid into a consolidated fund used for the purpose of funding initiatives that seek to promote the sustainable management of water or address water related initiatives.

6.2 The Cost Data Set for Victorian Water Businesses

Each water business produces an annual report that is presented to government, suppliers, and other interested parties. The reports contain data on consumption and financial information that is the basis for preparation of a cost data set to be used in estimation. The data set contains annual reported values for the variables of interest for a period of four years from 2002 to 2005. The data items extracted from annual reports are listed in 6.1. The data set is an unbalanced panel that contains cost related data for each of the seventeen water business (metropolitan and regional). Mergers during the period means that some businesses have less that four years of reporting data. Dummy variables have been introduced to account for the distinction between regional and metropolitan business, and for time effects.

In the following sections we describe the steps undertaken to transform accounting data into economic data suitable for use in the cost model.

6.2.1 Output

The output measure adopted is *total volume delivered to customers.* This is a common measurement indicator reported in annual aggregate by each business. Consumption includes both residential and non-residential (ie. business) users but does not include major industrial consumers of water who purchase water under wholesale contracts. Similarly agricultural users of water are excluded from this figure. In regional areas water businesses manage their own water harvesting and storage assets. Regional businesses operate under *bulk water entitlements* that govern amounts of water that may be extracted from catchments and river systems. In the Melbourne metropolitan area the businesses purchase bulk water from Melbourne Water who are responsible for harvesting and storage in local

TABLE 6.1

Cost and Revenue Items Identified in Financial Statements

Group	Cost Item
Labour	salaries, wages and employee benefits
Capital	interest
Capital Adjustment	capital expansion
	depreciation
	inventory write down
Service and Production	water treatment chemicals
	power, light, and water
	repairs and maintenance
	consultants
	BOOT payments
	taxes and licences
Revenue	service charges
	volumetric charges
	government contributions
	developer contributions
	interest
	asset sales and write downs
	bulk water sales

catchments. Our analysis does not extend to the production and supply of this bulk water.

Non-revenue water (NRW) is comprised of water that is lost in mains bursts, used for fire-fighting, due to meter inaccuracies, stolen, or used internally. In general the water businesses do not monitor NRW amounts. We do not include other measures of output such as water quality, wastewater treated, or supply disruptions.

6.2.2 Revenue

Revenue is not required for the cost model. However it is included in the data set as a means of computing the average price of water. Revenue includes service charges for water and sewerage for both residential and nonresidential customers, volumetric charges for water (ie. those in excess of connection fees), trade waste charges and licences and fees. The measure of revenue excludes government and developer contributions, interest, proceeds from the sale of assets and bulk water sales to industry. Developer contributions originate indirectly from home buyers in new housing areas.

6.2.3 Operational Costs and Factor Prices

The dependent variable is operational costs. This includes salaries, wages and employee benefits; interest payments; depreciation and asset write downs; water treatment chemicals; power, light, and water; repairs and maintenance; consultants; payments for BOOT[1] services; taxes and licences. Income taxation is not included. Overhead costs are included - these will be absorbed into the intercept term in the cost model. For the Melbourne water businesses the cost of bulk water is included in operational costs. Costs and factor prices are deflated

[1]Build Own Operate Transfer

to 2002 dollars.

6.2.3.1 Capital Costs

Water business borrowings are a mix of floating, fixed interest, and non-interest bearing debt. Businesses are required to report on their interest rate exposure which includes determination of the weighted average effective interest rate or weighted average cost of capital. We use this figure as our time-varying measure of cost of capital. The determination of cost of capital is a major difficulty for cost analysis of water utilities and there is ongoing debate regarding the use of Capital Asset Pricing Models (CAPM) and Weighted Average Cost of Capital approaches (WACC).

Depreciation and asset write downs is another area in which there appears to be no standard approach in cost modelling. There is some support for including depreciation as an operational cost, however, as pointed out in Sabbioni (2005) this is not correct as depreciation costs are generated by investment. Furthermore, depreciation is charged on the basis of accounting rules that may not accurately reflect the productive capacity of capital.

We have taken the view that depreciation is a proxy for the minimum expenditure required to maintain the capital stock at its current level, that is, capital expenditure allocated to renewal. Therefore assuming a constant capital output ratio, the inclusion of depreciation means that cost observations are a lower bound of both operating and investment costs (ie. long run cost). This compares with the usual approach of estimating a short run operating cost function. To compare results, we have estimated the cost function with and without depreciation. Another approach is the inclusion of an investment model that accounts for capital stock deterioration and population growth; and that would be estimated simultaneously with supply and demand models. This would require a longer time series of investment and capital expenditure data than currently available.

6.2.3.2 Labour

Annual expenditure on salaries and employee benefits and number of full time equivalent (FTE) staff is used to derive the labour cost variable. This is deflated to 2002 dollars.

6.2.3.3 Service Costs and Technology

We have considered a third cost factor to account for service costs such as power, fuel, chemicals used in water treatment, and outsourced services. Outsourcing is increasingly common. This includes repairs and maintenance, consultants, and BOOT payments. Examination of the data shows that service costs are highly correlated with Property, Plant and Equipment (PPE) asset values. PPE values are the written down value of assets including works in progress with adjustment for depreciation and asset write-downs. PPE can be treated as a proxy for capital stock.

Technological improvements can be captured by use of a time trend variable as a proxy for technology (Dougherty, 1992, p. 159).

6.3 Data Description

Table 6.2 and 6.3 show the variables and summary statistics for the cost data set split into regional and metropolitan businesses. The data set consists of annual observations for seventeen water businesses over a period of 2002-2005.

TABLE 6.2

Victorian Regional Water Businesses: Summary Statistics 2002-2005

Variable	Description	Mean	Median	Min.	Max.	SD.
C	operating costs (w/out deprecn.)	20,835	19,344	3,807	53,892	13,228
D	depreciation and write downs	11,114	11,141	1,718	30,940	7,158
WL	wage costs	6,532	4,893	1,100	21,756	5,201
RK	borrowing costs	570	153	0	4,378	1,063
SP	service costs	13,694	12,587	2,524	34,437	9,055
L	labour	122.2	101.0	21.0	362.0	85.9
W	wage rate	53	55	18	70	12
K	long term debt	8,430	2,153	0	62,902	15,823
R	cost of capital (WACC)	0.070	0.067	0.052	0.118	0.014
PPE	property plant and equipment	347,193	324,072	65,579	892,489	231,053
X	volume delivered (ML)	15,589.4	14,244.0	1,995.0	41,291.0	10,990.7
CNN	connections	43,118.1	41,141.0	7,805.0	122,637.0	29,123.8
RVN	revenue	25,261	24,185	4,326	72,719	16,648
p	average price per KL	1.93	1.79	0.77	4.26	0.84
XPC	per connection consumption	362.5	332.0	129.9	772.2	154.1

annual figures; all costs and prices are in AUD 1,000s

TABLE 6.3

Victorian Metropolitan Water Businesses: Summary Statistics 2002-2005

Variable	Description	Mean	Median	Min.	Max.	SD.
C	operating costs (w/out deprecn.)	215,419	222,538	142,108	266,728	38,037
D	depreciation and write downs	25,567	28,532	12,427	32,707	6,975
WL	wage costs	22,669	21,994	14,039	30,270	6,071
RK	borrowing costs	24,002	21,967	11,011	35,644	8,832
SP	service costs	35,391	35,539	20,295	47,675	8,113
L	labour	358.5	374.0	218.0	430.0	76.2
W	wage rate	63	63	51	76	7
K	long term debt	393,154	364,607	191,161	576,769	135,910
R	cost of capital (WACC)	0.061	0.060	0.058	0.063	0.002
PPE	property plant and equipment	1,101,813	1,163,784	669,045	1,372,657	240,600
X	volume delivered (ML)	144,401.1	147,419.5	108,800.0	170,143.0	21,753.2
CNN	connections	515,790.1	563,601.1	296,055.0	594,000.0	113,841.4
RVN	revenue	268,571	283,224	179,229	311,230	46,830
p	average price per KL	1.86	1.90	1.64	2.13	0.18
XPC	per connection consumption (KL)	288.0	287.5	232.0	369.9	45.6

annual figures; all costs and prices are in AUD 1,000s

6.4 Estimation of Two Factor Production and Cost Models

In this section we present several variants of production and cost models that have been described in Chapter 3. The models are estimated as log-linear models with correction for heteroskedasticity based on a *weighted least squares* procedure (Pindyck and Rubinfeld, 1991, p. 129).

Dummy variables are included to account for differences between Metropolitan (Melbourne) and regional businesses, and time effects. All models have been estimated with cost and price data items expressed in $000's, and all flows are annual.

6.4.1 Two Factor CRS Production Function

The two factor CRS production function with dummy and time variables is:

$$ln(X_{it}/L_{it}) = ln(A) + \delta ln(K_{it}/L_{it}) + \gamma_1 CLASS_i + \gamma_2 T_t$$

where:

X	=	volume delivered (ML)
K	=	plant, property and equipment
L	=	number of full time equivalent staff
$CLASS$	=	dummy variable 0:metropolitan water business 1:regional water business
T	=	time variable: number of years since 2002
i	=	firm index
t	=	time index

Table 6.4 shows the estimated coefficients for the basic production model and model variants with $CLASS$ and time dummy variables.

Standard errors are shown below the estimates in brackets. Variables that are significant at the 95% level are marked with an asterisk beside the standard error. The righthand columns show the adjusted $\bar{R}^2$ value and the standard error of the residuals.

The adjusted $\bar{R}^2$ parameter indicates a increasing level of fit for as dummy variables are added to the model. All variables are significant. The sign of the $CLASS$ dummy variable indicates that relative to regional water businesses, the metropolitan water businesses exhibit economies of scale. The coefficient on the time dummy variable also indicates some decrease in output over time. The most probable explanation of this is reduced output/consumption due to drought, water restrictions and increased prices; while inputs remained at the same level. Although this indicates some inefficiency, both capital and labour are more sticky than consumption and this result is consistent with expectations.

The output elasticity for K is the coefficient for K/L (ie. δ) and the output elasticity for L is $1-\delta$. The general result indicates a considerably higher output elasticity for capital than for labour; this suggests that future increases in output will occur through increased investment in productive capital.

6.4.2 Two Factor Cost Function with CRS Production

The two factor CRS minimum cost function with CRS production dummy and time variables is:

$$ln\left(\frac{C_{it}}{w_{it}X_{it}}\right) = ln(A) + \delta ln\left(\frac{r_{it}}{w_{it}}\right) + \gamma_1 CLASS_i + \gamma_2 T_t$$

where:

TABLE 6.4

CRS Production Function

Model	const	$ln(K/L)$	$CLASS$	T	$\bar{R}^2$	$\hat{\sigma}$
basic	-2.16	0.899				
	(1.25)	(0.155)*			0.361	1.91
class	-0.10	0.761	-1.1969			
	(1.21)	(0.151)*	(0.0844)*		0.824	2.15
class, time	-0.778	0.8651	-1.1864	-0.0855		
	(0.694)	(0.0858)*	(0.0698)*	(0.0350)*	0.860	1.99

C	=	operating cost
X	=	volume delivered
w	=	wage price
r	=	weighted average cost of capital
$CLASS$	=	dummy variable 0:metropolitan water business 1:regional water business
T	=	time variable: number of years since 2002
i	=	firm index
t	=	time index

Table 6.5 shows the estimated coefficients for the constant returns to scale cost model exclusive and inclusive of depreciation. The model variants are based on the inclusion of *CLASS* and time dummy variables. The coefficient for r/w (ie. δ) is the output elasticity for K in the Cobb-Douglas production dual. The output elasticity for L is $1-\delta$. In the restricted model the output elasticities are also the cost shares. The coefficients for the dummy and time variables are additive to the scaling constant $ln(A)$.

TABLE 6.5

CRS Cost Function

Model	const	$ln(r/w)$	$CLASS$	T	$\bar{R}^2$	$\hat{\sigma}$
depreciation excluded						
basic	-1.046	0.3827				
	(0.514)	(0.0806)*			0.271	2.35
class	-0.368	0.4798	-0.0657			
	(0.662)	(0.0960)*	(0.0810)		0.372	2.38
time	-0.877	0.4412		0.1353		
	(0.337)	(0.0564)*		(0.0289)*	0.516	2.14
class, time	-0.879	0.4401	0.0359	0.1129		
	(0.517)	(0.0759)*	(0.0739)	(0.0282)*	0.502	2.25
depreciation included						
basic	0.182	0.512				
	(0.832)	(0.128)*			0.206	2.18
class	-0.292	0.4782	0.2805			
	(0.675)	(0.0975)*	(0.0822)*		0.622	2.10
time	0.193	0.5531		0.1513		
	(0.266)	(0.0457)*		(0.0199)*	0.743	2.27
class, time	-0.131	0.5316	0.2465	0.1292		
	(0.471)	(0.0687)*	(0.0722)*	(0.0286)*	0.730	2.47

6.4.3 Two Factor Cost Function with Variable Returns to Scale

The two factor minimum cost function with variable returns to scale production, including dummy and time variables is:

$$ln\left(\frac{C_{it}}{r_{it}}\right) = \gamma_0 + \frac{1}{\alpha+\beta}ln\left(X_{it}\right) + \frac{\alpha}{\alpha+\beta}ln\left(\frac{w_{it}}{r_{it}}\right) + \gamma_1 CLASS_i + \gamma_2 T_t$$

where:

C	=	operating cost
X	=	volume delivered
w	=	wage price
r	=	weighted average cost of capital
$CLASS$	=	dummy variable 0:metropolitan water business 1:regional water business
T	=	time variable: number of years since 2002
i	=	firm index
t	=	time index

Table 6.6 shows the estimated coefficients for the variable returns to scale cost model exclusive and inclusive of depreciation. The model variants are based on the use of $CLASS$ and time dummy variables. In the model the estimated coefficients for $ln(w/r)$ are the cost shares for L; and the inverse of the coefficient for $ln(X)$ determines returns to scale. The output elasticities can be determined from the coefficients. The coefficients for the dummy and time variables are additive to the scaling coefficient $ln(A)$.

TABLE 6.6

Variable RTS Cost Function:

Model	const	$ln(X)$	$ln(w/r)$	$CLASS$	T	$\bar{R}^2$	$\hat{\sigma}$
depreciation excluded							
basic	-0.484	0.9233	0.645				
	(0.728)	(0.0319)*	(0.107)*			0.942	2.61
class	2.12	0.7965	0.5009	-0.478			
	(1.13)	(0.0580)*	(0.0853)*	(0.177)*		0.972	2.20
time	-0.505	0.9406	0.590		0.1262		
	(0.672)	(0.0275)*	(0.102)*		(0.0356)*	0.960	2.20
class, time	1.84	0.7954	0.521	-0.461	0.0766		
	(1.15)	(0.0566)*	(0.111)*	(0.170)*	(0.0284)*	0.971	2.16
depreciation included							
basic	1.584	0.8344	0.5212				
	(0.579)	(0.0311)*	(0.0765)*			0.931	2.27
class	2.62	0.7857	0.4632	-0.203			
	(1.11)	(0.0563)*	(0.0839)*	(0.177)		0.960	2.01
time	1.435	0.8901	0.414		0.1505		
	(0.712)	(0.0336)*	(0.104)*		(0.0413)*	0.931	3.22
class, time	3.21	0.8109	0.315	-0.246	0.0827		
	(1.21)	(0.0606)*	(0.107)*	(0.175)	(0.0280)*	0.971	2.23

6.5 Discussion of Results

Overall the variable returns model performed better than the constant returns model. Based on the adjusted $\bar{R}^2$ parameter, a superior level of model fit was achieved. The inclusion of dummy variables also improved the fit of the constant returns model. The most likely explanation of this is that the coefficient of the log of output is constrained to one in the constant returns models meaning that more of the variance in cost is explained by other factors, raising their significance. Based on F statistics shown in Table 6.8, every model variant was significant, ie. the null hypothesis of all slope parameters equal to zero was rejected in every case.

For both models, all of the explanatory variables are significant, with the exception of the $CLASS$ dummy variable which is only significant in the constant returns model when depreciation is included and in the variable returns model when this is not the case. The inclusion of depreciation in cost does not appear to improve the significance of the explanatory variables in any consistent manner.

The sign of the explanatory variables (output and factor prices) are in all cases positive and conform to expectations. The sign of the $CLASS$ dummy variable in each model points to different evidence in respect of costs between regional water and the metropolitan water businesses. For fixed input prices and output, the models do not reveal a consistent pattern of higher or lower costs for one class of business over the other. All cost models show a consistent increase in costs over time, holding other factors constant. All cost variables were adjusted for inflation, therefore this result indicates an increase in real costs over time, a not unexpected result.

The cost elasticities are the coefficients of the log linear function $\log C = f(\log X, \log r, \log w)$. These are equal to the cost shares. Using duality, the output elasticities of the cost minimising production function are determined from the factor price parameter estimates of the cost function. The returns to scale parameter is the inverse of the coefficient of output in the variable returns model. These estimated values appear in Table 6.7.

Output elasticities (changes in factor inputs) for capital are generally higher in the variable returns models with depreciation included, matching the production model results. The constant returns models do not show any consistent difference in output elasticities based on the inclusion or otherwise of depreciation. Cost elasticity for changes in output indicate the presence of economies of scale (increasing returns to scale) in all variants of the variable returns model. A test of the hypothesis for constant returns to scale as opposed to increasing returns to scale was rejected at the 95% level. This is detailed in the next section. The cost elasticity for labour prices is higher than for capital when depreciation is excluded but lower when depreciation is included. This indicates the sensitivity of results to the inclusion of depreciation, and suggests that long run costs (in the variable returns model) are more sensitive to interest rates than to wage rates. This provides some explanation as to why, under previous pricing arrangements, there has been limited capital investment by water businesses.

Finally, as shown in Table 6.9, we have carried out Regression Specification Error Test (RESET) tests for model misspecification using artificial models augmented with squared and cubed predicted values (Hill, Griffiths, and Judge, 2001, p. 187). In all but one case we were unable to reject the null hypothesis that the coefficients of the augmented regressors were both zero. This suggests that functional form and omitted variables are not a problem in these models and is supportive of correct model specification.

6.5.1 Testing for Constant Returns to Scale

Based on the regression results of the variable returns to scale models we would like to determine if the returns to scale parameters shown in Table 6.7 are significant. That is we would like to confirm that the Victorian water businesses exhibit increasing returns to scale. This has been carried out with a series of hypothesis tests, the results of which are summarised in Table 6.10. Test statistics are derived from the estimates and standard errors in the variable RTS model, equation 6.6.

In all cases the null hypothesis of constant returns to scale was rejected at the 95% level. In the case where the alternative was increasing returns to scale, the null hypothesis was also rejected. Therefore there is statistical evidence that the Victorian water businesses exhibit increasing returns to scale.

TABLE 6.7

Summary of Estimation Results: Victorian Cost Data

	Output Elasticity		Cost Elasticity		
Model	capital	labour	output	int.rate	wage rate
CRS Cost - excluding depreciation					
basic	0.383	0.617	1.0	0.383	0.617
class	0.480	0.520	1.0	0.480	0.520
time	0.441	0.559	1.0	0.441	0.559
class, time	0.440	0.560	1.0	0.440	0.560
CRS Cost - including depreciation					
basic	0.383	0.617	1.0	0.383	0.617
class	0.480	0.520	1.0	0.480	0.520
time	0.553	0.447	1.0	0.553	0.447
class, time	0.440	0.560	1.0	0.440	0.560
Variable RTS - excluding depreciation					
basic	0.384	0.699	0.923	0.355	0.645
class	0.626	0.629	0.797	0.499	0.501
time	0.436	0.627	0.941	0.410	0.590
class, time	0.602	0.655	0.795	0.479	0.521
Variable RTS - including depreciation					
basic	0.574	0.625	0.834	0.479	0.521
class	0.683	0.589	0.786	0.537	0.463
time	0.658	0.465	0.890	0.586	0.414
class, time	0.845	0.388	0.811	0.685	0.315

TABLE 6.8

F Tests for Model Significance

H_0: $\beta_2 = 0, \beta_3 = 0, \ldots, \beta_k = 0$ Model is of no significance
H_1: at least one of the $\beta_i \neq 0$

Model	Test Statistic	DF	$F_{95\%}$	Decision
CRS Cost - excluding depreciation				
basic	22.5	1,57	4.0	reject H_0
class	18.2	2,56	3.2	reject H_0
time	31.9	2,56	3.2	reject H_0
class, time	20.5	3,55	2.8	reject H_0
CRS Cost - including depreciation				
basic	16.1	1,57	4.0	reject H_0
class	48.8	2,56	3.2	reject H_0
time	84.7	2,56	3.2	reject H_0
class, time	53.3	3,55	2.8	reject H_0
Variable RTS - excluding depreciation				
basic	473.5	2,56	3.2	reject H_0
class	684.2	3,55	2.8	reject H_0
time	459.9	3,55	2.8	reject H_0
class, time	483.1	4,54	2.5	reject H_0
Variable RTS - including depreciation				
basic	390.1	2,56	3.2	reject H_0
class	467.5	3,55	2.8	reject H_0
time	260.9	3,55	2.8	reject H_0
class, time	493.7	4,54	2.5	reject H_0

TABLE 6.9

Ramsey RESET Tests for Model Specification Error

original model	$y_i = \beta_0 + \beta_1 x_{1,i} + \ldots + \beta_k x_{k,i}$
predictions	$\hat{y}_i = b_0 + b_1 x_{1,i} + \ldots + b_k x_{k,i}$
artificial model	$y_i = \beta_0 + \beta_1 x_{1,i} + \ldots + \beta_k x_{k,i} + \gamma_1 \hat{y}_i^2 + \gamma_2 \hat{y}_i^3$

H_0: $\gamma_1 = 0, \gamma_2 = 0$ (no specification error)
H_1: at least one of the $\gamma_i \neq 0$

Model	DF	Test Statistic (F_t)	$\Pr(F > F_t)$	Decision
CRS Cost - excluding depreciation				
basic	2,55	0.0963	0.908	do not reject H_0
class	2,54	0.4092	0.666	do not reject H_0
time	2,54	0.3851	0.682	do not reject H_0
class, time	2,53	0.1986	0.821	do not reject H_0
CRS Cost - including depreciation				
basic	2,55	0.1759	0.839	do not reject H_0
class	2,54	0.8538	0.431	do not reject H_0
time	2,54	0.3047	0.739	do not reject H_0
class, time	2,53	0.5368	0.588	do not reject H_0
Variable RTS - excluding depreciation				
basic	2,54	4.4291	0.017	reject H_0
class	2,53	0.1020	0.903	do not reject H_0
time	2,53	2.2409	0.116	do not reject H_0
class, time	2,52	0.0068	0.993	do not reject H_0
Variable RTS - including depreciation				
basic	2,54	1.0526	0.356	do not reject H_0
class	2,53	0.0351	0.966	do not reject H_0
time	2,53	0.3102	0.735	do not reject H_0
class, time	2,52	0.0342	0.966	do not reject H_0

TABLE 6.10

Hypothesis Tests for Constant Returns to Scale

Alternative is either increasing or decreasing RTS		
H_0: $1/(\alpha+\beta)=1$	H_1: $1/(\alpha+\beta)\neq 1$	
DF: 57	critical value: ± 2.003	
Model Variant	Test Statistic	Decision
basic	-2.406	reject H_0
class	-3.510	reject H_0
class, time	-3.612	reject H_0
Alternative is increasing RTS		
H_0: $1/(\alpha+\beta)=1$	H_1: $1/(\alpha+\beta)<1$	
DF: 57	critical value: -1.673	
Model Variant	Test Statistic	Decision
basic	-2.406	reject H_0
class	-3.510	reject H_0
class, time	-3.612	reject H_0

6.6 Applying a Translog Cost Function to Analyse the Impact of Service Costs

In this section we present the results of estimation of a system of cost share equations derived from a constant returns to scale translog cost function. The derivation of the equations has been described in Chapter 3 and follows the methodology presented in Greene (2003, p. 368) and originally applied in a study of US manufacturing industries by Berndt and Wood (1975).

We have augmented the data set with an additional factor: services, so that a system of three share equations can be estimated. Service costs include energy, use of contractors and consultants, and production costs such as bulk water and treatment chemicals. The objective in this case is estimation of short run operational costs, therefore depreciation has been excluded as a cost. Two methods are used to determine a price for service costs. The first is a value price that is the service cost per unit of capital employed. The second approach uses the Service Industries Producer Price Index published quarterly by the Australian Bureau of Statistics (2007). The use of price indices in lieu of market price data is appropriate in contexts where an aggregate of goods contributes to the relevant factor. In general, price indices are used when a system of share equations is to be estimated, see for example Dachraoui and Harchaoui (2004).

The system of share equations is:

$$\begin{aligned} sh_w &= \beta_w + \delta_{ww} \log w + \delta_{wr} \log r + \delta_{ws} \log s \\ sh_r &= \beta_r + \delta_{wr} \log w + \delta_{rr} \log r + \delta_{rs} \log s \\ sh_s &= \beta_s + \delta_{ws} \log w + \delta_{rs} \log r + \delta_{ss} \log s \end{aligned}$$

Where w, r, s are factor prices of labour, capital and service respectively. The third equation is eliminated and all prices expressed as ratios of the service price to avoid singularities. The system has been estimated using the SystemFit software package (Henningsen and Hamann, 2006). There are six parameters to be estimated and one restriction (the third parameter of the first equation and the second parameter of the second equation). Results are presented in Tables 6.11 and 6.12.

The signs of the estimates of the coefficients of the share equations are consistent regardless of the service price used. They indicate several points. Firstly an increase in the wage rate means that the cost share of labour increases while the cost share of services falls. An increase in the cost of capital produces a fall in borrowing share and an increase service cost share. An increase in service price produces a fall in labour cost share, increased borrowing cost share, and increased service cost shares. The results suggest that labour is sticky and not easily substituted by services, while in contrast services are more easily substituted for capital.

The own price elasticities have the expected signs and show a higher price elasticity for capital than for the other factors. This is supported by the low debt to equity ratios of most water businesses, particularly regional ones (Victorian Water Industry Association, 2005). Notable also is the greater demand elasticity of services in comparison to labour per unit cost of capital increase, and the high demand elasticity of services in response to a unit labour cost increase. Both of these suggest that there is a tendency to increase the use of services in response to increases in capital and labour costs.

TABLE 6.11

Share Equation Estimates: Translog Cost Function

	Services Value Price				Services Price Index			
cost share	β	$\log w$	$\log r$	$\log s$	β	$\log w$	$\log r$	$\log s$
labour	-1.008	0.184	0.006	-0.190	0.521	0.091	0.021	-0.112
borrowing	0.022	0.006	-0.055	0.050	-0.345	0.021	-0.054	0.033
services	1.986	-0.190	0.050	0.140	0.824	-0.112	0.033	0.079

TABLE 6.12

Estimates of Elasticities: Translog Cost Function

	Services Value Price				Services Price Index		
	w	r	s		w	r	s
w	-0.077			w	-0.395		
r	1.472	-2.323		r	2.765	-2.291	
s	0.026	2.836	-0.122	s	0.424	2.222	-0.214

CHAPTER 7

First Case Study

Urban Water Services in Victoria

Part B - Marginal Cost and Welfare

7.1 Introduction

Part A of this case study presented the results of estimation of linear Cobb Douglas (constant and variable returns to scale) and translog models of the cost function for the Victorian Water Businesses. Variants of these models employed a time dummy variable and a $CLASS$ dummy variable that distinguished between metropolitan and regional water services. We observed an improvement in model fit from the constant returns to the variable returns models. The hypothesis of constant returns to scale was rejected in favour of the alternative that water production exhibits increasing returns to scale. The cost elasticity of output was estimated to be in the range 0.786 to 0.941.

This part of the case study contains two main contributions. Firstly, we present several methods for determining the marginal cost of urban water based on the estimated cost function. These are classified by the selection of output level at which cost is determined and by the underlying model. Secondly, we examine the welfare effects associated with current price levels and our marginal cost estimates.

7.2 Estimating Marginal Cost

7.2.1 Constant Returns and Variable Returns Models

We define the *conditional* marginal cost function as the marginal cost function using mean values of the factor prices. The conditional marginal cost is the conditional marginal cost function evaluated at some representative value of output. The constant returns model yields a conditional marginal cost function that is a constant while the variable returns model yields a function that is nonlinear in output.

The following shows how the conditional marginal cost is determined for the variable returns model with a $CLASS$ dummy variable. Because we include the $CLASS$ dummy variable the cost functions for metropolitan and regional authorities will differ in the scale parameter, as will the factor price sample means $\bar{r}$ and $\bar{w}$.

We first restate the cost function from 3.4 as a conditional cost function:

$$C = exp(A)\bar{w}^{\frac{\alpha}{\mathcal{Q}}}\bar{r}^{\frac{\beta}{\mathcal{Q}}}x^{\frac{1}{\mathcal{Q}}}$$

where, for clarity $A = \gamma_0 + \gamma_1 CLASS$ from the model specification, and $\mathcal{Q}$ is the scale economies parameter. Differentiation with respect to output yields the conditional marginal cost function for which we take logs and simplify:

$$\begin{aligned} MC &= exp(A)\bar{w}^{\frac{\alpha}{\mathcal{Q}}}\bar{r}^{\frac{\beta}{\mathcal{Q}}}\frac{1}{\mathcal{Q}}x^{\frac{1}{\mathcal{Q}}-1} \\ log(MC) &= A + log\left(\bar{w}^{\frac{\alpha}{\mathcal{Q}}}\bar{r}^{\frac{\beta}{\mathcal{Q}}}\right) + log\left(\frac{1}{\mathcal{Q}}\right) + \left(\frac{1}{\mathcal{Q}} - 1\right)log(x) \end{aligned}$$

Hence substituting $B = A + log\left(\bar{w}^{\frac{\alpha}{\mathcal{Q}}}\bar{r}^{\frac{\beta}{\mathcal{Q}}}\right) + log\left(\frac{1}{\mathcal{Q}}\right)$, we have the conditional marginal cost function:

$$log(MC) = B + \left(\frac{1}{Q} - 1\right) log(x) \tag{7.1}$$

Marginal cost estimates are determined by evaluation of this function at factor price means for some specified level of output.

7.2.2 Partial Equilibrium Marginal Cost

In the previous section we used means of factor prices and output to determine the marginal cost. To contrast this we now determine marginal cost using a partial equilibrium of the marginal cost equation and a log-linear demand equation. The advantage of this approach is that the equilibrium (welfare maximising) level of output is also selected, avoiding the need for choosing the level of output at which to measure marginal cost.

We adopt a simple model of system demand with price as the only explanatory variable:

$$\log x = b_0 + \eta \log p$$

Substituting this into equation 7.1 and equating marginal cost and price, we have the marginal cost at the point of equilibrium between demand and supply:

$$log(MC) = \frac{B + \left(\frac{1}{Q} - 1\right) b_0}{1 - \left(\frac{1}{Q} - 1\right) \eta} \tag{7.2}$$

7.2.3 Translog Function Marginal Cost

In Part A of this Case Study we estimated the parameters of the translog *average* cost function for the Victorian Water Businesses. This was estimated as a three factor system without dummy variables. The estimation results were presented in Table 6.11. In this section we evaluate this function at output and factor means to form a conditional translog average cost estimate.

In the original share equation system, the estimate of the intercept term β_0 is not available because the average cost equation is excluded from the system. This estimate is required to compute marginal cost. Therefore, the system was augmented with the original average cost equation and re-estimated. Price ratios were again used to avoid singularities. The services value price was used as the numeraire. The estimates produce predicted average cost for any vector of prices. To determine aggregate average cost we have fitted the sample predicted values to a normal distribution and taken the mean of that distribution as the average cost.

The translog system is:

$$\begin{aligned}
\log g &= \beta_0 + \beta_w \log\frac{p_w}{p_s} + \beta_r \log\frac{p_r}{p_s} + \delta_{ww}\frac{1}{2}\log^2\frac{p_w}{p_s} + \delta_{rr}\frac{1}{2}\log^2\frac{p_r}{p_s} + \delta_{wr}\frac{p_w}{p_s}\frac{p_r}{p_s} \\
sh_w &= \beta_w + \delta_{ww}\log\frac{p_w}{p_s} + \delta_{wr}\log\frac{p_r}{p_s} \\
sh_r &= \beta_r + \delta_{wr}\log\frac{p_w}{p_s} + \delta_{rr}\log\frac{p_r}{p_s}
\end{aligned}$$

The estimated coefficients of the system differ slightly to the original share equation system because of the extra equation. For the depreciation excluded sample the equations are:

$$\begin{aligned}
\log g &= 2.647 - 0.950\log\frac{p_w}{p_s} - 0.036\log\frac{p_r}{p_s} + 0.088\log^2\frac{p_w}{p_s} - 0.030\log^2\frac{p_r}{p_s} + 0.014\frac{p_w}{p_s}\frac{p_r}{p_s} \\
sh_w &= -0.950 + 0.176\log\frac{p_w}{p_s} + 0.014\log\frac{p_r}{p_s} \\
sh_r &= -0.036 + 0.014\log\frac{p_w}{p_s} - 0.059\log\frac{p_r}{p_s}
\end{aligned}$$

For the depreciation included sample the equations are:

$$
\begin{aligned}
\log g &= 1.947 - 0.591 \log \frac{p_w}{p_s} + 0.345 \log \frac{p_r}{p_s} + 0.056 \log^2 \frac{p_w}{p_s} + 0.053 \log^2 \frac{p_r}{p_s} - 0.008 \frac{p_w}{p_s} \frac{p_r}{p_s} \\
sh_w &= -0.591 + 0.112 \log \frac{p_w}{p_s} - 0.008 \log \frac{p_r}{p_s} \\
sh_r &= 0.345 - 0.008 \log \frac{p_w}{p_s} + 0.105 \log \frac{p_r}{p_s}
\end{aligned}
$$

7.3 Discussion of Results

The three methods presented in the preceding section have been used to estimate marginal cost at a particular level of output. Table 7.1 summarises these results. The columns of this table are in order:

- *CLASS*: The model and data apply to all businesses, only metropolitan, or only regional businesses.
- Fn. Evaluation: The method used to evaluate the marginal cost function.
- Output (KL): The value of annual water delivered used in evaluation.
- no depn./with depn.: These columns show the marginal cost based on data sets exclusive and inclusive of depreciation.
- VP: The average volumetric charge for this class of water businesses.

Table 7.2 shows the sample means used in calculations. All prices and costs have been deflated to 2002 prices.

As expected, the different models yield different results. The constant returns translog model yielded higher marginal costs relative to the other models. The

TABLE 7.1

Marginal Cost Results: Victorian Water Authorities

			MC. ($/KL)		
CLASS	Fn. Evaluation(*)	Output (KL)	No Depn.	Depn.	VP.(**)
CES - Constant Returns to Scale					
combined	sample means (FP)	37,422	1.49	2.14	0.72
metropol.	sample means (FP)	206,710	1.55	1.70	0.80
regional	sample means (FP)	21,765	1.43	2.20	0.70
Translog - Constant Returns to Scale					
combined	sample means (FP)	37,422	1.96	0.74	0.72
combined	mean of predicted cost	37,422	1.75	2.52	0.72
CES - Increasing Returns to Scale					
combined	sample means (FP+OP)	37,422	1.29	1.58	0.72
metropol.	sample means (FP+OP)	206,710	1.17	1.28	0.80
regional	sample means (FP+OP)	21,765	1.12	1.68	0.70
combined	partial equilibrium	17,290	1.34	1.80	0.72
metropol.	partial equilibrium	198,148	1.07	1.19	0.80
regional	partial equilibrium	12,827	1.08	1.74	0.70

* FP=factor price; OP=output

** source: Victorian Water Industry Association (2005)

TABLE 7.2

Sample Means of Parameters: Victorian Water Authorities

Factor Variable		Sample	Metro	Region
cost of capital	r	0.067	0.061	0.070
wage rates ($000's)	w	54.721	62.940	53.021
output (ML)	x	37,421.9	206,709.5	21,764.5
connections	H	123,232	515,790	43,118
per connection output (ML)	$\tilde{x}$	0.350	0.288	0.363
price ($/KL)	p	0.72	0.80	0.70

variable returns model produced consistently lower estimates than the other models. The translog model would be expected to model the variation in factor prices better than the others as it allows second order effects compared to linear or exponential models that are constant or consistently decreasing. However, because the model assumes constant returns to scale, the slope of the cost function is constrained to be constant and does not capture the effect of increasing returns to scale (marginal costs decreasing) for higher levels of output.

The differences in model results are more striking when depreciation is taken into account. With depreciation included, the variable returns model shows a higher marginal cost for regional businesses over metropolitan businesses. An examination of the data shows that for regional businesses the cost share of depreciation was 33% while for metropolitan businesses it was 10%. For the period for which we have data there has been considerable depreciation and writeoff of assets by regional authorities, relative to their metropolitan counterparts. The percentage of capital expenditure directed towards renewal of assets in 2004/2005 was 40% for regional businesses, compared to 25% for metropolitan businesses (Victorian Water Industry Association, 2005). All models have captured this difference quite clearly. This suggests that the inclusion of depreciation in addition to capital expenditure is necessary to capture long run costs related to investment. As mentioned in Chapter 3, there is little uniformity in other applied studies in respect of the treatment of depreciation. These estimates indicate the inclusion of depreciation as a cost shifts the marginal cost curve upwards - without significantly changing its shape, or cost elasticity of output as was shown in Table 6.7.

The results when a system demand function is used to determine the equilibrium value of output do not substantially differ from the increasing returns model that sets output at the sample mean. The efficient level of output for regional water businesses is considerably lower than the sample data. This suggests that current consumption levels could be lowered in regional areas with a corresponding reduction in marginal cost.

We make two final observations regarding the marginal cost estimates. First, the disaggregated estimates (into metropolitan and regional water businesses) are preferable to the combined estimates because the sample output means are appropriate to that class of business. This suggests that size is an important factor in this type of analysis and needs to be incorporated at each step, from function estimation to pricing. Second, we can observe that all estimates are substantially higher than the prevailing average volumetric charges. This supports the generally accepted belief that water is under-priced.

7.3.1 Data Aggregation and Sensitivity Analysis

This work highlights the use of cost and demand functions in marginal cost determination - in contrast to conventional industry practice that is reliant on present value estimates based on historical records. As a result of the need to transform a functional form into a scalar quantity, the marginal cost estimates produced by the above described procedure depend on the mean values of factor prices and output. This is a common approach in applied work, the mean values used form part of the assumptions of the results. An alternative approach would be to leave the choice of representative values to the decision maker by presenting the results in the form of a two-dimensional plot of marginal cost against individual factor prices or output. If the former approach is adopted and functions are evaluated at mean values of their parameters we expect that the results will be sensitive to those mean values. A second source of dependency relates to the values of the coefficient estimates. These are reported in the regression analysis as scalars but of course a parameter estimate is only the most statistically likely one out of an entire distribution.

In this section we carry out sensitivity analysis on the sample mean values and parameter estimates that form the basis of marginal cost estimates. As we have estimated a number of models under differing conditions, it is not realistic to conduct sensitivity analysis on every model variant. Therefore we have restricted this analysis to an examination of the sensitivity of the variable returns model to changes in its parameters and mean value of output. This choice was also driven by the observation that marginal cost is not very sensitive to the value of output - indicating low economies of scale in production.

We have calculated lower and upper values of the marginal cost with coefficient estimates and mean output changed by one half of their standard error - a standard form of sensitivity analysis. We need to emphasise that these values are not confidence intervals, rather the range of each indicates the sensitivity of the model to changes in the parameter. Table 7.3 shows the results of estimation of lower and upper values of conditional marginal cost for the variable returns

TABLE 7.3

Sensitivity Analysis of Marginal Cost Estimates: Variable Returns Model

parameter	Lower/Upper MC (parameter ±0.5 std. err.) combined		metropol.		regional	
w/out depreciation						
intercept	0.90	1.86	0.66	2.06	0.64	1.98
$1/\mathcal{Q}$	1.08	1.56	0.80	1.71	0.82	1.54
δ	0.91	1.85	0.87	1.57	0.85	1.49
output $\bar{X}$	1.24	1.41	1.15	1.19	1.06	1.23
with depreciation						
intercept	1.18	2.11	0.73	2.23	0.96	2.92
$1/\mathcal{Q}$	1.32	1.90	0.88	1.85	1.23	2.28
δ	1.22	2.04	0.96	1.71	1.27	2.21
output $\bar{X}$	1.45	1.91	1.26	1.30	1.57	1.84

model using mean output. Sensitivity analysis was carried out on the intercept, the output elasticity estimate δ, the cost elasticity estimate $1/\mathcal{Q}$ (the coefficient of output), and output level. A combined and disaggregated estimate is shown and the analysis has been conducted on both the depreciation excluded data set and the depreciation included data set.

The main observation we can make in respect of this sensitivity analysis is that the largest range in marginal cost estimates occur in the intercept (ie. of the log-linear MC function). This is not unexpected as the intercept shifts the entire marginal cost curve. Furthermore, because the intercept and the coefficients are *exponents*, the value of marginal cost will be very responsive to these estimates. This is a feature of all log-linear models that is seldom considered in applied work.

The choice of output level is the least sensitive as a result of the scale economies being close to one. The lower range of estimates approximate existing prices. These results are confirmatory of the sensitivity of parameter estimates. It is interesting to note that use of a conventional polynomial cost function means that the marginal cost will be invariant to the intercept, in contrast to an exponential (log-linear) form where the intercept still remains after differentiation.

7.4 Measurement of Deadweight Loss and Required Subsidy

As indicated in Table 7.1, average prices are less than the marginal cost estimates that we have obtained from a variety of cost models. Starting in 2005, annual price increases are being awarded to Victorian water authorities on the basis of Water Plans submitted to the ESC. The motivation for price increases is to reduce consumption and cover investment costs in the near term.

In Chapter 5 we presented the methodology for calculating the deadweight loss arising from pricing below marginal cost based on Renzetti (1999), and the measure of additional subsidy required for increasing returns to scale production when marginal cost pricing is employed.

- deadweight loss: loss of welfare at current prices

  $DWL(x^0) = \int_{x^*}^{x^0} (MC(x) - MB(x))\ dx$

- deviation: deviation from efficient output

  $DEV(x^0) = (x^0 - x^*)/x^0$

- waste: average DWL per unit of current output

  $waste(x^0) = DWL(x^0)/x^0$

- subsidy required at efficient price with increasing returns to scale

$S = C\left(1 - \frac{1}{Q}\right)$

The initial output level is x_0 is determined from the demand function at the current price p_0. The efficient point (x^*, p^*) lies at the intersection of the demand and marginal cost curves. It is the solution to the system:

$$\begin{aligned}\log x &= \beta_0 + \eta \log p \\ \log p &= \gamma_0 + \gamma_1 \log x\end{aligned}$$

where η is the price elasticity of demand.

The results are shown in Table 7.4. Two additional metrics are shown: the subsidy required per unit of output (at the efficient point), and the subsidy required per unit of output as a percentage of the efficient price. The former is a measure of the amount the price would need to increase by to achieve full cost recovery.

We comment firstly on the results using the depreciation excluded data set. This shows that the regional water businesses are less efficient in terms of the percentage deviation from efficient levels of output and the waste (the average DWL per unit of output). A higher proportional increase in price would be required for regional consumers than for those in metropolitan areas. At the efficient level of output, both metropolitan and regional water businesses would require similar levels of subsidisation of around 30% of the efficient price to fully recover costs.

With the depreciation included data set the results are more striking. Recall that the inclusion of depreciation was motivated by the need to account for investment costs over a period that has been characterised by low levels of investment in Victorian water supply. Depreciation was considered to be a proxy for

TABLE 7.4

Welfare Measurements: Variable Returns Model

parameter	metropolitan	regional
w/out depreciation		
price 2004/05 ($/KL)	0.80	0.70
qty. demanded 2004/05 (ML)	272,140	26,243
efficient price ($/KL)	1.08	1.08
efficient output (ML)	215,024	18,703
dead weight loss (K$)	7,164	1,320
deviation (pct)	21.0	28.7
waste ($/ML)	26.32	50.30
subsidy at efficient price (K$)	59,129	5,168
subsidy per unit output ($/KL)	0.27	0.28
subsidy (pct of price)	29.6	29.9
with depreciation		
price 2004/05 ($/KL)	0.80	0.70
qty. demanded 2004/05 (ML)	272,140	26,243
efficient price ($/KL)	1.19	1.75
efficient output (ML)	198,171	12,829
dead weight loss (K$)	13,334	6,959
deviation (pct)	27.2	51.1
waste ($/ML)	49.00	265.16
subsidy at efficient price (K$)	64,543	6,114
subsidy per unit output ($/KL)	0.33	0.48
subsidy (pct of price)	38.9	83.3

infrastructure renewal costs. In the period for which data was available, proportionally higher levels of depreciation (and renewal investment) were undertaken by regional water businesses in comparison to their metropolitan counterparts. The effect of this is an increase both in total cost and in marginal cost. This explains the higher price for regional businesses at the efficient level of output, and the sharp drop in consumption (as a result of the unchanged demand curve), and the higher deviation measure. The waste is also significantly higher than the without depreciation case because the renewal investment cost has not been reflected in the current price. Similarly, because costs are higher the required subsidy is higher even when efficient pricing is carried out.

7.5 Conclusion

There is considerable informal and empirical evidence that the economic cost of water is not being fully accounted for in the provision of water services. This case study has explored a functional approach to determining the marginal cost of water supply for a sample of Victorian Water businesses covering the period 2002-2005. Based on this sample there is evidence that the Victorian Water Authorities marginal cost curves exhibit increasing returns to scale, or decreasing marginal and average costs. Evaluation of marginal cost functions at the means of factor prices and outputs indicate that prices generally are below marginal costs. The use of a translog function produces estimates of marginal cost that are higher than with log-linear models. The effect of including depreciation in cost is to shift the marginal cost curve upwards. There is a loss of welfare as a result of inefficient pricing and this is higher in average cost terms for regional water businesses than for metropolitan businesses. As water businesses operate under increasing returns to scale, a subsidy is still required if marginal cost pricing at efficient levels of output were to be undertaken. This subsidy increases when capital costs are taken into account.

A functional approach to marginal cost determination creates the problem of choice of factor price and output levels. In this case study we have explored several alternate solutions to this. We expect that functions need to be adjusted as variables change. Under regulatory pricing however, tariff changes generally lag behind changes in the underlying input costs and demand. We will discuss the possibility of more frequent price adjustments in the conclusion to this thesis. Another issue for the use of marginal cost to determine price is related to the case where there are increasing returns to scale. In this case, full cost recovery is not possible and therefore a form of subsidy or second best pricing is required.

The period for which data was available comes before a period, commencing in 2005, of considerable transformation in water management in Victoria. This has involved increasing the role of the regulator in price determination. Prices are expected to increase by up to 8% on the basis of authorities' water plans that set out planned capital investment projects over the next five years. Therefore as investment increases so will the long run marginal cost.

Our present understanding of the long run marginal cost of urban water supply is dependent on the cost reporting of utilities. This study has identified three areas in which reporting falls short of the requirements to understand these costs.

Firstly, a significant proportion of operational and investment costs born by the water authorities is in the form of outsourced services and BOOT projects. The costs associated with these services tend to be amortised over time and appear as fixed costs to the authority. As these costs are not accounted for in marginal output terms, and not disaggregated into labour, capital and energy inputs and prices, there is a loss of information concerning their influence on marginal costs.

Secondly, through developers, new home buyers pay connection fees and for a part of the network infrastructure costs. The fees are accounted for as revenues by the water businesses and form a considerable component of their income. This means that purchasers of houses in new residential developments are subsidising low water prices for everyone by paying for the network expansion. This is one reason that house prices are high in Australia. On the other hand, if the true cost of network expansion was borne by all in the form of higher water prices, then owners of established dwellings would be subsidising the infrastructure required to support new housing development at the fringes of our major cities.

Thirdly, reporting of costs by water authorities does not fully account for marginal societal or user costs. An environmental contribution charge has recently been introduced, but the actual assessment of the costs to which this charge applies is informal and qualitative, and depends on the initiative of individual authorities.

CHAPTER 8

Second Case Study

Urban Water Services in Manila

Part A - Cost

8.1 The Privatisation of Water Services in Manila

When the city of Manila was faced with critical water shortages during 1995, the Government passed the Water Crisis Act (Chotrani, 1999; Rosenthal, 2001), establishing the case for privatisation of the water supply. The public run system was in decay. Non-revenue water (NRW), the proportion of supplied water lost to leakages and illegal taps, was among the highest in the world. The Metropolitan Waterworks and Sewerage System (MWSS), a division of the Department of Public Works, was considered inefficient (Montemayor, 2003), and the cost of operation of the city's water supply was a significant contribution to the national budget deficit.

With support from the World Bank, the objectives of privatisation were laid out. These included increased efficiency in operation and management of the water supply, reduced government debt from interest payments and staff costs, the opportunity for a return on assets while retaining government ownership of major infrastructure, and increased investment in the water system leading to improved services to all residential and commercial customers.

The bidding process involved companies competing on the basis of investment, coverage, NRW reduction, and water quality. However, the six short listed companies competed ultimately on price - that being the weighted average price of water that they would be offering to their residential and commercial consumers. In August of 1997 the Government handed over responsibility for management of water and sewerage in the greater Manila region to two private companies, Manila Water Company Inc. (MWCI) and Maynilad Water Supply Inc. (MWSI). The city was split into an East and a West Zone, with each company responsible for one zone. MWCI successfully bid for the East Zone with an average price of PhP 2.32 ($0.08) per cubic metre[1]. This was 26% of the average price before privatisation. MWSI was successful in bidding for the West Zone with a price of PhP 4.96 ($0.17) per cubic metre, 56% of the rate before privatisation. Table 8.1 shows price and volumes before and since privatisation.

Under the concession agreement, the MWSS handed over its operational roles to the concessionaires and established a Regulatory Office (MWSS-RO). The regulator's responsibility was to monitor pricing, contract compliance, and performance, and to promote competition. The MWSS retained ownership of the storage and network assets. The new concessionaires would maintain and invest in the network, manage the billing systems, and pay monthly concession fees to the government. Tariffs within each zone would be set independently by the concessionaires, but any changes to these tariffs could only be allowed by the Regulatory Office according to strict guidelines.

In the initial period of operation consumers benefited from lower tariffs while the concessionaires commenced a programme of investment that was aimed at reducing NRW and increasing revenues. With the Asian Economic Crisis in late 1997 there was, however, a dramatic increase in the debt servicing cost for both concessionaires. This lead to insistence from both concessionaires that a mech-

[1]The currency is the Philippine Peso. At the time of privatisation the exchange rate was PhP 29.33 = USD1.

anism be incorporated in the tariff that would allow them to recover from customers the foreign currency losses that occurred as a result of Peso devaluation. In 2001 this was agreed to by the government and a tariff Currency Exchange Rate Adjustment (CERA) mechanism was introduced. This resulted in a series of extraordinary (ie. above CPI) price adjustments that have forced the government to defend its privatisation strategy and respond to increasing criticism over the cost of water and lack of adequate service, mostly from groups that represent the urban poor, but also from industry and the middle class. As shown in Table 8.1, since privatisation, the nominal average price of water has increased at an average annual rate of 20%.

Considerable domestic debate has been entered into regarding the bid process (Solon and Pamintuan, 2000), and subsequent performance of the companies involved in Manila's water privatisation. According to its critics, in many areas the service had not improved, infrastructure investment had not materialised, and there were not the promised number of new connections. The strategy of reducing NRW by more effective monitoring of illegal connections was not as successful as hoped. These themes are revisited frequently by the local media and domestic NGOs, see for example, Esguerra (2003). The price of water is a matter of great sensitivity in Manila - a number of NGOs exist purely for lobbying congress on water pricing issues and preventing local distribution monopolies in areas not serviced by the concessionaires. More recently however, the outlook for one of the concessionaires has become more promising. During 2005 MWCI was listed on the Philippine stock exchange and, with a new source of investment capital, is reporting significant decreases in NRW[2].

[2]MWCI reported a fall in NRW from 59% to 37% in 2005.

TABLE 8.1

Metro Manila Water Tariff and Production 1996-2003

		(Tariff PhP/m^3)			
Date	Event	Basic	All-In	Connections	Prodn.(MLD)
MWSS					
01-Aug-96	pre-privatisation	6.12	8.62	779,380	2,800.00
01-Aug-97	on privatisation	8.78	11.83	779,380	2,800.00
MWCI					
01-Aug-97	award of contract	2.32	4.02	310,682	1,542.00
01-Jan-99	CPI	2.61	4.37	332,582	1,668.34
01-Jan-00	CPI	2.76	4.55	339,491	1,689.50
01-Jan-01	CPI	2.95	4.78	352,982	1,724.00
21-Apr-01	CPI	3.22	5.11	352,982	1,724.00
21-Oct-01	AEPA	4.22	6.32	352,982	1,724.00
01-Jan-02	FCDA	6.75	9.37	369,699	1,662.91
01-Jan-03	rebasing	10.06	13.38	396,778	1,577.83
MWSI					
01-Aug-97	award of contract	4.96	7.21	449,234	1,864.36
01-Jan-99	CPI	5.80	8.22	498,051	2,177.13
01-Jan-00	CPI	6.13	8.62	547,880	2,250.77
01-Jan-01	CPI	6.58	9.17	577,637	2,417.42
21-Apr-01	CPI	6.58	9.17	577,637	2,417.42
21-Oct-01	AEPA	10.79	14.26	577,637	2,417.42
01-Jan-02	FCDA	11.39	19.92	573,194	2,362.85
01-Jan-03	rebasing	11.39	19.92	585,953	2,313.82

TABLE 8.1

Continued

Notes:	
Basic	weighted average price for residential and commercial users
All-In	basic price plus charges, levies and taxes
CPI	annual consumer price index increase
AEPA	accelerated extraordinary price adjustment
FCDA	foreign currency devaluation adjustment
Sources:	MWSS-RO, McIntosh and Yniquez (1997)
	Republic of Philippines (2002)
	Republic of Philippines (2004)

Pressured by government, both concessionaires have instigated programs for low cost water supply to households in economically depressed parts of the city, where the connection coverage is low or zero and where the population is dependent on more expensive suppliers such as water tankers. In the East Zone this scheme is called *Tubig para sa Barangay*, and in the West Zone it is called *Bayan-Tubig*; both literally translate to *Water for the Community*. These are low cost distribution schemes that provide service to multiple households from a single connection. These programmes have the potential to significantly reduce illegal taps and revenue lost to other suppliers who often source their water stocks from MWSS at cheap commercial rates and sell them at greatly inflated prices. In some areas of the city, public taps have been removed and the new low cost schemes provided some compensation for this. However many households still cannot afford the one-off connection fee and for that reason do not participate in the schemes although it would mean lower prices. Areas that are zoned for redevelopment within the next five years have missed out on these schemes because the water companies are unable to recover their investment costs within this period (Perez, 2003).

These positive accomplishments have been offset somewhat by a long-running dispute between Maynilad Water, the concessionaire for the West Zone, and the MWSS-RO. On March 8, 2001, Maynilad Water (MWSI) served a *Force Majeure* notice on MWSS and stopped paying its monthly concession fees of PhP 200M (US4M). Concession fees are the rental cost for the water supply and distribution network, and also are a means of the concessionaires contributing to development costs of new infrastructure projects that were committed to by the government before privatisation. Maynilad cited the effects of the El Niño drought from 1997 to 1998, and the failure of MWSS to complete vital infrastructure projects on time including the Umiray Angat Transbasin Project (UATP). When this project was finally completed on June 23, 2000, Maynilad claimed that the supply was insufficient to meet its requirements.

On 9 December 2002, MWSI sought to terminate its 25 year concession early by filing a *Notice of Early Termination*, citing breaches of the Concession Agreement by the MWSS. At the same time they sought the return of their US$120M performance bond and PhP 19 billion (about $365M) in compensation from Government. The consortium's foreign partner, the French firm Suez Lyonnaise des Eaux, withdrew. Subsequently, an arbitration panel declared on 7 Nov 2003, that there were no grounds for early termination, the concession agreement had to continue in force, and the parties were to find extra-judicial solutions to their problems. The panel further declared that the overdue concession fees, which had grown to PhP 6.77 billion by September 2003, were still payable. MWSI continued to service the West Zone during this dispute.

Under threat of MWSS being able to draw on the performance bond, Maynilad agreed to a Rehabilitation Plan that was approved in September 2004. Subsequent non-execution of this plan lead to Maynilad creditors executing a Debt Capital and Restructuring Agreement (DCRA) that involved write-off of advances and dilution of the parent company's equity interest. Under the DCRA, MWSS is given the right to subscribe to a majority (83.97%) of the shares of Maynilad Water and to assign any portion of those shares to a third party by way of a public offer. Benpres, the parent company of Maynilad, divested its equity in the firm on July 20, 2005.

These events highlight some of the risks involved in privatisation and the need for governments to ensure that private operators of essential services remain financially viable.

8.2 Production and Costs

We now turn our attention to the study of production and costs under the privatised system.

Metro Manila's water supply is sourced from the Angat, Ipo and La Mesa dams, to the north of the city. Angat is the main source, water is channelled directly into Ipo dam and then through a number of aqueducts that discharge into the Novaliches Reservoir and onto the two treatment plants. The Balara Treatment Plant serves the eastern part of the city (serviced by MWCI) and has a production capacity of 1,600 million litres daily (MLD). The La Mesa Treatment Plant serves the western half of the city (MWSI) and has a production capacity of 2,400 MLD. Combined, the plants service more than six million people throughout the metropolis. The concessionaires each have additional storage facilities with total combined storage capacity of 460 million litres.

The concessionaires annual aggregate production and costs are taken from annual reports, Security and Exchange Commission (SEC) filings, and Service

Performance Reports (SPR) produced monthly and annually for the Regulatory Office by each concessionaire. This data is available for the period from the commencement of the concession in August 1997 up to December 2005. The Philippine financial year is calendar based.

In the following paragraphs we discuss the steps undertaken to transform accounting data into economic data suitable for use in the cost model.

8.2.1 Output

There are several choices of output measurement. These include water produced before transfers or losses occur; water net of transfers; and water net of transfers and losses. Transfers between concessionaires were needed in the initial years of operation while some infrastructure works were completed but are no longer needed and have been phased out. A transfer can be considered profit neutral in the sense that it appears as a cost for one firm and revenue for the other. Water loss through leakage and pilfering (NRW) is lost revenue, but is not itemised as a cost by the concessionaires. Instead, reduction of NRW[3] is a measure of performance that is monitored by each firm and the MWSS-RO. We consider declining NRW as a technical efficiency gain brought about by investment that leads to increased net water. For the concessionaires then, water net of transfers and losses (*available water*) is the correct measure of output as it determines the revenue that the firm will receive. Therefore this is the measure of output we have used. As we will estimate a single output model, secondary measures such as water quality, waste water treated, or supply disruptions have not been included.

[3]NRW is measured as a percentage of available water.

TABLE 8.2

Manila Cost Data: Cost Items Identified in Financial Statements

Category	Cost Item
Labour	salaries, wages and employee benefits
Capital and Investment	interest
	foreign exchange losses
	concession fees
	interest on performance bond
	depreciation and amortisation
	provision for inventory write down
Production	power, light, and water
	water treatment chemicals
	repairs and maintenance
	waste water costs
	transfer costs
Managerial	regulatory fees
	management, technical and professional fees
	business meetings and representation
	postage, telephone and supplies
	advertising
	occupancy costs
	provision for doubtful accounts
	collection fees
	taxes and licences
	transportation and travel
	insurance

8.2.2 Operational Costs and Factor Prices

The dependent variable is operational costs. This is the sum of variable input costs and overhead costs but excludes capital expenditure and depreciation. All costs are deflated to 1997 Pesos. The following sections first discuss overhead costs followed by each of the variable input costs.

8.2.2.1 Overhead Costs

These include occupancy (office rental) costs, regulatory costs, and fees for managers and consultants. Regulatory costs equal to one-half of the annual MWSS budget are paid by each concessionaire and serve to cover the operational costs of the MWSS-RO. These are capped (at PhP 200.00 million in 2005) and are adjusted annually according to the CPI. Fees for managers and consultants are incurred in project management activities. For example, an infrastructure development project requires technical and managerial specialists for the duration of the implementation. The cost will be related to the total project cost, that is to the incremental level of capital stock, and this expansion is dependent on the cost of capital.

8.2.2.2 Labour

The measure of labour input was computed from staff per connection ratios contained in Annual and Service Reports. The price of labour was computed from total wage costs in the annual income statements. This compares favourably with both the June 2002 Occupational Wages Survey (Republic of Philippines, 2003) and daily nominal minimum wage rates (Republic of Philippines, 2005). The Occupational Wages Survey shows the average monthly wage for workers engaged in the collection, purification and distribution of water in the utilities, water treatment and related industries to be PhP 20,161. Average annual staff salaries have been deflated to 1997 Pesos.

8.2.2.3 Cost of Capital

We adopt the usual approach of considering capital to be the plant and equipment assets that are used in production. For the Manila concessions, ownership of these assets is distributed across both firms and the government. The concessionaires pay concession fees for those assets that are government owned and allocate additional funds for new investment[4]. Concession fees are calculated as a proportion of MWSS historical and current debt at the commencement of the concession in August 1997. This proportion depends on the location of the underlying assets - approximately 90% was located in the West Zone at the commencement of private operation. For the concessionaires the cost of capital is therefore the cost of their portion of the MWSS long term debt plus the cost of their own short and long term borrowings.

Over the period 1997-2005 for which we have data, both firms have been required to borrow to finance their business. The capital structures of both firms are a complex mix of debt and equity. Equity is sourced from parent companies and foreign investors. The debt of both companies is a mix of fixed and variable interest rate loans, and some small interest free loans. Loans are primarily denominated in USD, and to a lesser extent in Pesos and Yen. The benchmark interest rate for offshore borrowing is the six month London Interbank Overnight Rate (LIBOR) and for domestic borrowing it is the 364 day Treasury Bill rate. At the end of 2005, MWCI's long term debt amounted to US $84.7 million (PhP 4,526 million) and MWSI's long term debt was approximately US $115.7 million (PhP

[4]Under the concession agreement these investments will be returned to the government at the end of the 25 year concession.

6,179 million). The two firms account for their concession fees as a long term debt obligation and include concession assets in their own balance sheet reporting.

Newly borrowed funds have been utilised for two main purposes. Initially they have been used to fund the concession startup and the first few years of operation until the concession became profitable. The second purpose has been to invest in the supply network with the objective being to increase revenues through increasing the number of connections and decreasing water losses. Increases in water output are attributable to growth in service coverage[5] through increased connections rather than directly from population growth. Before privatisation, service coverage was around 67%, by 2003 this had grown to 85% (MWCI) and 78% (MWSI).

There are several approaches to modelling the cost of capital. One alternative used by Wolak (1994) employs a *user cost of capital* approach. This is determined as a time series autoregressive equation using as regressors the regulator's allowed rate of return, the change in prices of capital goods, and their depreciation. We have adopted a simpler approach based on available data that involves calculation of a weighted cost of capital (WACC). The weighted cost of capital of each firm can be calculated for each time period with knowledge of interest rates for each type of loan and the loan amount. We have simplified this by determining the proportion of total debt denominated in \$US and assuming the remainder is denominated in Peso. Therefore the WACC is:

$$r_t = \theta_t r_t^{US} + (1 - \theta_t) r_t^{Peso}$$

Where the θ_t is the proportion of \$US debt and r are the respective interest rates in period t.

[5]The proportion of households with a connection.

8.2.2.4 Energy Costs and Technology

Energy, chemicals, and water itself are inputs to the production of water. Electricity usage costs have been reported on by one concessionaire but not the other; neither supplier reports the unit prices of these inputs. As there are no suitable proxies for these factor prices they have been omitted from the analysis.

We have already mentioned that declining levels of NRW can be viewed as a technological improvement that leads to productivity gains. Other forms of technology improvements might include new treatment technologies that reduce costs. There is unlikely to be a proper time series measure of such technology. The favoured approach is therefore to use a time trend variable as a proxy for technology.

8.2.2.5 Environmental Costs

Environmental (user or society costs) are increasingly incorporated into economic models to account for the effects of human impact on the environment. The Philippines government has begun to address this by use of an Environmental Charge (EC) of 10% of the water charge that is levied upon water consumers. This is collected by the concessionaires as revenue. This charge is used to offset waste water costs and government imposed environmental levies or licences. The part that is returned to government is used by environmental agencies in rehabilitation and environmental law enforcement. Therefore there is no effect on cost minimisation choices.

8.2.2.6 Foreign Exchange Losses and Gains

Foreign exchange losses and gains are incurred due to currency movements impacting monthly amortised loan repayments in local currency. The local currency differential arising from a loss or gain is added to a foreign currency adjustment account and recorded as an accounting cost. The net adjustment account is reviewed every six months by the regulator and concessionaire to determine the adjustment to the Foreign Currency Differential Adjustment (FCDA) that is charged to customers as a recovery mechanism. This is in addition to the permanent Currency Exchange Rate Adjustment (CERA) that is levied on consumers at the rate of one Peso per cubic metre consumed. The mechanism allowing recovery of these costs was only introduced in October 2001, four years after commencement of the concessions. Accumulated foreign currency losses are amortised as expenses at the same rate that the FCDA allows recovery. Because of the delay in allowing these costs, and the need to amortise them, there is lag between the causal event - devaluation of local currency - and its cost recording. An examination of the cost data clearly shows the increase in costs commencing late 2001 and into 2002 as a result of this recording.

Therefore foreign exchange costs are recouped as lagged revenue. They will not enter the firms' short run production decisions but may do so in the capital adjustment process in particular when macroeconomic factors are impacting interest rates. However, knowing that consumers will pay all currency losses reduces the incentive for the firms to hedge against such losses.

8.3 Data Description

Table 8.3 shows the variables and summary statistics for the cost data set. Additional ratio variables used in estimation have not been included. The data set consists of annual observations for the two concessionaires over the period of 1997-2005.

TABLE 8.3

Manila Cost Data: Summary Statistics

Variable	Description	Mean	Median	Min.	Max.	SD.
C	Annual Operating Costs (M.Peso)	2,005.36	1,966.50	973.56	3,488.62	881.74
X	Available Water (MLD)	740.245	754.500	440.000	877.431	109.019
W	Average Annual Wage Rate (K.Peso)	272.243	264.529	252.430	298.163	17.701
RWACC	Cost of Capital (WACC)	5.45	5.74	1.56	8.39	2.17
RDOM	Domestic Interest Rate	12.03	10.9	8.9	18.4	3.13
LIBOR	London Interbank Rate	4.00	3.77	1.23	6.65	1.95
EXCHRATE	Exchange Rate	46.84	50.99	29.47	56.04	8.75

8.4 Estimation of the Minimum Cost Models

In this section we present the estimation results of both the constant returns to scale cost model and the variable returns to scale cost model that have been described in Chapter 3. A translog model was not estimated because it would require more observations to produce reliable results. The models are estimated in log-linear form with weighted least squares correction for heteroskedasticity. Unobserved time effects are accounted by use of an additive time variable which alters the scaling constant. We use duality to retrieve the parameters of the production function and have not estimated the direct production function. All local currency values have been deflated to 1997 Pesos.

The models account for cost of capital by use of a weighted cost of capital (WACC) approach computed as the weighted average of US dollar borrowings and Peso borrowings. Based on the available data, it was preferable to express this in terms of the proportion of total debt denominated in USD. The WACC can then be expressed as:

$$WACC_t = \theta_t LIBOR_t + (1 - \theta_t) RDOMESTIC_t$$

where:

$WACC_t$	=	weighted average cost of capital in time t
θ_t	=	proportion of debt denominated in USD
$LIBOR_t$	=	the London Interbank Overnight Rate[6]
$RDOMESTIC_t$	=	domestic interest rate

[6]The benchmark for foreign currency borrowings.

8.4.1 Two Factor Cost Function with CRS Production

The two factor CRS minimum cost function with CRS production dummy and time variables is:

$$ln\left(\frac{C_{it}}{w_{it}X_{it}}\right) = \gamma_0 + \delta ln\left(\frac{r_{it}}{w_{it}}\right) + \gamma_1 T_t$$

where:

C	=	operating cost
X	=	available water
w	=	wage price
r	=	weighted average cost of capital
T	=	time variable: number of years since 1997
i	=	firm index
t	=	time index

Table 8.4 shows the estimated coefficients using pooled data for the basic cost model and model variants with a time variable. The coefficient for r/w (ie. δ) is the output elasticity for K in the Cobb-Douglas production dual. The output elasticity for L is $1-\delta$. In the restricted model the output elasticities are also the cost shares. The coefficients for the dummy and time variables are additive to the scaling constant γ_0. Standard errors are shown below the estimates in brackets. Variables that are significant at the 90% level are marked with an asterisk beside the standard error. The rightmost columns show the adjusted R^2 value and the standard error of the residuals.

TABLE 8.4

Two Factor Cost Function with CRS Production

Model Variant	const	$ln(r/w)$	T	$\bar{R}^2$	$\hat{\sigma}$
basic	2.926	0.184			
	(0.621)	(0.160)		0.019	1.37
time	3.039	0.204	-0.0040		
	(0.706)	(0.202)	(0.0377)	0.020	1.29

8.4.2 Two Factor Cost Function with Variable Returns to Scale

The two factor minimum cost function with variable returns to scale production, including a time variable is:

$$ln\left(\frac{C_{it}}{r_{it}}\right) = \gamma_0 + \frac{1}{\alpha+\beta} ln\left(X_{it}\right) + \frac{\alpha}{\alpha+\beta} ln\left(\frac{w_{it}}{r_{it}}\right) + \gamma_1 T_t$$

where:

C = operating cost

X = available water

w = wage price

r = weighted average cost of capital

T = time variable: number of years since 1997

i = firm index

t = time index

Table 8.5 shows the estimated coefficients using pooled data for the basic cost model and model variant with time variable. In the model the estimated coefficients for $ln(w/r)$ are the cost shares for L; and the inverse of the coefficient for

TABLE 8.5

Two Factor Cost Function with Variable RTS Production

Model Variant	const	$ln(X)$	$ln(w/r)$	T	$\bar{R}^2$	$\hat{\sigma}$
basic	1.21	1.317	0.734			
	(3.48)	(0.550)*	(0.133)*		0.753	1.39
time	-7.72	2.572	0.975	-0.0926		
	(6.51)	(0.958)*	(0.203)*	(0.0661)	0.739	1.50

$ln(X)$ determines returns to scale. The output elasticities can be determined from the coefficients. The coefficients for the dummy and time variables are additive to the scaling coefficient γ_0.

This model is a significant improvement on the constant returns to scale model with higher adjusted R^2 values and all variables significant with the exception of the time variable.

8.5 Discussion of Results

Of the two models that we have estimated, the variable returns to scale model produces the better fit as indicated by the adjusted R^2 value. Excluding the time variable, all variables are significant at the 90% level. Based on F-test statistics shown in Table 8.7, the constant return model was not significant, ie. the null hypothesis of all slope parameters equal to zero could not be rejected. On the other hand F-tests indicate the variable returns model was significant in all parameters. Using the results from the variable returns model we can determine the output elasticities and cost shares. These are summarised in Table 8.6. For comparision we have included the CRS results as well although these are not statistically significant.

We can make two comments regarding these results. The first is that there appears to be some evidence that the output elasticity of labour is higher than for capital. We would conclude from this that water production is relatively labour intensive. The second observation that we make is that there is evidence of *decreasing* returns to scale (in the variable returns model). Decreasing returns to scale means that both marginal and average costs are increasing, and marginal costs are greater than average costs. If water were to be priced at marginal cost then the firm's revenue would be in excess of its costs (Luenberger, 1995, p. 63), leading to potential criticism by consumers and the regulator. On closer examination however, as will be shown in the following hypothesis test, this result cannot be confirmed statistically. We cannot reject the hypothesis that returns to scale are constant, that is that marginal costs and average costs are constant and that the firms make normal profits.

Finally, as shown in Table 8.8, we have carried out Regression Specification Error Test (RESET) tests for model misspecification using artificial models augmented with squared and cubed predicted values. Because the constant returns model did not pass the F-test we only carried out RESET tests on the variable returns model. In both variants we were unable to reject the null hypothesis that the coefficients of the augmented regressors were both zero. This suggests that functional form and omitted variables are not a problem in the variable returns model.

TABLE 8.6

Summary of Estimation Results: Manila Cost Data

	Output Elasticity		Cost Share		
Model	Capital	Labour	Capital	Labour	RTS
CRS production	0.184	0.816	0.184	0.816	1.0
Variable RTS production	0.202	0.558	0.266	0.734	0.760

TABLE 8.7

F Tests for Model Significance

H_0: $\beta_2 = 0, \beta_3 = 0, \ldots, \beta_k = 0$ Model is not significant
H_1: at least one of the $\beta_i \neq 0$

Model	Test Statistic	DF	$F_{95\%}$	Decision
Constant Returns Model				
basic	1.3	1,16	4.5	do not reject H_0
time	1.2	2,15	3.7	do not reject H_0
Variable Returns Model				
basic	27.0	2,15	3.7	reject H_0
time	17.0	3,14	3.3	reject H_0

TABLE 8.8

Ramsey RESET Tests for Model Specification Error

original model	$y_i = \beta_0 + \beta_1 x_{1,i} + \ldots + \beta_k x_{k,i}$
predictions	$\hat{y}_i = b_0 + b_1 x_{1,i} + \ldots + b_k x_{k,i}$
artificial model	$y_i = \beta_0 + \beta_1 x_{1,i} + \ldots + \beta_k x_{k,i} + \gamma_1 \hat{y}_i^2 + \gamma_2 \hat{y}_i^3$

H_0: $\gamma_1 = 0, \gamma_2 = 0$ (no specification error)
H_1: at least one of the $\gamma_i \neq 0$

Model	DF	Test Statistic (F_t)	$\Pr(F > F_t)$	Decision
Variable Returns Cost Model				
basic	2,13	0.7617	0.487	do not reject H_0
time	2,12	1.9124	0.190	do not reject H_0

8.6 Testing for Constant Returns to Scale

We have carried out a series of hypothesis tests to determine if the returns to scale parameters shown in Table 8.6 are significant. The results of these tests are summarised in table 8.9. Test statistics are derived from the estimates and standard errors in the variable returns to scale model 8.5. In both cases we do not reject the null hypothesis of constant returns to scale at the 90% level. Therefore there is statistical evidence that the Manila concessionaires' water production exhibits constant returns to scale.

TABLE 8.9

Hypothesis Tests for Constant Returns to Scale

Alternative is either increasing or decreasing RTS	
H_0: $1/(\alpha+\beta)=1$	H_1: $1/(\alpha+\beta)\neq 1$
DF: 16	critical value: ±1.746
Test Statistic	Decision
0.576	do not reject H_0
Alternative is decreasing RTS	
H_0: $1/(\alpha+\beta)=1$	H_1: $1/(\alpha+\beta)>1$
DF: 16	critical value: 1.337
Test Statistic	Decision
0.576	do not reject H_0

CHAPTER 9

Second Case Study

Urban Water Services in Manila

Part B - Demand

9.1 Urban Water Consumption and Prices in Manila

9.1.1 Sources of Data

Over the past decade there have been several studies related to domestic water use carried out in Manila. The most detailed survey of domestic water consumption was carried out in 1996 by the Philippine Institute for Development Studies (David, Inocencio, Abracose, Clemente, and Tabios, 1998) with the objective being determination of the economic price of water. This survey covered 500 households in the Metro Manila area within the National Capital Region[1] (NCR). Another large survey was conducted in 2000 by the MWSS Regulatory Office and the World Bank. This was a survey of MWSS water users (PAWS-*Public Assessment of Water Services*) that aimed to determine consumer's perceptions of the benefits of privatisation and concessionaires' performance. The concessionaires, private consulting firms, and development assistance donors such as the ADB are all potential sources of data, but this data is not available for research purposes.

For this study we have made use of two large data sets consisting of housing census and household expenditure information for estimation of parameters of the

[1]The Philippines is divided into regions. The NCR covers Manila and some outer districts. Manila itself consists of a number of cities, some of which are classed as municipalities.

demand function. This requires the use of household water expenditure and prices to derive consumption. The advantage of these data sets, in addition to the fact that they are in the public domain, is that they are random samples covering a wide geographical area, thereby reducing the risk of selection bias. In the following two sections we describe our chosen sources of information.

9.1.1.1 The 2000 Census of Population and Housing

The 2000 Census of Population and Housing (National Statistics Office, 2000b) was undertaken by the National Statistics Office (NSO) in May 2000. It was the eleventh census of population and the fifth census of housing undertaken in the Philippines since the first census in 1903. The objective of the census is to take an inventory of population and housing units all over the Philippines and to collect information about their characteristics. Census day was May 1, 2000. Enumeration lasted for about one month. The housing component of the census (hereafter referred to as the Housing Census) is a randomly selected 10% sample of 29,686 households that were required to complete additional questions concerning housing characteristics. The variables that are of interest in the Housing Census concern the household source of water for drinking and cooking, and for laundry and bathing.

9.1.1.2 The 2000 Family Income and Expenditure Survey

The NSO conducts the Family Income and Expenditure Survey (FIES) every three years. The objectives of this survey are to gather data on family income and expenditures, sources of income and income distribution, spending patterns, and the degree of inequality among families; to update weights used for estimation of the Consumer Price Index; and to assist in estimation of the national poverty threshold and incidence. The data collected are not used for taxation, investigation or enforcement purposes. The expenditure data are grouped into food and non-food expenditure. This latter category includes expenditure on domestic water, bottled water, power and lighting, durables, housing rental and maintenance, tobacco and alcohol, clothing, medical needs, transport and communications, recreation, education, and gifts. Income data are grouped by source. The survey also includes data related to family size and composition.

A national sample of 39,615 households was surveyed for the FIES. The primary survey division is a domain. A domain is an urban or rural administration unit (city, municipality, or district). Rural areas with population over 150,000 (based on the 1995 National Census) are also domains. The households were interviewed twice using the same questionnaire over a six month period. Each interview used the previous half-year period as the reference period. According to the NSO, this scheme improves data quality by reducing errors in survey responses and averages seasonal variation in income and expenditure. The first interview was in July 2000 while the second was in January 2001. The survey utilises a multi-stage sampling design for sample frame selection; details of which are provided in National Statistics Office (2000a).

9.1.2 Household Sources of Water

Households in Manila get their domestic water for drinking, cooking, bathing and laundry from different sources including the MWSS network, wells, roof tanks, and water carters. The choice of water supply depends on a number of factors including location, dwelling type and household income. Many households have alternative water sources, for example a roof tank and MWSS connection. Table 9.1 below shows the division of households by primary source of water in the National Capital Region (NCR).

The cost of a shared connection is divided equally or according to use among

TABLE 9.1

Source of Household Water in Manila NCR

		% of All Households	
Source of Household Water	Households	Drinking/Cooking	Laundry/Bathing
MWSS - single connection	1,083,072	50.78	51.50
MWSS - shared connection	518,091	24.29	24.20
Well - private/shared	317,591	14.89	16.78
Carter/Tanker	135,205	6.34	5.30
Bottled water	27,603	1.29	0.00
Spring lake river rain etc	3,629	0.17	0.20
Others	47,798	2.24	2.00
Total Households	2,132,989	100.00	100.00

Source: NSO 2000 Housing Census.

the households that share it. The account holder (this might be one family or the manager of a housing estate) will apportion the monthly account and may add a small service charge to each household. A well may incur a charge for the user if it is not on their land. The government is also seeking to register all wells and to charge households for groundwater extraction.

9.1.3 Water Prices and Household Income

Based on a survey of 500 households in Metro Manila conducted in 1996, David, Inocencio, Abracose, Clemente, and Tabios (1998) found that monthly water expenditure consumed around 2.4% of household income and 11.9% of per capita income for the most expensive service; private water carters selling direct to the household dwelling, a form of water source prevalent amongst the lowest income earning households. This secondary market is often characterised by local monopoly suppliers who, as reported in the study, source about 80% of the water from the MWSS network, and then distribute it at much higher prices throughout the poorer parts of Manila. Households have no option other than to pay these prices because they lack substitutes for essential domestic water Those households with the best form of water service, MWSS with a sewer, had the lowest ratio of water expenditure as proportion of income at around 0.3%. This survey demonstrated the inverse relationship between income and the average price of water. The household budget share for water is significantly higher for lower income groups – simply because these groups live in areas that are not serviced by the water network, or cannot afford the one-off connection fee.

Average prices paid by households for the different type of service have been reported by David (2000); David, Inocencio, Clemente, Abracosa, Largo, Tabios, and Walag (2000), based on surveys conducted in selected areas within the NCR during 1995. More recently, Inocencio (2003) presented prices based on a survey carried out in 2001. Table 9.2 summarises these prices and demonstrates the higher price paid by communities that are not serviced by the MWSS network.

Note that in Table 9.2 a community water system is a more restricted definition than that given by the NSO in Table 9.1. It is equivalent to a shared faucet whose users pay a surcharge for the management of the service. Typically new housing estates in outer suburbs are serviced in this manner, as the rate of MWSS network expansion does not keep up with housing development.

For Manila in general, water expenditure takes a greater proportion of the household budget than the rest of the country, and this proportion is highest for

TABLE 9.2

Inocencio Study of Household Water Source

NOTE: This table is included on page 150 of the print copy of the thesis held in the University of Adelaide Library.

($US1=P51)

lower income households. For the year 2000, the National Survey Office estimate of annual household expenditure on water for households in the NCR was PhP 2,528 ($62) based on a population of 2,188,675 households. For the country excluding the NCR this falls to PhP 645 ($16) based on a population of 13,150,980 households. Although the budget share of water based on the same survey data is quite low - less than one per cent - this figure is misleading because of large variation in incomes. When the households are grouped into income deciles we can see that for the NCR, the households in the top 10% of income pay only 0.7% of their income on water while for the lowest 10% of earners the proportion of income that is spent on water is 2.9%. For the rest of the country the expenditure share for water from highest income decile to lowest is much lower - ranging from 0.7% to 0.2%. While households living outside the NCR may have access to more alternatives to purchased water such as wells or water tanks, the distortions in household water expenditure in the NCR compared to the rest of the country, indicate that for many households water costs and pricing are an issue of major importance. Table 9.3 shows the distribution of household expenditure on water in NCR and for the rest of the country by income decile.

9.2 Consumption Analysis using Linear Methods

This section describes estimation of the domestic water demand function using conventional linear models. We begin with a discussion of the process of preparation of a data set of household annual water consumption, expenditure and prices that covers a sample of households in the NCR. This is followed by presentation of econometric results and a discussion of results.

TABLE 9.3

Water's Share of Household Budget (%)

Income Decile	1	2	3	4	5	6	7	8	9	10
NCR	2.9	1.8	1.5	1.9	1.9	1.8	1.6	1.3	1.2	0.7
Rest of Country	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.8	0.8	0.7
Source: calculated from NSO FIES 2000										

9.2.1 Data Preparation and Description

The water data set is based on the 4,141 household observations within the NCR from the FIES 2000 survey. For each observation record a weighted average water price, unit value of bottled water, and household water consumption has been determined. The use of unit values (expenditure divided by consumption) as a proxy for price is discussed by Deaton (1997, p. 149). Water consumption is the expenditure divided by the weighted average water price. A small number of households (56) that have recorded no water expenditure are excluded from the data set.

The weighted average water price was calculated by use of the NSO Housing Census. Based on the given weights, the sample was converted to population estimates. The variables related to source of water were then aggregated by city. Proportions of households that pay for domestic water were calculated in three categories: households with a water connection, those who share a connection, and those using carted water[2]. These form a set of weights that are used in the average price calculation:

[2] Households were excluded if their primary source is a well, river, lake or other free source.

$$\{w_{j,1}, w_{j,2}, w_{j,3}\}$$

where j is the city index, and the weights are ordered as direct, shared, and vended.

Next two sets of prices were determined. The first set applies in the areas serviced by MWCI and the second set in the areas serviced by MWSI. These contain first, the *all-in* price (the average price per cubic metre charged by the provider to which all taxes and levies are added); secondly the price of shared connection, estimated at the *all-in* price plus 10%; thirdly, the price of vended water which is assumed constant across the metropolitan area at PhP 50 per cubic meter based on estimates provided by Inocencio (2003). The set of prices is $\{p_{j,1}, p_{j,2}, p_{j,3}\}$.

Finally, the weighted average price for city j is:

$$P_j = \sum_{i=1}^{3} (w_{j,i} * p_{j,i})$$

The domestic water price estimates by city are shown in Table 9.4 below. The summary statistics for the water consumption, pricing, and expenditure data set for 4,085 households in the NCR are shown in Table 9.5.

TABLE 9.4

Weighted Average Domestic Water Price (Pesos per m^3)

City	Population	Population Density	Weighted Avg. Price
Manila	1,581,082	63,294	10.09
City of Mandaluyong	278,474	29,976	5.29
City of Marikina	391,170	18,177	7.06
City of Pasig	505,058	10,422	7.89
Quezon City	2,173,831	12,660	7.40
San Juan	117,680	19,778	4.71
Kalookan City	1,177,604	21,104	12.80
Malabon	338,855	21,569	9.08
Navotas	230,403	25,772	12.41
City of Valenzuela	485,433	10,324	18.35
City of Las Piñas	472,780	14,463	16.33
City of Makati	444,867	24,296	5.61
City of Muntinlupa	379,310	9,542	12.85
City of Parañaque	449,811	9,659	20.41
Pasay City	354,908	25,405	9.13
Pateros	57,407	5,520	5.82
Taguig	467,375	10,338	15.84
TOTAL	9,932,560	16,091	

Source: NSO Population Census of 2000.

TABLE 9.5

NCR Water Consumption, Pricing, and Expenditure Data Set:

Summary Statistics

Variable	Description	Mean	Median	Min.	Max.	SD.
QWATER	water consumption (m^3)	21.2	14.9	0.4	534.8	24.7
QBOTLE	bottled water cons. (litres)	3.0	0.0	0.0	205.8	10.3
PWATER	weighted average water price	10.4	10.4	4.7	20.4	4.3
PBOTLE	bottled water price	18.7	18.7	10.0	30.3	1.9
WATER	water expenditure	197.2	140.0	3.0	3,000.0	204.7
BOTLE	bottled water expenditure	49.8	0.0	0.0	4,116.7	168.4
TOTEX	total expenditure	18,819.8	13,849.3	884.8	515,791.7	21,654.4
FSIZE	family size	5.0	5.0	1.0	19.5	2.2

(monthly consumption and expenditure)

(prices and expenditures are in Pesos)

9.2.2 Estimation of the Linear Demand Function

This section presents the results of estimation of the demand function using two log-linear models and one non-linear model. In the first linear model the coefficients are the estimates of price and income elasticity:

$$\ln q_i = \beta_0 + \beta_1 \ln p_i + \beta_2 \ln m_i + \beta_3 \ln f_i$$

where:

$$\begin{aligned} q &= \text{monthly HH consumption } (m^3) \quad (QWATER) \\ p &= \text{weighted average price of water (pesos per } m^3) \quad (PWATER) \\ m &= \text{monthly HH expenditure/income (pesos)} \quad (TOTEX) \\ f &= \text{family size} \quad (FSIZE) \end{aligned}$$

The second is a log-linear model with an interaction term:

$$\ln q_i = \beta_0 + \beta_1 \ln p_i + \beta_2 \ln m_i + \beta_3 \ln p_i \ln m_i + \beta_4 \ln f_i$$

where the variables are the same as for the log-linear model. This specification appears in Rietveld, Rouwendal, and Zwart (1997). The elasticities are linear combinations of the log of the other interaction variable:

$$\begin{aligned} &\text{price elasticity of demand:} \qquad \rho_p = \beta_1 + \beta_3 \phi(\ln TOTEX_i) \\ &\text{income elasticity of demand:} \qquad \rho_m = \beta_2 + \beta_3 \phi(\ln PWATER_i) \end{aligned}$$

where ϕ is an aggregation function carried out over all observations.

The non-linear model alters the basic linear specification to include a power term for the log price of water.

$$\ln q_i = \beta_0 + \beta_1 \ln p_i^{\beta_2} + \beta_3 \ln m_i + \beta_4 \ln f_i$$

TABLE 9.6

Estimates of Demand Function - NCR Water Consumption

model	const	$\ln p$	$\ln m$	$\ln f$	$\ln m * \ln p$
basic	-1.148	-0.5647	0.5034	0.1894	
	(0.183)*	(0.0279)*	(0.0176)*	(0.0243)*	
interaction	-1.755	-0.291	0.5660	0.1901	-0.0283
	(0.919)	(0.406)	(0.0945)*	(0.0243)*	(0.0420)

model	const	$\ln p$	$expnt(\ln p)$	$\ln m$	$\ln f$
non-linear	-2.740	3.55	-2.61	0.4836	0.1984
	(0.330)*	(1.55)*	(1.39)*	(0.0178)*	(0.0244)*

NB: dependent variable: $\ln q$
linear models: $\bar{R}^2 = 0.284$; $\hat{\sigma} = 0.71$

This lets us model changes in price elasticity with water price itself:

$$\rho_p = \beta_1 \beta_2 \phi (\ln PWATER_i)^{\beta_2 - 1}$$

This model has been estimated using non-linear least squares.

The estimation results are shown in Table 9.6. Note that in the basic linear model all variables are significant, but in the model with the interaction term, both the coefficients of price and the interaction term are not significant. This suggests that model specification may be a problem. All coefficients in the linear models have the expected signs. The non-linear model has significant coefficients but the exponent term on $log(PWATER)$ is significant only at the 90% level.

TABLE 9.7

Price and Income Elasticities - NCR Water Consumption

			Quartile				
Model	$\phi()$	Mean	Min	2	Median	4	Max
Price Elasticity							
basic linear		-0.56					
interaction term	$\ln(TOTEX)$	-0.56	-0.48	-0.55	-0.56	-0.57	-0.66
non-linear	$\ln(PWATER)$	-0.49	-1.90	-0.76	-0.53	-0.31	-0.17
Income Elasticity							
basic linear		0.50					
interaction term	$\ln(PWATER)$	0.50	0.52	0.51	0.50	0.49	0.48
non-linear		0.48					

The elasticities are shown in Table 9.7. These are within the expected range, have the expected signs and compare favourably with other studies (see for example the meta-analysis conducted by Dalhuisen, Florax, de Groot, and Nijkamp (2003)). Price elasticities in the interaction model are calculated at each income quartile and the mean. For the non-linear model they depend on $\ln(PWATER)$ and are calculated at each quartile and the mean. Note that in the interaction model, price elasticity increases with budget. The reason for this is likely to be that lower budget households have a lower discretionary use of water (for example, car washing or use of washing machines) and are less elastic in their basic water needs. The non-linear model gives us an insight into how prices themselves affect price elasticity. According to the results, price increases when prices are low have a greater effect on consumption that when prices are high. This result is difficult to interpret because the model does not distinguish MWSS households that pay a high marginal price because they consume more, from households who rely on water from secondary sources and pay even higher prices. In the latter case demand is likely to be less elastic because of basic needs. In the former case demand at the higher rate may be less elastic because the household can easily afford increased charges. In the case of income elasticity, there is little variation in the figures - this suggests that income elasticity does not depend on the price, and therefore does not depend on the source of purchased water.

In the following section we will estimate demand using a data set of households that have a MWSS connection as their primary water source.

9.3 Consumption Analysis using Maximum Likelihood Methods

This section describes maximum likelihood estimation of the domestic water demand function using the two error model described in Chapter 4. We begin with a discussion of the process of preparation of a data set of household annual water consumption. This is a selective data set in the sense that observations are limited to those households with a connection to the MWSS supply. In contrast, the data set used in the previous section was a sample of all households in Manila NCR that pay for their water. Following from description of the data, we present and discuss the econometric results of estimation of the two error demand function.

9.3.1 Data Preparation and Description

The NSO FIES survey data does not include information about the source of domestic water for each household. To overcome this limitation, our approach is to select two cities that have the highest proportion of households using the MWSS network, based on the 2000 Household Census. The aggregated figures for NCR were shown in Table 9.1. Disaggregating this data by city we find that the two cities with the highest proportions of households with a direct or shared connection are San Juan (99.41%) and Malabon (99.73%). These cities are situated entirely within different service zones (MWCI and MWSI respectively) - and therefore face different tariffs. This will increase the variance in prices, which we expect will improve estimation results.

9.3.1.1 Calculation of Water Consumption

Discussion with staff at the NSO confirmed that during the FIES survey, when households in connected areas were asked to estimate their water expenditure, they simply presented the most recent invoice from the supplier. Therefore there is justification for determining household water consumption by reverse application of the supplier's bill. The domestic water bill is computed in the following manner.

1. Connection fee = PhP 9.25 (MWCI) 20.63 (MWSI)
2. Consumption charge = based on Table 9.8 below.
3. Basic Charge (A) = connection fee + consumption charge
4. CERA[3] (B) = PhP 1 per m^3 of consumption.
5. Water Charge (WC) = A+B
6. Environmental Charge (EC) = 10% of water charge
7. Maintenance Charge (MC) = PhP 1.50 (based on the meter type - residential customers usually have a 13mm meter)
8. VAT = 10% of WC+EC+MC
9. TOTAL Bill = WC+EC+MC+VAT.

We now describe the algorithm to determine water consumption. For each block, the marginal price is increased by one Peso to account for CERA. The block base water charge is computed - this is the cost of consumption on the kink.

[3]Currency Exchange Rate Adjustment.

TABLE 9.8

Tariffs for Domestic Water Use - Manila 2000

		cubic metres							
Firm	fixed	10-20	20-40	40-60	60-80	80-100	100-150	150-200	200+
MWCI	9.25	1.13	2.14	2.82	3.29	3.45	3.60	3.76	3.91
MWSI	20.63	2.51	4.79	6.29	7.35	7.68	8.03	8.39	8.74

Note: fixed charge connection fee includes usage up to $10m^3$.
Block prices are pesos/m^3.

For example, the MWCI block 1 base is the PhP 9.25 connection fee, while the block 2 base is PhP 9.25 + PhP 10 (10 m^3 at a marginal rate of one Peso) = PhP 19.25, and so on. Block bases define the range of expenditure for each block, so each household's water charge must map to a unique block. The consumption for a household is computed by removing the VAT, MC, and EC from the bill, leaving the water charge. The block is determined, and consumption is the sum of the block base consumption and the block marginal consumption.

In creating the consumption data set, we have selected households in those cities where the primary source of water is the MWSS network. This does not preclude supplementation by other sources of water, or the small (less than 0.6%) probability that the household does not have a connection to the network. In the latter case, we assume that household expenditure is higher than an equivalent household with a connection and so the estimated consumption would also be higher. In the former case, when MWSS water is supplemented with free water (there would be no reason for a household to purchase more expensive water), expenditure would be lower than for an equivalent household without a free source, therefore the estimated consumption would also be lower. We also need to consider the effect of including households with a shared connection in the data set. Such households may pay an higher or lower average price depending on whether the owner of the connection applies a surcharge and the marginal rate of consumption. Groups of households with low total consumption can expect to pay a lower average price because the connection fee is shared; however at higher levels of consumption the average price would increase above that paid by a household with a direct connection[4]

Given the above, there appears to be justification for assuming that the errors in our estimate of water consumption that are due to supplementation of water sources, inclusion of non-MWSS users, and connection sharing, will be random normal with zero mean. These errors are in addition to the errors generated within the survey process itself.

[4]Sharing is usually among 2-3 households.

TABLE 9.9

MWSS Water Consumption Data Set : Summary Statistics

Variable	Description	Mean	Median	Min.	Max.	SD.
QWATER	water consumption (m^3)	34.78	29.82	1.78	130.43	21.61
WATER	water expenditure	144.05	100.00	15.00	800.00	114.16
TOTEX	total expenditure	17,077.00	11,964.00	2,296.00	133,533.00	17,181.65
FSIZE	family size	4.79	5.00	1.00	13.00	2.24
CITY	city code					

Notes:
- monthly consumption and expenditure
- prices and expenditures are in Pesos
- cities are Malabon (MWSI) and San Juan (MWCI)
- sample size 355 households in population of 98,742 households

9.3.1.2 Descriptive Statistics

Table 9.9 shows the descriptive statistics for the MWSS consumption data set. The mean value of household consumption compares favourably with other sources. MWCI reported residential account holder consumption of 41,828,150 m^3 for the three months from January to March 2001. They also estimate that there are 413,242 households serviced by their network (including those with shared connections and those that participate in *Tubig para sa Barangay* programmes. Therefore the estimate of mean consumption for MWCI serviced areas is 33.7 m^3. In that same period MWSI delivered 73,633.05 m^3 to customers across 602,424 households, so the mean consumption is 40.7 m^3. The ADB estimates (McIntosh and Yniquez, 1997) of mean consumption for households with a MWSS connection is 44 m^3. Other collaborating estimates of mean household water consumption for MWSS customers are 34.7 m^3 (David and Inocencio, 2002). The same authors also report on average consumption ranging from 6.8 to 11.4 m^3 for households that do not have a MWSS connection and who rely on the secondary market. This explains the much lower average consumption (21.2 m^3) that appears in Table 9.5 that is based on the weighted average water price and includes all households that pay for their water.

9.3.2 Estimation Results

The two error model was estimated using maximum likelihood technique with the likelihood function as presented in Section 4.3.2.2 modified to cover a nine block tariff. Again, we have used a log-linear model with interaction term where the elasticities are linear functions of the other interaction variable:

$$\ln q_i = \beta_0 + \beta_1 \ln p_i + \beta_2 \ln m_i + \beta_3 \ln p_i \ln m_i + \beta_4 \ln f_i$$

The maximum likelihood estimates have been estimated by use of a computer programme written in the R statistical processing language (R Development Core Team, 2006). As each supplier has a different tariff (but the same block structure), the programme applies different prices according to the $CITY$ variable. Maximisation of the log likelihood function is performed using the algorithm of Nelder and Mead (1965) which, although relatively slow, is quite robust and is suitable for highly non-linear and non-differentiable functions. Comparable results were also achieved using an optional conjugate gradients method of Fletcher and Reeves (Fletcher and Reeves, 1964). Standard errors of the parameters have been computed by taking the square root of the diagonal of the inverted Hessian matrix, and these have been used to compute t-statistics.

The estimated coefficients and the elasticities are shown in Tables 9.10 and 9.11 below. The standard errors and t-statistics indicate that all variables but income are significant. However, to confirm this, a likelihood ratio test has been carried out. This involves estimating a restricted and unrestricted model and comparing the ratio of likelihoods with a chi-squared distribution. The null hypothesis is that the two models are the same and therefore the coefficient is not different from zero. The results of this test are shown in table 9.12 and, as we reject the null hypothesis, we conclude that income does have a non-zero coefficient.

On first sight the estimates of the standard deviation of the two error distributions appear quite large. Indeed considering the nature of the data, this should not be surprising. However, these are not in log units and equate to cubic metres of consumption. Therefore we can see that the α error term has a standard deviation of just over the average block width of $25m^3$ while the ϵ error term has a standard deviation of about one quarter that. The model was designed specially to cater for household consumption in another block to the optimal choice, and in this case, appears to have accounted for that situation quite well. Exposure to a variety of additional data sets would increase our knowledge as to the conditions under which heterogeneity affects household consumption choices.

The elasticities are of considerable interest. First, as there is an interaction term, the price elasticity varies with the budget. The results clearly show that as incomes increase, household consumption of water becomes less price elastic. However, closer examination shows that (because of the distribution of incomes) elasticity is fairly constant over the range of incomes, but drops off significantly in the higher quantiles of income. This indicates that higher income households are much less likely to reduce consumption in the face of increased prices than median and lower income households. Note that this result stands in contrast to the result shown in Table 9.7 - where we suggested that lower income households were less willing to decrease consumption than higher income households. Comparing the two, households with a connection to the MWSS network have a substantially more elastic response than households in general. The reason for this most likely to be that they are consuming more in the first place (refer to the mean consumption figures in Tables 9.5 and 9.9); it is easier to cut back on nonessential uses in the face of price increases. Finally, income elasticities show an increase as prices increase. This means that higher income households will consume more water as their incomes increase and that this effect increases with higher consumption (as the block rate is increasing). Although more research is needed, these results suggest that price and income elasticities are an important factor in block rate tariff design. This type of information can be used by regulators and utilities to predict the likely response to price changes for consumers grouped by current consumption and income - thereby helping to achieve specific revenue outcomes and to manage the resource. Cross subsidisation may also be an objective of the tariff design where knowledge of price elasticity for the different groups is essential. Households who consume more water per capita than average would be required

TABLE 9.10

Estimates of Demand Function - MWSS Connected Households

Model	const	$\ln p$	$\ln m$	$\ln f$	$\ln m \ln p$	$\hat{\sigma_\alpha}$	$\hat{\sigma_\epsilon}$
interaction	5.41	-4.72	-0.050	0.2572	0.354	26.430	5.587
	(2.45)*	(1.77)*	(0.245)	(0.0815)*	(0.174)*	(1.801)*	(0.819)*

dependent variable: $\ln q$
log likelihood: -1478.86

to pay above the marginal cost of supply while those who consume less per capita would pay less than the marginal cost.

TABLE 9.11

Price and Income Elasticities - MWSS Connected Households

					Quartile		
Model	$\phi()$	Mean	Min	2	Median	4	Max
Price Elasticity							
interaction	$\ln(TOTEX)$	-1.27	-1.98	-1.52	-1.40	-1.25	-0.54
Income Elasticity							
interaction (MWCI)	$\ln(PWATER)$	0.41	-0.05	0.36	0.47	0.49	0.51
interaction (MWSI)	$\ln(PWATER)$	0.64	-0.05	0.57	0.70	0.73	0.76

TABLE 9.12

Likelihood Ratio Test

Null Hypothesis: $\ln(TOTEX)$ is not a significant determinant of consumption.

H_0: $\beta_2 = 0$ H_1: $\beta_2 \neq 0$ DF: 1 χ^2 95% critical value: 3.841

$L(\beta_{UR})$	$L(\beta_R)$	Test Statistic λ	Decision
-1478.86	-1642.88	328.04	reject H_0

nb: $\lambda = -2\,(L(\beta_R) - L(\beta_{UR}))$

CHAPTER 10

Second Case Study
Urban Water Services in Manila
Part C - Marginal Cost and Welfare

10.1 Introduction

Part A of this case study presented estimation results of the constant returns to scale and variable returns to scale cost functions for the Manila water concessions. We observed a significant improvement in model fit for the variable returns compared to the constant returns models. The results indicated that the concessions exhibited decreasing returns to scale in production, however the hypothesis of constant returns to scale was not rejected in favour of the alternative of decreasing returns. The estimated returns to scale parameter was 0.767. Part B of this study estimated demand for water using a metropolitan wide sample that contained households that pay for water from a variety of sources; and a restricted sample that, with few exceptions, consisted only of households with a connection to the MWSS network. The price elasticity of demand was estimated to be -0.56 for the former sample and -1.27 for the latter sample. We postulated that the difference in elasticities between the two samples was related to the former having a lower mean consumption and therefore having a higher proportion of their water for essential needs; in contrast to the connected group sample that consumed more and had a larger proportion of water available for non-essential use.

In this part of the case study we turn our attention to issues of welfare in the pricing of urban water services. We will restrict ourselves to consideration of the welfare effects for consumers who have a piped water connection. The reason for this is that policy can address prices set by the regulator for this form of service, whereas local independent entrepreneurs who supply the remaining households operate in an unregulated market outside the control of government.

We commence by presenting variable return to scale cost functions evaluated at the mean values of co-variates and at a partial equilibrium of marginal cost and benefit functions. This will be followed by estimation of several welfare statistics that compare current price/demand values with the efficient values obtained at the partial equilibrium. We conclude with some overall observations related to this case study.

10.2 Marginal Cost Estimation

In this section we calculate the marginal cost of a household water connection in KL per month. This will provide a reference to compare with the current monthly tariff. We will base this on the estimated cost and demand functions for the Manila water concessions and employ three methods: marginal system cost at mean output, marginal cost at output per connection, and marginal cost at an equilibrium of supply and demand. Table 10.2 shows sample means for parameters used in calculations. We have used the combined means rather than the values disaggregated by concessionaire. Prices are the average tariffs set at January 2000 including the currency exchange rate adjustment (CERA) but excluding all taxes. The results are summarised in Table 10.1.

10.2.1 Marginal System Cost

The annual cost function was shown in Table 8.5. It exhibits decreasing returns to scale Cobb-Douglas production:

$$C = 3.349\, r^{0.266}\, w^{0.734}\, x^{1.317}$$

This function was estimated with output in MLD, and cost and factor prices in K. Pesos. Differentiating with respect to output,

$$MC = 424.836 x^{0.317}$$

The annual marginal cost in PhP of a one MLD increase at mean output (MLD) of 740.245 is estimated to be PhP 3,449.958. Converting this into a monthly cost per KL gives a marginal cost of PhP 9.45.

10.2.2 Marginal Cost in Per Connection Terms

This approach alters the units of the cost function so that marginal cost is determined in per connection terms. Note this is still the marginal cost of an increase in output, not the marginal cost of an additional connection.

We express annual cost as a monthly per connection cost with output in m^3 per month:

$$C^h = \frac{1}{H}\, 3.349\, r^{0.266}\, w^{0.734} \frac{1000}{12} \left(\frac{12}{365000}\right)^{1.317} (H\ \tilde{x})^{1.317}$$

where C^h is monthly per connection cost in Pesos, H is number of connections, and $\tilde{x}$ is per connection output.

At the factor price sample means of $r = 5.45$ and $w = 272.243$, with $H = 887,371$, the decreasing returns to scale cost function evaluates to:

$$C^h = 2.583\ \tilde{x}^{1.317}$$

The marginal cost is therefore:

$$MC^h = 3.402\ \tilde{x}^{0.317} \tag{10.1}$$

At the mean monthly household consumption of 32.78 KL, this equates to PhP 10.25.

10.2.3 Marginal Cost at a Partial Equilibrium

This third method uses a partial equilibrium of the supply and demand curves to determine marginal cost at the efficient level of output. We use the marginal cost function in monthly per connection terms derived in the preceding section and the household demand function that was derived by use of the two error model for a block rate tariff.

We need to point out that the application of partial equilibrium analysis to determine marginal cost is one way in which a block rate tariff can be designed. For example, individual demand curves for groups of consumers with similar consumption levels would be combined with the marginal cost data to establish the marginal cost for a range of output[1]. By increasing the marginal rates for households with high levels of consumption, the utility can cross-subsidise households with low levels of consumption and ensure that their marginal utility of expenditure is higher. As this approach requires a detailed level of cost and consumption data that is beyond the reach of this study, the partial equilibrium analysis that follows assumes only a single marginal rate and one consumer group with no cross-subsidisation.

[1]The industry approach is to use present value estimates of average cost and demand.

TABLE 10.1

Summary of Marginal Cost Estimates: Manila Water Concessions

Evaluation Method	Output	Marginal Cost (PhP/KLM)	Charge(**)
Variable Returns to Scale			
system mean output	740.25 MLD	9.40	5.84
per connection mean output/cons.	32.78 KLM	10.20	5.84
partial equilibrium	14.81 KLM	7.93	5.84

** average price of both concessionaires

The parameter estimates of household demand function with an interaction term (from Table 9.10) were:

$$\ln x = 5.41 + \ln p(-4.72 + 0.354 \ln m) - 0.050 \ln m + 0.257 \ln f$$

Substituting mean values for monthly income $m = \text{PhP}17,077$ and family size $f = 4.79$, and removing logs, we have the household monthly demand function at the means:

$$x = 205.54\ p^{-1.27} \tag{10.2}$$

Solving equations 10.1 and 10.2 for x and p yields the equilibrium price and consumption level: $p = 7.93$, and $x = 14.81$.

10.3 Welfare Effects at Average Price Levels

If we refer to Table 10.2, is is apparent that average prices are less than the marginal cost estimates obtained in the previous section. In Chapter 5 we presented the methodology for calculating the deadweight loss arising from pricing below marginal cost based on Renzetti (1999). In this section we calculate the deadweight loss based on these estimates of marginal cost and the prevailing average prices corresponding to the data set. Current consumption x^0 is determined from the demand curve at the prevailing average price.

The welfare estimates appear in Table 10.3. This table includes sensitivity estimates of two critical parameters: the intercept of the cost function, and the coefficient of output (cost elasticity). Each of these parameters have been varied by 10% of their standard errors. Figure 10.1 shows the marginal cost and benefit curves with an overlay of the 2000 average price and predicted consumption. We can see from this diagram that the the equilibrium price is higher than the weighted average price, and that this results in a loss in welfare. The formulae for the welfare statistics are repeated below:

- deadweight loss: loss of welfare at current prices

  $DWL(x^0) = \int_{x^*}^{x^0} \left(MC(x) - MB(x)\right)\, dx$

- deviation: deviation from efficient output

  $DEV(x^0) = \left(x^0 - x^*\right)/x^0$

- waste: average DWL per unit of current output

  $waste(x^0) = DWL(x^0)/x^0$

TABLE 10.2

Sample Means of Parameters: Manila Water Concessionaires

Factor	Variable	Sample	MWCI	MWSI
monthly income (PhP)	m	17,077	21,906	12,220
family size	f	4.79	4.74	4.84
cost of capital (%)	r	5.45	5.15	5.76
annual wage rates (PhP 000's)	w	272.243	272.266	272.221
connections	H	887,371	339,491	547,880
mthly per connection cons./output	$\tilde{x}$	32.78	43.17	26.34
price (PhP/m^3)	p	5.84	3.76	7.13

TABLE 10.3

Welfare Measurements: Variable Returns Model

			minus 10% SD.		plus 10% SD.	
parameter	units	Mean Est.	β_0	$\frac{1}{Q}$	β_0	$\frac{1}{Q}$
avg. price Jan. 2000	PhP/KL	5.84				
qty. demanded 2000	KLM	21.84				
efficient price	PhP/KL	7.93	6.19	5.98	10.16	10.23
efficient output	KLM	14.81	20.29	10.72	10.81	21.20
DWL per connection	PhP	12.00	0.39	0.06	43.87	48.00
total DWL	KPhP	10,656	346	53	38,928	42,581
deviation	pct	32.20	7.10	2.95	50.52	50.91
waste	PhP/KL	0.55	0.02	0.00	2.00	2.20

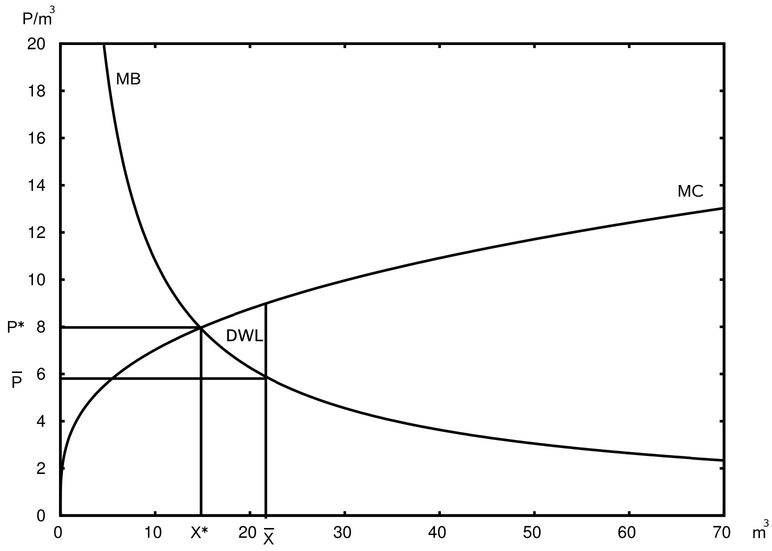

Figure 10.1. Partial Equilibrium for the Manila Concessions

10.4 Conclusion

Based on a sample of data from 1997 to 2005, there is evidence that the production of urban water in Manila exhibits decreasing returns to scale and increasing marginal costs[2]. Demand, based on data from a household expenditure survey is substantially price elastic but at higher levels of consumption for households with a water connection. This is in contrast to the less elastic price response for households who lack a connection and rely on more expensive water supplies. Estimates of marginal cost evaluated at sample data mean values of consumption, and at a partial equilibrium of marginal cost and benefit curves indicate that, in the year 2000, the average price of MWSS water was less than its marginal cost. This suggests that a piped water connection delivered benefits in excess of its

[2]The hypothesis of constant returns to scale was not rejected however.

cost to consumers, resulting in higher consumption for those households with a water connection in comparison to those without one. Estimates of annual system deadweight loss caused by inefficient pricing are approximately PhP 10.7 million (US$0.24 million). The analysis indicates that a price increase of about 36% would be required to reach the efficient level of output. Because demand would decline with a higher price, a better approach might be to increase by 6% (the lower estimate of efficient price) and monitor changes to demand. Sensitivity analysis indicates that adjustments to coefficients can result in substantial changes to the results - this should not be surprising as the coefficients are variable exponents in the cost equation.

Substantial tariff increases were awarded in 2001 and 2003 to both MWSS concessionaires. In January 2003, at the beginning of the new five year rate rebasing period, the *all-in* price for MWCI was increased to PhP 13.43/m^3 while for MWSI the new average price became PhP 19.92/m^3. These are both well above the efficient price estimated here, even when adjusted for inflation. The basis of non-CPI price increases awarded to the concessionaires are primarily the increase in foreign debt service costs brought about by the currency devaluation during the Asian Economic Crisis of late 1997. These increased costs would be reflected in increases in the cost of capital and therefore we would expect the marginal cost estimates to increase once the variable returns model was re-estimated. Prices in Manila are regulated under a rate of return system, which, as noted in Chapter 2, has substantial reporting requirements in comparison to price cap regulation and can involve lengthy negotiations with the regulator[3]. This implies that price adjustments themselves add to compliance overhead costs under rate of return regulation.

[3]In Manila it took four years to award price increases based on currency devaluation after the 1997 Asian Economic Crisis.

CHAPTER 11

Performance Based Pricing

11.1 Introduction

In Chapter 2, we briefly noted some of the limitations of the marginal cost approach to water pricing. This chapter expands on these, based on the experience gained in the case studies. In particular we present an alternative to the main behavioural assumption implicit in empirical analysis - that utilities strive to minimise costs, because in the regulated environment this is the only way that profits can be increased. This alternative approach views firms as heterogeneous in their efficiency, with some able to perform at higher levels than others based on a set of benchmarks. We posit that the cost functions of the better performing utilities be used as the basis for marginal cost pricing methods described in previous chapters. Performance based pricing is likely to become important as competition is introduced in urban water supply and changes in the regulatory environment see the introduction of benchmarking and performance based regulation.

In this chapter we first review some of the main findings of the two case studies that were presented in Chapters 6-10. We then examine some issues related to the marginal cost approach and question the assumption that firms focus on cost minimisation. This chapter then presents a method for estimation of efficiency that has been used in benchmarking studies - Stochastic Frontier Analysis. In the chapter that follows, we will present a case study in which this technique will be applied to a cross section of water utilities, and discuss some consequences of performance based pricing.

11.2 Review of Case Studies

The case studies contained in the previous five chapters have applied marginal cost principles to water utilities in Victoria and the Philippines. We observed in both cases, based on empirical analysis of sample cost and demand data, that average prices prevailing at the time were substantially less than the estimated marginal cost of supply. For the Victorian water businesses, estimates of the dead weight loss at current prices were 3.3% of revenues for metropolitan and 7.2% of revenues for the regional businesses. For the Manila concessions the dead weight loss as a proportion of revenue was estimated at 9.4%.

For the Victorian water businesses recovery of these losses primarily occurs through two forms of redistribution. First, metropolitan water business have generally been able to return accounting profits to the state government, part of this is redistributed to regional businesses - who are not profitable - in the form of government contributions. Second, income is received from connection fees, and new distribution assets are handed over to the utility by developers of new housing areas at city fringes[1]. In the case of the Manila concessions losses are born entirely by the owners. Because the government has an interest in ensuring that concessionaires remain financially viable, and if these costs are unavoidable, prices must be adjusted so that costs are recovered.

We saw evidence of increasing returns to scale (decreasing marginal cost) for the Victorian water businesses and decreasing returns to scale (increasing marginal cost) for the Manila concessions (although the null of constant returns could not be rejected). Application of marginal cost pricing in Victoria would result in

[1]These are termed Gifted Assets.

efficient levels of consumption but subsidies or a form of Ramsey pricing would still be required to recover costs. With increasing returns the quantity of water demanded will be below the predicted level of demand when either average or marginal cost pricing is used - providing a safe buffer of capacity[2]. For the Manila concessions, or any utility that operates under decreasing returns to scale, there is the risk of erosion of this safe buffer when average cost pricing is used and predicted demand is underestimated. This is because the low price encourages consumption in excess of what has been costed for. This risk also exists under marginal cost pricing and decreasing returns to scale, but is less because prices are higher.

In general, factor price cost elasticities[3] for the Victorian water businesses are higher for labour than capital, but when depreciation is included as a cost, this is reversed. We expect that as more capital investment is undertaken by the Victorian water businesses, overall expenditure will be more responsive to the cost of capital. For the Manila concessions, the difference in elasticities is more apparent. The cost elasticity for labour is significantly greater than for capital. Again we would expect that as investment increases, capital cost shares also increase.

The case studies represent contrasting tariff structures. In the case of Victorian water authorities for the period of analysis, tariffs were predominantly based on a single volumetric rate with a basic access charge. For Manila an increasing nine block rate tariff is used. Modelling demand under block rate tariffs is complex as the demand curve is non-linear. The estimates of price elasticity for consumers serviced by the Manila concessions are comparable with other studies, for example in Indonesia (Rietveld, Rouwendal, and Zwart, 1997), but are substantially higher

[2]The marginal cost price must be at or above the equilibrium price.
[3]These are equal to cost shares in the CES models.

in comparison to a sample consisting of all households including those without a connection. This supports the stylised fact that lower income households, those who cannot afford a connection or who live in areas not serviced by the network, have a less elastic response to increases in the water price, in comparison to those with a permanent water connection.

The case studies are contrasted in the form of utility ownership and in the regulatory environment. The Victorian water businesses are fully owned by state government. They are regulated by the state's Essential Services Commission (ESC). Prices are set by each business but must be agreed by the ESC and in accordance with business' existing Water Plans. The basis of price is average cost using discounted historical and projected costs and demand. The Manila concessions are private concerns under which government retains ownership of existing assets and assumes ownership of new assets at the end of the concession period of 25 years. Prices are set by rate of return regulation where the regulator decides allowable costs and the return on capital. In the event that prices were set at marginal cost we expect the outcome in each case to differ. For the Victorian businesses, prices would remain below average cost and therefore subsidisation would still be required. For the Manila concessions, with marginal cost increasing, there is a possibility of windfall profits. The concessionaires would need to reinvest these profits to avoid the regulator forcing a reduction in price.

The marginal cost approach is based on economic principles of efficiency and equilibrium between supply and demand for the service. In this study we have employed statistical approaches based on a number of cost and demand models. This contrasts with industry approaches that are primarily based on present value of historical and forward predictions of average cost. Both approaches have considerable data requirements but the average cost method necessitates use of a discount rate. We have seen that a functional approach is dependent on knowledge of demand and factor prices, our approach uses mean values and a welfare maximising partial equilibrium to arrive at the marginal cost. A hybrid approach is also possible where marginal cost is determined by evaluation of the marginal cost function at the present value of projected annual demands.

There will be greater focus on efficiency and marginal cost approaches in the future, caused by changes in the regulatory environment, increased competition in the water sector, and awareness of scarcity of the resource. As noted in Chapter 2, no single solution or formula exists in water management and pricing. Regulatory authorities and utilities will need to utilise an array of tools and evaluate the merits of each alternative outcome. In the following sections we reconsider the problem of pricing based on marginal cost to establish the motivation for alternative performance based and hybrid approaches.

11.3 Price and Sustainable Water Management

An increase in the price of urban water can be expected to have three main effects. First, the full cost of service provision is more likely to be met. Second, long term funding commitments can be made for investment in infrastructure or technology that will ensure the sustainability and quality of future supply. Third, price increases can reduce water consumption to adjust for reduced inflows caused by seasonal or long term climatic conditions.

Despite some signs of change, governments have generally been reluctant to use price to achieve these objectives. This is for several possible reasons: water is an essential service and governments are keenly aware that price increases may be politically risky; price increases may place some people under financial hardship and require introduction of rebates or similar measures that have a cost; high water users may not respond to increased prices; and windfall revenue increases through higher prices may also be politically unpopular. Water restrictions, backed up by monetary penalties are used by Australian state governments in preference to price increases to cope with increased seasonal demand or reduced supply. This is despite there being no evidence that consumers would be unable to adjust to fluctuating water prices. As we have seen in Manila, private owners will increase prices so that the full cost of provision is met, subject to the constraints of the regulator.

Price is not the only lever that can be used to ensure sustainable water supplies. Public awareness campaigns can have an impact, for example the *Water Proofing Adelaide* programme (Government of South Australia, 2005). There are numerous options for improvement of urban water management: stormwater recycling, greywater, and wastewater recycling, and desalination are all feasible. In Australia, the federal government has initiated a programme involving repurchase of agricultural water entitlements, while state governments are purchasing water allocations from agricultural producers.

In the case studies we examined the welfare effects of current pricing. The measurement of welfare by present value of net benefit is a basic tool of cost-benefit analysis that has been in use for over two decades. When there are externalities, however, a purely monetary measure of well-being presents some shortcomings. Consider the case where a water utility invests in water quality technology. The marginal cost will increase and, unless the investment is subsidised, the price must eventually adjust. When this occurs either consumers demand less of the more expensive water, or they are willing to pay more for the same quantity of better quality water. In the first case, there is a decrease in consumer surplus, while in the second case the demand curve shifts outward and consumer surplus is unchanged. We expect that there is, however, a clear benefit of improved health to those households who consume the better quality water. The externality will only be captured in the cost benefit analysis if consumption also increases because the water quality has improved.

11.4 Cost Minimisation in the Supply of Urban Water

In this study, we have taken the view that price and output are exogenous to the firm's cost model. Practically the only option that a regulated utility has to increase profits is by cost minimisation. Under some conditions however, the behavioural assumption of cost minimisation might be flawed. First, for a rate of return regulated utility, it might be sufficient to hold costs at the level agreed by the regulator so that the allowed return on capital is achieved, thereby avoiding the possibility of windfall profits. The regulatory environment provides a disincentive to stray from the agreed cost structure by increasing efficiencies, and investors will not demand cost reductions providing returns on their investment match expectations. Second, cost minimisation is generally applied to competitive rather than regulated markets. The regulator may try to make up for the absence of competition but this does not guarantee that firms will behave as they would in a competitive environment. Firms may not operate in markets where factors are traded competitively. Capital may be only available at higher than market rates because the lending risk is perceived higher, suppliers may overprice their services because they regard the utility to be a monopoly, or alternately the utility may be able to exercise monopsony power in its purchase of labour and services. Third, firms may be prepared to undergo short term cost inefficiencies so that they receive long term efficiency gains. An investment decision, for example, may be guided by this approach. Despite these potential flaws, the behavioural assumption of cost minimisation dominates most applied research in the area of cost modelling of utilities.

In the case studies we estimated constant elasticity of substitution production and cost models. The results can be used to predict *expected* or average production and cost for a representative utility at different input levels or factor prices. If we relax the assumption that firms minimise costs then a *minimum* cost function will not explain the sample as well as expected. The distributional assumptions of the models may mask individual differences in firm behaviour; in particular, those that effect cost efficiency. We may be unable to account for these *a-priori* as we do not know what variables to measure. We can however, introduce error terms to the model to account for more heterogeneity in firm behaviour as we did for households in the block rate demand model presented in Chapter 4. Pricing based on assumptions about cost minimisation may yield incorrect results if the marginal cost has been determined from a sample that contains inefficient firms. This may lead to consumers paying higher than necessary prices.

11.5 A Performance Based Approach to Urban Water Pricing

The foregoing discussion suggests several initial objectives of a performance based approach to water pricing. First, it should model a frontier of performance, rather than mean cost minimising behaviour. Second, there should be a metric for the distance of each firm from the frontier. Third, although production and cost are the usual criteria for measuring performance, other measures of efficiency, for example service and water quality, could be incorporated into a multiple output model.

The measurement of performance and efficiency has received considerable attention in the literature. In Saal and Parker (2004) the authors use a measure of Total Factor Productivity (TFP) to determine efficiency under a RPI+K regulatory pricing system for a sample of English and Welsh water utilities. Fox and Hofler (1986) used composed error frontiers to measure water utility efficiency with a dual output model and a sample of US rural water producers. Tupper and Resende (2004) used a form of Data Envelopment Analysis (DEA) to examine the efficiency of water and sewerage companies in Brazil. This work has been followed by two studies, also based in Brazil, that use Stochastic Frontier Analysis (SFA): Sabbioni (2005), and Faria, da Silva Souza, and Moreira (2005). Estache and Rossi (2002) use Stochastic Frontier Analysis to measure the efficiency of water utilities in the Asian Pacific region. They use error components and technical efficiency effects as measures of efficiency. While much of the applied work has been dominated by interest in the public/private ownership debate; recently, pricing of utilities based on performance based measures has received attention, particularly to establish the X-factor for RPI+X price cap regulation (Thakur and Singh, 2005).

Stochastic Frontier Analysis (Aigner, Lovell, and Schmidt, 1977; Battese and Coelli, 1988; Jondrow, Lovell, Materov, and Schmidt, 1982), and (Greene, 2003, p. 505) rests on the notion that firms in practice do not achieve the theoretical optimum levels (frontiers) of output maximisation or cost minimisation in production. Instead, sub-optimal levels of output or cost are achieved and the proximity to the optimum is governed by firm level heterogeneity. Furthermore this proximity is measurable and can be considered to be a measure of individual firms' efficiency.

SFA contrasts in two ways with the measurement of the welfare maximising level of output described in Chapter 5 and applied in the preceding two case studies. First, the parameter of interest is the efficiency distribution rather than the parameters of the production/cost function itself. Second, it provides a ready measure for comparison of firms with similar characteristics. Indeed it is possible to rank firms according to their SFA measure of efficiency. In the preceding two case studies we showed that there were significant deadweight losses involved in current prices[4], therefore welfare would be increased if prices were increased. To

[4]Based on the time of the data set.

contrast this, the SFA approach is that welfare is increased by *benchmarking* - where firms improve their performance by striving to reach efficient frontiers set by and among their domestic or international peers. One other distinction, not addressed in the literature, is that frontier methods are focused on firm behaviour and do not directly include consumer demand in the efficiency model.

11.5.1 Stochastic Frontier Analysis

The stochastic frontier model augments the basic linear regression model with a non-negative random term that is a firm specific measure of sub-optimality or distance from the efficient optimum:

$$y_i = \mathbf{x}_i'\boldsymbol{\beta} + v_i - u_i$$

where $\mathbf{x}$ is a vector of explanatory variables for the i^{th} cross sectional unit, and v is an assumed random disturbance due to idiosyncratic firm specific effects ($v_i \sim N[0, \sigma_v^2]$), uncorrelated with any other variables. The inefficiency term u_i is non-negative random term, which, when data is in log form is a measure of the percentage by which an observation fails to reach the frontier.

Much of the theoretical work in SFA has focused on estimation of SFAs with different distributions of u. Two of the most common are the absolute value of a normal distribution (the half normal) and an exponentially distributed variable.

The log likelihood of the half normal is:

$$\ln L = -n \ln \sigma - \frac{n}{2} \ln \frac{2}{\pi} - \frac{1}{2} \sum_{i=1}^{n} \left(\frac{\varepsilon_i}{\sigma} \right)^2 + \sum_{i=1}^{n} \ln \phi \left(\frac{-\varepsilon_i \lambda}{\sigma} \right) \tag{11.1}$$

where $\sigma^2 = \sigma_u^2 + \sigma_v^2$, $\varepsilon_i = v_i - u_i$, $\lambda = \sigma_u / \sigma_v$, and ϕ is the standard normal probability distribution.

Although numerical methods may be used to maximise this function, an analytic solution is available by a process of substitution, and deriving the second differentials. The parameter estimates are then obtained by back-substitution into the asymptotic covariance matrix. This process is described in detail in Greene (2003, p. 504) and will not be reproduced here.

As mentioned the parameter of interest in SFA is usually u rather than the parameters β of the production or cost function. The procedure above only provides a firm level estimate of the total error ε. An approximation that is in widespread use is attributed to Jondrow, Lovell, Materov, and Schmidt (1982) (for the half normal model):

$$E[u|\varepsilon] = \frac{\sigma\lambda}{1+\lambda^2}\left[\frac{\phi(z)}{1-\phi(z)} - z\right]$$

$$z = \frac{\varepsilon\lambda}{\sigma}$$

and, for the exponential model:

$$E[u|\varepsilon] = \frac{\sigma\lambda}{1+\lambda^2}\left[\frac{\phi(z)}{1-\phi(z)} - z\right]$$

$$z = \frac{\varepsilon\lambda}{\sigma}$$

The proportion of the total variance of ε that is due to the inefficiency term is half normal:

$$var[\varepsilon] = var[u] + var[v] = (1 - 2/\pi)\sigma_u^2 + \sigma_v^2$$

and for the exponential model this is $1/\theta^2 + \sigma_v^2$.

CHAPTER 12

Third Case Study

Performance Based Pricing:

A Frontier Analysis of Asian and Australian Water Utilities

12.1 Introduction

The objective of this case study is to present the results of estimation of a cost efficiency frontier for a cross section of water utilities, using Stochastic Frontier Analysis as the econometric tool. We use a sample of data obtained from a World Bank sponsored utility benchmarking database to estimate the frontier for two log-linear cost models, and present the cost efficiency estimates of the utilities in the sample. We propose that a regulator could set the volumetric price at the marginal cost of the most cost efficient firms[1], based on a ranking or grouping of utilities by efficiency. Alternately, for a price cap form of regulation, data from the most efficient firms can be used to set the X-factor. We have not estimated X-factors or marginal cost for the firms in this sample as this requires data on costs and production from each utility at the same level of detail of the first and second case studies.

12.2 Source of Data

The input data set originates from public domain data available at the International Benchmarking Network for Water and Sanitation Utilities (The World

[1]Reasonably we would expect the sample to be restricted to one country in this case.

Bank, 2005). This is an initiative of the World Bank that started in the late 1990s and is supported by the UK Government Department for International Development (DFID) and the Bank's Water and Sanitation Programme. The IBNET aims to support and promote benchmarking in the global water and sanitation sector by providing data, software and documentation to assist utility managers to undertake benchmarking and analyse their own and their peers' performance information over time.

Benchmarking, in the IBNET context, is the comparison of service performance among peer utilities - the goal being to enable improvement in quality and performance. The motivation for using benchmarking is well expressed in their own words:

> If benchmarking contributes to improving utility performance, customers will benefit when the savings result in improved service and/or lower tariffs. Policymakers and regulators can compare sector performance with that achieved within the country and with other countries, while global institutions (such as the international finance institutions) can improve policy advice based on using available sector performance data.
>
> ... Inter-utility performance comparison is needed in the water and sanitation sector, because the sector offers limited scope for direct competition. Firms operating in competitive markets are under constant pressure to out perform each other. Water utilities are often sheltered from this pressure, and it frequently shows: some utilities are on a sustained improvement track, but many others keep falling further behind best practice. This matters, because a well-run water utility is essential to people's lives. Only the most efficient, financially viable utilities are able to respond to urban growth, connect the poor, and improve wastewater disposal practices. (source: www.ib-net.org)

A number of countries and regions have initiated their own performance benchmarking in addition to contributing to IBNET. These include the UK Office of Water (OFWAT) which benchmarks against utilities in Australia, the Netherlands, Canada and the United States. In Latin America, the Association of Water and Sanitation Regulatory Entities of the Americas (ADERASA) is conducting an international performance comparison to provide better information to regulators and policy-makers. In South East Asia, the Southeast Asian Water Utilities Network (SEAWUN) is benchmarking its member water suppliers. In Africa, the Water Utility Partnership (WUP) performs a similar role. In Australia, a National Benchmarking Framework for Urban Water Utilities (Government of Australia, 2006) has been drawn up under the auspices of the Government's National Water Commission.

12.3 Data Description

The IBNET database consists of water and wastewater indicators, gathered from utilities throughout many countries. The data are yearly figures covering the period 2000 to 2005. The database is evolving as more countries and utilities participate. The indicators cover a wide range of performance categories including service coverage, quality of service, consumption and production, non-revenue water, cost and staffing, billing and collections, financial performance, metering, assets, network performance, and consumer affordability. The sample selected for this analysis has been drawn from Asian and Australian suppliers. To minimise the need for data imputation, only those utilities with substantially complete data records have been selected. Where imputation is required this has been achieved by use of additional source material such as annual reports and the ADB's Water Utility Data Book (McIntosh and Yniquez, 1997). Additionally, an average of the annual indicator values was taken, because few records contained a complete six years of annual data.

Table 12.1 shows the indicators and summary statistics for the benchmarking sample. Table 12.2 shows the sample means disaggregated by country. Country codes are listed in Table 12.3. Although our objective is not to compare countries, this table is quite revealing in itself. The sample means of operating cost, wage cost, and per capita production for Australia are the highest in the sample. For non-revenue water Australia has the lowest sample mean. As production less non-revenue water approximately equals consumption, this implies that the mean per capita consumption in Australia is the highest of all countries in the sample. Note that production/consumption in the IBNET database include residential, commercial and institutional users. Cambodia and Malaysia also have high levels of per capita output but with higher rates of non-revenue water than shown by the Australian statistic.

TABLE 12.1

IBNET Performance Indicators: Summary Statistics 2000-2005

Variable	Description	Mean	Median	Min.	Max.	SD.
$COST$	operating cost per m^3 produced	0.212	0.150	0.050	0.800	0.155
W	wage cost per m^3 produced	0.057	0.045	0.009	0.251	0.042
X	litres per capita per day output	293.85	207.46	80.56	1129.89	208.28
$QUAL$	hours of service per day	19.7	23.8	1.5	24	6.8
$METER$	meter coverage (% of connections)	90.7	100	0	100	23.6
NRW	non-revenue water (% of production)	30.34	32.08	1.00	69.33	12.67
$COSTRAT$	revenue cost coverage ratio	1.28	1.30	0.18	3.43	0.57
$DUMCLO$	chlorinated supply (Y=1,N=0)	0.24	0	0	1	0.43

all costs are in USD, inflation adjusted.

TABLE 12.2

IBNET Performance Indicators: Sample Means Comparison 2000-2005

Indicator		Sample	AUS	CHN	IDN	IND	KHM	LAO	MYS	PHL	THA	VNM
utilities		114	13	10	15	17	1	1	15	1	1	40
COST	operating cost	0.21	0.52	0.15	0.17	0.22	0.11	0.05	0.26	0.24	0.12	0.13
W	wage cost	0.06	0.10	0.03	0.05	0.08	0.02	0.01	0.05	0.08	0.04	0.05
X	output (lpc)	294	598	182	207	190	592	81	467	209	210	237
QUAL	hours service	19.7	24.0	22.6	22.4	5.3	24.0	24.0	24.0	23.3	24.0	20.8
METER	meter coverage	91	100	99	100	52	100	100	100	100	100	94
NRW	non-revenue	30.3	11.8	20.2	32.3	32.0	21.5	28.0	35.4	29.0	32.8	35.8
COSTRAT	coverage ratio	1.3	1.8	1.2	1.2	0.6	2.7	1.2	1.1	1.6	1.5	1.4
DUMCLO	chlorine	0.2	0	0.5	0.8	0	1	1	0.1	1	1	0.1

costs are in USD, inflation adjusted.

TABLE 12.3

IBNET Country Codes

AUS	Australia	LAO	Laos
CHN	China	MYS	Malaysia
IDN	Indonesia	PHL	Philippines
IND	India	THA	Thailand
KHM	Cambodia	VNM	Vietnam

12.4 Estimation Results

We have estimated the parameters of two log-linear cost models. The first bears some similarity to the model used by Estache and Rossi (2002) for the purposes of performance comparison. Due to data differences however, the same variables and units cannot be used. Regressors were expressed in log form based on the observed sample distribution. Model SFA1 is:

$$\ln COST = \beta_0 + \beta_1 \ln W + \beta_2 \ln X + \beta_3 METER + \beta_4 QUAL + \beta_5 DUMCLO$$

The second model omits two variables that were found not to be significant in the first and adds two additional variables that were available in the data and considered to be relevant to efficiency. Model SFA2 is:

$$\ln COST = \beta_0 + \beta_1 \ln W + \beta_2 \ln X + \beta_3 METER + \beta_4 NRW + \beta_5 CRATIO$$

Table 12.4 presents the Stochastic Frontier Analysis estimates of models SFA1 and SFA2 using OLS and MLE methods. Standard errors are shown to three significant digits, estimates shown to the same number of decimal places. Significant variables are flagged by appending the standard error with an asterisk. The software programme used was Frontier V4.1 (Coelli, 1997).

12.5 Discussion of Results

In Model SFA1, the $QUAL$ variable is not a significant determinant of $COST$, nor is the $DUMCLO$ dummy variable. In Model SFA2 we omitted $QUAL$ and $DUMCLO$ and added NRW and $CRATIO$. All the variables in this model are significant. An additional model, not shown here, that included the omitted variables $QUAL$ and $DUMCLO$ was also estimated with no change in their significance. The signs and magnitudes of the estimates of labour and output are as expected for both models. Metering, which was not in log form, indicates that a one percent increase in the rate of metering results in about 0.3 cents per m^3 increase in operational cost. The sign of NRW in Model SFA2 indicates that $COST$ decreases with increasing NRW as proportion of total production. This is a result of simultaneity between the two, as the more appropriate way to express this is that NRW rates decrease with increased expenditure on leak detection and maintenance. The operating coverage ratio of revenue to cost would be expected to fall as the denominator ($COST$) increases.

The efficiency of each firm is the ratio of expected cost with the firm efficiency effect to cost without the effect (Battese and Coelli, 1988):

$$\begin{aligned} TE_i &= \frac{E\left(COST_i|u_i, \mathbf{x}_i\right)}{E\left(COST_i|u_i = 0, \mathbf{x}_i\right)} \\ &= exp(u_i) \end{aligned}$$

TABLE 12.4

Stochastic Frontier Analysis: Cost Function

Model: SFA1	OLS		MLE	
Parameter	Estimate	Std.Error	Estimate	Std.Error
β_0	-2.500	0.457*	-2.089	0.522*
W	0.5975	0.0656*	0.6638	0.0714*
X	0.4322	0.0726*	0.3257	0.0819*
$METER$	0.00267	0.00186*	0.00183	0.00167*
$QUAL$	-0.00271	0.00714	-0.00020	0.00690
$DUMCLO$	0.0169	0.0901	0.0323	0.0788
σ^2	0.1369		0.2943	0.0655
γ			0.8677	0.0871
$loglik$	-45.320		-42.874	

Model: SFA2	OLS		MLE	
Parameter	Estimate	Std.Error	Estimate	Std.Error
β_0	-2.263	0.405*	-2.186	0.434*
W	0.5888	0.0579*	0.6266	0.0607*
X	0.4691	0.0623*	0.3881	0.0730*
$METER$	0.00320	0.00149*	0.00387	0.00134*
NRW	-0.01048	0.00262*	-0.00787	0.00268*
$CRATIO$	-0.19246	0.0639*	-0.2143	0.0602*
σ^2	0.1153		0.2514	0.0573
γ			0.8741	0.0884
$loglik$	-35.55		-33.17	

NB: γ is the ratio-variance parameter $\sigma_u^2/\left(\sigma_v^2+\sigma_u^2\right)$

Table 12.5 shows the estimated efficiency scores for each utility based on each estimated model. For a cost model with dependent variable in logs, the scores range from 1 at the frontier, to infinity. In view of the sensitivity to model specification and formulation of the efficiency statistic, a clustering approach was considered appropriate and the results have been grouped into 10% deciles. The highest deciles have the highest efficiency scores and can be regarded as benchmark leaders in cost efficiency subject to the models used. These included, in Australia, the Central Gippsland Region Water Authority; in China the Yuncheng Water Supply Company LT; in Indonesia PDAM Kota Malang, PDAM Kota Padang Panjang, PDAM Tirta Marta Yogyakarta, PDAM Tirta Sukapura Kabupaten Tasikmalaya, and PDAM Tirtanadi. In India PHED - Jaipur, PWSSB - Bathinda, and PWSSB - Dasuya; while in Malaysia, Pulau Pinang, and Terengganu were in the top decile. In Vietnam, Da Nang Water Supply Co., Ha Giang Water Supply and Sewerage Co., Khanh Hoa Water Supply and Sewerage Co., Lam Dong Water Supply Co., Long Khanh Water Enterprise, Quang Ngai Water Supply Co., Quang Tri Water Supply and Sewerage Co., and the Water Supply Co. of Ba Ria - Vung Tau Province were in the top decile.

We can observe that the Australian utilities City West, South East Water, Hunter Valley and Yarra Valley rated in the lowest decile of efficiency scores in both models. The Chinese utilities Shenzhen and Tianjin also were placed in the lowest decile for both models. Other consistently low ranked utilities included PDAM Bandarmasih Banjarmasin in Indonesia, BWSSB in India, and Johor in Malaysia. Some utilities responded negatively to the changed model (inclusion of NRW or coverage ratio lowered the efficiency score). These included SA Water in Australia and CMWSSB in Indonesia. For others there was an improvement, Labuan and Sibu Water Board in Malaysia for example.

In general we can observe that this form of benchmarking analysis is a powerful tool that is also sensitive to specification and data. In practice any organisation that engages in benchmarking will need to back up its results and be able to show why a utility achieved some score. There may be unaccounted for effects that are specific to some countries, making it difficult to carry out comparative benchmarking such as this example. Comparisons at the domestic or even regional level are less likely to have these differences, making performance based pricing more acceptable. If the utilities trust the method and reliability of the estimates, and the process is transparent, it is reasonable to expect that they will respond with increased efforts to improve efficiency.

Price determination based on performance means that the most efficient firms are used as model firms for the purpose of setting tariffs. The procedure depends on the regulatory environment. For rate of return regulation, the firms operating at the frontier would form the basis for determination of allowable costs and the agreed rate of return on capital. For price caps, the adjustment factor X could be based on firm level efficiency or the mean firm efficiency. Marginal cost pricing would entail determination of the marginal cost function of the most efficient firms and using that to set price. Less efficient firms (with higher marginal cost) would have an incentive to reduce costs, and possibly change their production technology to ensure their financial viability. The regulator may also be able to subsidise the less efficient firms with price increases for a period of time subject to measurable increases in efficiency.

In practice when performance measurement is extended to price setting, the group of model firms may need to be restricted both to a geographical region and utility size. This is to avoid heterogeneity in utility size, regulatory environment, and service catchment area that are not explicitly accounted for in the cost function. The Victorian rural and regional water businesses are a good example of a reasonably homogeneous group of which one or two utilities might become benchmark price leaders. These businesses' marginal supply cost might become the basis of a uniform pricing scheme applicable to all firms, with individual firms compensated for service area, population growth, and other factors unrelated to efficiency. This is not dissimilar to the X-factor in CPI-X pricing and presents the same problem of setting the compensation value. Ultimately it may be the case that once the benchmark price is set, each utility will be in a position to estimate its revenue shortfall and appropriate measures can be taken to either reduce costs or recover the losses from consumers or the owners. More study is required before a specific model can be selected, however, besides the expected efficiency gains, this approach does address the criticism that disparate tariff schemes in the same geographical region are undesirable for consumers.

12.6 Conclusion

In this case study we have presented an example of the use of Stochastic Frontier Analysis for benchmarking cost efficiency using a sample of water utilities located in Australia and Asia. The main objective has been to demonstrate the viability of this approach for urban water pricing. The Stochastic Frontier Analysis allows us to drop the assumption that all firms are cost minimisers and instead assumes that some firms are more cost efficient than others. The parameters of the model when using the maximum likelihood method include a measure of the deviation from the cost frontier and therefore a normalised measure of cost efficiency can be estimated. This can be used to rank or cluster firms by efficiency, or as we have proposed here, to identify the firms whose cost structures would be used to set prices under either a rate of return form of regulation, price caps or marginal cost.

TABLE 12.5

Stochastic Frontier Analysis: Cost Efficiency Scores

		Efficiency		Decile	
Country	Utility	SFA1	SFA2	SFA1	SFA2
AUS	Barwon Region Water Authority	1.47	1.31	5	6
AUS	Central Gippsland Region Water Authority	1.29	1.14	7	10
AUS	Central Highlands Region Water Authority	1.42	1.30	5	7
AUS	City West Water Limited	3.11	2.60	1	1
AUS	Coliban Region Water Authority	2.28	2.02	2	2
AUS	Goulburn Valley Water	2.06	1.69	2	3
AUS	Hunter Water Corporation	2.93	2.50	1	1
AUS	Power and Water Corporation	2.02	1.78	2	3
AUS	South Australian Water Corporation	2.26	2.50	2	1
AUS	South East Water Limited	2.72	2.36	1	1
AUS	Sydney Water Corporation	1.95	1.75	2	3
AUS	WA Water Corporation	1.38	1.60	6	3
AUS	Yarra Valley Water Limited	3.21	2.78	1	1
CHN	Ankang Water Company	1.89	1.45	2	5
CHN	Bozhou Water Company	1.70	1.61	3	3
CHN	Haerbin Water Company	1.91	1.80	2	2
CHN	Handan Water Company	1.60	1.44	4	5
CHN	Hangu Water Company	1.40	1.38	6	5
CHN	Jiaozuo Water Company	1.30	1.24	7	8
CHN	Shenzhen Water Company	2.90	2.51	1	1
CHN	Tianjin Water Company	3.41	3.22	1	1
CHN	Weifang Water Company	1.97	1.73	2	3
CHN	Yuncheng Water Supply Company LTD.	1.21	1.11	9	10
IDN	PDAM Bandarmasih Banjarmasin	2.32	2.45	1	1
IDN	PDAM Kabupaten Banyumas	2.10	1.99	2	2
IDN	PDAM Kabupaten Pandeglang	1.20	1.19	9	9

TABLE 12.5

Continued

		Efficiency		Decile	
Country	Utility	SFA1	SFA2	SFA1	SFA2
IDN	PDAM Kabupaten Purwakarta	1.27	1.22	7	8
IDN	PDAM Kabupaten Sleman	1.50	1.43	5	5
IDN	PDAM Kota Makassar	1.71	1.80	3	2
IDN	PDAM Kota Malang	1.19	1.17	10	9
IDN	PDAM Kota Padang Panjang	1.27	1.12	8	10
IDN	PDAM Kota Pangkal Pinang	1.61	1.56	4	4
IDN	PDAM Kota Surakarta	1.42	1.26	5	7
IDN	PDAM Tirta Marta Yogyakarta	1.14	1.21	10	9
IDN	PDAM Tirta Pakuan Kota Bogor	1.20	1.19	9	9
IDN	PDAM Tirta Sakti Kab. Kerinci	1.82	1.69	3	3
IDN	PDAM Tirta Sukapura Kabupaten Tasikmalaya	1.13	1.14	10	9
IDN	PDAM Tirtanadi	1.13	1.14	10	10
IND	AMC	1.82	1.96	3	2
IND	BMC - HED	1.50	1.60	4	3
IND	BWSSB	2.32	2.40	1	1
IND	CMWSSB	1.85	2.48	3	1
IND	DJB	1.32	1.33	7	6
IND	MCC	1.51	1.27	4	7
IND	PHED - Bharatpur	1.58	1.41	4	5
IND	PHED - Bikaner	1.45	1.28	5	7
IND	PHED - Jaipur	1.22	1.13	9	10
IND	PHED - Jodhpur	2.12	1.88	2	2
IND	PHED - Udaipur	1.88	1.40	3	5
IND	PWD - Goa	1.34	1.30	6	7
IND	PWSSB - Bathinda	1.25	1.19	8	9
IND	PWSSB - Dasuya	1.25	1.14	8	10
IND	PWSSB - Dera Bassi	1.29	1.17	7	9
IND	PWSSB - Gurdaspur	1.33	1.50	6	4

TABLE 12.5

Continued

Country	Utility	Efficiency SFA1	Efficiency SFA2	Decile SFA1	Decile SFA2
IND	PWSSB - Patran	1.21	1.24	9	8
KHM	Phnom Penh Water Supply Authority	1.27	1.36	7	6
LAO	Vientiane City Water Supply Enterprise	1.55	1.48	4	4
MYS	Johor	2.34	2.40	1	1
MYS	Kelantan state	1.22	1.22	9	8
MYS	Kuching	1.45	1.34	5	6
MYS	Labuan	2.92	2.23	1	2
MYS	LAKU	1.80	1.62	3	3
MYS	Melaka	1.66	1.54	3	4
MYS	Negeri Sembilan	1.47	1.52	5	4
MYS	Pahang State	1.35	1.26	6	7
MYS	Perak State	1.69	1.53	3	4
MYS	Perlis	1.58	1.45	4	5
MYS	Pulau Pinang	1.19	1.14	10	10
MYS	Sabah	2.22	2.19	2	2
MYS	Sarawak	1.57	1.25	4	7
MYS	Sibu Water Board	2.51	2.36	1	2
MYS	Terengganu	1.14	1.14	10	10
PHL	Silay City Water District	1.40	1.46	5	4
THA	Universal Utilitites	1.24	1.25	8	7
VNM	Bac Kan Water Supply and Sewerage Co.	1.28	1.49	7	4
VNM	Bac Ninh Water Supply and Sewerage Co.	1.31	1.42	7	5
VNM	Ben Tre Water Supply and Sewerage Co.	1.25	1.25	8	7
VNM	Binh Duong Water Supply and Sewerage Co.	1.36	1.37	6	6
VNM	Binh Thuan Water Supply and Sewerage Co.	1.26	1.23	8	8

TABLE 12.5

Continued

		Efficiency		Decile	
Country	Utility	SFA1	SFA2	SFA1	SFA2
VNM	Cao Bang Water Supply Co.	1.25	1.21	8	9
VNM	Da Nang Water Supply Co.	1.14	1.13	10	10
VNM	Dong Nai Water Supply and Construction Co.	1.23	1.25	9	8
VNM	Dong Thap Urban Water Supply, Sewerage and Environment Co.	1.45	1.38	5	5
VNM	Ha Dong Water Supply Co.	1.81	1.86	3	2
VNM	Ha Giang Water Supply and Sewerage Co.	1.13	1.14	10	10
VNM	Ha Noi Clean Water Business Co.	1.26	1.23	8	8
VNM	Ha Tinh Water Supply Co.	1.19	1.18	10	9
VNM	Hai Duong Water Supply Co.	1.64	1.90	3	2
VNM	Ho Chi Minh Water Supply Co.	1.28	1.23	7	8
VNM	Hoa Binh Water Supply and Sewerage Co.	1.20	1.23	9	8
VNM	Khanh Hoa Water Supply and Sewerage Co.	1.10	1.13	10	10
VNM	Kien Giang Water Supply and Sewerage Co.	1.34	1.39	6	5
VNM	Lam Dong Water Supply Co.	1.14	1.14	10	10
VNM	Lang Son Water Supply Co.	1.35	1.33	6	6
VNM	Long Khanh Water Enterprise	1.16	1.22	10	8
VNM	Nghe An Water Supply Co.	1.43	1.38	5	5
VNM	Ninh Thuan Water Supply Co.	1.62	1.75	4	3
VNM	Phu Tho Water Supply Co.	1.24	1.19	8	9
VNM	Quang Binh Water Supply and Sewerage Co.	1.24	1.34	8	6
VNM	Quang Ngai Water Supply Co.	1.20	1.13	9	10
VNM	Quang Tri Water Supply and Sewerage Co.	1.08	1.06	10	10

TABLE 12.5

Continued

Country	Utility	Efficiency SFA1	Efficiency SFA2	Decile SFA1	Decile SFA2
VNM	Soc Trang Water Supply Co.	1.35	1.24	6	8
VNM	Son Tay Water Supply Co.	1.30	1.38	7	6
VNM	Tam Ky Quang Nam Water SupplyCo.	1.28	1.34	7	6
VNM	Thai Binh Water Supply Co.	1.35	1.27	6	7
VNM	Thai Nguyen Water Supply Co.	1.41	1.49	5	4
VNM	The Water Supply and Sewerage Co. of Binh Phuoc Province	1.39	1.54	6	4
VNM	The Water Supply Co. of Ba Ria - Vung Tau Province	1.06	1.08	10	10
VNM	Thua Thien Hue Water Supply and Sewerage Co.	1.26	1.26	8	7
VNM	Thua Thien Hue Water Supply and Sewerage Co.	1.19	1.34	10	6
VNM	Tra Vinh Water Supply and Sewerage Co.	1.50	1.55	4	4
VNM	Tuyen Quang Water Supply and Sewerage Co.	1.23	1.30	9	6
VNM	Vinh Phuc No 2 - Water Supply - Sewerage and Environment Co.	1.59	1.60	4	3
VNM	Water Supply Enterprise of Long Xuyen City	1.20	1.19	9	9

CHAPTER 13

Conclusion and Directions for Future Research

13.1 Resume of this Research

We began this thesis by asking some questions about marginal cost water pricing in an urban context. How is the marginal cost of water determined? How is the price of water established using marginal cost as the basis? How do current water prices compare with estimated price based on marginal cost? What is the welfare impact of current water pricing relative to a proposed marginal cost based price? In attempting to answer these questions we have examined both theoretical and practical issues. We began with a selective review of the theoretical and applied basis for water pricing, examining different aspects of this theory including cost, demand and welfare.

With cost we have relaxed the assumption of constant long run returns to scale of production and derived variable returns to scale minimum cost functions that can be used in empirical work. The lumpy nature of investment in water infrastructure means that utilities are at any one time likely to produce under increasing or decreasing returns rather than constant returns, and that marginal cost is not constant, even over a considerable length of time.

We have considered the demand for water in the estimation of marginal cost. General practice is to determine long run demand based on historical records of average and seasonal consumption. This information, coupled with population and demographic data is used for investment planning. Pricing water on the basis of knowledge of a demand function is not common practice, although block rate pricing - charging higher marginal rates for water as consumption increases - is becoming more widespread. In examining demand we focused on modelling a consumer demand function subject to a block rate tariff. In this case the budget constraint is piecewise linear, and normal assumptions about linearity of the demand curve no longer hold. We derived the likelihood function for this model based on use of a two error specification for the demand function.

We presented a method for determination of marginal cost based on mean factor prices and output, and on a partial equilibrium of marginal cost and the demand curve. We examined the welfare loss arising from pricing at below marginal cost and the level of subsidisation required at marginal cost when there are increasing returns to scale.

Two case studies applied this theory to data sets drawn from Australia and the Philippines. The first looked at cost and welfare in the supply of water to domestic users in Victoria. Our conclusion was that urban water is produced under increasing returns to scale - commonly this is associated with regulated industries and the need to maintain essential supply reserves. We determined that the current volumetric rate for metropolitan water businesses was around 26% less than the actual marginal cost of water, while for regional businesses it was 35% less. If marginal cost pricing were to be used, a subsidy of about of 3.3% of current revenues would still be required for metropolitan businesses, while for regional businesses a subsidy of 7.2% would be required.

The second case study was focused on recent events in water privatisation in Manila. The government owned water utility was considered to be inefficient and the infrastructure in need of significant investment to cater to the demands of urban population growth. Privatisation was expected to reduce the burden of debt that had been accumulated by the government in operating the water and sewerage services. Two firms were awarded contracts for the supply of domestic and commercial water in 1997, and the department previously responsible for water supply assumed the role of regulator. Estimates of cost functions indicated decreasing returns to scale, although the hypothesis of constant returns was not rejected. Household demand was estimated using two methods. First we used a sample of households consisting of those with a water connection and those that relied on other sources such as water carters. A weighted average price was determined and least squares used to estimate the parameters of a log-linear demand model. The second method involved maximum likelihood estimation of household demand using a two error model derived in Chapter 4. The sample consisted only of households with a water connection. The results of these revealed that, for the mixed sample, price was less elastic than for the sample of connected households. We interpreted this to mean that those households with a water connection pay an overall lower price than the average household, and consume more. They are able to reduce consumption when faced with higher prices because essential requirements can still be met. The welfare effects of a price increase for households with a connection were found to be positive, and in 2000 average prices were about 26% below marginal cost at the efficient output level. Prices have increased significantly since 2001, however the basis for price determination by the regulator continues to be governed directly by the concessionaires costs without consideration of impacts on consumer welfare or predictions of changes in demand.

Estimation results have been discussed independently in each case study and jointly in Chapter 11. There we have contrasted both sets of results with regards to scale economies, elasticities, pricing, tariffs, ownership, and regulation. Following on, we presented a contrasting approach to marginal cost and pricing that relaxes assumptions about cost minimisation, assumptions that form the basis for the cost models used in the case studies. We presented a model that allows us to estimate the deviation of firms from a performance frontier, in contrast to an estimate of their mean cost. This was followed by an applied example that used benchmarking data from the World Bank to estimate a cost frontier for a sample of water utilities throughout Australia and Asia. By assignment of efficiency scores to clusters (deciles) we proposed that the higher performing utilities, as well as providing leadership in efficiency, would form the basis of the information used by regulators to price the service. Performance based pricing such as this would encourage firms to become more efficient as their prices would effectively be capped at the marginal cost of the most efficient firms.

13.2 Originality of this Contribution

In the introduction to this thesis we previewed the novelty of our approach in three areas: the use of functional forms to describe the key variables: cost, demand, and welfare; the recognition that water utilities often operate with increasing returns to scale and the implications of this in respect of cost recovery and over use of the resource; and the acknowledgement that utilities may not behave as cost minimisers in all cases, particularly if operating under rate of return regulation. We have considered solutions to these problems in the form of Ramsey pricing and an alternative pricing mechanism based on use of efficiency frontiers. These areas are commonly dealt with independently but seldom in a unified manner. Additionally, we have taken consumer demand into account; as part of the estimation of efficient levels of output, and in examining the properties of consumer demand subject to a increasing block rate tariff.

This work has emphasised an alternative approach to conventional water price and demand analysis based on the use of econometric modelling. The econometric models that we have presented in this thesis are characterised by their parsimony in respect of choice of regressors, an approach that follows after Varian (1984, Ch. 4). The advantage of this approach is in the relative ease of interpretation of results in comparison to the case when there are many regressors, some of which are likely to be correlated. The use of econometric models, in contrast to established methods involving discounted cost and demand, has produced useful results that will improve with better data and more research in the models used. Most importantly this approach allows us to measure parameters of water production and consumption including economies of scale, cost and output elasticities, and price and income elasticities of demand. By use of sensitivity analysis we have shown that the dependent variables (marginal cost and welfare) are not sensitive to the level of output but are sensitive to changes in the coefficients of the underlying cost and demand functions.

The application of econometric models in the form of three case studies, each involving a different data set and regulatory environment, forms the main original applied contribution. These results are expected to be of interest to those engaged in applied research as well as the involved utilities and regulators.

13.3 Urban Water Pricing Policy

In the introductory chapter when stating the objectives of this research we also asked: what are the main policy issues that we need to address in a debate on water pricing - particularly one based on marginal cost? In this section we will attempt to provide some answers to this question based on the experiences and findings of this research. The detail of empirical findings upon which some of these remarks are based can be found at the end of each case study and at the beginning of Chapter 11. A broader water policy discussion is beyond the scope of this work as it would need to address all of the uses of water including agricultural, mining, cultural, recreational, and ecological. The interested reader is referred to reports that set out policy directions in the global context with emphasis on developing parts of the world: United Nations (2006); and specifically in the Australian context: Business Council of Australia (2006); Marsden and Pickering (2006); Young, Proctor, Qureshi, and Wittwer (2006).

13.3.1 Tariff Design and Variable Unit Pricing

For regulators interested in setting price, or price caps, or influencing tariff design, an understanding of the scale economies and the marginal cost function of the utilities is essential. This is because the relationship between marginal cost, average cost and price will determine: first, whether the utility has to subsidise its operation by offering its services to different classes of user at different prices or by direct assistance from its owners; and second, whether the utility is engaging in monopoly pricing. Because costs change over time, continuous monitoring of utility production and investment costs, is necessary for the regulator to carry out this function.

The choice of price and tariff design should be governed by efficiency and equity concerns and the need for sustainable resource management. To reflect the presence of scarcity, the marginal cost curve will be increasing and there will be decreasing returns to scale. If scarcity is not taken into account, and there are increasing returns to scale, marginal cost pricing, although more efficient in the economic sense, will result in both over use of water and in revenues below the total cost of supply. A regulator therefore must price the unknown scarcity component of marginal cost by adding its user cost so that the marginal cost curve is increasing. This is achieved with the use of a rising block tariff. The unresolved difficulty, however, is that the shadow price of scarcity remains difficult to quantify, in particular in the urban water context.

A rising block tariff will therefore increase revenues for the utility operating under increasing or constant returns to scale relative to production and distribution costs. These revenues can be used to offset the scarcity premium by investment in projects that increase future supply, or to subsidise low volume consumers, or a combination of both. The risk of this approach is that it still does not cap consumption for users for whom price is unimportant. Therefore, in times when supplies are under stress, a combined approach that includes restrictions and financial penalties for excessive consumption will still be required in addition to the rising tariff. Where water supplies are not under stress, there is less of a need to incorporate the scarcity component in marginal cost, but Ramsey pricing will still be required to avoid financial losses.

Despite their increasing use, rising block rate tariffs are an imperfect instrument for dealing with increasing marginal costs and scarcity. First, determination of the parameters of a block rate tariff - the block lengths and prices - is difficult to implement, despite the research that has been devoted to this area. Leaving this to individual utilities (as is being done in Victoria) places demands on the available skills and results in a variety of different tariffs for utilities whose production and costs are unlikely to be greatly different. Second, a simple one or two block rate tariff aims to combine market signals (increasing marginal price) and essential service security (constant unit price for a quota) in one. These two ought be regarded independently so that the nonessential component becomes fully marginal cost based. This could be effected in different ways. The nonessential usage block prices can be reset at regular intervals, to account for changing seasonal demands and supply constraints. Alternately, the volumetric price could vary continuously with consumption[1]. The application of market pricing in urban

[1]The price would be $p = \beta + kQ^{\alpha}$, where Q is consumption in excess of the essential component, and β, k and α are adjustable parameters.

water is lagging behind other areas including agricultural water and domestic and industrial electricity supply. *Smart metering* in electricity supply where consumers can modify their consumption and the price they pay according daily variation in supply and demand is one area that utilities and regulators could investigate to see how market pricing might work.

The use of an increasing block rate tariff when marginal production and distribution costs are decreasing affords the opportunity of cross-subsidisation of the low-cost essential component of water supply. This creates a problem of equity because this component is offered to all consumers at the same price, regardless of income or total consumption. High volume consumers would in effect be subsidising part of their own consumption. One possible solution to this would be to offer two different tariff structures, one with and one without the low-cost essential component. Average consumption over the last period (not proxied income) would determine which one was applied, but care would be needed to avoid penalising large households with normal per capita levels of consumption. We must emphasise again that this approach would only apply when total marginal costs are increasing because of scarcity or other supply constraints. Without these constraints, there does not appear to be any reason for offering water at anything other than its (decreasing) marginal supply cost, providing supplies are abundant and all investment and user costs accounted for.

The point is sometimes made that water prices need to be predictable. This is interpreted to mean they should be constant and that any variability will have adverse effects. The use of marginal cost pricing has been criticised for these reasons, as has been the use of seasonal adjustments to price. As efficiency becomes more important, these arguments become harder to justify and more variability in price may be necessary. This may be applied only to unit prices for consumption above the level of the essential component, the price of which could remain fixed for much longer periods. Publication or issuing notices of price adjustments in advance of their implementation would be one way of ensuring predictability.

13.3.2 Efficiency and Competition

In the later chapters of this thesis we turned our attention to the area of efficiency measurement in pricing water. For regulators and those who determine national water policy, efficiency in production and efficiency in consumption are two areas for consideration. Pricing water according to the production costs of the most efficient producers reduces the risk of having a price that reflects side-effects arising from regulatory weakness that does not give the utility an incentive to reduce costs, or that encourages abuse of monopoly powers. It also makes up for the absence of a competitive market among peers who will be forced to reduce their costs. Promoting efficiency in consumption, by smart metering, public awareness campaigns, or by the use of water saving appliances should also be encouraged.

The other area that competition can play a role is in service provision. This involves splitting off some non-core services to outside firms who would compete to offer the lowest cost service. These services include maintenance, meter installation and reading, accounting and billing systems, water treatment and storage, waste disposal, management, and even distribution. This is becoming more common, however competitive bidding does not ensure that the most efficient firm will win because of the potential for underbidding; although there are solutions for this, for example as described in Solon and Pamintuan (2000). Generally, more competitive supply in the urban water supply sector should be encouraged in the light of evidence that the presence of competition contributes to efficiency.

13.3.3 Agricultural Water Use and Trade

It is difficult, particularly in the Australian case, to discuss efficiency in the urban water sector in isolation. This is because, on a national scale, the urban sector accounts for only about 12% of consumption while the agricultural production sector accounts for almost 70% of consumption (Kaspura, 2006). The greatest gains nationally, will therefore be made by increasing efficiency in agricultural water use. Existing water trading schemes mean that rural water is already priced at its marginal benefit and therefore there is a strong incentive for users to introduce technological improvements so that efficiency in use is increased. Supply constraints where they exist will not be resolved through the water market as the tradeable price does not include the investment cost of increased supply. There is therefore a need for increased investment in securing agricultural water supply in the current environment. One idea that has gained some attention in recent times is the purchase of rural water entitlements for residential use to overcome shortages in urban areas (Quiggin, 2006). The adoption of this appears to be increasingly less likely as existing water allocations are reduced because of drought.

13.3.4 Data Standardisation

The use of innovative analytical and statistical approaches, and performance benchmarking and monitoring is predicated on the availability of quality data. Many studies have noted that data availability is a considerable constraint in applied research. A worrying concern is that useful data is kept out of the public domain; it is considered proprietary or of no research value. Regulators have a role to play in ensuring that data is available, shared, and conforms to common standards. In the words of the United Nations (2006):

> It is only when the data has been collected and analysed that we can properly understand the many systems that affect water (hydrological,

socio-economic, financial, institutional and political alike), which have to be factored into water governance.

Urban water policy needs to address these weaknesses by making water accounting mandatory practice for regulators and utilities, based on standards commensurate with professional practice.

13.3.5 Other Implications of Pricing Policy

Throughout the course of this study we have made the point that welfare losses are associated with existing water pricing systems in many parts of the world. We estimated these losses in the Case Studies for Victoria and Manila. This means that many utilities operate at an economic loss and require subsidisation from their owners. In the broader sense this inefficiency leads to a undervaluing and overuse of the resource with the resultant loss to other competing uses. Continuation of this situation poses a very serious threat to our society when associated with decreased inflows and population growth.

This and other studies have demonstrated the welfare gains that can be made by increasing urban water prices and adopting a marginal cost approach to price determination. This policy is now being put into practice in many parts of the world including Australia. Although deemed welfare improving, we need to ask if higher prices create new or additional problems of equity. In Australia these issues are likely to be addressed through the existing concession schemes for pensioners and welfare recipients that are linked to CPI increases. However, with a new round of above CPI water price increases likely in most states the next few years, additional concessional allowances may be required for some. Other equity improving measures such as the use of Ramsey pricing have in some studies shown to decrease net welfare (Renzetti, 1992). The requirement for some form of price discrimination among different classes of user, according to elasticity of demand for example, is however unlikely to diminish with a more efficient pricing policy. Block rate pricing and connection charges based on property valuations (Sibly, 2006) are potential but partial solutions to this problem. It is important to note that these proposals are in contrast to the current use of water restrictions which does not manage scarcity by price signaling and forfeits revenue from those users who are willing to pay for high levels of consumption. Regardless, some form of cap on high volume users would still be required when capacity constraints are present.

Another implication of an increase in water prices based on the long run marginal cost is that there may be periods when utilities make windfall profits that are difficult to justify to consumers. Indeed this is already the case with the Victorian state government under criticism for not directly reinvesting profits from the metropolitan water businesses. The lack of investment in water infrastructure in Victoria and other parts of the world might have resulted in this way, however, as shown in the First Case Study, utilities may be reluctant to borrow to finance capital investment. There may be political reasons for this, but we also have shown that for certain models, costs are more sensitive to interest rates than wages. The implication of this is that debt financing of capital projects by government owned corporations is unpopular and alternative methods of financing such as equity ownership and Build Own Operate and Transfer (BOOT) schemes need to be examined further.

Long run marginal cost pricing also becomes problematic when the factors that lead to its adoption are no longer relevant. The scarcity premium may not be required because the investment has been carried out and paid for and capacity constraints are not present. These issues add to the viability of proposals such as seasonal based pricing and adjusting prices relative to storage supplies (Grafton and Kompas, 2006). Additionally, a long term downward price adjustment is not unreasonable if seasonal and long term inflows are adequate. Recently all major capitals of Australia with the exception of Darwin have decided to build desalination plants, while Perth already has one in operation and is embarking on its second. Ignoring environmental costs, desalination has become a viable alternative because its cost is comparable to the long run marginal costs of supplying surface water. If capacity constraints are not present however and surface water prices can again be set below the cost of desalinated water, then the plant will only operate in a standby mode. This is unlikely to be acceptable and therefore the possibility is that water prices in the future might be governed by the marginal cost of desalinated water, at least in the Australian capitals.

13.4 Future Research Directions

In conducting this research, we have been presented with alternate paths and opportunities that appear interesting and potentially rewarding. It is impossible to explore all of these in the space of a thesis. They relate to both application and theory.

In applied work, there is a need to more fully account for user costs and externalities by use of shadow pricing methods such as contingent valuation and coping cost (Devicienti, Klytchnikova, and Paternostro, 2004). Two data sets have recently become available that can contribute to our understanding in this area. The first is a sample of water supply firms from Cambodia, and originates from research conducted by Basani, Isham, and Reilly (2005). The second is based on Philippines price indices and presents an opportunity to explore linear expenditure systems as described in Deaton and Muellbauer (1980). In terms of econometric methods used, the use of non-linear models, multiple equation estimation, and multiple output models are potentially useful in applied work, especially as data sets become more complex, and we seek to explain more complex relationships.

In theory development, the relationship between returns to scale, elasticity, and welfare is an area where more research is needed. Similarly, capital adjustment needs to be explained within the cost model, which implies that a dynamic model is required. More work is needed in the area of water trading and rural-urban transfers; this work may need to consider opportunity costs when water rights are traded, including impact on land valuations and conversion to dryland agriculture, and the impact on agricultural prices.

13.5 Closing Comments

Increasingly there is a need to fully account for the economic cost of water service including opportunity costs, externalities, and investment in the long run. To justify future price increases, authorities and regulators need to take these costs into account so that the economic case for price increases can be made. As part of this undertaking, a re-examination of the reporting and accounting of water services needs to take place so that economic costs are quantified, made more transparent, and employed in decision making to the fullest extent possible.

The estimation and use of functional forms for the analysis of urban water costs and demand is promising and merits place in an array of tools used by utilities, regulators, and policy makers. The results that we have obtained with this approach provide some evidence that urban water has been undervalued in recent years. The value of water should be reflected in its price and the value that consumers place on its use. We need to fully understand production, investment and opportunity costs, the cost of scarcity and externalities, and what impact price has on demand.

Water is essential to our survival and prosperity. In abundance, it is thought of as a public good. It is increasingly acknowledged however, that water is an economic good and needs to be priced accordingly. The objective of this thesis has been to demonstrate the use of marginal cost as an economic basis for pricing water and to give examples of how this might be applied. The recent evidence is that valuing water on such as basis is becoming something of an imperative for our society.

APPENDIX A

Properties of the Variable Returns to Scale Cost Function

In the following we will express the variable returns cost function 3.4 in the equivalent form:

$$C = Aw^{\alpha\mu}r^{\beta\mu}x^{\mu}$$

where $\mu = \frac{1}{\alpha+\beta}$.

1. Homogeneous of degree one in factor prices.

$$\begin{aligned} C' &= A(kw)^{\alpha\mu}(kr)^{\beta\mu}x^{\mu} \\ &= k^{(\alpha+\beta)\mu}C \\ &= kC \end{aligned}$$

2. Homogeneous of degree μ in output.

$$\begin{aligned} C' &= Aw^{\alpha\mu}r^{\beta\mu}(kx)^{\mu} \\ &= k^{\mu}C \end{aligned}$$

3. Nondecreasing in factor prices.

$$\begin{aligned}\frac{\partial C}{\partial w} &= \frac{\alpha\mu}{w}C \\ &= \frac{\alpha}{w(\alpha+\beta)}C\end{aligned}$$

It follows that this last expression is non-negative from the definitions of α and β. By symmetry the same holds for all other factors.

4. Nondecreasing in output.

$$\frac{\partial C}{\partial x} = \frac{\mu}{x}C$$

It follows that this last expression is non-negative from the definitions of α and β.

5. Concave in factor prices.

$$\begin{aligned}\frac{\partial C}{\partial w} &= A\alpha\mu w^{\alpha\mu-1}r^{\beta\mu}x^{\mu} \\ \frac{\partial^2 C}{\partial w^2} &= A\alpha\mu(\alpha\mu-1)w^{\alpha\mu-2}r^{\beta\mu}x^{\mu} \\ &= \alpha\mu(\alpha\mu-1)\frac{C}{w^2}\end{aligned}$$

We only need to examine the term $\alpha\mu - 1$ in this last expression.

$$\begin{aligned}\alpha\mu - 1 &= \frac{\alpha}{\alpha+\beta} - 1 \\ &= \frac{-\beta}{\alpha+\beta} \\ &\leq 0\end{aligned}$$

Note that the minimum cost function is not concave in output, as:

$$\frac{\partial^2 C}{\partial x^2} = \mu(\mu - 1)\frac{C}{x^2}$$

and the term $(\mu - 1)$ has ambivalent sign.

APPENDIX B

Transformation of the Two Error Model Likelihood Function

B.1 Introduction

The purpose of this transformation is to create a new pair of standardised error variables that are uncorrelated. This enables the use of univariate standard normal and cumulative density functions in the likelihood function. A set of identities used in this derivation is included at the end of this Appendix.

B.2 Segment Likelihood

The transformation entails decomposition of the bivariate normal distribution into the product of conditional and univariate density functions (see Johnston and DiNardo, 1997, p. 15):

$$f(v_i, \alpha_i) = f(v_i) f(\alpha_i | v_i)$$

We begin with the conditional density function which is by definition:

$$f(\alpha_i | v_i) = \frac{1}{\sigma_{\alpha|\nu}\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{\alpha_i - \mu_{\alpha|v}}{\sigma_{\alpha|v}}\right)^2\right]$$

The conditional mean is:

$$\mu_{\alpha|v} = \mu_\alpha - \rho\frac{\sigma_\alpha}{\sigma_v}\mu_v + \rho\frac{\sigma_\alpha}{\sigma_v}v = \rho^2 v$$

where ρ is correlation between v and α. The conditional variance is:

$$\sigma^2_{\alpha|v} = \sigma^2_\alpha(1-\rho^2)$$

Therefore:

$$\begin{aligned} f(\alpha_i|v_i) &= \frac{1}{\sigma_\alpha\sqrt{2\pi(1-\rho^2)}}\exp\left[-\frac{1}{2}\left(\frac{\alpha_i-\rho^2 v}{\sigma_\alpha\sqrt{(1-\rho^2)}}\right)^2\right] \\ &= \frac{1}{\sigma_\alpha\sqrt{2\pi(1-\rho^2)}}\exp\left[-\frac{1}{2}\left(\frac{\alpha_i/\sigma_\alpha-\rho v/\sigma_v}{\sqrt{(1-\rho^2)}}\right)^2\right] \end{aligned}$$

Now define three new standardised variables:

$$\begin{aligned} z_i &= v_i/\sigma_v \\ t_i &= \alpha_i/\sigma_\alpha \\ r_i &= \frac{t_i-\rho z_i}{\sqrt{(1-\rho^2)}} \end{aligned}$$

Note that we need to verify that r is a standardised variable. By inspection, its mean is zero. For the variance:

$$\begin{aligned} var(r) &= var\left(\frac{t}{\sqrt{1-\rho^2}}\right)+var\left(\frac{-\rho z}{\sqrt{1-\rho^2}}\right)+2*cov\left(\frac{t}{\sqrt{1-\rho^2}},\frac{-\rho z}{\sqrt{1-\rho^2}}\right) \\ &= \frac{1}{1-\rho^2}+\frac{\rho^2}{1-\rho^2}-\frac{2\rho^2}{1-\rho^2} \\ &= 1 \end{aligned}$$

Therefore we have for the conditional density:

$$f(\alpha_i|v_i) = \frac{1}{\sigma_\alpha\sqrt{(1-\rho^2)}}f(r_i)$$

Now we can reformulate the bivariate density function, with reference to the identity that converts a normal density into standard normal density:

$$\begin{aligned} f(v_i,\alpha_i) &= f(v_i)f(\alpha_i|v_i) \\ &= \frac{1}{\sigma_v\sigma_\alpha\sqrt{(1-\rho^2)}}f(z_i)f(r_i) \end{aligned}$$

Finally, we can express the likelihood of the first segment in terms of the new standard variables:

$$\begin{aligned} \int_{-\infty}^{x^*-g_i(1)} h(v_i,\alpha_i)d\alpha_i &= \frac{1}{\sigma_v\sigma_\alpha\sqrt{(1-\rho^2)}}\int_{-\infty}^{\alpha_{1i}=x^*-g_i(1)} f(z_i)f(r_i)d\alpha_i \\ &= \frac{1}{\sigma_v\sqrt{(1-\rho^2)}}\int_{-\infty}^{t_{1i}} f(z_i)f(r_i)dt_i \\ &= \frac{1}{\sigma_v}\int_{-\infty}^{r_{1i}} f(z_i)f(r_i)dr_i \\ &= \frac{1}{\sigma_v}f(z_i)F(r_{1i}) \end{aligned}$$

Note that each change of variable of integration is achieved by differentiation of the standardised variables and that the limits of integration must also change when this is carried out. The likelihood for the second segment follows by the symmetry of the density function.

B.3 Kink Likelihood

The kink likelihood only requires standardisation of the errors:

$$\begin{aligned}
\int_{x^*-g_i(1)}^{x^*-g_i(2)} f(\varepsilon_i)f(\alpha_i)d\alpha_i &= \frac{1}{\sigma_\varepsilon}f(\frac{\varepsilon_i}{\sigma_\varepsilon})\int_{\alpha_{1i}=x^*-g_i(1)}^{\alpha_{2i}=x^*-g_i(2)} \frac{1}{\sigma_\alpha}f(\frac{\alpha_i}{\sigma_\alpha})d\alpha_i \\
&= \frac{1}{\sigma_\varepsilon}f(s_i)\int_{t_{1i}}^{t_{2i}} f(t_i)dt_i \\
&= \frac{1}{\sigma_\varepsilon}f(s_i)[F(t_{2i}) - F(t_{1i})]
\end{aligned}$$

where s_i is the standardised form of ε_i.

B.4 Identities used in Transformations

B.4.1 Properties of the Error Variables:

$v_i = \alpha_i + \varepsilon_i$

$var(v) = var(\alpha) + var(\varepsilon)$

$cov(\alpha, \varepsilon) = 0$

$cov(v, \alpha) = \sigma_\alpha^2$

$cov(v, \varepsilon) = \sigma_\varepsilon^2$

$\rho = corr(v, \alpha) = cov(v, \alpha)/(\sigma_v \sigma_\alpha) = \sigma_\alpha/\sigma_v$

$\sigma_\varepsilon/\sigma_v = \sqrt{1-\rho^2}$

$\sigma_\varepsilon/\sigma_\alpha = \rho^2/\sqrt{1-\rho^2}$

B.4.2 Properties of the Standardised Error Variables:

$$\begin{aligned}
cov(z,t) &= \frac{1}{n-1}\sum_i\sum_j z_i t_j \\
&= \frac{1}{n-1}\frac{1}{\sigma_v\sigma_\alpha}\sum_i\sum_j v_i\alpha_j \\
&= \frac{1}{\sigma_v\sigma_\alpha}cov(v,\alpha) \\
&= \rho \\
&= corr(z,t) \\
&= corr(v,\alpha)
\end{aligned}$$

$$\begin{aligned}
f(v) &= f(\sigma_v z) \\
&= \frac{1}{\sqrt{2\pi var(\sigma_v z)}}exp\left[-\frac{1}{2}(\sigma_v z)^2/var(\sigma_v z)\right] \\
&= \frac{1}{\sigma_v}\frac{1}{\sqrt{2\pi}}exp\left[-\frac{1}{2}(z)^2\right] \\
&= \frac{1}{\sigma_v}f(z)
\end{aligned}$$

The following identity confirms the use of the conditional density transformation:

$$\begin{aligned}
cov(z,r) &= \frac{1}{n-1}\sum_i\sum_j z_i r_j \\
&= \frac{1}{n-1}\sum_i\sum_j(z_i t_j/\sqrt{1-\rho^2}) - \frac{1}{n-1}\sum_i\sum_j(\rho z_i z_j/\sqrt{1-\rho^2}) \\
&= 0
\end{aligned}$$

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