Estimating the marginal value and price elasticity of demand for water in the industrial sector in South Africa: An application and assessment of the marginal productivity approach

Report to the

WATER RESEARCH COMMISSION

by

Anton Nahman and Willem de Lange

CSIR: Natural Resources and the Environment

WRC Report No. 2103/1/13

ISBN 978-1-4312-0456-6

July 2013

Obtainable from

Water Research Commission
Private Bag X03
Gezina, 0031

orders@wrc.org.za or download from www.wrc.org.za

EXECUTIVE SUMMARY

BACKGROUND

Sustainable long term water resources management requires an integrated mix of supply and demand-side management strategies, in accordance with the principle of Integrated Water Resources Management (IWRM). However, the scope for supply-side management strategies in South Africa is decreasing rapidly, with the only remaining options for increasing water supply becoming increasingly expensive and infeasible, such as inter-basin transfers and desalination of seawater or acid mine drainage. The key to strategic water resource management therefore lies in effective demand-side management approaches.

In particular, the economic principle of pricing, which implies that a resource will be allocated efficiently and equitably if it is priced correctly, is an important component of water demand management. Water charges in South Africa tend to focus on recovering the costs associated with water supply; water research; and the construction, operation and maintenance of water schemes. However, the final price[1] paid by water users in South Africa does not generally reflect the opportunity costs of water use, or the scarcity value of water (Cummings and Nercissiantz, 1992a; Department of Water Affairs and Forestry, 2005; Dinar and Subramanian, 1998; Eberhard, 1999a, b, 2003b). Water therefore tends to be under-priced, and as such it is often not allocated or used in an economically efficient and equitable way. The need has therefore been identified for an allocation and pricing system that reflects the economic value of water as a resource (including scarcity value and opportunity costs), so that appropriate incentives are created regarding resource use and conservation (National Treasury, 2006).

RATIONALE, OBJECTIVES AND AIMS

The need for this project has arisen in the context of the National Water Act (Act 36 of 1998) (Department of Water Affairs and Forestry, 1998) and its emphasis on demand-side management; specifically, the economic principle of encouraging more efficient water use by means of water pricing. Designing and implementing water pricing strategies for a particular user group requires information on the *marginal value* of water to that user group, i.e. the increase in economic value generated per unit increase in water use (Gibbons, 1986) (in order to assess whether there is *scope* for increasing water prices); as well as the *price*

[1] Note that in the context of this study, we define 'water prices' as the final price that the end-user pays per kilolitre (kl) of water. We acknowledge that end-user prices are constructed on the basis of a variety of components, and that various tariff structures exist, such that there is no single water 'price' in South Africa. Nevertheless, in the context of water pricing as a tool for water demand management, it is ultimately the final price paid by the end-user that is of concern.

elasticity of demand, i.e. the responsiveness of the user group to changes in water prices (in order to assess the potential *impacts* of changes in water prices on water use behaviour).

For many groups of water users in South Africa, including industry, there is a shortage of robust information on the marginal value and price elasticity of demand for water. This project aimed to fill this gap by estimating the marginal value of industrial water use in South Africa, and the associated price elasticity of demand for water, using a production function approach; specifically, the marginal productivity approach developed by Wang and Lall (1999, 2000). Given that this method has not previously been applied in South Africa, the emphasis of the study was on critically appraising the method in the South African context.

METHODOLOGY

In the marginal productivity approach, water is included along with capital, labour, energy and raw materials as inputs in a production function. As such, application of this approach requires data on water use (as well as data on output produced and on the use of other inputs), for a sufficiently large sample of companies (and/or over a sufficient time-span) to enable statistical estimation of a production function. Thereafter, marginal values and elasticities can be calculated based on the results of the regression model.

The estimated marginal values and elasticities provide useful information regarding the scope for and potential impacts of water demand management strategies based on water pricing. Firstly, the estimated marginal value of industrial water use (which reflects firms' maximum willingness to pay for water) can be compared with prevailing water prices (what firms *actually* pay); in order to assess the scope for increasing water prices through some form of water pricing strategy. If the marginal value of water use is higher than actual water prices, then there is evidence to suggest that water prices can be increased to better reflect firms' willingness to pay.

Secondly, price elasticity of demand for water is an indicator of the responsiveness of firms to changes in water prices, and therefore of the expected impact of a change in price on water use and on revenues to the water services provider. More specifically, price elasticity of demand refers to the percentage change in water use resulting from a 1% change in the price of water. For example, a price elasticity of demand of -1 suggests that a 1% increase in tariffs would lead to a 1% reduction in water use. A high negative price elasticity of demand (higher than 1 in absolute value, e.g. -2) implies that firms' water use is highly responsive to changes in price; i.e. that an increase in water prices will result in a significant reduction in water use; and therefore that a demand-side management strategy which results in higher water prices is likely to be effective in reducing water demand. On the other hand, a price elasticity of demand less than one in absolute value (e.g. -0.5) implies that firms would be less responsive to changes in price. In this case, although an increase in water prices would lead to a reduction in water use, the % reduction in water use would be comparatively lower than the % increase in price. As such, in the case of 'inelastic' demand, an increase in water prices would be less effective in reducing water demand as compared to a case of higher elasticity; although it would be effective in terms of increasing revenues to the water services provider.

This study applies and assesses the marginal productivity approach to estimate the marginal value of industrial water use in South Africa, and the associated price elasticity of demand. Primary data was obtained from South African companies in the industrial sector[2] by means of a structured questionnaire, which was distributed to a large number of companies in various ways. Fifty-six responses were received, of which 28 had to be omitted for various reasons (questions left blank, etc.), leaving 28 valid responses. In order to increase the sample size, this primary data was supplemented with secondary data from the annual reports and sustainability reports (or integrated annual reports) of a further 30 companies, giving rise to a sample of 58 companies in total.

RESULTS AND DISCUSSION

The production function was estimated statistically by means of an ordinary least squares (OLS) regression in EViews (Quantitative Micro Software (QMS), 2009). On the basis of the estimated coefficients and the sample averages for the different variables; the marginal value of water use, as well as the price elasticity of demand for water, both for all firms in the sample, as well as for each specific industry, were calculated.

The marginal value of water use, for the sample as a whole as well as for specific industries within the sample, was found to be negative, in contrast to theoretical expectations. This counter-intuitive result arises due to the presence of negative coefficients on certain variables in the production function, which in turn seems to arise owing to the presence of multicollinearity in the regression model (i.e. a high degree of correlation between two or more of the explanatory variables). Indeed, the multicollinearity issue appears to be an inherent problem with this method, given the way in which the variables are constructed,

[2] The industrial sector is defined to include only those companies involved in 'secondary' activities such as manufacturing and processing; that is, the conversion of raw materials and/or intermediate goods into an intermediate or final product. Companies involved in 'primary' activities such as agriculture and mining, as well as 'tertiary' activities such as finance and retail, were ignored.

particularly in the presence of a relatively small sample size, as was the case in the current study.

On the other hand, the price elasticity of demand for water among the sample of industrial water users was estimated in the range of -0.66 to -0.78 (depending on the specification of the model), which is in line with theoretical expectations and comparable with estimates for the industrial sector from other countries, as well with estimates for other sectors in South Africa. The estimated elasticities suggest that, for every 1% increase in water tariffs, water use in the industrial sector can be expected to decrease by between 0.66% and 0.78%, all else being equal. However, given the limitations of the method, and of this study in particular, further research is warranted.

CONCLUSIONS AND RECOMMENDATIONS

This study applied and tested the marginal productivity approach to estimate the marginal value of water to industrial users in South Africa, as well as the associated price elasticity of demand, based on a sample of 58 companies. The results indicate that the method is vulnerable to statistical issues such as multicollinearity, particularly in the presence of a relatively small sample size, which leads to unexpected results regarding the marginal value of water use.

On the other hand, the estimated price elasticities of demand (in the range of -0.66 to -0.78) are in line with theoretical expectations and comparable to estimates for the industrial sector in other countries, and for other sectors in South Africa, and are fairly robust to changes in the specification of the model. The estimated elasticities suggest that, as expected, an increase in water prices would lead to a reduction in water use, all else being equal; although the percentage reduction in water use is comparatively lower than the percentage increase in price. This provides some evidence to suggest that an increase in water tariffs would lead to a reduction in water use among industrial users, although this reduction in water use would be outweighed by the increase in tariffs, such that total expenditure on water by industrial users (or total revenues received by the water services provider) would increase.

However, water pricing is a sensitive issue, affecting various stakeholders. As such, policy recommendations cannot be made on the basis of this analysis alone; particularly given the limitations of the method (e.g. the possibility of multicollinearity), and of this study in particular (e.g. the relatively small sample size). Further research is therefore warranted. In particular, future research should be aimed at improving the method (e.g. by making adjustments to overcome the statistical issues, or making use of a larger sample size), or at identifying alternative methods. Furthermore, in addition to this purely micro-economic analysis, stakeholder consultation is essential, while the wider socio-economic and macroeconomic impacts of an increase in water prices need to be assessed.

In summary, the information generated by this study should be seen as just one necessary, but certainly not sufficient, piece of information to be taken into account in formulating water pricing strategies. There is therefore a need to supplement and verify the preliminary findings of this study by means of further research, including industry-specific studies, making use of wider-ranging surveys of a much larger sample of companies; as well as meetings with various stakeholders in national government, local government and business. Finally, there is a need to model the wider socio-economic and macroeconomic impacts of an increase in water prices across different user groups, in order to assess whether the benefits of increasing water prices justify the costs.

ACKNOWLEDGEMENTS

The authors would like to thank the Water Research Commission for funding this project, and in particular Valerie Naidoo (Research Manager) and Benny Mokgonyana (Project Co-ordinator); as well as Gerhard Backeberg.

In addition, we would like to thank members of the project Reference Group for their constructive comments and suggestions during the duration of the project; and in particular:

- Dr K Murray : Water Research Commission
- Prof SG Hosking : Nelson Mandela Metropolitan University
- Dr THJ. Huang : Sasol Technology
- Mr R Dyer : eThekwini Municipality: Water & Sanitation
- Dr M Machingambi : Department of National Treasury

We would also like to thank the numerous individuals and entities who assisted in designing, pre-testing and distributing questionnaires; and those who provided feedback on the preliminary findings; including members of the Department of Water Affairs' (DWA's) Pricing and Economics Regulations Reforms (PERR) project, the National Business Initiative (NBI), Johannesburg Water, Rand Water, City of Johannesburg Metropolitan Municipality, City of Tshwane Metropolitan Municipality, eThekwini Metropolitan Municipality, Nelson Mandela Bay Metropolitan Municipality, and City of Cape Town Metropolitan Municipality.

Finally, a special word of thanks to the survey respondents without whose participation this research would not have been possible.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

CAC	Command and control
CGE	Computable General Equilibrium
CSIR	Council for Scientific and Industrial Research
DSM	Demand side management
DWA(F)	Department of Water Affairs (and Forestry)
FBW	Free Basic Water
FTSE	Financial Times and London Stock Exchange
GDP	Gross domestic product
GNP	Gross national product
IWRM	Integrated Water Resources Management
JSE	Johannesburg Stock Exchange
kl	Kilolitres
KWh	Kilowatt hours
ln	Natural logarithm
m^3	Cubic metre
MB	Marginal benefit
MBI	Market based instrument
MC	Marginal cost
MJ	Megajoules
ML	Megalitres
MV	Marginal value
NBI	National Business Initiative
NWRS	National Water Resource Strategy
OECD	Organisation for Economic Cooperation and Development
OLS	Ordinary least squares
P	Price
PERR	Pricing and Economic Regulations Reform project
Q	Quantity
SRI	Socially Responsible Investment Index
VAT	Value added tax
WDCS	Waste Discharge Charge System
WRC	Water Research Commission
yr	year

1 INTRODUCTION AND OBJECTIVES

1.1 Background

South Africa is a relatively dry country, with an estimated average annual rainfall of only 450 mm per year. This average, however, hides the significant variability in rainfall across the country; with less than 100mm falling along South Africa's west coast and more than 1,000mm falling on the east coast per year. The country is also susceptible to periodic and sometimes long-lasting droughts. The mean annual runoff from this rainfall (i.e. the internal renewable water resource) is about 49,000 million m^3 yr^{-1} (Department of Water Affairs and Forestry, 2004a; UNESCO, 2006). However, because of the high variability in rainfall, the high rates of evaporation and the location of water users, UNESCO (2006) estimates that only 11% (5,400 million m^3 yr^{-1}) of this total amount is available for economic development.

There are substantial demands for this limited resource from many competing users; including agriculture, mining, industry, forestry, domestic use and the environment. The industrial sector (including power generation and mining) currently uses between 13% and 16% of the total available water in South Africa (Department of Water Affairs and Forestry, 2004b; UNESCO, 2006). It is also the fastest growing sector in South Africa (UNESCO, 2006)[3]; and its future water demand is expected to increase substantially. In addition, the demand for water of a suitable quality from all other users is also expected to increase; due to: (1) South Africa's rapidly increasing population[4] and consequent increase in demand for energy and food; (2) the government's "Accelerated and Shared Growth Initiative" (ASGISA), whose objective is to halve unemployment and poverty by 2014, by ensuring an average annual growth in gross domestic product (GDP) of 5% per year between 2005 and 2014; (3) The National Water Act of 1998, which makes provision for the protection of aquatic ecosystems through the setting aside of the ecological reserve; (4) the Water Services Act[5], which ensures access to effective water supply and sanitation to all households, clinics and schools; and (5) the requirement that South Africa share water with neighbouring states, who also have continually increasing demands. Compounding the effect of this increased competition for scarce water supplies are the effects that ever-greater quantities of pollution and wastewater will have on water quality.

[3] UNESCO (2006) estimates that the industrial sector generates 29% of the GDP and 54% (including mining) of all exports and employs over 25% of the total work force.
[4] The average annual population growth rate between 1990 and 2004 was 1.8% (UNICEF, 2005).
[5] The Free Basic Water (FBW) programme of 2000 falls under this Act and aims to ensure that poor households receive 6,000 litres of FBW per month. This is being extended to schools and clinics.

In 1998, the South African government promulgated the National Water Act (Department of Water Affairs and Forestry, 1998), which recognised water as a national asset and a strategic resource for economic and social development. The Act also acknowledges the need to protect the environment and ensure quality of life. Therefore, the National Water Resource Strategy (NWRS) (Department of Water Affairs and Forestry, 2004a) and the Waste Discharge Charge System (WDCS) (Department of Water Affairs and Forestry, 2000a) were developed to help guide and enable government to implement the National Water Act and address the management of water resources to meet the country's development goals. One of the key objectives of the NWRS is to identify areas of the country where water resources are limited and constrain development, as well as development opportunities where water resources are available. In addition, industrial users are required to develop and submit a water management plan if they draw their water directly from a water source (Department of Water Affairs and Forestry, 2004a).

An essential requirement to achieving the goals of economic growth while protecting the environment and supplying quality water for human use and consumption is the development and implementation of water conservation and water demand management (or demand-side management) strategies (Lange and Hassan, 2006). Management of water resources has generally focussed on the supply side, that is, on the development of physical infrastructure to meet water demand, which is seen as being exogenously determined and thus beyond the control of water supply authorities (Renzetti, 2003). However, the scope for supply-side management strategies in South Africa is decreasing rapidly. Most of South Africa's available water supply has already been allocated. As such, apart from inter-sectoral re-allocations, options for increasing water supply are becoming increasingly expensive and infeasible, such as inter-basin transfers and desalination of seawater or acid mine drainage. Thus, as the Department of Water Affairs and Forestry (2004a: 78) has recognised, "the options for further augmentation of water supply by the development of physical infrastructure are limited and in future attention will have to be on managing the increasing demand for water in order to achieve a sustainable long-term balance between water availability and water requirements." In other words, supply-side engineering solutions "are becoming less viable, and water managers are turning to the attractive solutions offered by demand-side management" (King, 2004: 208).

Demand-side management (DSM) or water demand management refers to "measures and interventions aimed at encouraging and supporting water institutions and water users to increase the efficiency of their water use and reduce their demand for water" (Department of Water Affairs and Forestry, 2004a: 78). The South African government recognises this and explicitly states in its National Water Resource Strategy that "water-demand management and water conservation can be achieved through the efficient use of water combined with pollution abatement, re-use and recycling of water and water-efficient technologies" (Department of Water Affairs and Forestry, 2004b: 6). More detail on the distinction between supply-side and demand-side management of water, and on the role of demand-side management in an Integrated Water Resources Management approach (comprising both supply-side and demand-side management) is provided in Appendix 1.

The economic principle of pricing, which implies that a resource will be allocated efficiently and equitably if it is priced correctly, is an important component of water demand management. Economic theory predicts that the demand for a good or service is a function of its own price; the prices of substitutes and complements; and income, or, in the case of industry, the level of production. If the price of a resource is artificially low or non-existent, as in the case of many public goods and open-access resources (such as water), the quantity of the resource demanded will be too high as compared to a situation in which it was correctly priced, all else being equal. This inefficiency in demand occurs because the resource users have less incentive to conserve the resource than they would if the price was higher, all else being equal[6].

For example, when the price of water is too low, there is less incentive for users to recover, recycle, improve efficiency and/or decrease their demand for water, as compared to a situation in which they have to pay more for water. Note that in the context of this study, we define water prices as the final price that the end-user pays per kilolitre (kl) of water. We acknowledge that end-user prices are constructed on the basis of a variety of components, and that various tariff structures exist, such that there is no single water 'price' in South Africa. Nevertheless, in the context of water pricing as a tool for water demand management, it is ultimately the final price paid by the end-user that is of concern; as it is this final price that the user responds to in terms of his or her water use behaviour[7].

In practice, the two main reasons for prices not being at an economically efficient level are: (1) market failure and (2) policy, government or intervention failure (Pearce and Turner, 1991; Tietenberg, 1996) (see also Appendix 2 for more detail). Market failure arises when market prices do not reflect the true social costs or benefits of an activity or resource. An example of this is when a company discharges wastewater from its production process into

---

[6] We acknowledge that price is not the only determinant of behaviour. Nevertheless, economic theory predicts that, all else being equal, there is a negative relationship between the price of a good, and the quantity demanded – i.e. as the price rises, the quantity of the good demanded declines.

[7] See previous footnote

rivers or groundwater, and the social and environmental costs of the polluted water are not reflected in the company's cost structure or in the price of the company's product (i.e. are not incurred by the producer or consumer of the good). Economists refer to the social/environmental benefit or cost as an external effect or *externality*. In the case of resource use (e.g. water use), external costs also include opportunity costs and/or scarcity costs; that is, the costs associated with water use by one particular user, which makes it unavailable for alternative users, particularly in a context of water scarcity.

On the other hand, policy, government or intervention failure "occurs when the government creates incentives for environmentally damaging activity by intervening through subsidies, price controls, physical output targets, exchange controls and tariffs" (Miltz and Pearce, 1995: 34). This occurs, for example, if government subsidises the price of water, such that water tariffs are too low to enable cost recovery.

End-user prices for water in South Africa are currently comprised of a number of elements, including the "water resource management" charge, the "water resource development and use of water works" charge, the "water research fund" levy, as well as bulk and/or retail water tariffs. Generally speaking, these charges and tariffs are based on cost recovery principles. The first two of these charges vary according to sector and/or geographical area and are designed to recover the costs associated with water resource management (former) and the construction, operation and maintenance of water supply schemes and infrastructure (latter). The third charge is a levy earmarked to fund the operations of the Water Research Commission. Bulk tariffs are designed to recover the costs associated with raw water abstraction, bulk water treatment and distribution, while retail water tariffs are designed to recover the costs of reticulation of water to consumers (Eberhard, 2003b).

Historically, however, the costs of providing water services in South Africa have not been fully recovered, generally speaking; while the final price paid by water users does not generally reflect the value derived from water, the opportunity costs of water use, or the scarcity value of water (Cummings and Nercissiantz, 1992a; Department of Water Affairs and Forestry, 2005; Dinar and Subramanian, 1998; Eberhard, 1999a, b, 2003b). The result is that excessive quantities of water have tended to be withdrawn, leaving little to sustain ecosystems; while excessive quantities[8] of wastewater and pollution tend to be discharged into surface- and ground-water sources. In spite of the Water Act making provision for an

[8] Quantities that exceed the assimilative capacity of the resource

ecological reserve, there is still little incentive for users to conserve, recycle or reuse water resources.

It is therefore important that government moves towards an allocation and pricing system that reflects the economic value of water as a resource (including scarcity value and opportunity costs), so that appropriate incentives are created concerning resource use and conservation (National Treasury, 2006). To the extent that this creates incentives for water users to reduce their water use, water pricing can be an effective way of managing water demand, particularly where water users are shown to be responsive to changes in water prices.

The National Water Act of 1998 recognises this, and provides for the use of economic instruments to encourage water conservation and the reduction of waste. In light of this, the Department of Water Affairs (DWA) and local government have undertaken major reforms in the water sector, moving away from sole reliance on traditional supply-side management approaches, towards a greater emphasis on demand-side management approaches, particularly water pricing. Most recently, DWA has initiated a Pricing and Economic Regulation Reform (PERR) project, which is currently reviewing the national water pricing strategy (Department of Water Affairs, 2012).

Internationally, water pricing policies have been implemented using taxes and other market-based instruments, such as tradable permits (see Appendix 2 for more detail). For example, the problem of excessive demand for water owing to under-pricing can in theory be corrected (internalised) by increasing the price of water through the imposition of a tax or removal of an existing subsidy (see Figure 1). The South African government has investigated the use of taxes and tradable-permit systems to manage the country's growing water demands, and has developed a Waste Discharge Charge System (Department of Water Affairs and Forestry, 2000a) in order to provide a framework for charging those individuals or firms who dispose of their waste into water (these market-based approaches are discussed in more detail in Appendix 2).

The example of increasing the price of water faced by industries, e.g. through a tax (or removal of a subsidy), is depicted in Figure 1. The quantity of water use is plotted along the x-axis and the price (cost) of water is plotted on the y-axis. The marginal cost curve[9] for

[9] The marginal cost curve shows the additional cost incurred per unit of water use (a step function may be more realistic, but a continuous curve is assumed for simplicity); while the demand curve or marginal benefit curve shows the additional benefit derived per unit of water use.

water faced by users (e.g. industry) is labelled MC. The marginal benefit (MB) per unit of water used in production is depicted by the downward sloping demand curve. Before the imposition of a tax (or removal of a subsidy), the market for water is in equilibrium where the MC curve and MB curve intersect; thus, the price of water is P1, and the total quantity of water demanded is Q.

However, this marginal cost curve (MC) only reflects ‘private’ costs, that is, costs incurred by industry for use of its water (i.e. water prices). If water prices do not reflect the economic value of water as a resource (including externalities relating to opportunity costs and scarcity value), then industry’s MC curve does *not* reflect the true social costs (which includes private costs as well as *external costs* (negative externalities) associated with water use); and therefore underestimates the costs of industry’s water use to society as a whole. Assuming that the true (‘social’) marginal cost of water use (including external costs) is reflected by the curve labelled ‘MC + Tax’, the actual water price (P1) is too low, and the resulting quantity of water use (Q) is too high, relative to the socially ‘efficient’ price (P2) and quantity (Q*). The resulting cost to society of prices at the level of P1 and water use at the level Q is represented by the shaded area.

The effect of raising the price of water from P1 to P2 through the introduction of a tax or removal of a subsidy is represented by a shift in the marginal cost curve faced by industry from MC to MC + Tax (a constant tax rate per unit of water is assumed). The effect of increasing the price of water in this way is that the total quantity of water use by industry decreases from Q to Q*; and the external cost of industry’s water use is now internalised by the responsible water users (industry), rather than borne by other water users (society and the environment).

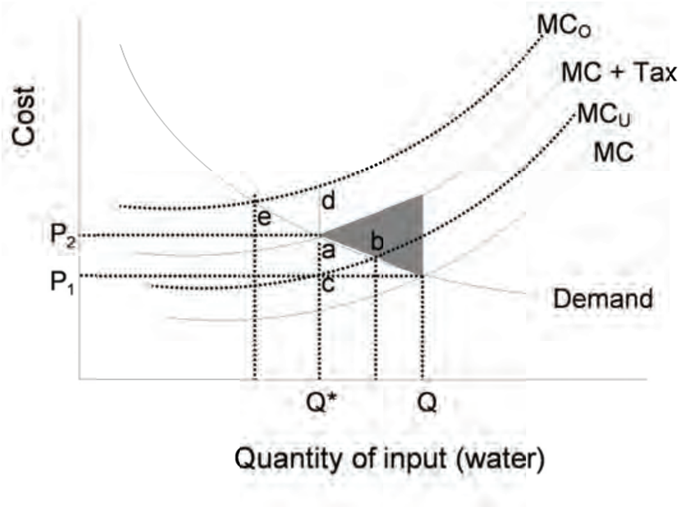

Figure 1: Effect of increasing the price of water (removing a subsidy or imposing a tax per unit of water) to internalise externalities that may result from under-pricing the resource.

In this case it has been assumed that the external cost of water use is known with certainty and that the tax is set equal to this amount. In the more likely event that this cost is not known with certainty, the effects of over- and under-estimating the external costs are depicted by the dashed lines MC_O and MC_U, respectively. In the former case the effect is that the tax is set too high; such that too little water is used and too little output produced, leading to a loss in social welfare (firm closures and unemployment) equal to area *ade*. In the latter case, the tax is set too low, such that too much water is used, resulting in external costs equivalent to area *abc*. Although in both cases this may represent an improvement compared to the status quo, where the price of water is P1 and the quantity of water use is Q; the fact that there are still costs to society highlights the importance of correctly estimating the true value of water (inclusive of negative externalities) in order for a tax to be set at the ‘right’ level to achieve an efficient outcome.

The impact of an increase in water prices depends on how water users respond to changes in price. Taxes and charges may either have a behavioural impact, or a revenue-raising impact (or both); depending on how companies respond to the tax; which in turn depends on the *price elasticity of demand* for the resource subject to the tax. For example, if companies are relatively price *inelastic* with respect to water use (i.e. if their water use behaviour is relatively unresponsive to changes in price); then imposition of a tax on water use will not lead to a significant decrease in water use; however, it will lead to an increase in revenues. On the other hand, if price elasticity of demand for water is high among the tax base (responsive to changes in price); then the tax will be environmentally effective in terms of reducing the demand for water. As such, in addition to information regarding the value of water, information regarding the price elasticity of demand for water is also an important input to water pricing strategies.

In conclusion, a key challenge in South Africa's short- and medium-term future will be the reconciliation of water demand and water supply. While there has been acknowledgement of the need for demand-side management, implementation thereof has been slow (Eberhard, 2003a; Louw and van Schalkwyk, 2001; Mukheibir and Sparks, 2005). Reducing demand has the benefit of causing or increasing an excess in supply, thereby creating a greater margin of safety for future drought periods. It has been calculated that the total opportunity in reducing water demand in the water services sector is approximately 39% of the total existing demand (Department of Water Affairs and Forestry, 2000b).

1.2 Rationale, objectives and aims

The need for this project has arisen in the context of the National Water Act (Act 36 of 1998) (Department of Water Affairs and Forestry, 1998), and its emphasis on demand-side management; specifically, the principle of encouraging more efficient water use by means of water pricing. Effective demand-side management requires a thorough understanding of behaviour with regard to water use. As such, it is imperative that research be undertaken into issues such as the price elasticity of demand for water, water-use efficiency, water productivity, and the institutions required to successfully implement market-based instruments; so as to achieve the goal of continued economic development, while meeting wide-ranging needs for water.

In particular, designing and implementing water pricing strategies for a particular user group requires information on the *marginal value* of water use to that user group, i.e. the increase in economic value generated per unit increase in water use (Gibbons, 1986) (in order to assess whether there is *scope* for increasing water prices); as well as the *price elasticity of demand* for water, i.e. the responsiveness of the user group to changes in water prices (in order to assess the potential *impact* of changes in water prices on water use behaviour)[10]. In other words, the value that different categories of water users place on water use relative to the prices they actually pay, as well as their responsiveness to changes in water prices, needs to be understood in order to determine the scope for and potential impacts of water

[10] The responsiveness of water use to changes in price is reflected by the concept of price elasticity of demand for water, which measures the percentage change in the quantity demanded of water when the price increases or decreases by one percent. Lower price elasticity of demand (i.e. inelastic demand) indicates a lower responsiveness to changes in price, and implies that water use will not change to a significant extent in response to changes in price; or that larger price changes are needed before such users change their use to the same extent as compared to users with a higher price elasticity of demand (elastic demand).

pricing policies. As such, there is a need to better understand the value currently derived from water use, and how water use is likely to change in response to changes in water prices, in order to design and formulate water pricing policies and strategies that incentivise the use of water in a more efficient way.

For many groups of water users in South Africa, including industry, there is a shortage of robust information on the marginal value and price elasticity of demand for water. Water is used by a diverse set of users, who value water in different ways, and who respond differently to different pricing strategies and tariff structures. Water users can be divided into six main categories. These are agricultural, industrial (including energy), mining, domestic, environmental, and forestry uses. A number of studies have attempted to estimate the marginal value of water use and to determine price elasticities of demand, but these have focussed mainly on household, agricultural, and forestry uses (Arouna and Dabbert, 2009; Birol et al., 2006; Eberhard, 2003b; Jansen and Schultz, 2006; Lange and Hassan, 2006; Law, 2007; Mahumani et al., 2009a, b; Palmer et al., 2002; Thomas and Syme, 1988; Turpie and van Zyl, 2002; Van Heerden et al., 2008; Van Vuuren et al., 2004; Van Zyl and Leiman, 2002; Van Zyl et al., 2003; Veck and Bill, 2000).

Surprisingly, literature concerning industrial water use is significantly less extensive, particularly in developing countries. A few studies are evident, and these tend to focus on a cost approach to econometric estimation (Féres and Reynaud, 2003; Renzetti, 2005; Renzetti and Dupont, 2003), although some have attempted to value water by using the marginal productivity approach (Wang and Lall, 1999). Reasons for this situation may be explained by the historically low pricing structures (in general) that industry has faced, and the widely held perception that industrial water use is better suited to engineering rather than economic analysis (Renzetti and Dupont, 2003).

Within South Africa, the industrial sector is one of the fastest growing economic sectors. The industrial sector relies to varying degrees on water resources as an input to many production processes. Currently, it is estimated that the industrial sector (including power generation and mining) in South Africa uses between 13% and 16% of total usable water resources (Department of Water Affairs and Forestry, 2004b; UNESCO, 2006) (Statistics South Africa, 2004). It is therefore a significant water-use sector, in spite of observations that many industries rely on relatively low levels of water inputs into their production processes.

WRC ‘NATSURV’ reports (see Appendix 4) and more recently WRC Report K5/1547 provide information on water use and effluent discharge by the various industrial sectors in South

Africa. However, these do not provide information on the marginal value of industrial water use, or on the responsiveness of industry to changes in water prices (i.e. price elasticity of demand). International literature has offered mixed results, with industrial price elasticities ranging from very inelastic (unresponsive to changes in price) to more elastic (Wang and Lall, 1999). In the context of the National Water Act (Act 36 of 1998) (Department of Water Affairs and Forestry, 1998) and its emphasis on economic pricing, and taking into account the significant contribution of industrial water use to total demand within South Africa, it is necessary to understand the marginal value of industrial water use in South Africa (in order to assess whether there is scope for water pricing strategies), and the responsiveness of these industries to changes in water prices (in order to assess the potential impacts of such strategies).

This project[11] aimed to fill this gap by estimating the marginal value of industrial[12] water use in South Africa, and the associated price elasticity of demand for water, using a production function approach; specifically, the marginal productivity approach. (Given that this method has to date not been applied in South Africa, a further aim was to critically appraise the method in the South African context). It therefore aimed to contribute to policy and decision making regarding appropriate water pricing strategies, by providing information on the marginal value and associated price elasticity of demand for industrial water use, which is necessary information in the formulation of such strategies. Ultimately, it aimed to ensure more efficient use of water by industry, based on an improved understanding of the marginal value of industrial water, and of the responsiveness of industry to water pricing strategies. This is in keeping with the National Water Act's objective to price water correctly.

[11] The study follows up on a previous WRC project (K5/1366), which commenced in April 2002 but was not completed owing to data limitations, due largely to a lack of buy-in from industry, with companies unwilling to make the required data available. However, in May 2010, the WRC requested a follow-up proposal on condition that industry buy-in could be obtained prior to submission. To this end, buy-in was secured from a number of companies, all of whom agreed to make the required data available, making it possible for the project to proceed. In addition, it was anticipated that data could be obtained from a far wider range of companies than those who had agreed to participate from the outset; for a number of reasons. In particular, much had changed since 2002 in terms of the willingness of companies to share information regarding their water use and related behaviour. In addition, the project team was in the process of developing a far more streamlined, concise questionnaire as compared to that originally envisaged. As anticipated, this turned out to be an important selling-point in convincing more companies to take part in the survey, which enabled a sufficiently large sample to be obtained.

[12] The industrial sector is defined to include only those companies involved in 'secondary' activities such as manufacturing and processing; that is, the conversion of raw materials and/or intermediate goods into an intermediate or final product. Companies involved in 'primary' activities such as agriculture and mining, as well as 'tertiary' activities such as finance and retail, were ignored.

2 METHODS

There are various methods for valuing industrial water use and for estimating the price elasticity of demand for water (see Appendix 3 for a summary of these methods and of their application to industrial water use). The most appropriate of these methods in any given case depends on the data available and the manner in which industry obtains its water. However, many of the available methods rely on the assumption that the water price can be used to infer the marginal value of water use; or that the average cost of water can be used as an adequate proxy of the marginal cost. However, the price of water is generally not a reliable indicator of its marginal value, while economic theory suggests that firms respond to the marginal cost of water in their decision making, rather than the average cost. In addition, in many of the available methods, the quantity of water appears on both sides of the demand equation, introducing the problem of simultaneity bias (see Appendix 3 for details).

This study estimates the marginal value and price elasticity of demand for water among industrial water users in South Africa using the marginal productivity approach developed by Wang and Lall (Wang and Lall, 1999, 2002). While it has been claimed that this method is able to overcome the above-mentioned problems, it has not previously been subjected to rigorous scrutiny, and may be vulnerable to statistical problems of its own (such as multicollinearity[13]); while it has not previously been applied in South Africa. As such, the aim of this study was not simply to apply the marginal productivity approach, but also to critically appraise this method in the South African context, with particular reference to potential statistical issues.

In the marginal productivity approach, the structure of industrial water demand is characterised through the estimation of a production function, from which the marginal value and price elasticity of demand for water can be determined through differentiation. The production function associated with a particular firm's product can be defined as the mathematical expression of the relationship between the quantity of the firm's output, and the quantity of one or more inputs (Miller and Meiners, 1986). Production functions take the following general form:

$$Q = A\,(K, L, W, E, M, \text{etc.}) \tag{1}$$

[13] In a multiple regression model, multicollinearity refers to a high degree of correlation between two or more explanatory variables

Where Q represents the quantity of output; K, L, W, E and M are the quantities of inputs (respectively capital, labour, water, energy and raw materials) used in producing the output; and A represents technology, which determines the relationship between output and inputs.

The production function can be estimated econometrically using ordinary (or generalised) least squares regression techniques, and once estimated can be used to calculate the marginal value of water use, and the price elasticity of demand for water. In turn, this information can be used to make important policy recommendations regarding the scope for and potential impacts of water pricing strategies.

This approach of using marginal productivity to estimate the value of water use by industry was first proposed by Wang and Lall (1999, 2002), who develop a marginal productivity model for valuing industrial water use, where water is included along with capital, labour, energy and raw materials as inputs in a production function. Wang and Lall posit a translog[14] production function (which is quadratic and therefore twice differentiable), where the value of output (Y)[15] is determined by five inputs; namely capital (K), labour (L), water (W), energy (E), and raw materials (M); and assume the existence of constant returns to scale. The marginal productivity (or marginal value) of industry with respect to water is determined using this production function. Associated with this marginal productivity approach, a model on price elasticity of water demand is developed by assuming price is equal to the marginal cost of water use. These models were estimated using data on 2000 firms in the Chinese manufacturing sector. More detail on the methods applied and results obtained by Wang and Lall can be found in Appendix 3.

The current study aimed to apply and test this approach in the South African context, using data from a number of South African firms in the industrial sector[16], obtained via a structured questionnaire (see Appendix 5). However, in the current study we focus on only four inputs, namely capital (K), labour (L), water (W), and energy (E); i.e. raw materials (M) is dropped from the model[17]. In the case of a four-input model, the steps involved in calculating marginal values and price elasticities associated with water use are as follows:

---

[14] The transcendental logarithmic (translog) production function was first proposed by Christensen et al. (1973) and provides a greater variety of substitution-of-transformation patterns than those imposed by the restrictive constant elasticity of substitution assumption implicit in the traditional Cobb-Douglas function.

[15] In a conventional production function, the dependent variable is Q, the physical quantity of output. However, in the marginal productivity approach, the dependent variable is specified as Y, the value of output in monetary terms.

[16] The industrial sector is defined to include only those companies involved in 'secondary' activities such as manufacturing and processing; that is, the conversion of raw materials and/or intermediate goods into an intermediate or final product. Companies involved in 'primary' activities such as agriculture and mining, as well as 'tertiary' activities such as finance and retail, were ignored.

[17] M is dropped from the model for the following reasons. Firstly, for the variables Y, K, L, W and E; respondents should be able to obtain the required information relatively easily, e.g. from their financial statements or water/energy bills (for example,

1. Estimation of the translog function, which, in the case of a four-input model, takes the following form:

$$\ln Y = \beta_0 + \beta_1 \ln K + \beta_2 \ln L + \beta_3 \ln W + \beta_4 \ln E + \beta_5 \frac{\ln K^2}{2} + \beta_6 \frac{\ln L^2}{2} + \beta_7 \frac{\ln W^2}{2} + \beta_8 \frac{\ln E^2}{2} +$$
$$\beta_9 \ln K \ln L + \beta_{10} \ln K \ln W + \beta_{11} \ln K \ln E + \beta_{12} \ln L \ln W + \beta_{13} \ln L \ln E + \beta_{14} \ln W \ln E \quad (2)$$

Where

- ln*Y* = natural logarithm of the total value of output
- ln*K* = natural logarithm of the value of fixed capital
- ln*L* = natural logarithm of the number of employees
- ln*W* = natural logarithm of the quantity of water use
- ln*E* = natural logarithm of the quantity of energy use
- β_0 = the intercept term
- β_1 - β_4 = the coefficients on the independent variables ln*K,* ln*L,* ln*W* and ln*E* respectively
- β_5 - β_{14} = the coefficients on the various quadratic and interaction terms constructed on the basis of ln*K,* ln*L,* ln*W* and ln*E*; and which must be included as further explanatory variables in estimation of the quadratic production function in order to enable calculation of marginal values and elasticities through differentiation.

Thus, in a four-input model, the quadratic production function consists of 14 explanatory variables (including quadratic and interaction terms)[18].

'revenues,' which can be used as a proxy for the total value of output (*Y*), appears as a standard line item in a company's income statement). On the other hand, *M*, the value of raw materials used in production, does not tend to appear as a standard line item in companies' financial statements; or does so in an inconsistent way. In many cases, the value of raw materials appears under 'inventories,' where it refers to the company's current stock of raw materials, rather than the quantity of raw materials used in production for the previous year. In addition, the specific 'raw materials' used by different companies will differ significantly; and will tend to consist of a range of different items, and be reported in a variety of different units. The value of these raw materials is therefore likely to be difficult for respondents to estimate. Because of these various complications, it was decided to drop the *M* variable from the model. This is not expected to significantly influence the results. Indeed, Wang and Lall (1999, 2002) find that information on different types of raw materials is only available for a few dozen of the 2,000 firms in their dataset. They consequently drop this variable from their model, and still obtain an R^2 varying between 0.72 and 0.79, indicating an adequate fit. Importantly, though, dropping '*M*' from the model implies that the quadratic and interaction terms based on this input are also dropped from the model. Thus, as explained in the following footnote, the numbering of coefficients differs slightly in this report as compared to in Wang and Lall (1999, 2002), which affects the way in which formulae based on these coefficients are specified.

[18] Note that dropping 'M' from the model (as explained in previous footnote) implies that the quadratic and interaction terms based on this input are also dropped from the model. In Wang and Lall's 5-input model (see Appendix 3), there are a total of 20 explanatory variables (including quadratic and interaction terms); whereas in our 4-input model there are only 14 explanatory variables. Thus, the numbering of coefficients differs slightly in this study as compared to in Wang and Lall (1999, 2002).

2. The elasticity (σ) of production with respect to each input (that is, the % change in output resulting from a 1% change in the quantity of the input used[19]) is then calculated; by taking the partial derivatives of output with respect to the input under consideration. Specifically, the elasticity of output with respect to water is calculated as follows:

$$\sigma_w = \frac{\partial \ln Y}{\partial \ln W} = \beta_3 + \beta_7 \ln W + \beta_{10} \ln K + \beta_{12} \ln L + \beta_{14} \ln E \quad (3)$$

Where β_3, β_7, β_{10}, β_{12}, and β_{14} are the statistically estimated coefficients associated with specific terms in the production function; and ln*W*, ln*K*, ln*L*, and ln*E* are averages over all observations included in the model, or for all firms in a specific industry (e.g. food and beverages, automobile manufacturing, etc.), or both (depending on whether the aim is to calculate a single marginal value (MV) and price elasticity of demand for all firms in the industrial sector, or to calculate industry-specific MVs and elasticities, or both).

3. The marginal productivity of water in industrial production (ρ) is then calculated by multiplying the elasticity of output with respect to water (i.e. the first partial derivative of the estimated production function, as derived in Equation 3) by the average value of output per unit of water ($\frac{Y}{W}$):

$$\rho = \sigma_w \cdot \frac{Y}{W} \quad (4)$$

Similarly, the marginal productivity of capital, labour, and other factors of production can be calculated. If *Y* is the sample average of the total value of output, Equation 4 gives the marginal value of water use for the firms in the sample.

4. Then, to determine the price elasticity of demand for water, it is assumed that the water price, *P*, is equal to the marginal cost of water use. The marginal cost of water (MC_w) is calculated based on the following economic theory: that profit maximising firms produce where the marginal value of output (or marginal revenue) is equal to the marginal cost. This applies to each input in turn, hence the marginal value of

[19] Note that the elasticity of production (or output) with respect to an input is a different concept to the price elasticity of demand. While price elasticity of demand refers to the percentage change in quantity demanded associated with a % change in price; the output elasticity with respect to an input refers to the % change in output associated with a % change in the level of the input used.

water (ρ) equals the marginal cost of water (i.e. $MC_w = \rho$). Since we assume $P = MC_w$ it follows that $P = \rho$. The price elasticity of demand for water can now be calculated:

$$\gamma = \frac{\partial \ln W}{\partial \ln P} = \frac{\partial \ln W}{\partial \ln \rho} = -\frac{\sigma}{\sigma - \sigma^2 - \beta_7} \tag{5}$$

Where σ is the elasticity of output with respect to water as calculated in Equation 3, and β_7 is one the estimated coefficients of the original production function.

The resulting estimates of the marginal value and price elasticity of demand for industrial water use provide useful information regarding the scope for and potential impacts of water demand management strategies based on water pricing. Firstly, the estimated marginal value of industrial water use (which reflects firms' maximum willingness to pay for water) can be compared with prevailing water prices (i.e. what firms *actually* pay); in order to assess the scope for increasing water prices through some form of water pricing strategy. If the marginal value of water use is higher than actual water prices, then there is some evidence to suggest that water prices can be increased to better reflect firms' willingness to pay.

Secondly, price elasticity of demand for water is an indicator of responsiveness of firms to changes in water prices, and therefore of the expected impact of a change in price on water use and on revenues to the water services provider. Specifically, price elasticity of demand refers to the percentage change in water use resulting from a 1% change in the price of water. For example, a price elasticity of demand of -1 suggests that a 1% increase in tariffs would lead to a 1% reduction in water use. A high negative price elasticity of demand (higher than 1 in absolute value, e.g. -2) implies that firms' water use is highly responsive to changes in price; i.e. that an increase in water prices will result in a significant reduction in water use; and therefore that a demand-side management strategy which results in higher water prices is likely to be effective in reducing water demand, thereby contributing to the water conservation objective. On the other hand, a price elasticity of demand less than one in absolute value (e.g. -0.5) implies that firms would be less responsive to changes in price. In that case, although an increase in water prices would be expected to lead to a reduction in water use, the % reduction in water use would be comparatively lower than the % increase in price. As such, in the case of 'inelastic' demand, an increase in water prices would be less effective in reducing water demand as compared to a case of high elasticity, although it would be effective in terms of increasing revenues to the water services provider.

Note that estimating industry-specific marginal values and price elasticities of demand based on Wang and Lall's method does *not* require that a separate production function be estimated for each industry individually. Instead, a single production function is estimated for all firms in the sample. This increases the likelihood that the production function will be estimated based on a sufficiently large (statistically significant) number of observations. Thereafter, it is possible to estimate industry-specific marginal values and price elasticities of demand based on the results of the common production function; by substituting industry-specific (rather than sample-wide) average values into the equations above. In other words, the parameters of the common production function are used to estimate industry-specific elasticities and marginal values using "the sample average data of variables in the model" for each industry (Wang and Lall, 1999: 14).

3 DATA COLLECTION

3.1 Development of questionnaire

Application of the marginal productivity approach requires data on company-specific water consumption, as well as data on the value of output and the use of other inputs, for a sufficiently large sample of companies (and/or over a sufficient time-span) to generate a large number of independent observations, with sufficient variation between observations, to enable statistical estimation of a production function; from which marginal values and price elasticities of demand can be derived.

Primary data for estimating the production function were obtained via responses to a structured questionnaire. Recall from Equation 2 that the production function to be estimated consists of 14 explanatory variables, together with the dependent variable (output (*Y*)). However, ten out of the 14 explanatory variables are interaction and quadratic terms, which are calculated on the basis of the first four terms, namely the inputs capital (*K),* labour *(L),* water (*W),* and energy *(E).* Thus, for each company in the sample, primary data only needed to be obtained for five variables (the dependent variable, *Y*, and the four input variables *K, L, W* and *E*[20]. As such, for each company, the survey questionnaire needed to capture annual data on the following:

> *Y*: Value of output (sales revenue or turnover as per the firm's income statement, in Rands)
> *K*: Value of capital (original value of fixed assets, i.e. property, plant and equipment, as per the firm's balance sheet or statement of financial position, in Rands)
> *L*: Number of employees (full-time and part-time)
> *W*: Total quantity of water use in kilolitres (kl)
> *E*: Total quantity of energy use in megajoules (MJ)

---

[20] In other words, to estimate a production function, one simply needs data on the total value (in Rands) of output, as well as the total quantity of each input used in the production process (capital, labour, water, energy and other inputs), per company in the sample. Note that for each variable, all observations need to be in the same unit across all companies in the sample. Thus, to ensure comparability between heterogeneous firms, the appropriate unit for the dependent variable (Y) is Rands rather than a physical quantity; since different types of products are quantified in different physical units. However, for the independent (explanatory) variables, a unit of physical quantity is generally preferable to the Rand value, because the quantity of inputs used is more closely related to the amount of output generated as opposed to the Rand value of inputs, because the value of inputs depends on input prices as well as input quantities, while production processes depend on the physical quantities of inputs used rather than their value. The exception here is the value of K (fixed assets) and M (raw materials); which is a heterogeneous category of inputs that is best quantified in terms of a common Rand value unit.

In addition, information must be obtained on the type of industry; while it can also be useful to obtain contextual information relating to location, ownership structure, and any other possible exogenous factors affecting differences in output levels.

In terms of the required sample size; statistical theory suggests that the required number of observations increases with the number of explanatory variables in the estimated model (Gujarati, 2003). In this case, with 14 explanatory variables (Equation 2), it is evident that a large sample size is required to ensure statistical significance. Given the large required sample size, the underlying principle in developing the questionnaire and accompanying cover letter was on maximising the potential response rate. Much time was therefore spent on streamlining the questionnaire to the extent possible, such that the time and informational burden on respondents would be minimised (limited to the set of key variables needed to estimate the production function), in order to encourage a positive response.

In order to ensure that a sufficiently large number of observations could be generated, it was initially proposed that historical time-series data be collected from each company; such that a pooled (or panel) dataset (a dataset consisting of both cross-section and time-series data) could be obtained. In this way, the number of observations could potentially be increased: Instead of having only *N* observations, where *N* is the number of companies (cross-sectional units) in the sample; *N* * *T* observations can be obtained, where *T* is the number of years over which time-series data is obtained from each cross-sectional unit (Gujarati, 2003). Thus, for each company, it was proposed that annual data on each of the above-mentioned variables be obtained over a five year period. It was reasoned that this would increase the number of observations obtained from a given number of respondents; or, likewise, reduce the required number of respondents required to obtain a given number of observations.

However, following the inaugural reference group meeting for the study, and after further efforts at refining the questionnaire, it was decided that a more fruitful approach would be to only request data from a single time period from each company. Statistically, a pooled data set with 5 data points from each of, say, 50 companies, is not the same as a cross sectional data set with a single data point from each of 250 companies. Specifically, with only 50 companies as opposed to 250; certain information will be lost; such that there will not be 250 *independent* observations. Even if five data points are obtained from each company, these five data points are not independent of each other to the same degree that they are independent of data points from *other* companies. In addition, it was deemed likely that many companies would not provide data for all five years, such that an ‘unbalanced panel’ would arise. These considerations seemingly eliminated any advantage of the panel data method in terms of ensuring a statistically significant number of independent observations.

Furthermore, during the process of refining the questionnaire, it became evident that asking companies for data over a five year period would severely increase the informational burden on companies, and therefore the time and effort required to complete the questionnaire; and as a result would be likely to significantly reduce the response rate. Instead, it became apparent that companies would be far more likely to respond if data from only one year was requested. This would eliminate the need for companies to search for archival information pertaining to the five variables, and would result in a significantly simplified and shortened questionnaire, thereby reducing the time and effort needed to complete it, and increasing the likely response rate.

Consequently, the questionnaire was redesigned such that companies were only requested to provide data from the last financial year (generally this was for the financial year ending 2011), for each of the variables referred to above (i.e. only cross-section data was obtained, rather than pooled cross-section and time-series data). In addition, unnecessary questions were removed from the questionnaire, such that every question was aimed at obtaining data for a specific variable required for estimating the production function. For example, contextual questions such as location and ownership structure, which were seen as 'nice-to-haves' rather than necessary for estimating the production function, were not included.

As such, the final version of the questionnaire (see Appendix 5) consisted of only seven questions, with initial pre-testing suggesting that it would take approximately 15 minutes to complete[21]. Pre-testing was conducted in the form of asking acquaintances of the project team who work in the industrial sector to complete the questionnaire and to comment on its clarity, the ease of accessing information necessary for answering the questions, and the time taken to complete the questionnaire. In addition, a 'dry run' of the production function was estimated based on hypothetical data, in order to ensure that the production function could be estimated, and the marginal values and price elasticities of demand calculated, on the basis of the type of data that would be obtained based on the draft questionnaire. The questionnaire and cover letter were subsequently further refined.

[21] This one-page questionnaire was therefore seen as a significant improvement over the draft questionnaire produced in the original WRC study (K5/1366), which consisted of eight pages, and was therefore likely one of the reasons for the poor response rate from companies.

The remainder of this section provides a short overview and explanation of each question in the questionnaire (see Appendix 5). Questions 1 and 2 were contextual questions aimed at allocating the respondent to a particular industry. Because a single production function is estimated for all companies in the sample rather than per industry (as mentioned above); it was not deemed necessary to impose an industry classification from the outset. In addition, initially it was not possible to foresee the complete list of companies that would be included in the sample; such that imposing such a classification from the outset would not be possible. Instead, it was proposed to allow the industry classification to evolve based on the range of companies that ultimately participated in the study.

The allocation of companies into specific industries was therefore done after all the responses were obtained, based on companies' responses to questions 1 and 2. The reason for asking companies to specify both their 'sector' (question 1) and 'core business' (question 2) is that industrial classifications are inevitably hierarchical, consisting of both broad and specific categories. If respondents are only asked to indicate which 'sector' they work in, a company that manufactures soft drinks, for example, might reply that they work in the soft drink manufacturing sector, or the food and beverage sector, or even the manufacturing sector more broadly; making it difficult to classify respondents by industry. Asking for both a broad 'sector' (e.g. the food and beverage sector) and a more specific 'core business' (e.g. soft drink manufacturing) would therefore aid consistency in responses to some extent, and would allow an industry classification to evolve on the basis of the participating companies.

Questions 3 to 7 were aimed at extracting information pertaining to specific variables in the production function. Information on the dependent variable in the production function, namely the value of *output* (*Y*) in Rands, is requested in Question 4. Firms were asked to provide their revenue for the previous financial year, as revenue refers to income generated through sales of products (price multiplied by quantity), and therefore provides a proxy of the value of output. Furthermore, revenue is a standard line item in a company's income statement, and should therefore be easily obtainable and not prone to ambiguity. The only potential complication arises in the case of respondents misreading the number of zeros in the income statement (figures in income statements are often presented in units of thousands or millions of Rands, depending on the size of the company). We therefore specified that data should be provided in 'Rands' (as opposed to R'000s or R'000,000s), to ensure consistency.

The remaining questions relate to the independent variables (i.e. the inputs) in the production function. Questions 3 and 5 address the traditional inputs *labour* (*L*) and *capital*

(K) respectively. Labour is based on the number of employees at the end of the financial year (including part-time and contract workers), while capital is based on the book value of property, plant and equipment at the end of the financial year. As with revenue, the latter is a standard line item in any company's balance sheet or statement of financial position; and respondents were therefore not expected to have any difficulty in retrieving the information.

Question 6 was aimed at extracting information for the independent variable *water* (W), another input in the production function. Specifically, respondents were asked to specify the volume of water use, either in total, or from each source (purchased from a water service provider, and self-supplied water). Respondents were also asked to specify the units in which their responses were reported (e.g. m^3, litres, etc.), so that all data could be converted to a common unit (kl).

Finally, question 7 was used to generate information for the independent variable *energy* (E), the final input in the production function. Although it would have been far simpler to ask respondents to provide only their electricity use, which may be an adequate proxy for total energy use in some cases; the share of electricity in the total energy use profile of a company varies significantly between industries. For many types of companies, other sources of energy, such as diesel and other liquid fuels, coal, various gases, biomass, etc. are significant inputs to the production function, and therefore needed to be included. As such, respondents were asked to provide their consumption of various types of energy (electricity, coal, diesel and biomass; as well as an 'other' category and a request for more details pertaining to the 'other'), and to specify the units in which the data was provided. On this basis, consumption of the various sources of energy could be converted into standard units of energy (in megajoules, MJ), using standard conversion factors for each form of energy in South Africa; and aggregated to obtain data for the *energy* variable.

In addition, a cover letter was drafted (see Appendix 5), which was distributed along with the questionnaire. The purpose of the cover letter was to explain the purpose of the questionnaire, clarify what was required, and motivate companies to participate. Respondents were also assured that all responses would be kept strictly confidential; while respondents could also choose to remain anonymous, by completing their questionnaires online or returning them by fax. As with the questionnaire itself, many of the comments received from the project reference group were incorporated in the content and wording of the cover letter.

See Appendix 5 for a copy of the final questionnaire and accompanying cover letter.

3.2 Sampling and distribution of questionnaires

Given the need to ensure a large, statistically significant sample size, the sampling approach used in the study was based on maximising the number of respondents, rather than selecting specific companies so as to ensure representivity in terms of industry coverage. As such, rather than attempting to draw a representative sample from the outset; questionnaires were sent to as many companies in the industrial sector in South Africa as possible. The sample would then be comprised of those companies that responded to the questionnaire. Thereafter, respondents could be categorised on the basis of the specific industry in which they operate.

Questionnaires were distributed in various ways, including via direct correspondence with companies, and indirectly via municipalities; while respondents had the option either to complete the survey online or to return the questionnaire by email or fax.

Twenty-four municipalities (including the eight metropolitan municipalities) were contacted for assistance with distributing questionnaires to companies in their jurisdiction. Specifically, we contacted the department responsible for distributing rates and water accounts, with a request to include a copy of the questionnaire (or at least a link to the online questionnaire) in the next round of accounts distributed to companies (or via a separate correspondence).

In addition, over 1,000 emails were sent directly to companies by the project team. Initially, these emails were accompanied by introductory and follow-up phone calls to explain the purpose of the research, obtain contact details for the relevant person within the organisation, and obtain buy-in. However, given the large number of respondents required for the research, it became evident that it would not be possible to make telephone contact with every potential respondent. It therefore became necessary to rely on emails. Where possible, emails were directed to the best possible person in the organisation (such as an environmental, sustainability, or corporate social responsibility manager), based on information obtained from company websites, annual reports, sustainability reports, or online environmental directories such as http://www.enviropaedia.com. We focused initially on companies that participate in the JSE Socially Responsible Investment (SRI) Index (http://www.jse.co.za/Products/SRI.aspx); as it was assumed that those companies would be most willing and able to respond to the questionnaire. Once these options were exhausted, emails were sent to the ‘general enquiries’ address of a large number of manufacturing companies, obtained from the online business directory, http://www.brabys.co.za.

After approximately two months, follow-up emails were sent to all 1,000-plus companies, reminding them to complete the questionnaire if they had not already done so. This persistence paid off, with the number of responses increasing rapidly in response to the follow-up emails. In total, 56 responses were received via the various channels; with 40 responses received via the online platform, 15 responses by email, and one response by fax. Of these responses, 28 had to be omitted, for the following reasons:

- Some responses were received from companies operating in sectors outside of the scope of the study (e.g. retail or distribution[22])
- Some questions had been left unanswered or had been answered in such a way that it was not possible to convert the response into usable data for the process of estimating a production function[23]

This left a total of 28 valid responses. This sample size was not considered sufficient for statistically significant results. Econometric theory suggests that the more explanatory variables included in a model (in our case, there are 14 explanatory variables, including quadratic and interaction terms); the more observations are required to ensure adequate degrees of freedom. In order to assess whether this sample size would be sufficient, a preliminary run of the regression model was conducted, based on data obtained from the 28 respondents. Although reasonable regression results were obtained (R^2 was 0.76, suggesting that the explanatory power of the model is fairly high), the adjusted R^2 value (which adjusts for the number of explanatory variables included in the model) was only 0.5, suggesting that much of the apparent goodness of fit resulted from the large number of variables included in the model (including the various quadratic and interaction terms), and that there were too few data points in the sample relative to the number of variables.

It was therefore assumed that the model results could be improved by the inclusion of more observations in the sample. As such, it was deemed necessary to supplement the primary data obtained from survey respondents with secondary data for companies that had not responded. For many publically listed companies, particularly those participating in the SRI

[22] For the purposes of this study, the industrial sector is defined to include only those companies involved in 'secondary' activities such as manufacturing and processing; that is, the conversion of raw materials and/or intermediate goods into an intermediate or final product. Companies involved in 'primary' activities such as agriculture and mining, as well as 'tertiary' activities such as finance and retail, were ignored.

[23] In particular, there were a number of non-responses under questions 4 and 5 (associated with the 'output' and 'capital' variables in the production function respectively). This was most likely because these questions required information on sales revenues and the book value of fixed assets respectively. Some companies may have been unwilling to provide this financial data – indeed, one respondent indicated 'not disclosing' in both cases, implying an unwillingness to disclose this type of information. In another case, a respondent indicated that this data was still being finalised for the most recent financial year. There were also a number of non-responses to questions 6 and 7, relating to water use and energy use respectively. There are a number of possible reasons for this, including the perceived complexity of the questions, a lack of monitoring and reporting of such data (particularly in the case of self-supplied water, for example), and an unwillingness to share this type of data.

Index (see above), data on the variables required for estimating the production function could be found in their annual and sustainability reports, which in many cases are freely available on companies' websites. These reports, where available, were therefore used to boost the number of observations in the sample. Although the original project plan focused on the use of primary data; it was felt that secondary data should not be ignored if such data would add value to the analysis and could be obtained relatively easily.

For the purposes of obtaining secondary data, companies were selected on the basis of participation in the SRI Index, since participation in this initiative involves reporting on sustainability (including environmental) performance, such that data on these companies' water and energy use was likely to be obtainable. A list was therefore compiled of all companies participating in this initiative over the three years preceding the study (2009-2011). Companies in sectors not forming part of this research (primary sectors such as agriculture and mining, as well as tertiary sectors such as finance and retail) were ignored. A search was then conducted for the most recent (generally the 2011) annual and sustainability reports (or, in some cases, the 'integrated annual report') of each of the remaining companies (i.e. those operating in the industrial sector as defined in this study[24]). In some cases, sustainability reports could not be obtained (some of the companies were no longer participating in the SRI initiative, and were therefore no longer producing such reports); while in other cases the reports did not present data on water and/or energy use, at least not in a format that could be utilised in the production function.

In obtaining data from companies' annual and sustainability reports, care was taken to ensure that companies that had already responded to the survey were excluded, so as to avoid duplication of data. Since questionnaire responses were anonymous, this was done by cross-checking all data obtained from annual/sustainability reports with the data obtained from survey respondents. Three cases were identified where it was clear that the company had already responded to the survey (i.e. the data from a specific company's annual/sustainability reports exactly matched that of a company who had already responded to the survey). These duplicates were eliminated.

In this way, a full set of secondary data was obtained from 30 companies who had not responded to the survey. This was added to the original data set of 28 survey respondents, giving rise to a total sample size of 58 companies. A second run of the regression model

[24] For the purposes of this study, the industrial sector is defined to include only those companies involved in 'secondary' activities such as manufacturing and processing; that is, the conversion of raw materials and/or intermediate goods into an intermediate or final product. Companies involved in 'primary' activities such as agriculture and mining, as well as 'tertiary' activities such as finance and retail, were ignored.

yielded much improved results (R^2 = 0.88, adjusted R^2 = 0.84), suggesting a good fit between the model and the data, even after adjusting for the large number of explanatory variables in the model. The regression results will be described in more detail in Section 4.

4 DATA ANALYSIS

4.1 Data capturing

Responses to the questionnaire were captured in an Excel spread-sheet, which was programmed to convert the raw data as obtained from questionnaire respondents into data pertaining to each variable required for estimating the production function. For some of the variables (output, capital, and labour), the raw data could be used directly in estimating the production function. For water and energy, on the other hand, data was obtained for different sources of water and energy use, and in various units. The spread-sheet was designed to convert and aggregate the disparate water and energy use data into a single variable for each of *water* and *energy*, in kl and MJ, respectively. In this way, raw questionnaire data could be captured in the spread-sheet and automatically converted into a format for estimation of the production function.

Raw data was captured in the first worksheet, which contained a dedicated column for each response block in the survey questionnaire. The second worksheet contained conversion factors for converting the raw data (which was provided in various units, particularly in the case of water and energy) into consistent units.

For example, for many companies, the consumption volume of different forms of energy was reported in varying units. These were all converted to a common energy unit (megajoules, MJ) based on the calorific values of different fuel types, published by the Department of Energy (2009). In some cases, where liquid fuel use was reported in terms of mass rather than volume, it was necessary to convert from mass to volume as an intermediate step, based on the density of the different fuel types, also from the Department of Energy (2009). In other cases, energy usage was reported in terms of Rand values spent per fuel type, rather than physical units used (e.g. KWh or litres); in these cases, rand values were converted back to physical units based on prices per fuel type as per the Department of Energy (2010) Energy Price Report, plus VAT. Finally, once the consumption of the various fuel types had been converted into MJ, these were aggregated to obtain the total energy consumption for each company.

The converted data appears in the third worksheet. Finally, in the fourth worksheet, all data pertaining to each variable required for estimating the production function was gathered and aggregated into a single column (i.e. one column for each of the five variables output, capital, labour, water and energy).

In order to calculate industry-specific marginal values and price elasticities of demand, it was necessary to define industry classifications for the sample and to allocate each firm to a specific industry. Initially, it was deemed preferable to adopt the same classifications as those used in the NATSURV reports, in order to ensure consistency with previous WRC research. However, many of the companies in the sample operated in industries not covered by the NATSURV reports, such as pharmaceuticals, electronics, automobiles, etc.[25]

It therefore became necessary either to develop new categories to supplement the existing NATSURV classification, or to use an alternative classification system. For the sake of consistency, and to ensure that a recognised classification system was used throughout rather than adding categories to the existing NATSURV classification on an ad-hoc basis, it was decided to adopt the FTSE/JSE Industrial Sector Classifications (http://www.jse.co.za/Products/FTSE-JSE/Classification-System.aspx) throughout. Each company in the sample was allocated to one of these industries on the basis of their responses to questions 1 and 2 of the questionnaire; or, in the case of companies for which secondary data was obtained, on the basis of the company's product offering as described on their websites or in their annual reports. The resulting industry categories, as well as descriptive statistics (number of companies in the sample, and average value of each variable; both per industry and for the whole sample), are summarised in Table 1.

[25] NATSURV reports have been produced for the following industries: malt brewing (NATSURV 1 TT 29 / 87), metal finishing (NATSURV 2 TT 34 / 87), soft drink and carbonated waters (NATSURV 3 TT 35 / 87), dairy (NATSURV 4 TT 38 / 89), sorghum malt and beer NATSURV 5 TT 39 / 89, edible oil (NATSURV 6 TT 40 / 89), red meat (NATSURV 7 TT 41 / 89), laundry (NATSURV 8 TT 42 / 89), poultry (NATSURV 9 TT 43 / 89), tanning and leather finishing (NATSURV 10 TT 44 / 90), sugar (NATSURV 11 TT 47 / 90), pulp and paper (NATSURV 12 TT 49 / 90), textiles (NATSURV 13 TT 50 / 90), wine (NATSURV 14 TT 51/90), oil refining and re-refining (NATSURV 15 TT 180 / 05) and power generating industries (NATSURV 16 TT 240 / 05).

Table 1: Industries (as per the FTSE/JSE Industrial Sector Classifications) and summary statistics for the sample

Industry	N	Sample averages				
		Y (R Millions)	K (R Millions)	L (no.)	W (1000 kl)	E (1000 MJ)
Food producers and processors	12	60 095	17 772	31 239	96 763	11 494 297
Beverages	3	80 050	23 283	25 060	24 240	8 470 755
Chemicals	2	62 697	6 243	4 200	1 581	3 098 083
Diversified industrials	7	30 683	3 938	14 197	485	853 372
Household goods and textiles	5	66	20	298	55	14 766
Electronic & electrical equipment	7	208 762	31 897	29 161	16 397	3 201 636
Steel and other metals	5	9 597	6 044	3 182	7 835	45 502 958
Pulp and paper	3	38 748	20 531	13 200	204 367	103 135 255
Pharmaceuticals & biotechnology	4	96 429	25 800	29 884	109 470	21 390 381
Construction & building materials	3	23 895	5 145	21 662	986	9 808 353
Automobiles and parts	4	850 583	161 398	220 392	3 771 784	31 501 248
Oil and gas	3	1 185 474	394 830	42 403	120 927	564 242 482
ALL RESPONDENTS	**58**	178 336	44 605	34 694	308 595	46 011 008

In the sample, the category ‘food producers and processors’ is dominated by poultry producers and fruit and vegetable processors. The category ‘household goods and textiles’ consists mostly of clothing manufacturers. ‘Diversified industrials’ includes firms in industries not elsewhere classified, such as arms manufacturers, as well as manufacturers of industrial textiles and materials (plastics, etc.) The other categories are self-explanatory.

4.2 Regression results

The production function (Equation 2, see Section 2) was estimated statistically by means of an ordinary least squares (OLS) regression in EViews (Quantitative Micro Software (QMS), 2009), an econometric software package which specialises in regression analysis.

The regression results are presented in Table 2. The R^2 of 0.88 suggests that 88% of the variation in the dependent variable can be explained by the set of explanatory variables included in the model, indicating an excellent fit of the model to the data, while the significance of the F-statistic (probability = 0.0000) suggests that the explanatory variables are collectively statistically significant.

Table 2: Regression results for the full translog model

Dependent Variable: $\ln Y$
Method: Least Squares
Date: 08/20/12 Time: 11:42
Observations: 58

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	4.282915	11.18913	0.382775	0.7038
$\ln K$	-0.292453	2.279054	-0.128322	0.8985
$\ln L$	1.175433	2.299878	0.511085	0.6119
$\ln W$	-0.821084	1.623923	-0.505618	0.6157
$\ln E$	1.227449	1.418530	0.865296	0.3917
$\ln K^2/2$	0.112909	0.294302	0.383651	0.7031
$\ln L^2/2$	0.009165	0.360158	0.025447	0.9798
$\ln W^2/2$	0.018142	0.109520	0.165646	0.8692
$\ln E^2/2$	0.048679	0.067387	0.722370	0.4740
$\ln K \ln L$	0.031509	0.291017	0.108273	0.9143
$\ln K \ln W$	0.026341	0.150011	0.175595	0.8614
$\ln K \ln E$	-0.095437	0.137092	-0.696156	0.4901
$\ln L \ln W$	-0.047211	0.149616	-0.315551	0.7539
$\ln L \ln E$	-0.037841	0.167648	-0.225716	0.8225
$\ln W \ln E$	0.010893	0.082328	0.132307	0.8954

R-squared	0.880025	Mean dependent var	22.14047
Adjusted R-squared	0.840963	S.D. dependent var	3.613357
S.E. of regression	1.440988	Akaike info criterion	3.786533
Sum squared resid	89.28714	Schwarz criterion	4.319406
Log likelihood	-94.80945	Hannan-Quinn criter.	3.994098
F-statistic	22.52905	Durbin-Watson stat	1.875809
Prob(F-statistic)	0.000000		

However, it is evident that the explanatory variables are individually statistically insignificant (low t-statistics), have high standard errors, and that some have negative coefficients, which is in contrast with theoretical expectations of a significant positive relationship between output and each of the inputs. It was hypothesised that these results arise owing to the presence of multicollinearity in the regression model (i.e. to a high degree of correlation between two or more of the explanatory variables in the model). Indeed, according to Gujarati (2003), the consequences of multicollinearity often include low t-statistics and high standard errors, but a high R^2 value, which is the case here. In turn, it was hypothesised that this multicollinearity arises owing to the way in which the multiplicative and interactive terms in the model are constructed on the basis of the four "base" variables, namely the inputs capital (*K*), labour *(L)*, water *(W)*, and energy (*E*). In other words, because the ten multiplicative and interactive terms are simply calculated on the basis of the four base terms, it is highly likely there will be a high degree of correlation between the explanatory variables (multicollinearity), which can in turn distort the significance and sign of the coefficients on the individual explanatory variables. Indeed, according to Gujarati (2003), multicollinearity often arises owing to model specification, such as adding polynomial terms to a regression model.

In order to test for the existence of multicollinearity, a correlation test was performed on the fourteen explanatory variables (see Table 3). As expected, the correlations are high, particularly between multiplicative/interaction terms and the original variables on which they are based (e.g. the correlation between ln*K* and lnK^2/2 = 1.00).

Table 3: Correlations between the fourteen explanatory variables in the full model

Variable	$\ln K$	$\ln L$	$\ln W$	$\ln E$	$\frac{\ln K^2}{2}$	$\frac{\ln L^2}{2}$	$\frac{\ln W^2}{2}$	$\frac{\ln E^2}{2}$	$\ln K \ln L$	$\ln K \ln W$	$\ln K \ln E$	$\ln L \ln W$	$\ln L \ln E$	$\ln W \ln E$
$\ln K$		0.91	0.87	0.86	1.00	0.89	0.83	0.88	0.95	0.94	0.96	0.91	0.94	0.89
$\ln L$	0.91		0.83	0.77	0.92	0.99	0.80	0.78	0.99	0.89	0.87	0.95	0.96	0.83
$\ln W$	0.87	0.83		0.85	0.86	0.79	0.97	0.86	0.84	0.98	0.89	0.93	0.87	0.97
$\ln E$	0.86	0.77	0.85		0.86	0.73	0.81	0.99	0.80	0.87	0.97	0.82	0.89	0.93
$\ln K^2/2$	1.00	0.92	0.86	0.86		0.91	0.84	0.88	0.96	0.94	0.96	0.93	0.95	0.89
$\ln L^2/2$	0.89	0.99	0.79	0.73	0.91		0.78	0.75	0.99	0.87	0.85	0.95	0.96	0.80
$\ln W^2/2$	0.83	0.80	0.97	0.81	0.84	0.78		0.84	0.82	0.97	0.86	0.94	0.86	0.97
$\ln E^2/2$	0.88	0.78	0.86	0.99	0.88	0.75	0.84		0.82	0.89	0.98	0.84	0.91	0.95
$\ln K \ln L$	0.95	0.99	0.84	0.80	0.96	0.99	0.82	0.82		0.92	0.91	0.96	0.98	0.86
$\ln K \ln W$	0.94	0.89	0.98	0.87	0.94	0.87	0.97	0.89	0.92		0.94	0.97	0.93	0.98
$\ln K \ln E$	0.96	0.87	0.89	0.97	0.96	0.85	0.86	0.98	0.91	0.94		0.90	0.96	0.95
$\ln L \ln W$	0.91	0.95	0.93	0.82	0.93	0.95	0.94	0.84	0.96	0.97	0.90		0.96	0.93
$\ln L \ln E$	0.94	0.96	0.87	0.89	0.95	0.96	0.86	0.91	0.98	0.93	0.96	0.96		0.92
$\ln W \ln E$	0.89	0.83	0.97	0.93	0.89	0.80	0.97	0.95	0.86	0.98	0.95	0.93	0.92	

In order to test the hypothesis that this multicollinearity arises as a result of the specification of the model, which incorporates multiplicative and interactive variables constructed on the basis of the four 'base' variables *K, L, W* and *E*; rather than as a result of an inherent problem with the underlying model; a simple model was estimated whereby output (*Y*) was regressed only on the four 'base' variables. The results are provided in Table 4.

Table 4: Regression results for the underlying model

Dependent Variable: *Y*
Method: Least Squares
Date: 05/15/13 Time: 11:17
Sample: 1 58
Included observations: 58

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.63E+10	1.07E+10	1.526705	0.1328
K	4.363969	0.219079	19.91957	0.0000
L	378058.9	167414.4	2.258222	0.0281
W	10.06305	5.313475	1.893875	0.0637
E	-1.062182	0.171092	-6.208234	0.0000

R-squared	0.982329	Mean dependent var	1.78E+11
Adjusted R-squared	0.980996	S.D. dependent var	5.32E+11
S.E. of regression	7.33E+10	Akaike info criterion	52.95551
Sum squared resid	2.85E+23	Schwarz criterion	53.13313
Log likelihood	-1530.710	Hannan-Quinn criter.	53.02469
F-statistic	736.5749	Durbin-Watson stat	1.961562
Prob(F-statistic)	0.000000		

The results presented in Table 4 suggest that the underlying model, in which output is regressed simply on the four inputs, performs well. The R^2 value of 0.98 is extremely high, while the F-statistic is highly significant. Furthermore, all of the variables are now individually statistically significant, and the coefficient on all variables is positive, with the exception of *E* (energy), which has a negative coefficient. The results of a correlation test on the four base variables (Table 5) suggest that the unexpected negative coefficient on the *E* variable may arise owing to a relatively high pair-wise correlation between *E* and *K* (= 0.91)*;* although it is important to note that the correlation between all other variable pairs is low.

Table 5: Correlations between the four base variables

	K	*L*	*W*	*E*
K		0.438931	0.142504	0.908758
L	0.438931		0.370889	0.155437
W	0.142504	0.370889		0.013065
E	0.908758	0.155437	0.013065	

Tables 4 and 5 therefore suggest that the results could be improved, and the multicollinearity problem addressed, by dropping the problematic *E* variable from the model. Indeed, omitting the *E* variable from the underlying model yields results as presented in Table 6. This shows that all variables are now individually statistically significant and have the expected positive coefficients. This suggests that there is no inherent problem with the underlying model, particularly when the *E* variable is omitted. Instead, the unexpected results in the full translog model (Table 2) can be explained by multicollinearity, which arises from two sources, namely the specification of multiplicative and interactive terms in the model, which are constructed on the basis of the four base variables; and from pair-wise correlation between the *E* and *K* variables, which can be resolved by dropping *E* from the model.

Table 6: Regression results for underlying model with 'energy' variable omitted

Dependent Variable: *Y*
Method: Least Squares
Date: 06/19/13 Time: 14:15
Sample: 1 58
Included observations: 58

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.02E+09	1.36E+10	0.148196	0.8827
K	3.075701	0.091471	33.62484	0.0000
L	1014992.	172248.7	5.892592	0.0000
W	12.68926	6.896228	1.840029	0.0713

R-squared	0.969479	Mean dependent var	1.78E+11
Adjusted R-squared	0.967783	S.D. dependent var	5.32E+11
S.E. of regression	9.54E+10	Akaike info criterion	53.46753
Sum squared resid	4.92E+23	Schwarz criterion	53.60963
Log likelihood	-1546.558	Hannan-Quinn criter.	53.52288
F-statistic	571.7544	Durbin-Watson stat	1.980836
Prob(F-statistic)	0.000000		

The full quadratic translog model (including multiplicative and interactive terms) was therefore run once again, although this time without the *energy* variable, while the multiplicative and interactive terms based on *E* were also omitted. Although it can be expected that the multicollinearity problem may return in this case, as a result of the construction of the multiplicative and interactive terms, the inclusion of these terms is necessary in order for the marginal value and price elasticity of demand for water to be estimated. The results are provided in Table 7.

Table 7: Regression results for translog model after omission of 'energy' variable

Dependent Variable: $\ln Y$
Method: Least Squares
Date: 05/15/13 Time: 11:46
Sample: 1 58
Included observations: 58

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	9.276108	9.843974	0.942313	0.3508
$\ln K$	-0.462968	2.138097	-0.216533	0.8295
$\ln L$	1.930367	2.084308	0.926143	0.3590
$\ln W$	0.119912	1.332023	0.090022	0.9286
$\ln K^2/2$	0.114459	0.239832	0.477247	0.6354
$\ln L^2/2$	0.091845	0.337575	0.272071	0.7867
$\ln W^2/2$	0.055944	0.077175	0.724893	0.4720
$\ln K \ln L$	-0.081823	0.243123	-0.336551	0.7379
$\ln K \ln W$	-0.037917	0.122002	-0.310791	0.7573
$\ln L \ln W$	-0.030427	0.128232	-0.237285	0.8134

R-squared	0.874413	Mean dependent var	22.14047
Adjusted R-squared	0.850865	S.D. dependent var	3.613357
S.E. of regression	1.395404	Akaike info criterion	3.659830
Sum squared resid	93.46330	Schwarz criterion	4.015079
Log likelihood	-96.13508	Hannan-Quinn criter.	3.798207
F-statistic	37.13391	Durbin-Watson stat	1.827747
Prob(F-statistic)	0.000000		

Table 7 (translog model excluding energy) shows a slight improvement in the results as compared to Table 2 (translog model including energy). Specifically, the adjusted R^2 has increased slightly (from 0.84 to 0.85), while the other statistics similarly show a slight improvement. However, as expected, even without the *E* variable, with the inclusion of the multiplicative and interactive terms in the model, the multicollinearity problem returns, resulting in the explanatory variables not being individually statistically significant, and in some of the coefficients showing a negative sign.

However, to the extent that the multicollinearity problem results from the construction of the multiplicative and interactive terms, this problem seems to be unavoidable, because in applying the marginal productivity approach, the multiplicative and interactive terms are necessary in order to estimate the marginal value and price elasticity of demand for water through differentiation. In other words, the inclusion of these terms is dictated by the quadratic functional form required by the method. The resulting multicollinearity therefore seems to be an inherent problem with this particular method, at least when the researchers are faced with a relatively small sample size, as in the current study.

However, this does not necessarily imply that the model breaks down, or that the results of the study are not useful. Firstly, the results of the simple models presented in Tables 4 and 6 suggest that the underlying model (whereby output is explained by the four inputs capital, water, labour and energy) performs well, with all variables statistically significant and following the correct signs, particularly when energy is excluded. Furthermore, although the variables in the full translog models (Tables 2 and 7) are not individually statistically significant, it could be argued that it is the *interaction* between the variables that is important in determining the level of output, rather than any individual variable alone. In other words, the inputs in a production function are complementary – an increase in one input will not on its own lead to a significant increase in output, without corresponding increases in the other inputs, given a particular technology. And indeed, collectively, the variables in both specifications of the translog model (Tables 2 and 7) are statistically significant, as shown by the high R^2 and F statistics.

As such, Section 5 will present the results of the marginal value and elasticity calculations for both specifications of the translog model, i.e. the full model including energy (Table 2), as well as the model with energy excluded (Table 7). This is done because the regression results associated with the omission of energy (Table 7) show only a slight improvement over the results of the full model with energy included (Table 2), so it could be argued that there is not sufficient evidence for dropping the *E* variable, which would generally be expected to be important in explaining the level of output. Furthermore, providing the results for two different specifications allows for sensitivity analysis, i.e. for an assessment of whether the results are robust to changes in the specification of the model.

5 RESULTS AND DISCUSSION

5.1 Calculating marginal value and price elasticity of demand for water

On the basis of the estimated coefficients from the two translog models (Tables 2 and 7), and the sample averages for the different variables (Table 1); the marginal value of water use, as well as the price elasticity of demand for water, both for all firms in the sample, as well as for each specific industry, were calculated; using Equations 3 – 5 in Section 2.

The results are presented in Tables 8 and 9 (associated with the models in Tables 2 (with energy) and 7 (without energy) respectively), both for each industry, and for the sample as a whole. The third column of each table presents the elasticity of output with respect to water (σ_w, see Equation 3). The fourth column presents the marginal value of water use, that is, the increase in the Rand value of output per kilolitre increase in water use (ρ , see Equation 4). Finally, column 5 presents the price elasticity of demand for water (γ , see Equation 5).

Table 8: Marginal value and elasticity calculations: Full model including 'energy' variable

Industry	N	σ_w	MV (ρ) per kl of water	Price elasticity of demand (γ)
Food producers and processors	12	-0.19	-115.77	-0.78
Beverages	3	-0.15	-494.28	-0.79
Chemicals	2	-0.13	-5250.71	-0.79
Diversified industrials	7	-0.27	-17124.83	-0.75
Household goods and textiles	5	-0.36	-431.60	-0.71
Electronic and electrical equipment	7	-0.23	-2871.58	-0.77
Steel and other metals	5	-0.07	-89.00	-0.76
Pulp and paper	3	-0.02	-3.06	-0.47
Pharmaceuticals and biotechnology	4	-0.17	-153.41	-0.78
Construction and building materials	3	-0.20	-4816.27	-0.78
Automobiles and parts	4	-0.13	-29.36	-0.79
Oil and gas	3	-0.05	-466.78	-0.70
ALL RESPONDENTS	**58**	**-0.18**	**-105.40**	**-0.78**

Table 9: Marginal value and elasticity calculations: 'Energy' variable excluded

Industry	N	σ_w	MV (ρ) per kl of water	Price elasticity of demand (γ)
Food producers and processors	12	-0.10	-61.20	-0.60
Beverages	3	-0.14	-454.47	-0.65
Chemicals	2	-0.18	-7117.87	-0.67
Diversified industrials	7	-0.17	-10669.55	-0.67
Household goods and textiles	5	-0.18	-219.42	-0.67
Electronic and electrical equipment	7	-0.21	-2713.03	-0.68
Steel and other metals	5	-0.12	-148.49	-0.63
Pulp and paper	3	0.02	3.19	0.43
Pharmaceuticals and biotechnology	4	-0.17	-148.87	-0.67
Construction and building materials	3	-0.25	-6042.61	-0.68
Automobiles and parts	4	-0.22	-49.64	-0.68
Oil and gas	3	-0.16	-1526.67	-0.66
ALL RESPONDENTS	**58**	**-0.15**	**-88.30**	**-0.66**

For both models (Tables 8 and 9), the estimated output elasticities of water (column 3) and marginal values of water use (column 4) were generally negative (with the exception of the pulp and paper industry in Table 9). These results conflict with theoretical expectations, which suggest that a 1% increase in water use should result in an increase in output (and therefore that the output elasticities with respect to water in column 3 should be positive); and similarly that a 1 unit increase in water use should result in an increase in the value of output (and therefore that the marginal values of water use in column 4 should be positive).

These counter-intuitive results arise from the presence of negative coefficients for specific variables in the translog production function, in both models (Tables 2 and 7). In turn, as discussed in Section 4.2, these negative coefficients are likely to have arisen owing to multicollinearity between the explanatory variables, which seem to be an inherent problem with the marginal productivity method, given the way in which the model is specified, particularly in the presence of a relatively small sample size. This suggests that the marginal productivity method does not produce reliable results regarding the marginal value of water use, unless a large sample size can be obtained (as was the case for Wang and Lall (1999 and 2002), who had access to a database of 2,000 manufacturing firms in China).

On the other hand, the estimated price elasticities of demand (Tables 8 and 9, column 5) are generally in the range of -0.6 to -0.8, depending on industry and on the model specification. More specifically, in the full model with energy included (Table 8), the price elasticities of demand range between -0.7 and -0.8 for different industries; while in the model where energy is excluded (Table 9), they range between -0.6 and -0.7. The exception is for the pulp and paper industry, where price elasticity of demand is -0.47 in the case of the full model, and 0.43 for the model excluding energy.

However, given the small sample size per industry (ranging from 2 to 12), it is not recommended that conclusions be drawn based on the estimated price elasticity of demand for specific industries. On the other hand, it can be seen from Tables 8 and 9 respectively that the price elasticity of demand for the industrial sector as a whole (i.e. for the full sample of 58 companies) is estimated at -0.78 in the full model, or -0.66 in the model where energy is excluded. In other words, based on the analysis in the current report, using a sample of 58 companies, the price elasticity of demand for water among industrial water users in South Africa is estimated in the range of -0.66 to -0.78. However, it must be borne in mind that even these results are based on a relatively small sample size, suggesting that they should be interpreted with extreme caution.

5.2 Interpretation of results

The estimated price elasticity of demand for water among industrial water users, estimated in the current study to be in the range of -0.66 to -0.78, can be interpreted as follows: For every 1% increase in water tariffs, water use in the industrial sector can be expected to decrease by between 0.66% and 0.78%. The price elasticities of demand estimated in this study therefore suggest that, as expected, an increase in water prices would lead to a reduction in water use, all else being equal; although the percentage reduction in water use is comparatively lower than the percentage increase in price. This provides some evidence to suggest that an increase in water tariffs would lead to a reduction in water use among industrial users, although this reduction in water use would be outweighed by the increase in tariffs, such that total expenditure on water by industrial users (or total revenues received by the water services provider) would increase.

However; given the statistical issues associated with the method, discussed in Section 4.2, and the small sample size on which these results are based; further research is warranted. The limitations of the method, and of this study in particular, are summarised in Section 6; as are recommendations for future research.

Nevertheless, it is worth noting that the price elasticities of demand estimated in this study are in line with theoretical expectations. In economic terms, all else being equal, an increase in the price of a good would be expected to lead to a decrease in the quantity of the good demanded (i.e. price elasticity of demand for water is expected to be negative, as is the case with most goods). However, given that few substitutes exist for water in many of its uses, it is expected that the price elasticity of demand for water would be relatively low (less than one) in absolute value (i.e. in the range of 0 to -1); i.e. that the demand for water would be relatively inelastic to changes in price. The price elasticity of demand estimated in this study (ranging from -0.66 to -0.78) therefore conforms to these theoretical expectations.

Furthermore, the price elasticities of demand estimated in this study are comparable with estimates for the industrial sector in other countries (see Tables 11 and 12 in Appendix 3). In addition, the estimates for industrial water use in the current study seem to fit well with estimates for other sectors in South Africa (see Table 10).

Table 10: Price elasticity of demand for water: Range of estimates from previous studies in South Africa

Sector	Low estimate	High estimate
Irrigation	-0.00	-0.25
Domestic	-0.04	-0.81
Industry & mining	-0.04	-0.95

Sources: Blignaut et al. (2004), Hassan and Farolfi (2005), Hassan and Mungatana (2006), Van Heerden et al. (2008), Van Vuuren et al. (2004), Veck and Bill (2000), Walter et al. (2011).

For industrial water use, we would expect price elasticities of demand to be higher in absolute value as compared to the irrigation sector, for example. This is because, for many industrial water use applications (e.g. cleaning, cooling, etc.), there are substitutes to water (e.g. dry cooling); whereas in the irrigation sector, there are no substitutes for water. As such, we would expect industrial water users to be more responsive to changes in price as compared to agricultural water users; as industrial water users are better able to find substitutes to water, generally speaking. Indeed, Table 10 suggests that the price elasticities of demand estimated in the current study for the industrial sector, in the range of -0.66 to -0.78, are significantly higher in absolute value than estimates for the irrigation sector, which range between 0 and -0.25.

6 CONCLUSIONS AND RECOMMENDATIONS

Water quantity and quality are considered to be major risks for society, industry and business in the 21st century, particularly in a water-scarce country like South Africa. These challenges have emerged as a result of both high and growing demand for water, as well as the rising costs associated with options for increasing water supply. Water scarcity is therefore likely to become a major limiting factor to economic and social development in South Africa. Given that supply augmentation schemes are becoming increasingly expensive and infeasible, the key to future strategic water resource management lies in effective demand side management approaches. The concept of water pricing is therefore becoming increasingly recognised as an important tool for water resources management, which can help to ensure that the future freshwater needs of society and business are met. This is necessary if South Africa is to grow and develop its economy and society in a manner that accommodates both present and future generations.

This study has used the marginal productivity approach to estimate the marginal value of water to industrial users in South Africa, as well as the associated price elasticity of demand for water, based on a sample of 58 companies. Such estimates can potentially provide important information for effective water pricing strategies. The results indicate that the method is vulnerable to statistical issues such as multicollinearity, particularly in the presence of a relatively small sample size, which leads to unexpected results regarding the marginal value of water use.

On the other hand, the estimated price elasticities of demand (in the range of -0.66 to -0.78) are in line with theoretical expectations and comparable to estimates from other countries, and from previous studies in South Africa, and are fairly robust to changes in the specification of the model. The estimated price elasticities of demand suggest that, for every 1% increase in water tariffs, water use in the industrial sector can be expected to decrease by between 0.66% and 0.78%, all else being equal. Thus, the analysis presented here provides some evidence to suggest that increasing water tariffs can be expected to lead to a reduction in water use among industrial users; although the percentage reduction in water use would be comparatively lower than the percentage increase in tariffs.

However, water pricing is a sensitive issue, affecting various stakeholders. As such, policy recommendations cannot be made on the basis of this analysis alone; particularly given the limitations of the method (e.g. in terms of statistical issues such as multicollinearity), and of this study in particular (such as the relatively small sample size). Further research is therefore warranted. In particular, future research should be aimed at addressing some of the statistical issues with the method, making use of a larger sample size, or identifying alternative methods. Furthermore, in addition to this purely micro-economic analysis, stakeholder consultation is essential, while the wider socio-economic and macroeconomic impacts will need to be assessed.

Indeed, as part of the study, some preliminary discussions with representatives of key stakeholder groups were initiated, although further stakeholder consultation is required. Key stakeholder groups that were identified (specifically in terms of industrial water use) were as follows:

1) National government, specifically members of the Department of Water Affairs' Pricing and Economic Regulation Reform (PERR) project, who are currently reviewing the national water pricing strategy (Department of Water Affairs, 2012); as well as the National Treasury.
2) Local municipalities, with a particular focus on the metropolitan municipalities (under whose jurisdiction the majority of large industrial water users are to be found), specifically those individuals or departments involved in setting water tariffs.
3) Business, as represented by the various business associations.

To date, no responses have been received from business associations, although there was some interest from the PERR project management office. On the other hand, valuable comments were received from the National Treasury, which were incorporated in the final report; as well as from representatives of the larger metropolitan municipalities. Some of the feedback from this latter group included criticism regarding the small sample size, and therefore the inability of the study to allow for general deductions to be made.

Another response from this group relates to "the competition between municipalities to attract industries and [the way] that industries locate in locations with the lowest input costs. Big water[-using] industries… give annual quotas to their plants according to the input cost to produce [their product] and an increase in water cost to one plant will cause a move of production to another plant in another municipality. The model is thus valid only if all municipalities apply it simultaneously and where no competition exists between municipalities to attract business." This implies that an increase in water prices will have to be regulated to some extent at the national level, to avoid a situation where municipalities attempt to 'under-cut' water prices in order to attract industry.

A number of further limitations of the study, and suggestions for overcoming these limitations in future research, were highlighted by the project reference group:

- The survey sample may lack representivity; as a result of the relatively small sample size (particularly at the level of particular industries, where the sample size per industry ranged from 2 to 12); and because a disproportionate number of respondents were large companies, and therefore unlikely to be representative of all companies in South Africa. As such, the results of the study (particularly the industry-level results) are not generalizable. While the estimates of price elasticity of demand for the industrial sector as a whole are based on a larger sample (n = 58) than the industry-specific results, it is nevertheless difficult to draw any firm conclusions or policy implications from the study. This needs to be addressed in future research.
- The derivation of the equation for calculating price elasticity of demand (Equation 5) is not explained in sufficient detail in Wang and Lall (1999, 2002). This makes it difficult to scrutinise the derivation of this equation. This should be addressed in future research.
- Price elasticities of demand are not estimated directly; i.e. based on any actual observed or hypothetical (via stated preference) response to changes in prices (as in Veck and Bill's (2000) study of domestic water use). However, observed data on changes in behaviour in response to actual price changes are difficult to come across (and in any case it would be difficult to attribute any change in behaviour specifically to the change in prices); while stated preference surveys are open to a range of biases.
- Purchased water and self-supplied water were included together in the same variable; when in fact they should have been separated to enable examination of the interactions between them (i.e. substitutability from purchased to self-supplied water as the price of purchased water increases). The production function approach requires data on total water use in order to investigate how water enters the production function (irrespective of source); nevertheless, in future research, it would be useful if total water use could be split into two separate variables.
- The raw materials ('*M*') variable was excluded from the model. This is likely to be a significant omission, since '*M*' is likely to be an important explanatory variable in explaining output. This variable should therefore be included in future research.
- Because the dependent variable (*Y*) is the *value* of output, rather than the physical quantity of output, the function estimated in this study is in fact a revenue function, rather than a production function. This was necessary to account for the fact that the different companies in the sample all produce different products, which are measured in different units; such that it would not have been possible to combine them in a

single production function where the physical quantity of output was the dependent variable. Nevertheless, in this case, price should have been included as one of the explanatory variables, particularly so as to distinguish between the different price per unit of output for different products produced by different companies in different industries. This differentiation in prices per unit of output suggests that revenue may not be an adequate proxy of output. However, it should be noted that Wang and Lall similarly used the value of output as the dependent variable in their study; and indeed it is not clear whether the physical quantity of output can be used as the dependent variable in the marginal productivity approach, given the assumptions required in estimating marginal value and price elasticity of demand.

- The accuracy of responses regarding the quantity of self-supplied water can be questioned, as this can be difficult for users to monitor. Once again, this should be addressed in future research.
- Finally, the failure to account for the quality of water discharges or return flows was a significant omission, and should be addressed in future research; as the costs of wastewater collection and treatment should form part of the overall water pricing strategy.

More generally, past experience with water pricing as a water management tool has been mixed (Conradie and Hoag, 2004; Department of Water Affairs and Forestry, 1999; Eberhard, 1999a, b, 2003b; Lange et al., 2007; Nieuwoudt et al., 2004; Palmer Development Group, 2000; Tsegai et al., 2009; Tsur et al., 2004). International experience suggests that there has been limited success for marginal cost water pricing as a tool for water demand management (Abu Qdais and Al Nassay, 2001; Albersen et al., 2003; Cummings and Nercissiantz, 1992b; Dinar and Subramanian, 1998; Eberhard, 1999a, b, 2003b; Johansson et al., 2002; Jones, 1998; Kumar and Singh, 2001; Moilanen and Schulz, 2002; Tsegai et al., 2009; Tsur et al., 2004; Wang and Lall, 1999); and that pricing should instead be regarded primarily as a tool for cost recovery (Department of Water Affairs and Forestry, 2005; Eberhard, 2003b; Tsur et al., 2004).

In particular, pricing as a water management tool is not likely to be effective in cases where the demand for water is inelastic (i.e. relatively unresponsive to changes in price). This is often the case for water uses for which there are few or no substitutes for water, as is the case with irrigation water, for example (Eberhard, 2003a) (see Section 5.2). On the other hand, generally speaking, price elasticities of demand for industrial (as well as domestic) water use tend to be higher as compared to those associated with irrigation (see Table 10). This suggests that industrial and domestic users are more responsive to changes in water prices as compared to agricultural users. As such, water pricing can be expected to be more effective as a demand management strategy for industrial and domestic water use as compared to a similar strategy for agricultural water use.

However, even in cases where the price elasticity of demand for water suggests that water pricing may be effective in terms of reducing the demand for water, the socio-economic and macro-economic impacts of an increase in water prices would need to be assessed. Specifically, price increases will generally be met with social and political resistance; such that they may be politically difficult to motivate and implement, both because of impacts on firms' profitability and competitiveness, and also because the equity impacts of such increases are often uncertain. For example, the impact of increased water prices could be regressive at the household level (Roibas et al., 2007), which implies that welfare losses fall disproportionally on lower-income households. This could partly be due to the fact that high-income households are able to employ water saving technologies, and that water-related expenses constitute a smaller proportion of their household costs as compared to low-income households. Similarly, in the case of water use charges for industrial users, it is possible that higher prices could have a disproportionate negative impact on smaller companies, who may be less able to absorb or adjust to higher prices. It is also likely that higher input prices will be passed on to consumers to an extent, through higher product prices. As such, stakeholder consultation regarding the impacts of water pricing is required. In the absence of such consultation, the risk of non-compliance arises.

In addition to stakeholder consultation, the socio-economic and macroeconomic impacts of an increase in water prices will need to be modelled. In particular, the impacts of higher input costs on firms' profitability and on industry competitiveness (particularly as compared to imports from other countries, as well as in the export market), as well as the resulting impacts on national welfare and on employment, will need to be quantified. For example, De Lange (2011) used computable general equilibrium (CGE) modelling to assess the macroeconomic impacts of an increase in water use charges for agricultural users in the Western Cape. However, given the vast differences between agriculture and industry (as well as other water use sectors) in terms of their water use profiles and contributions to the South African economy, it is crucial that a similar modelling exercise be conducted specifically to investigate the impacts of an increase in water tariffs for industrial (and other) water users.

In summary, the information generated by this study should be seen as just one necessary, but certainly not sufficient, piece of information to be taken into account in formulating water pricing strategies. There is therefore a need to supplement and verify the preliminary findings of this study by means of further research, including industry-specific studies, making use of wider-ranging surveys of a much larger sample of companies; as well as meetings with various stakeholders in national government, local government and business. Finally, there is a need to model the wider socio-economic and macroeconomic impacts of an increase in water prices, in order to assess whether the benefits of increasing water prices justify the costs.

7 LIST OF REFERENCES

Abu Qdais, H.A., Al Nassay, H.I., 2001. Effect of pricing policy on water conservation: A case study. Water Policy 3, 207-214.

Albersen, P.J., Houba, H.E.D., Keyzer, M., 2003. Pricing a raindrop in a process-based model: General methodology and a case study of the Upper-Zambezi. Physics and Chemistry of the Earth 28, 183-192.

Arouna, A., Dabbert, S., 2009. Determinants of domestic water use by households without access to private improved water sources in Benin. Water resources management.

Arrow, K., 1963. Uncertainty and the welfare economics of medical care. American Economic Review 5, 941-973.

Arrow, K., 1984a. A difficulty in the concept of social welfare., Collected papers of Kennith Arrow: Social choice and justice, Oxford, UK.

Arrow, K., 1984b. Formal theories of social welfare., Collected papers of Kenneth Arrow: Social choice and justice, Oxford, UK.

Arrow, K., 1984c. Values and collective decision making, Collected papers of Kenneth Arrow: Social choice and Justice, Oxford, UK.

Babin, F., Willis, C., Allen, P., 1982. Estimation of substitution possibilities between water and other production inputs. American Journal of Agricultural Economics 64, 148-151.

Backeberg, G.R., 1994a. Die politieke ekonomie van besproeiingsbeleid in Suid Afrika., Agricultural Economics and Rural Development. University of Pretoria, Pretoria.

Backeberg, G.R., 1994b. 'n Polities-ekonomiese benadering tot aanpassing van waterinstitusies in besproeiingslandbou. Agrekon 33, 225-242.

Backeberg, G.R., 1997. Water institutions, markets and decentralised resource management: Prospects for innovative policy reforms in irrigated agriculture. Agrekon 36, 350-384.

Bell, R.G., Russell, C., 2002. Environmental policy for developing countries. Issues in Science and Technology 18, 63-70.

Bergson, A., 1938. A reformulation of certain aspects of welfare economics. Quarterly Journal of Economics 52, 310-334.

Bergson , A., 1954. On the Concept of Social Welfare. Quarterly Journal of Economics.

Birol, E., Karousakis, K., Koundouri, P., 2006. Using economic valuation techniques to inform water resources management: A survey and critical appraisal of available techniques and an application. Science of the Total Environment 365, 105-122.

Blignaut, J., Steyn, F., Van Heerden, J., Schoeman, N., Ramos, R., Mabugu, M., 2004. Prudent environmental management: A catalyst for economic development. University of Pretoria, Pretoria.

Blignaut, J.N., De Wit, M., 2004. Sustainable options: Development lessons from applied environmental economics. UCT Press, Cape Town.

Christensen, L., Jorgenson, D., Lau, L., 1973. Transcendental logarithmic production function frontiers. Review of Economics and Statistics 55, 29-45.

Conradie, B., Hoag, D.L., 2004. A review of mathematical programming models of irrigation water values. Water SA 30, 287-292.

Cummings, R.G., Nercissiantz, V., 1992a. The use of water pricing as a means for enhancing water use efficiency in irrigation: Case studies in Mexico and the United States. Natural Resource Journal 32, 731-755.

Cummings, R.G., Nercissiantz, V., 1992b. The use of water pricing as a menas for enhancing water use efficiency in irrigation: Case studies in Mexico and the United States. Natural Resource Journal 32, 731-755.

De Lange, W.J., 2006. Multi-criteria decision-making for water resource management in the Berg water management area., Department of Agricultural Economics. Stellenbosch University, Stellenbosch.

De Lange, W.J., 2011. The economic impact and reallocation effects of increased water user charges: A scenario analysis., Report number: CSIR/NRE/RBSD/IR/2011/0008/A. CSIR, Pretoria.
De Rooy, Y., 1974. Price responsiveness of the industrial demand for water. Water Resources Research 10, 403-406.
Department of Energy, 2009. Digest of South African Energy Statistics: 2009. Department of Energy, Directorate: Energy Information Management, Process Design and Publications, Pretoria.
Department of Energy, 2010. South African Energy: Price Report: 2010. Department of Energy, Directorate: Energy Information Management, Process Design and Publications, Pretoria.
Department of Environmental Affairs and Tourism, 1993. The use of economic instruments in environmental management: A project aimed at influencing state and private sector environmental policy, Research Report 5. Produced for the Department of Environmental Affairs and Tourism (DEAT) by The BP Chair of Environmental Policy and Management, the Institute for Natural Resources, University of Natal, and Economic Project Evaluation (Pty) Ltd, Pretoria.
Department of Water Affairs, 2012. Raw Water Pricing Strategy Gap Analysis: Draft report under PERR project WP10465: Revision of Pricing Strategy and Development of a Funding Model and an Economic Regulator. Department of Water Affairs, Pretoria.
Department of Water Affairs and Forestry, 1994. Western Cape System Analysis: Water demand management., PG000/00/4693. Department of Water Affairs and Forestry, Cape Town.
Department of Water Affairs and Forestry, 1998. National Water Act No. 36 of 1998. Statutes of the Republic of South Africa: Water, Pretoria.
Department of Water Affairs and Forestry, 1999. Establishment of a pricing strategy for water use charges in terms of section 56(1) of the National Water Act, 1998. Department of Water Affairs and Forestry, Pretoria.
Department of Water Affairs and Forestry, 2000a. Development of a waste discharge charge system: Framework document. Second edition. Department of Water Affairs and Forestry (DWAF), Pretoria.
Department of Water Affairs and Forestry, 2000b. Draft water conservation and demand management strategy for the water services sector. Department of Water Affairs and Forestry, Pretoria.
Department of Water Affairs and Forestry, 2004a. National Water Resource Strategy of South Africa. Department of Water Affairs and Forestry, Pretoria.
Department of Water Affairs and Forestry, 2004b. Water conservation and water demand management strategy for the industry, mining and power generation sectors. Department of Water Affairs and Forestry, Pretoria.
Department of Water Affairs and Forestry, 2005. Establishment of a pricing strategy for water use charges in terms of section 56(1) of the National Water Act, 1998. Department of Water Affairs and Forestry, Pretoria.
Dinar, A., Subramanian, A., 1998. Policy implications from water pricing experiences in various countries. Water Policy 1, 239-250.
Dupont, D., Renzetti, S., 2001. Water's role in manufacturing. Environmental and Resource Economics 18, 411-432.
Eberhard, R., 1999a. Supply pricing of urban water in South Africa: Volume I., 678/1/99. Water Research Commission, Pretoria.
Eberhard, R., 1999b. Supply pricing of urban water in South Africa: Volume II., 678/2/99. Water Research Commission, Pretoria.
Eberhard, R., 2003a. Economic regulation of water. Trade and Industry Monitor 26, 12-17.
Eberhard, R., 2003b. Water pricing in South Africa: A Report for National Treasury., unknown. Palmer Development Group, Cape Town.

Eberhard, R., Joubert, A.R., 2002. CMA bulk water supply study: An evaluation of additional water supply options using MCDA, 3245 / 9531. Palmer Development Group and Ninham Shand Consulting Services, Cape Town.

Féres, J., Reynaud, A., 2003. Industrial water use, cost structure and environmental policy in Brazil, LERNA Working Paper 03.08.114 LERNA, University of Toulouse, Toulouse. http://www2.toulouse.inra.fr/lerna/english/cahiers2003/0308114.pdf

Féres, J., Reynaud, A., 2005. Assessing the impact of environmental regulation on industrial water use: Evidence from Brazil. Land Economics 81, 396-411.

Field, B.C., Field, M.K., 2002. Environmental economics: An introduction. McGraw Hill, New York.

Gibbons, D.C., 1986. The economic value of water. Resources for the Future. Washington DC.

Goodstein, E.S., 1999. Economics and the environment. Prentice Hall Publishers, New Jersey.

Goodstein, E.S., 2008. Economics and the environment. John Wiley & Sons, Lewis & Clark, Portland, Oregon, USA.

Grebenstein, C., Field, B., 1979. Substituting for water inputs in U.S. manufacturing. Water Resources Research 15, 228-232.

Gujarati, D.N., 2003. Basic Econometrics, Fourth edition ed. McGraw Hill Publishers, New York.

Haddad, M., Lindner, K., 2001. Sustainable water demand management versus developing new and additional water in the Middle East: A critical review. Water Policy 3, 143-163.

Hassan, R., Mungatana, E., 2006. The value of water for off-stream uses in South Africa, in: Lange, G.-M., Hassan, R. (Eds.), The Economics of Water Management in Southern Africa. Edward Elgar Publishing Limited, Cheltenham, UK.

Hassan, R.M., Farolfi, S., 2005. Water value, resource rent recovery and economic welfare cost of environmental protection: A water-sector model for the Steelpoort sub-basin in South Africa. Water SA 31, 9-16.

Jaffe, A.B., Stavins, R.N., 1995. Dynamic incentives of environmental regulations: The effects of alternative policy instruments on technology diffusion. Journal of Environmental Economics and Management 29, S43-S63.

Jansen, A., Schultz, C., 2006. Water demand and the urban poor: A study of the factors influencing water consumption among households in Cape Town. South African Journal of Economics 74, 593-609.

Johansson, R., Tsur, Y., Roe, T., Doukkalid, R., Dinar, A., 2002. Pricing irrigation water: a review of theory and practice. Water Policy 4, 173-199.

Jones, T., 1998. Recent developments in the pricing of water services in OECD countries. Water Policy 1, 637-651.

King, N.A., 2004. The economic value of water in South Africa, in: Blignaut, J.N., De Wit, M.P. (Eds.), Sustainable options: Development lessons from applied Environmental Economics. UCT Press, Cape Town.

Kleynhans, S., 2002a. CMA bulk water supply study: Main report, 3245/9531. Ninham Shand Consulting Services, Cape Town.

Kleynhans, S., 2002b. Integration of raw water sources supplying the CMA, 3243/9690. Ninham Shand Consulting Services, Cape Town.

Kumar, M., Singh, O., 2001. Market instruments for demand management in the face of scarcity and overuse of water in Gujarat, Western India. Water Policy 3, 387-403.

Kumar, S., 2004. Analysing industrial water demand in India, Discussion paper 2004-12. National Institute of Public Finance and Policy, New Delhi. www.nipfp.org.in/working%20paper%5Cwp12.pdf

Lange, G.M., Hassan, R.M., 2006. The economics of water management in Southern Africa-An environmental accounting approach. Edward Elgar press, UK.

Lange, G.M., Mungatana, E., Hassan, R.M., 2007. Water accounting for the Orange River Basin: An economic perspective on managing a transboundary resource. Ecological Economics 61, 660-670.
Law, M.C., 2007. Willingness to pay for the control of water hyacinth in an urban environment of South Africa, A thesis submitted in fulfilment of the requirements for the degree of Master of Commerce. Rhodes University, Grahamstown.
Little, I.M.D., 1949. The Foundations of Welfare Economics. Oxford Economic Papers 1, 237-238.
Little, I.M.D., 1950. A Critique of Welfare Economics. Oxford University Press, UK.
Louw, D.B., 2001. Modelling the potential impact of a water market in the Berg river basin., Agricultural Economics. University of the Orange Free State, Bloemfontein.
Louw, D.B., Kassier, W.E., 2002. The costs and benefits of water demand management. Centre for International Agricultural Marketing and Development, Paarl.
Louw, D.B., van Schalkwyk, H.D., 2001. The impact of transaction costs on water trade in a water market allocation regime. Department oif Agricultural Econoics, University of the Orange Free State, Bloemfontein.
Mahumani, B.K., Lombard, J.P., De Wit, M.P., 2009a. The rural and agricultural value of groundwater as an economic resource in the Limpopo region. Department of Agricultural Economics, Stellenbosch University, Stellenbosch.
Mahumani, B.K., Lombard, J.P., De Wit, M.P., 2009b. The value of groundwater as an economic resource in rural Limpopo.
Malla, P.B., Gopalakrishnan, C., 1999. The economics of urban water demand: The case of industrial and commercial water use in Hawaii. Water Resources Development 15, 367-374.
Mansfield, E., 1988. Micro-economics: Theory and applications (6th Ed.). Norton, New York.
Miller, R.L., Meiners, R.E., 1986. Intermediate Microeconomics (3rd Ed.). McGraw-Hill. , Singapore.
Miltz, D., Pearce, D., 1995. Market based environmental and resource policies: International Perspectives on the opportunities and challenges facing the new South Africa, Research Report 10. Department of Environmental Affairs and Tourism (DEAT), Pretoria.
Mirrilees, R.I., Forster, S.F., Williams, C.J., 1994. The application of economics to water management in South Africa, 415/1/94. Water Research Commission, Pretoria.
Moilanen, M., Schulz, C.E., 2002. Water pricing reform, economics welfare and equality., Forum for Economics and Environment, Cape Town.
Moore, M., 1999. Estimating irrigators' ability to pay for reclamation water. Land Economics 75, 562-578.
Moore, M., Dinar, A., 1995. Water and land as quantity-rationed inputs in California agriculture: Empirical tests and water policy implications. Land Economics 71, 445-461.
Mueller, D.C., 1997. Perspectives on public choice. Cambridge University Press, UK.
Mukheibir, P., Sparks, D., 2005. Climate variability, climate change and water resource strategies for small municipalities. Report to the Water Research Commission. WRC Project: K5/1500. University of Cape Town, Cape Town.
National Treasury, 2006. A framework for considering market-based instruments to support environmental fiscal reforms in South Africa. National Treasury, Tax Policy Chief Directorate, Cape Town.
Nieuwoudt, W.L., Backeberg, G.R., Du Plessis, H.M., 2004. The value of water in the South African economy: Some implications. Agrekon 43, 162-183.
Onjala, J., 2001. Industrial water demand in Kenya: Industry behaviour when tariffs are not binding. Department of Environment, Technology and Social Studies, Roskilde University, Denmark. www.environmental-economics.dk/papers/waterkenya.pdf
Organisation for Economic Cooperation and Development, 1990. Economic instruments for environmental protection. Organisation for Economic Cooperation and Development, Paris, France.

Organisation for Economic Cooperation and Development, 1994a. Evaluating economic incentives for environmental policy. Organisation for Economic Cooperation and Development, Paris, France.
Organisation for Economic Cooperation and Development, 1994b. Managing the environment – The role of economic instruments. Organisation for Economic Cooperation and Development, Paris, France.
Palmer Development Group, 2000. Supply pricing of urban water in South Africa: Methods to inform urban water pricing policy., Working paper 4. Water Research Commission, Pretoria.
Palmer, R.W., Turpie, J., Marnewick, G.C., Batchelor, A.L., 2002. Ecological and economic evaluation of wetlands in the upper Olifants river catchment, South Africa., 1162/1/02. Water Research Commission, Pretoria.
Pearce, D.W., 1993. Economic values and the environment. The MIT Press, UK.
Pearce, D.W., Turner, R.K., 1991. Economics of natural resources and the environment. John Hopkins University Press, Maryland.
Purnama, D., 2003. Reform of the EIA process in Indonesia: Improving the role of public involvement. Environmental Impact Assessment Review 23, 415-439.
Quantitative Micro Software (QMS), 2009. EViews Version 7.
Rees, J., 1969. Industrial demand of water: A study of South East England. Weidenfeld and Nicolson., London.
Renzetti, S., 1988. An econometric study of industrial water demands in British Columbia, Canada. Water Resources Research 24, 1569-1575.
Renzetti, S., 2002. Economics of Industrial Water Use. Edward Elgar, London.
Renzetti, S., 2003. Incorporating demand-side information into water utility operations and planning. Accessed http://139.57.161.145/papers/DSM_chapter_Brock.pdf.
Renzetti, S., 2005. Incorporating demand-side information into water utility operations and planning in: Chenoweth, J., Bird, J. (Eds.), The Business of Water Supply and Sustainable Development. Greenleaf Publishing.
Renzetti, S., Dupont, D.P., 2003. The value of water in manufacturing, CSERGE Working Paper ECM 03-03. CSERGE.
Reynaud, A., 2004. An econometric estimation of industrial water demand in France. Environmental and Resource Economics 25, 213-232.
Roibas, D., Garcia-Valinas, M., Wall, A., 2007. Measuring welfare losses from interruption and pricing responses to water shortages: An application to the case of Seville.". Environmental and Resource Economics 38, 231-243.
Rosenhead, J., Mingers, J., 2002. Rational analysis for a problematic world revisited. John Wiley & Sons, New York.
Schneider, M.L., Whitlach, E.E., 1991. User-specific water demand elasticities. Journal of Water Resources Planning and Management 117, 52-73.
Shand, M., Sparks, A., Kleynhans, S., Beuster, H., 2003. Challenges in managing and developing the region's water resources to meet the demands of Cape Town and other users, unknown. Ninham Shand Consulting Services, Cape Town.
Sparks, A., 2001. Water demand management policy for the City of Cape Town, unknown. City Council and Ninham Shand Consulting Services, Cape Town.
Statistics South Africa, 2004. Natural resource accounts: Water accounts for nineteen water managment areas., 04-05-01. Statistics South Africa, Pretoria.
Sterner, T., van den Bergh, J.C.J.M., 1998. Frontiers of Environmental and Resource Economics. Environmental and Resource Economics 11, 243-260.
Thomas, F., Syme, G., 1988. Esimating residential price elasticity of demand for water: A Contingent Valuation Approach. Water Resources Research 24, 1847-1857.
Thomas, J.S., Durham, B., 2003. Integrated Water Resource Management - Looking at the whole picture. Desalination 156, 21-28.
Thrall, R.M., 1976. Economic modelling for water policy evaluation. North Holland Publishing Company, Amsterdam.

Tietenberg, T., 1996. Environmental and resource economics. Harper Collins College Publishers, New York.

Tsegai, D.W., Linz, T., Kloos, J., 2009. Economic analysis of water supply cost structure in the Middle Olifants sub-basin of South Africa., Discussion Papers On Development Policy No. 129 (http://ssrn.com/abstract=1402624). Zentrum für Entwicklungsforschung - Center for Development Research, Bonn.

Tsur, Y., Roe, T., Doukkali, R., Dinar, A., 2004. Pricing irrigation water: Principles and cases from developing countries. REF Press, Washington.

Turnovsky, S., 1969. The demand for water: Some empirical evidence on consumers' response to a commodity uncertain in supply. Water Resources Research 5, 250-361.

Turpie, J., van Zyl, H., 2002. Valuing the environment in water resources management., in: Hirji, R., Johnson, P., Maro, P., Chiuta, T.M. (Eds.), Defining and mainstreaming environmental sustainability in water resources management in Southern Africa Maseru, pp. 85-110

UNESCO, 2006. Water a shared responsibility. The United Nations World Water Development Report 2. United Nations Educational, Scientific and Cultural Organization (UNESCO): World Water Assessment Programme,. www.unesco.org/water.wwap

UNICEF, 2005. Information by country: South Africa Demographic Statistics. Accessed http://www.unicef.org/infobycountry/southafrica_statistics.html#17.

Van der Veeren, R., Lorenz, C.M., 2002. Integrated economic-ecological anlysis and evaluation of management strategies on nutrient abatement in the Rhine basin. Journal of Environmental Management 66, 361-376.

Van Heerden, J.H., Blignaut, J., Horridge, M., 2008. Integrated water and economic modelling of the impacts of water market instruments on the South African economy. Ecological Economics 66, 105-116.

Van Vuuren, D.S., Van Zyl, H.J.D., Veck, G.A., Bill, M.R., 2004. Payment strategies and price elasticity of demand for water for different income groups in three selected urban areas., 1296/1/04. Water Research Commission, Pretoria.

Van Zyl, H., Leiman, A., 2002. Development of a framework for the economic evaluation of water conservation/water demand management measures with specific application to decision-making in Cape Town., 1275/1/02. Water Research Commission, Pretoria.

Van Zyl, J.E., Haarhoff, J., Husselman, M.L., 2003. Potential application of end-use demand modelling in South Africa. Journal of the South African Institute of Civil Engineering 45, 9-19.

Veck, G.A., Bill, M.R., 2000. Estimation of the residential price elasticity of demand for water by means of a Contingent Valuation Approach., 790/1/00. Water Research Commission, Pretoria.

Walter, T., Kloos, J., Tsegai, D., 2011. Options for improving water use efficiency under worsening scarcity: Evidence from the Middle Olifants Sub-Basin in South Africa. Water SA 37, 357-370.

Wang, H., Lall, S., 1999. Valuing water for Chinese industries: A marginal productivity assessment, http://www.worldbank.org/nipr/work_paper/wps22. The World Bank Development Research Group.

Wang, H., Lall, S., 2002. Valuing water for Chinese industries: A marginal productivity assessment. Applied Economics 34, 759-765.

Williams, M., Suh, B., 1986. The demand for urban water by customer class. Applied Economics 18, 1275-1289.

Winpenny, S., 1994. Managing water as an economic resource. Routledge publishers, London.

APPENDIX 1: THE ROLE OF DEMAND-SIDE MANAGEMENT IN INTEGRATED WATER RESOURCES MANAGEMENT

Water resources management refers to the management of both water allocation and water quality. Water quality management focuses on the preservation of the inherent quality (usefulness) of the resource, while allocation management focuses on the logistics of water provision – i.e. how much water should be allocated to specific uses and users.

Allocation management can be further sub-divided into water supply and water demand management. Water supply management focuses on the expansion of the existing supply capacity to provide for a growing demand (Eberhard and Joubert, 2002; Kleynhans, 2002a). Such strategies are normally associated with the construction of infrastructure (large storage dams or water production schemes like desalination plants or recycling to a potable standard). Supply management strategies are more capital-intensive compared to most demand management strategies, with numerous uncertainties regarding the long-term implications of the construction and operation of supply schemes. Environmental impact assessments attempt to quantify such uncertainties, but numerous obstacles, such as the proper quantification of long-term impacts of different supply options, still remain (Purnama, 2003; Van der Veeren and Lorenz, 2002). Such obstacles have an obvious negative impact on the legitimacy of environmental impact assessment studies.

Water demand management, on the other hand, can be defined as management strategies specifically developed to impact the demand for water (Kleynhans, 2002b; Louw and Kassier, 2002; Shand et al., 2003). Such strategies typically focus on the development of appropriate tariff structures, often accompanied by user education and guideline campaigns on how to increase water use efficiency (Haddad and Lindner, 2001). Demand management strategies can also be accompanied by the use of technologies such as low pressure household appliances as well as enhanced irrigation technologies to further increase water use efficiencies (Department of Water Affairs and Forestry, 1994). A wide range of pricing policy options are available, ranging from direct pricing to 'green' taxes, effluent fees and direct subsidies for utilities or users. The choice of policy depends upon the local political and social conditions (Department of Water Affairs and Forestry, 1994).

It should be clear that a combination of demand and supply management strategies should be followed to ensure efficient and sustainable water resource management. Each is appropriate in different situations. Figure 2 illustrates the appropriate timing of demand versus supply-side management strategies.

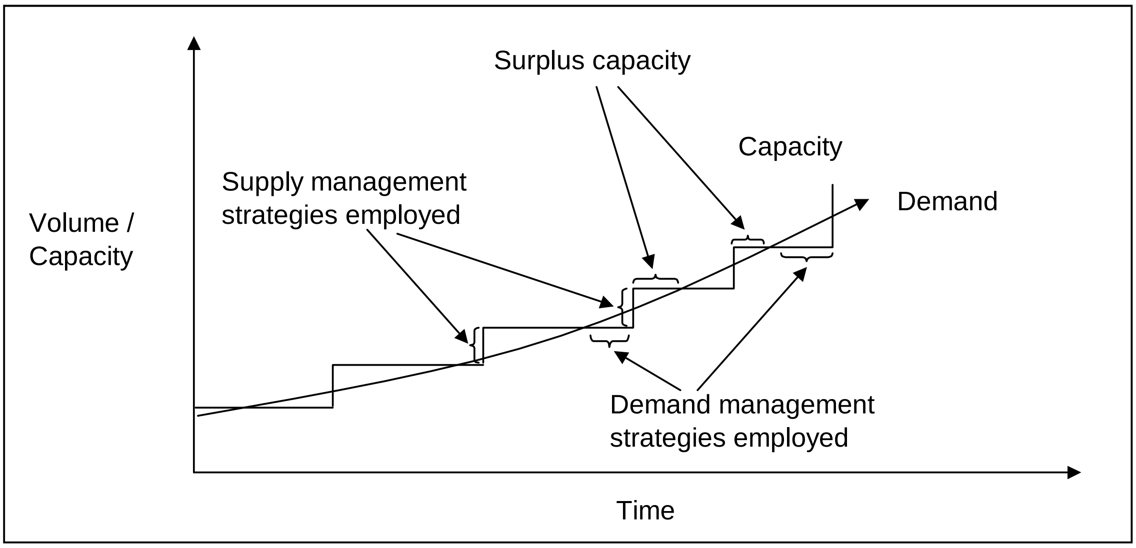

Figure 2: Demand and supply management strategies (De Lange, 2006).

Supply (capacity) expansion paths have a typical step-wise expansion pattern over time. After the implementation of a given supply scheme, a temporary surplus capacity will exist in the bulk distribution system. However, as demand increases, the surplus will start decreasing until demand equals supply. When demand starts to exceed supply, demand management strategies should be used to dampen demand (not indicated in Figure 2) until the next supply expansion scheme can be developed. Such an expansion pattern will continue until the growth in demand starts to stabilise as a result of impacts on the drivers of demand.

South Africa has a legacy of managing the growing demand for water resources with capacity expansion strategies (Backeberg, 1994a, b, 1997; Nieuwoudt et al., 2004). One reason for this is that that policy makers typically operate in a four to five year decision making horizon, while strategic decision-making in bulk water supply management requires a twenty-year planning horizon. However, long-term bulk water supply planning can be hampered if politicians continuously opt for short-term water supply solutions. Although mainly politically motivated, such an approach is costly in terms of capital investment and involves the development of new water supply infrastructure to satisfy the growing demand for water, with little emphasis placed on effective use of water. Capacity expansion approaches unintentionally create the public perception of water not being a scarce and valuable resource. Little incentive is created for the development of water saving technology, because water is 'cheap' and is often even subsidised. This situation has led to the creation of negative externalities, including negative impacts on the natural environment. Since water supply networks have not been optimised for water saving strategies, South Africa, like most countries in the world, can no longer afford to continue on this path. Indeed, as water has become more scarce relative to growing demand, South Africa has gradually begun to implement water demand management practices. Such strategies have become an important part of water management portfolios, in parallel with bulk supply management in the long-term.

Managing water resources from a *demand perspective* would imply improvements in the co-ordination of water resource management, including enhancements in dam and reservoir flexibility operations as well as the adoption of new analytical tools. Water demand management strategies would strive to restrain demand for capital at a time when available funds are limited and promote the efficient use of water, thus easing competition for water resources and helping to minimise the pressure on the natural environment. The objective of demand management is to encourage more efficient use of water, with numerous regulatory and water-pricing options available to promote the development and use of efficient water use technologies and practices. Demand management options include such measures as:

- Modifying tariff structures. However, precautions must be taken to minimise impacts on the poor. It is therefore important that pricing policies be structured in such a way as to not deny access to sufficient clean water for basic survival and hygiene to the poorest of the poor;
- Better maintenance;
- Upgrading to water saving technology;
- User education;
- More efficient metering; and
- Development of water markets.

Water demand management approaches therefore concentrate on techniques and technologies to curtail growth in demand by implementing water saving strategies to increase the level of efficiency in water use. These strategies thus focus on the more efficient use of existing water infrastructure and supplies. Efficiency gains could offset or postpone the construction of costly infrastructure developments. Demand-management measures often have shorter payback periods, adding to the attractiveness of such strategies. The successful implementation of demand management objectives is not restricted to water authorities, but also often requires a change in public consumptive behaviour. User education is therefore an important aspect of successful water demand management.

An important requirement for most water demand management strategies is the ability to understand and take into account the value of water in relation to its cost of provision, thereby allowing for measures to be introduced that require consumers to relate their usage more closely to costs. This often entails treating water more like a commodity, as opposed to a free public good (Louw, 2001; Louw and Kassier, 2002; Mirrilees et al., 1994; Winpenny, 1994). Tradable water rights have been found to be an appropriate measure for dealing with direct abstractions as they occur in agriculture and in the allocation of water between local authorities. However, such markets do not have as much scope for application among individual urban (residential or industrial) users due to the complexity of the system. Within such markets, users for whom water has low use-value will have an incentive to sell or lease their water use rights, while users with higher use-values will have an incentive to buy or lease water rights in order to expand their activities.

Water demand management results in both direct and indirect costs and benefits; these need to be assessed before implementing a demand management strategy. Typical direct benefits associated with water demand management include the postponement of expensive bulk supply infrastructure (however, this should be compared against the potential economic injection to the regional economy associated with developing water supply schemes), water and energy costs savings and job creation (e.g. the Working for Water programme). Typical direct costs include costs associated with installing and maintenance of water saving devices and higher water tariffs. These direct costs and benefits accrue to individuals as well as to society. Typical indirect benefits would include cheaper and cleaner water for the poor, less pollution and societal awareness of the value of water and a clean environment. Typical indirect costs include the impacts associated with limiting individuals' freedom, and real or perceived inconveniences.

A distinction should be made between water demand management and water restrictions. Water demand management is a broader concept, and is intended as an equal partner to water supply management. Water demand management can be defined as any socially beneficial action that reduces or reschedules average or peak water withdrawals or consumption from either surface or groundwater, consistent with the protection or enhancement of water availability and quality. Water restrictions refer to efforts made to save water during situations of severe water shortage and are reserved for short-term drought conditions.

The link between supply and demand management is to be found when water use efficiency is realised in terms of water savings, i.e. when additional water resources become available, creating additional supply. However, no water management system will ever operate perfectly efficiently. As a water distribution system becomes more efficient, the marginal gain in additional investments for efficiency gains will decrease. This illustrates the inherent limited capacity of demand management strategies to fully manage the demand for water. Capacity expansion is therefore needed in conjunction with demand management, in order to keep up with growing demand. A combination of demand and supply management strategies is therefore necessary if efficiency, equity and sustainability objectives are to be achieved. In other words, an integrated approach to water resources management is required.

APPENDIX 2: MARKET AND NON-MARKET BASED INSTRUMENTS FOR MANAGING WATER DEMAND

Water supply authorities (such as government) generally endeavour to promote an efficient but equitable and sustainable allocation of water (Eberhard, 2003b; Shand et al., 2003; Thomas and Durham, 2003). While a completely efficient, equitable and sustainable allocation is not easily achieved, this should nevertheless serve as a management guideline. Different types of strategies exist to engage in the problem of resource management. Given a budget constraint, decision makers need to find a management option that balances sustainable development, environmental conservation and social welfare maximisation (social welfare creation includes sustainable development and environmental conservation).

One option is to turn to the market for water resource allocation, the assumption being that the competitive market is the ideal mechanism for allocating scarce water resources to the most efficient use (Eberhard, 2003a; Pearce, 1993; Thrall, 1976). Neo-classical economics promotes the market as an allocation mechanism to resolve resource allocation problems, relying heavily on an assumption of rationality[26] (Pearce, 1993; Pearce and Turner, 1991; Rosenhead and Mingers, 2002). Market allocation theory states that an efficient and equitable allocation of water resources will be made if the suitable market structures are in place (i.e. the assumption of perfect competition), while the functioning of the state remains an unknown (Mueller, 1997). However, the assumption of a large number of independent sellers and buyers often breaks down, such as in the case of tradable water use-rights in semi-arid areas. In addition, frequent market failures occur in the case of public goods such as water, due largely to the presence of externalities (Blignaut and De Wit, 2004; Goodstein, 1999; Pearce, 1993; Pearce and Turner, 1991). For a free market to be efficient, social costs must correspond with private costs (i.e. no externalities must be present). If externalities exist, the drive to private gain will not simultaneously lead to an increase in social welfare (Arrow, 1984a). Market failures could therefore cause the market to misallocate resources in terms of efficiency, equity and sustainability criteria (Goodstein, 1999).

The free market can also be criticised on the basis that it is impossible to achieve an objective social optimum allocation of water rights with any voting procedure (like the market), because the market gives a weighted price aggregation of individual choices

---

[26] This is in contrast to revealed preference theory (Mueller, 1997). However, decision makers do not necessarily reveal their preferences through their choices (refer to the prisoners dilemma (Bergson, 1938; Bergson 1954; Little, 1949, 1950)).

(Arrow, 1984b, c). The social outcome of such an allocation is not evaluated and may therefore be politically unpopular. The result is that no claims can be made that the market realises a truly objective and efficient resource allocation. The market allocation is merely one among a number of alternative allocations. Arrow (Arrow, 1984b, c) has therefore shown the inherent impossibility of welfare economics to present an objective method to reveal social welfare via any given voting procedure (like the market) from an aggregation of individual welfare functions[27]. See Arrow (1963) for practical implications in the medical field.

When the market mechanism fails, an argument can be made for government intervention to resolve the market failure. Numerous policy instruments are available to governments to overcome market failures; and thereby to improve the efficiency with which natural resources are allocated and used, and to minimise environmental exploitation and degradation. On a simple theoretical level these instruments can be divided into Market Based Instruments (MBIs) and regulatory or Command and Control (CAC) policies, which are non-market based. The main difference between these is that CAC instruments are mandatory in nature and achieve their outcomes directly via administrative and/or judicial procedures, whereas MBIs are voluntary in nature, with their outcomes achieved via their impact on market prices and therefore on economic incentives[28]. Some of the main non-market and market-based instruments available to policy makers to manage the demand for water are discussed in this appendix.

A2.1: Command and control regulations

The term ‘Command and Control’ refers to the non-market based regulations traditionally used in environmental policy, where governing authorities introduce legislation that imposes direct controls on economic agents in order to restrict detrimental impacts to within tolerable limits. These generally take the form of standards specifying required technologies, designs, processes, input qualities or types, or emission levels; and usually impose the same requirements on all sources of pollution or users of resources.

An advantage of the non-market CAC approach is the relative ease of design, implementation, monitoring and enforcement. However, CAC regulations have been shown to be inherently deficient and inappropriate when:

---

[27] For critique against the work of Arrow refer to Sparks (2001).
[28] MBIs are voluntary in that although firms are obliged, in the case of an emissions tax for example, to pay a pollution tax per unit of emissions; they can *choose* whether (and to what extent) to change their behaviour and reduce pollution (and thereby their tax liability) in response to the tax (Organisation for Economic Cooperation and Development, 1990).

1) Implemented in a blanket fashion on firms with very different marginal costs of abatement. This makes the total cost of compliance higher than necessary and inequitably distributed amongst polluters.

2) Prescribed on an individual basis, suited to the situations facing many different polluters or exploiters of natural resources. This presents huge administrative problems (Department of Environmental Affairs and Tourism, 1993), is difficult and costly to police, and consequently the effectiveness of the regulations may erode over time.

Furthermore, CAC regulations may not readily accommodate or encourage technological innovation, and may fail to provide incentives to reduce pollution beyond what would be undertaken to comply with the standard[29].

A2.2: Market-based instruments

The term ‘market based instruments’ (MBIs) refers to a group of policy instruments that work through the market system (in particular the price mechanism) to alter the incentives and therefore behaviour of economic agents. Essentially, MBIs incorporate environmental considerations into mainstream economic decision-making by altering the prices of inputs, outputs and/or emissions. They therefore ‘internalise’ external effects (externalities) associated with the under-pricing of environmental resources by correcting the market/government failures that lead to such resources being under-priced. As a consequence, MBIs tend to outperform the more traditional CAC regulatory methods with regards to their economic efficiency and the distribution of benefits and costs within the economy.

The most commonly used MBIs are environmentally-related taxes, charges and subsidies; as well as marketable permit systems, where emission permits are allocated and traded amongst polluters. The former are ‘price-based’ and the latter ‘quantity-based’ mechanisms. Other approaches included within the general classification of MBIs are deposit-refund systems; offsets and bubbling; insurance/financial assurance requirements; liability rules; and information provision. For a more detailed description and evaluation of the theory and application of MBIs used for environmental protection, the interested reader is referred to the substantial and growing literature, some of which includes: Tietenberg (1996), Sterner and

[29] Jaffe and Stavins (1995) give a review of the empirical literature supporting this point.

van den Bergh (1998), Pearce and Turner (1991), Bell and Russell (2002), Field and Field, (2002), Goodstein (2008), and many others.

A2.2.1 Taxes, charges and subsidies (price-based instruments)

Taxes and charges[30] essentially put a 'price' on the environment by attaching a cost to what was formerly the free use of natural resources and the services they provide. For example, the problem of excessive demand for water as an input in production can be corrected (internalised) by increasing the price of water through the imposition of a tax or removing an existing subsidy (see Section 1.1 and Figure 1 in the body of the report). Taxes and charges may also be imposed on discharges of emissions/effluents into the environment based on the quantity and/or quality of the pollutant. These can take the form of 'user charges' (payments of the costs of collective or public treatment of effluents), and may be uniform or vary according to the amount of effluent treated. Taxes and charges may also be imposed on products that are polluting, and can be set based on some product characteristic (e.g. the sulphur content of coal) or on the product itself (coal). The subsequent decisions about the level of resource use or emissions are left up to the economic agents based a comparison of the costs of abatement versus the potential tax liability.

Subsidies can be applied in many different forms, from tax breaks to direct, budget-financed payments in support of certain activities (or people). Subsidies may apply to payment for certain "services", prices for certain inputs or technology, loans, or access to credit markets. Subsidies can take the form of a payment for each unit of abatement undertaken compared with a baseline level of pollution, or a (partial) repayment of verified abatement costs (e.g. fixed capital costs for a filter or catalytic converter). Subsidies are appropriate where other instruments are infeasible, such as where no polluter can be identified or the polluter is bankrupt.

A2.2.2 Marketable permit systems (quantity-based instruments)

External effects of market failure can also be corrected using marketable permits, and the environmental improvements that result are similar to those provided by taxes and charges. Marketable permit systems, however, function differently in that the permit approach puts a

[30] Taxes and charges are used interchangeably in this report. Taxes, however, are usually reserved for politically rather than administratively decided fees and typically go to the treasury, whereas charges may be levied and appropriated by sectoral agencies (Sterner 2003)

‘cap’ on the total quantity of emissions or resource use, while taxes and charges set the effective ‘price’ of emitting pollutants or resource use.

The idea behind marketable (tradable) permits is that the total level of pollution is decided by authorities, based on the latest scientific information; where after ‘permits’ are created and allocated to polluters that give them ‘rights to pollute’ up to a certain level. The creation of the permits helps remove the externalities implied by the absence of property rights or the ‘public good’ character of the environment. The market then allocates the pollution rights among firms to reflect their demand for pollution or their abatement costs. In this way, the total level of pollution is capped at the pre-determined level, but this total is divided between polluters in a way that minimises overall abatement costs. The creation of permits need not only apply to the capacity of the environment to assimilate waste, but can also be used to create property rights to the sustainable rent production of ecosystems (such as provided by fresh water).

A2.3: Summary: Comparing market-based instruments and command-and-control

In theory, the advantages of MBIs over CAC regulations are numerous. MBIs generally result in (1) pollution control activities being encouraged; (2) natural resources being more efficiently allocated between competing users (on both the supply and demand sides); (3) savings in public expenditure by reducing the ‘transaction costs’ (including the administrative and enforcement costs) of environmental policy; and (4) industries having incentives to develop and adopt new, efficient and environmentally-friendly technologies. In practice, however, these outcomes depend on the quality of available information, particularly regarding the external costs associated with pollution or over-exploitation (which affect the appropriate rate at which taxes should be set) and/or the optimal quantity of emissions or resource use (which affect the number of permits which should be issued).

Another issue surrounding the use of taxes concern the collection of revenues and the distribution of economic ‘rents’ from these programs (e.g. should the revenues be used to reduce other types of taxes on the regulated entities, or redistributed to finance other public services?). Similarly, if subsidies are incorrectly designed they can create perverse incentives or unintended negative side-effects (possibly even resulting in the opposite outcome to what was intended), because they may encourage the entry (or delay the exit) of polluting firms by reducing the firms’ total and average costs, resulting in too many firms and too much production and pollution (Field and Field, 2002).

Information requirements for implementing taxes can be substantial, as authorities need to know (1) the marginal costs of abatement for firms and the marginal damages of pollution, in order to set the optimal level of the tax; and (2) how individuals respond to price changes, measured by the price elasticity of demand. If authorities want to change behaviour, for example, they will need to raise prices for consumers who will respond significantly (i.e. those with a high price elasticity of demand). However, if the aim is to raise revenues, authorities would do better to target those consumers who will not change behaviour substantially (i.e. those with a low price elasticity of demand).

On the other hand, the major disadvantages of using CAC regulations to control environmental problems, particularly on a large scale, are that they impose substantial welfare costs by way of lost opportunities for economic growth and are often not cost-effective. Therefore, the use of economic incentives as alternatives to or in conjunction with CAC measures is becoming more generally accepted around the world as the more flexible and cost-effective way for governments to respond to new and existing environmental pressures.

The most appropriate regulatory approach, whether market-based, non-market based or a mix of both, depends on a wide variety of factors, such as the nature of the market failure being addressed, the specific circumstances of the environmental problem (resource over-exploitation or pollution), the level of uncertainty with regard to key information requirements, the distributional effects of each policy and the ultimate goals of policy makers. Two OECD reports, in which these aspects are discussed, are particularly helpful when comparing among different approaches (Organisation for Economic Cooperation and Development, 1994a, b).

APPENDIX 3: LITERATURE REVIEW ON APPROACHES TO VALUING INDUSTRIAL WATER USE

Demand-side management of industrial water use requires information on price elasticity of demand for industrial water (i.e. the responsiveness of industrial water use to changes in water prices); as well as information on the marginal value of water use by different sectors. Information on price elasticity of demand can only be obtained empirically (Renzetti, 2003), and in the case of industrial water use, such empirical research is lacking, largely because "[little] is known about the role of water in the production process and the substitution possibilities between water and other production inputs" (Féres and Reynaud, 2005: 396).

Likewise, "in order to achieve an efficient level of water use…, it is necessary to balance the marginal costs and benefits of consumption, where the latter can only be estimated by determining [the specific user group's (e.g. industry's)] valuation of water use" (Renzetti, 2003: 4). While numerous studies have assessed domestic and agricultural water demand and the valuation of these groups' water use, very few studies have analysed industrial water demand and the value of industrial water use, particularly in developing countries (Féres and Reynaud, 2005; Renzetti and Dupont, 2003; Wang and Lall, 2002).

A small number of studies have attempted to model the structure of industrial water demand (Dupont and Renzetti, 2001; Renzetti, 2002), but specific research regarding the value of industrial water use, and the determinants of these values, is limited (Renzetti and Dupont, 2003). Therefore, "while it is commonly believed that industrial water use is a relatively high-value application of water, there is actually relatively little empirical evidence to support this" (Renzetti and Dupont, 2003: 1). This lack of research into the value of industrial water use is particularly evident in developing countries due to a lack of firm-level water consumption and price data (Féres and Reynaud, 2005; Kumar, 2004; Wang and Lall, 2002). Thus, due to data availability problems, empirical evidence on industrial water demand in developing countries is particularly scarce. This is problematic especially in the context of ongoing water policy reforms and increasing quality-related water problems that most developing countries experience (Féres and Reynaud, 2005). Nonetheless, four developing country studies (Féres and Reynaud, 2005; Kumar, 2004; Onjala, 2001; Wang and Lall, 2002) were found in the literature; these are discussed in detail below. Summaries of their findings are presented in Table 12. In addition, Table 11 presents findings from studies in developed countries.

Table 11: Estimates of industrial water demand in developed countries

Author	Location	Data	Method	Price elasticity of demand
Turnovsky (1969)	Massachusetts	Cross-section & time-series (1950-1965)	Single equation demand model. Water price is ratio of total cost to total quantity	-0.5
Grebenstein and Field (1979)	USA (state-level)	Cross-section Aggregate data	Single translog cost function	-0.33 to -0.80
Babin *et al.* (1982)	USA (several industries)	Cross-section Aggregate data	Translog cost function	0.14 (food) -0.66 (paper & wood)
Williams & Suh (1986)	-	-	Estimate water demand using linear & log-linear forms.	-0.735 (avg) -0.438 (marginal)
Renzetti (1988)	British Columbia	Cross-section, firm-level, 1981	Cobb-Douglas cost function to derive demand function (4 water-use types)	-0.12 (Petrochemicals) -0.54 (Light Industry)
Schneider & Whitlach (1991)	Columbus, Ohio	-	GLS regression to estimate 8 single equation demand models.	Very weak
Malla & Gopalakrishnan (1999)	Honolulu, Hawaii	Time series	Water function of price & output, where labour is used to proxy output	-0.32 to -0.39 (food) -0.07 to -0.11 (other)
Dupont & Renzetti (2001)	-	-	-	-0.77
Renzetti & Dupont (2003)	Canada	Cross-section of industries for each of 3 years	Restricted translog cost function where water is a quasi-fixed input	-0.13
Reynaud (2004)	France	-	-	-0.10 to -0.79

Table 12: Estimates of industrial water demand in developing countries

Author	Location	Data	Method	Price elasticity of demand
Onjala (2001)	Kenya	Time series & cross section data (1996 – 2000) on input prices & production levels	Estimate single water-demand equations using a dynamic adjustment model	-0.60 to 0.37 (high variation across sectors)
Wang & Lall (2002)	China	Cross-section Firm-level data, 2000 firms, 1999	Marginal productivity approach, i.e. estimate a translog production function and an associated model on water demand	-1.0 (avg)
Kumar (2004)	India	Panel data 1996/7 - 1998/9	Input-distance function (in translog form) estimated using linear programming. Cost function is dual of input distance function.	-1.11 (avg)
Feres & Reynaud (2005)	Sao Paulo, Brazil	Cross-section (1999)	Translog cost function (including effluent emissions)	-1.08 (avg)

The main results of these developing-country studies are: (1) industrial price elasticities are small but in general higher than domestic ones; (2) price elasticity estimates strongly depend upon the industry (sector) considered; (3) water and labour are mostly substitutes whereas capital and water are complementary inputs; and (4) water price elasticities are greater than those for developed countries, except for Onjala's (2001) study of water use in Kenya. According to Kumar (2004), it is difficult to attribute this trend to structural differences. Rather, it could be due to the difficulties of getting accurate water-related data in developing countries. In Kumar's study, for example, the water price corresponds to the marginal cost; whereas the prices paid by Indian farmers are far below this level, leading to an upward bias in the estimates.

The value of water for industry can only be determined through knowledge of how water is used in the production process of firms and being able to model this process. The existing research in this area is presented below based on the methodology used to model this process and thereby to estimate industrial water demand. The main findings of each of the studies presented below are summarised in Tables 11 and 12.

The methods proposed and developed to estimate industrial water demand and the value of industrial water use fall into two main categories: (1) *direct* (based on actual market prices for water) and (2) *indirect* (estimated by modelling how water enters the firm's production process). The most appropriate method to use depends on how the industry gets its water and on the data that is available. The simplest case is where market prices and quantities exist and industrial water demand can be estimated directly from these data. In cases where raw (untreated) water intake is acquired at little or no cost, or where there is insufficient data regarding the price paid, other valuation techniques that do not rely on the market price can be used to infer the value of industrial water use indirectly (Renzetti and Dupont, 2003) and to estimate water demand. Each of these methods (direct and indirect) is presented below, along with a summary of the literature pertaining to each.

A3.1: Direct methods: Using data on prices and quantities

The simplest case is where firms pay per unit intake of raw water (i.e. a market price exists) and where adequate data are available regarding the price paid (Renzetti and Dupont, 2003). In this case, firms' valuations of water can be estimated based on the market price paid; assuming that prices can be seen as an adequate proxy of the marginal value of water use (which is often not the case). The market price "indicates the firm's marginal willingness to pay for intake water and, as such, provides a minimum bound on the firm's valuation of [marginal] quantities of intake water" (Renzetti and Dupont, 2003: 3). Furthermore, if data on water consumption exists, it may be possible to estimate firms' demand for intake water based on the market price and on consumption (quantity demanded), from which firms' total willingness to pay for (and thus total valuation of) intake water can be inferred. An example of this is where Malla and Gopalakrishnan (1999) estimate urban (industrial and commercial) water demand in Hawaii as a function of price and output/sales level:

$$W = f\ (P, O) \tag{A3.1}$$

Where, *W* = water consumption per month by a company; *P* = the real price of water; and *O* = output. For estimation purposes, sales/output data were not available so ‘number of employees’ was used as a surrogate. Food and beverage processing industries were among the top water users; therefore a separate equation was estimated for this industry. The rest of the industrial users were lumped together and dummy variables were introduced to account for differences in the type of industry activity.

A3.2: Indirect methods

A3.2.1: Ratio of total expenditure to total quantity of water demanded

When data on water prices and quantities are not available, or when actual water prices cannot be used as a reliable proxy of the marginal value of water use (which is often the case), water demand must be estimated indirectly. Early studies (e.g. Turnovsky (1969), Rees (1969), De Rooy (1974)) did this by estimating single-equation water demand models where the ratio of total water expenditures to total quantity purchased was used as a proxy for price. Price is therefore estimated based on the average cost of water, and can then be used to infer marginal or total willingness to pay (value). This approach is problematic, however, as it fails to account for the contributions to production of non-water inputs, and for differences in revenue across firms that arise from factors other than water use, such as the structure of output markets (Renzetti and Dupont, 2003). Another problem with this approach is that water quantity appears on both sides of the demand equation, which may introduce simultaneity bias.

A3.2.2: Cost function approach

The early studies on industrial water demand modelling have been extended in a number of ways, such as by including water as an input in a cost function (commonly in the form of Cobb-Douglas or translog functions), along with traditional inputs such as labour, capital and raw materials; and using the average cost to estimate price (e.g. Grebenstein and Field (1979); Babin *et al*. (1982); Féres and Reynaud (2003)). In these cases it is assumed that the sector's technology may be characterised by a cost function which is dual to the production function and which relates the total cost of production to the prices of the inputs and the level of output.

For example, Onjala (2001) analysed industrial water demand in Kenya by estimating a translog cost function. The marginal price of water was found to be an insignificant parameter in all industrial user categories (self-provided and publicly dependent), except in paper mills. Specifically, the average price elasticity of demand for water intake in paper mills ranged from -0.21 to -0.37; in the leather tanning industry from -0.35 to -0.60; and in the textile industry from -0.09 to -0.14. Some of the general findings of the study were as follows: Firstly, overall, the beverage sub-sector consumes the most water followed by the leather and textile firms. Second, there is a predominance of private intake systems among firms, even in cases where public supply seems less stochastic. Finally, there is an apparent over-capitalisation by firms for water sourcing (mainly due to water supply constraints).

Renzetti (1988) also uses a cost-function approach, but considers four separate components of industrial water use, namely intake, pre-use treatment, internal recirculation and discharge. The prices for the last three of these were proxied by their respective average costs. Renzetti then used these data within a Cobb-Douglas cost function to derive the demand function for water. Kumar (2004) states that the results from these studies should be considered with caution since they are based on aggregate data and do not take into account the specificity of water as an input. Moreover, water quantity appears on both sides of the demand equation, and therefore may introduce simultaneity bias. Another problem with these approaches is that they use average cost as a proxy for price, which is not consistent with economic theory since firms respond to marginal (rather than average) costs in their decision-making processes (Kumar, 2004).

None of the studies listed above integrates effluent emissions when estimating the industrial cost function (i.e. they assume that production and discharge decisions are separable). Féres and Reynaud (2005: 397), however, argue that "effluent control decisions cannot be considered *a priori* separable from production decisions;" and then attempt to integrate effluent emissions when estimating industrial cost functions[31] for Brazilian firms. They do this by considering effluent discharge as a joint negative output of the production process, and thereby assessing the impact of environmental regulation on firms' production decisions. Due to the lack of pollution monitoring systems in developing countries, however, plant-level

[31] Estimating industrial water demand requires the ability to fully identify the cost structure of firms as water can be viewed as an input to the production process.

effluents are not systematically measured. Consequently, Féres and Reynaud construct an index measuring effluent discharge to overcome this problem.

Féres and Reynaud ask three questions in their study of industrial water use in Brazil: (i) How does water enter the production function and what are the complementary or substitutability relationships between the different inputs; (ii) What can be said about the price elasticity of industrial water demand in Brazil; and (iii) What are the effects of new environmental policy instruments (e.g. water charges or environmental norms) on firms' costs and input choices? They conclude that Brazilian firms exhibit significant price elasticity, approximately -1.0 on average for their sample; and that implementation of water charges will only have a limited impact on firm's cost. Therefore, given the low impact on cost and the high responsiveness of water demand to price, water charges may be both acceptable by firms and act as an effective instrument for water conservation. Their simulations also provide evidence of the strong relationship between effluent discharge and industrial water needs, implying that reductions in effluent discharge may lead to a substantial increase in water demand. Hence, water managers face a trade-off concerning environmental goals: water quality improvement policies may have a detrimental effect on water conservation.

Another approach involves the use of restricted cost or profit functions, which treat water as a quasi-fixed input, that is, an input whose quantity is fixed in the short run and can only be changed in the long run (Renzetti and Dupont, 2003). The coefficients of the estimated cost or profit function are then used to estimate shadow values for water. In practice, however, the use of this approach has largely been restricted to agricultural water use (e.g. Moore, 1999; Moore and Dinar, 1995); with limited application to industrial water use (Renzetti and Dupont, 2003).

Finally, when data on both water prices and quantities are unavailable, "some analysts have examined the marginal cost of in-plant water recirculation as a proxy for the marginal value of intake water" (Renzetti and Dupont, 2003: 4). Since recirculated water is a substitute for intake water, the marginal cost of recirculation can be seen as the firm's marginal willingness to pay for intake water. Recirculated water, however, is not a perfect substitute for intake water, since such water may be of a lower quality than intake water. On the other hand, recirculation may bring benefits to the firm that are absent in the case of intake water use, such as reclaimed heat or materials, or avoided effluent charges (Renzetti and Dupont, 2003). Gibbons (1986) reviews these studies.

A3.2.3: Marginal productivity approach

To address the average cost problem, Wang and Lall (1999, 2002) develop a marginal productivity model for valuing industrial water use, where water is included along with capital, labour, energy and raw materials as inputs in a production function. Production functions describe the relationship between a firm's inputs and outputs. The production function associated with a particular firm's product can be defined as the mathematical expression of the relationship between the quantity of a firm's output, and the quantity of one or more inputs (Miller and Meiners, 1986). It can take the form of a "table, a graph or an equation showing the maximum output rate that can be achieved from any specified usage rates of inputs" (Mansfield, 1988: 160) given the prevailing technology. Production functions take the following general form:

$$Q = A\ (K, L, W, E, M, etc) \qquad \text{(A3.2)}$$

Where *Q* represents the quantity of output; *K, L, W, E* and *M* are the quantities of inputs (respectively capital, labour, water, energy and raw materials) used in producing the output; and *A* represents technology, which determines the relationship between output and inputs.

The production function can be estimated econometrically using ordinary (or generalised) least squares regression techniques, and once estimated can be used to provide information on the contribution of water use to the industrial production process and to highlight sector-specific differences in the value of water. Once the production function has been estimated, the marginal productivity of industry with respect to water can be determined by taking the first partial derivative of the estimated production function with respect to water and multiplying this by the average value of output per unit of water input[32].

This approach of using the marginal productivity to estimate the value of water use by industry was first proposed by Wang and Lall (1999, 2002), who develop a marginal productivity model for valuing industrial water use, where water is included along with capital, labour, energy and raw materials as inputs in a production function.

[32] In a similar manner, the marginal productivity of capital, labour, and other factors of production (inputs) can be calculated.

Wang and Lall posit a translog[33] production function (which is quadratic and therefore twice differentiable), where the value of output is determined by five inputs, capital (*K)*, labour (*L)*, water (*W*), energy (*E*) raw materials (*M*); and assume the existence of constant returns to scale. The marginal productivity of industry with respect to water is determined using this production function. Associated with this marginal productivity approach, a model on price elasticity of water demand is developed by assuming price is equal to the marginal cost of water use. These models were estimated using data on 2000 firms in the Chinese manufacturing sector.

Wang and Lall were the first to apply an econometric analysis to a developing-country context. They estimate that the marginal value of industrial water in China ranges between 0.9 Yuan m^{-3} (metal mining) and 26.8 Yuan m^{-3} (transportation equipment), with an average value across all sectors of 2.45 Yuan m^{-3}. Although this figure is relatively low, it is higher than water prices at the time, which ranged between 0.7 and 1.2 Yuan m^{-3}. This suggests that prices can be increased to reflect firms' willingness to pay. Furthermore, the price elasticity of industrial water demand was estimated at -1.0, implying that a 100% increase in prices would result in a 100% decline in water use, which indicates a very high responsiveness to price. This indicates that higher prices can be used as an instrument to ensure water conservation (Wang and Lall, 1999, 2002). Thus, both of these findings (the relatively high value of industrial water compared with water prices, and the high responsiveness of industrial water use to changes in price), suggest that prices can and should be increased.

A criticism of Wang and Lall's study, however, is that because the explanatory variables used were input quantities and the data was plant-level data, the estimated equation suffers from simultaneity bias and multicollinearity; and that these problems were not corrected for by the authors.

A3.2.4: Input-distance function approach

As indicated above, a firm's production technology can be modelled using the production function, the profit function or the cost function; from which one can derive the compatibility between the demand for inputs and the production of outputs. Kumar (2004), however, adopts a different approach to modelling the production process of firms; using a distance

[33] The transcendental logarithmic (translog) production function was first proposed by Christensen et al (1973) and provides a greater variety of substitution-of-transformation patterns than those restricted by the constant elasticity of substitution implicit in the traditional Cobb-Douglas function.

function to measure technology. This 'input-distance function' "completely describes multiple output technology and is dual to the cost function" (Kumar, 2004: 3). The advantages of the input-distance function are that it allows for multiple outputs and joint production; no information on input prices is required; no specific behavioural goal is embedded (e.g. cost minimisation); and it allows one to calculate the shadow prices of the inputs.

Kumar investigates the water demand of Indian manufacturing plants. Data used are from 1996/97 to 1998/99, for a sample of 92 firms (which may not be fully representative), and include: sales value, capital stock, wage bill, other material input costs and water consumption. A number of sectors were sampled, including leather, distilleries, chemicals, sugar, paper and paper products, fertilisers, pharmaceuticals, petro-chemicals, and miscellaneous.

Kumar estimates the input-distance function using a translog form, since this form is twice differentiable and flexible. Since the input-distance function is the reciprocal of the input-based measure of *technical efficiency,* the parameter estimates determine the technical efficiency of industries; of which the mean = 0.46; chemicals (worst) = 0.34 and leather (best) = 0.64. The *shadow price of water* is calculated by making the assumption that the observed price of one of the inputs is equal to its shadow price. The shadow prices of water are positive, implying that it is a normal input, and there is large variation across firms and industries, which is explained by the degree of water intensity (water used relative to sales value). The shadow price of water is found to be increasing with the degree of water intensity of firms. The average shadow price for water is 7.21 rupees kl^{-1}. *Cross and own-price elasticities* can be derived from the distance function. All own-price elasticities have the expected negative sign. The own-price elasticity for water is high (-1.11) at the sample mean. This suggests that pricing policies can be a potential instrument for water conservation. The cross-price elasticity for water shows water to be a substitute for capital and a complement to materials and labour[34].

[34] The own-price elasticity of demand for materials is more elastic than all other inputs. The cross-price elasticity of demand shows labour to be a complement to all other inputs, as is materials. Capital, however, appears to be a complement to materials and labour and a substitute for water.

APPENDIX 4: INDUSTRIAL WATER USE IN SA: RESULTS OF THE NATSURV STUDY

Previous research for the WRC (including the NATSURV reports and more recently WRC Report K5/1547) provide information on water use and effluent discharge by the various industrial sectors in South Africa. The NATSURV study was carried out to: (1) establish a database containing information on water intake, raw-material use, products, waste-water quality and waste-water quantity, to determine targets for water intake and pollution loadings that could reasonably be achieved by industry; and (2) establish areas where research is needed to assist industry in improving its water and waste-water management at minimum cost or even to its own advantage. In conducting the study, 539 companies were surveyed and reports compiled for 16 priority industries[35].

The findings of the NATSURV study for 14 of the 16 priority industries are summarised in Table 13. The industries are sorted in descending order based on their specific water intake (SWI) values. The SWI is the volume of water required per unit of product for a given industrial activity, and allows for the relative water-use efficiencies to be compared between industries.

Some significant findings from this research, with particular reference to the Vaal-Barrage catchment area responsible for producing about 50% of the country's gross national product (GNP), and experiencing the greatest water demands and supply shortage, include:

- 48% of the 289 ML of water intake per day (106 km^3 yr^{-1}) is returned via sewage works or directly to water courses (34% of the water returned directly to water courses is discharged via on-site treatment works). Clearly, the quality of the wastewater generated is as important as water use efficiency; as an industry with a large water intake will discharge large amounts of wastewater, irrespective of its efficiency. Indeed, the NATSURV study provides data on the quality of wastewater discharges in addition to data on water intake and water use efficiency. However, since the focus of the current study is only on water intake, data on wastewater quality is not presented here.

[35] The 16 priority industries were: malt brewing (NATSURV 1 TT 29 / 87), metal finishing (NATSURV 2 TT 34 / 87), soft drink and carbonated waters (NATSURV 3 TT 35 / 87), dairy (NATSURV 4 TT 38 / 89), sorghum malt and beer NATSURV 5 TT 39 / 89, edible oil (NATSURV 6 TT 40 / 89), red meat (NATSURV 7 TT 41 / 89), laundry (NATSURV 8 TT 42 / 89), poultry (NATSURV 9 TT 43 / 89), tanning and leather finishing (NATSURV 10 TT 44 / 90), sugar (NATSURV 11 TT 47 / 90), pulp and paper (NATSURV 12 TT 49 / 90), textiles (NATSURV 13 TT 50 / 90), wine (NATSURV 14 TT 51/90), oil refining and re-refining (NATSURV 15 TT 180 / 05) and power generating industries (NATSURV 16 TT 240 / 05).

- The total water intake figure of 106 $km^3 yr^{-1}$ is very low compared with the 1986 WRC estimate of 335 $km^3 yr^{-1}$.
- Industry improved their water management considerably between 1980 and 1990, making further reductions difficult to achieve for most industries (e.g. the SWI for the malt brewing industry reduced from an average of 9 ML of water per ML of beer to about 6 ML per ML in the ten-year period).
- Three super-factories used 67% of the total water intake and a further 28% of the water intake was used by just ten other companies.

Table 13: Aggregated water-intake data for 14 priority industries from the NATSURV project, sorted in descending order based on specific water intake (SWI)

Industry	SWI	Min SWI	Max SWI	Target SWI	Units	Total Water use (kl / yr)	Total Output	Output units	*n*	Location
Textiles	176.91	95.00	458.94	-	kl per tonne	30 000 000	-	tonnes	-	W. Cape, E. Cape, & Natal
Pulp and paper – Entire	54.75	17.00	92.50	-	kl per tonne	-	3,000,000	tonnes	21	-
Poultry- Entire	18.15	21.79	24.29	17.50	kl per 1000 birds	6 000 000	330,000,000	birds	140	-
Laundry – Entire	15.10	8.00	58.40	-	kl per tonne	3 000 000	-	tonnes	-	Every city throughout SA
Malt beer brewing	7.15	5.50	8.80	5.00	kl per kl of beer	8 700 000	1,200,000	kl	8	-
Dairy – Entire	4.71	2.73	7.97	2.71	kl per kl	-	-	kl	150	Throughout SA
Sorghum malt	3.40	2.50	12.30	3.40	kl per kl	630 000	185,400	tonnes	33	Gauteng (40%) & Natal (25%)
Edible oil – Entire	3.25	2.65	3.85	-	kl per tonne	1 750 000	-	tonnes	16	-
Sugar	3.00	1.50	5.00	-	kl per tonne of sugar	-	12,000,000	sugar	16	-
Soft drinks & carbonated water	2.70	-	-	2.30	kl per kl of soft drink	4 000 000	1,500,000	kl	-	Most large cities
Wine – Entire	2.53	0.97	4.23	0.00	kl per output	0	900,000	kl	-	W. Cape & N. Cape
Sorghum beer brewing	2.50	2.30	4.80	2.50	kl per kl	2 750 000	1,100,000	kl	36	Gauteng (40%) & Natal (25%)
Red meat – Entire	1.55	0.71	3.80	-	kl per cattle unit	5 800 000	3,745,000	cattle units	285	Main cities
Tanning & leather finishing	0.43	0.32	0.74	0.43	kl per hide	600 000	2,000,000	hides	20	Gauteng; Free State; Natal; W.Cape; E.Cape
Metal Finishing – entire	0.27	0.03	0.88	0.1 - 0.2	kl per m^2 treated surface	9 000 000	-	m^2 treated surface	-	PWV

APPENDIX 5: COVER LETTER AND QUESTIONNAIRE DISTRIBUTED TO COMPANIES

WATER RESEARCH COMMISSION

CSIR our future through science

Water use questionnaire

Water is becoming an increasingly scarce and expensive input in industrial production processes. Improved water use efficiency has therefore become an important way of managing water-related risks and reducing production costs. In addition, customers and shareholders are increasingly concerned with companies' environmental performance, including their water footprint.

The CSIR is conducting research to help companies manage these costs and risks, and to benefit from the competitive advantage of an improved water footprint. You are invited to participate in this important research by completing a brief questionnaire aimed at helping companies take advantage of these opportunities. The questionnaire consists of just seven questions, takes approximately fifteen minutes to complete, and is completely anonymous and confidential – we will not ask you to provide your company's name or contact details.

Responses will be used to assess the efficiency of water use per Rand of output generated by industry in South Africa. As such, we require information on your company's revenues, as well as various inputs (fixed capital, labour, water and energy), for the most recent financial year for which you have information. Most of this information should be available in your company's annual report or financial statements, water and electricity bills, or sustainability / corporate social responsibility report. Otherwise, please forward the questionnaire to someone in your company who may have this information.

Again, we must emphasise that your responses will be kept strictly confidential - all information will be used for the sole purpose of calculating an industry-wide production function.

Do try to complete the entire questionnaire - if you have insufficient information to answer a particular question, please provide an estimate, rather than leaving the answer blank. For example, if you don't know your company's annual water or electricity consumption, simply multiply the most recent monthly consumption by 12. Please feel free to contact us if any of the questions are unclear.

There are various options for completing and returning the survey to us, depending on what is most convenient to you:

1. Go to: https://www.surveymonkey.com/s/78WPJ9G to complete the questionnaire online
2. Complete the attached questionnaire and return to us by
   - e-mail: wdelange@csir.co.za, or
   - fax: 021 886 6518 (for attention Willem de Lange)

Please return your questionnaire by 30 April, 2012. Many thanks in advance for participating in this exciting and ground-breaking research!

Dr Willem de Lange
Council for Scientific and Industrial Research
PO Box 320, Stellenbosch, 7599
Tel: 021888 2462

Water Use Questionnaire

CONFIDENTIAL

WATER RESEARCH COMMISSION

CSIR our future through science

1. In which sector does your company operate? (e.g. pulp and paper, automotive, food and beverage, textiles, etc)	
2. What is its core business? (e.g. paper manufacturing, motor vehicle assembly, wine making, leather products, etc)	
3. Total number of employees (including permanent, contract, full time and part-time) at the end of the last financial year:	
4. Stated revenue (as per income statement) for the last financial year (SA Rands):	
5. Book value of tangible fixed assets (property, plant & equipment) as per balance sheet / statement of financial position at end of last financial year (SA Rands):	

6. Complete either 6a or 6b. You may wish to consult your water bills or sustainability report.

6a. Please state your annual water use from each source; OR

6b. Please state your total annual water use

	Source	Annual water use	
		Volume	*Unit of measure*
6a	Water purchased from a water service provider (e.g. municipality or water user association)		
	Self-supplied water (water drawn directly from source; not internally recycled/re-used water) (if applicable)		
OR: 6b	Total water use (intake water only; i.e. excluding internally recycled/re-used water)		

IMPORTANT: Please specify the unit of measure (e.g. hL, kL, m^3, ML)

7. Complete either 7a or 7b. You may wish to consult your energy bills or sustainability report.

7a. Please state either your annual consumption, OR your annual expenditure, for each of your main sources of energy use.

7b. ALTERNATIVELY, please state your total annual energy use from all sources combined (typically reported in Joules, Megajoules or Terajoules):

	Source		Annual Consumption		OR Annual Expenditure (Rands)
			Consumption	*Unit of measure*	
7a	Electricity (From National Grid)				
	Coal (if applicable)				
	Diesel (if applicable)				
	Other (e.g. crude oil, LPG, paraffin, butane, propane, wood, bagasse etc.)	*Specify:*			

IMPORTANT: If stating your consumption, please specify the unit of measure (e.g. kilowatt hours (kWh), megawatt-hours (MWh), litres (L), kilolitres (kL), tonnes (t) etc.)

OR: 7b	TOTAL ENERGY USE		

IMPORTANT: Please specify the unit of measure (Joules (J), Megajoules (MJ), Terajoules (TJ) etc.)

Thank you for completing the questionnaire!

Please return to: wdelange@csir.co.za OR by fax to 021-886 6518