The determinants of urban residential water demand in Sydney, the Blue Mountains and Illawarra

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INDEPENDENT PRICING AND REGULATORY TRIBUNAL
OF NEW SOUTH WALES

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Increasing policy discussion about the need to reduce Sydney's water demand to ensure its long term sustainability with existing water supplies has led to considerable interest in alternative pricing structures and factors which influence residential water demand. By developing a model of residential water use in the Sydney region, the contribution of water using appliances and the implications of household size, income and payment of water usage charges on total water demand are estimated.

The results show that the payment of water usage charges by the household has the most significant impact on average annual water demand. Households are estimated to use on average 19 per cent more water if they do not pay water usage charges.

The results also show that the number of occupants of a household has a significant and large impact on average annual water demand. Income also has a significant but small effect, possibly because the influence of swimming pools and household size are specifically accounted for in the model.

The estimated model can be used to consider the likely effect of water saving appliances on total water use, as well as provide an understanding of the characteristics of water users when setting prices.

1 The author wishes to thank Professor Robert Bartels from Sydney University for useful comments on an earlier draft of this paper, and Brett Everett of IPART for his assistance with the data verification and checking of the household survey data which allowed this analysis to be undertaken. This paper does not in any way reflect the views or opinions of the Tribunal. The author accepts full responsibility for any errors or omissions. For further correspondence or queries on the methodology used the author may be contacted at adrian_kemp@ipart.nsw.gov.au.

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1 INTRODUCTION

As an alternative to directly measuring the contribution of indoor and outdoor water use on a residential household's total annual demand, statistical methods applied to survey data can be used. This approach also allows the estimation of the impact of household size, income and the payment of water usage charges on the total water demand by end-uses. This information is useful to a water utility and regulators as it provides information on the influences of household characteristics on residential demand.

During 2003, IPART undertook a survey of residential households in Sydney, the Blue Mountains and Illawarra regions, collecting data on a range of household characteristics.[2] These included:

- water and energy consumption
- household income
- household size and structure
- payment of water usage charges
- the number of water and energy using applications in the household
- property size and type (for example apartment or house) and
- a range of other factors which may influence water and energy demand.

Water and energy consumption data were collected from the relevant utility after obtaining the consent of the survey respondent.

The survey was conducted between June and August 2003 and involved face to face interviews with over 2600 households. Both residential houses and units were included in the survey. Where metered consumption was not available, for example water consumption in bulk metered units, the consumption was estimated based on the average consumption for each unit in the block.

The survey data has allowed the Tribunal to gain a better understanding of the characteristics of water used by households, by conducting a partial analysis of the relationships between income, consumption and household size amongst others. This paper takes the analysis a step further by considering the independent relationships between various end uses and household characteristics.

This paper investigates the literature on the estimation of water demand, and develops a model of the determinants of water demand which can be applied to Sydney. The 2003 IPART household survey data is then used to estimate the model before general conclusions are drawn.

2 See IPART (2004) for an analysis of the survey results including summary statistics for all of the variables collected.

2 THE LITERATURE ON THE ESTIMATION OF WATER DEMAND

Most of the literature on the estimation of water demand has been undertaken within the United States[3] and Europe, where supply expansion has been limited, and policy makers have wanted to examine alternative demand management techniques, including understanding the impact of price changes. Pint (1999) notes that the pressure to consider demand management has come from increasing environmental standards impacting on the cost of water, concern about the environmental impacts of expanding supply capacity, and the possibility of global climate change increasing the uncertainty of weather patterns which may increase the variability of rainfall patterns. With concerns about the sustainable water supply falling in New South Wales and the need to provide water for environmental purposes in the Hawkesbury Nepean river system – which would need to be sourced from water in the supply catchment – there is renewed focus on demand management options including the use of price.

A concern with using US and European studies to draw conclusions on water demand in Australia is how applicable they are to conditions within Australia. For example, the contribution of a swimming pool is unlikely to be the same in Europe, compared with the United States and certainly Australia. An understanding of the conditions where water demand is being analysed is critical, both when formulating an econometric model for estimation, and also when interpreting its results.

Nieswiadomy and Molina (1988) when discussing an insignificant price effect in their model, argue that other factors may be influencing the outcomes of significant price effects in earlier studies. They argue that whilst Billings and Agthe (1980) find a significant price effect in their model, the result may have been because the price structure change occurred at the same time as a significant education campaign to reduce water use. Once this campaign had ended Martin et al (1984) found that water use per capita rose again to levels prior to the campaign. Nieswiadomy and Molina argue that the price effect was therefore masking the causal impact on demand from the education campaign.

Understanding local factors influencing demand is therefore important when developing the water demand model for estimation. Hansen (1996) when estimating water demand in Copenhagen incorporates the cost of energy in their model because approximately two thirds of water is used for heating purposes.

The study most frequently cited when considering water demand in Sydney is Warner (1995). This study estimated price and income elasticity using aggregate level data for water consumption, income and price. Climatic conditions and water restrictions were explicitly factored into the model which was estimated for the period of 1959/60 to 1993/94. The average price elasticity was estimated to be -0.13.

Warner's work is similar to most of the early US studies by using aggregate household data either for a given city over a period of years or between cities for a given year. Hanke and de Mare (1982) note that using cross sectional aggregate data especially across cities requires the assumption that the relative effects are consistent across these cities. They argue that it is

[3] See for example Jones and Morris (1984), and Hewitt and Hanemann (1995). For a useful discussion of the literature including practical issues on the estimation of residential water demand see Gracia, Valina and Martinex-Espineira (2003).

difficult to use price elasticities estimated on cross sectional data between cities for a given year, and apply it to a single city through time, due to the inconsistency between estimation and application.

Despite concerns about the applicability of studies based in the US and Europe for Australian residential water demand, they are useful for comparative purposes with estimates based on Australian data. Gracia, Valina and Martinex-Espineira (2003) in their review of the literature indicate that price elasticities have been calculated in the range of -0.02 to -0.96 and income elasticities in the range of 0.051 and 7.829. Given the consistency of the price elasticity results, it is reasonable to conclude that price elasticity for water demand is likely to be low and somewhere within this range.

Consideration of the variables included in other water demand studies and how they were formulated is important for considering water demand in Sydney. As many of the studies use aggregate data, income is incorporated either through the use of a wealth proxy variables such as land value, or by the use of income data from census information. Invariably the effect has been found to be positive.

Household size has also been considered important where household consumption is used. Most studies have found that there are economies of scale associated with increasing household numbers. Arbues et all (2000) however found that there was some point beyond which the increasing economy of scale reverses.

A number of studies have also focussed on the relationship between indoor and outdoor water use. For example, Carver and Boland (1980) considered aggregate water demand in winter and summer, finding that winter demand was less sensitive to price changes than summer demand. Despite this seasonal variation in the price elasticity estimates, the estimated price elasticities for both winter and summer were still low. There has been other studies looking at the price elasticity of water used in sprinklers (Howe (1982)) finding that it was higher than for other water uses.

Finally, while the focus of this paper is on residential water demand, when considering demand management policy options, invariably an understanding of industrial water demand is also important. There have been a very limited number of studies investigating industrial water demand, and these have produced price elasticities in the range of -0.08 to -1.16 (Reynaud 2003). The difficulty with these estimates is that they are expected to be very specific to the locality and conditions at the time of estimation, given the diverse nature of industrial water use.

3 A CROSS-SECTIONAL MODEL OF WATER DEMAND

The literature on water demand focuses primarily on the impacts of price, income and a range of other factors on the demand for water, mainly by residential household customers, for water. The data used is typically time series aggregate data due to it being readily available. The use of individual household data has only been used in a limited number of studies, mainly due to the costs associated with collecting the large amount of data needed to analyse demand.

Given the availability of a consistent set of residential household water consumption, income and demographic characteristics data for the Sydney region, a model is developed to estimate the determinants of water demand within a year. This model will not allow the consideration of price change impacts on water demand – a critical question for the section 12 investigation into alternative price structures for Sydney Water (IPART 2003) – but will assist the Tribunal in its identification of the characteristics of different water users.

Whilst water is used directly for drinking purposes to sustain human life, this is a very small proportion of overall water demand in a community. Most water is demanded for indirect uses such as for garden watering, clothes and dish washing, flushing toilets, swimming pool and spa uses, and car washing amongst others. Water therefore is an input to the enjoyment of a range of other benefits around a home.

Consider water demand to be a function of price such that y = f(p), where f′(p)<0 to acknowledge that demand is downward sloping with respect to price. There are a range of functional forms considered in the literature. A common approach is to consider the constant elasticity demand curve where $y = AP^{-e}$. For a constant price, P_0, which can be normalised to 1, q=A. Therefore, within a year, total consumption equals A.[4]

A represents consumption which is not dependent on price. As total water demand is simply the sum of its component uses, total water demand can be broken into its usage components as expressed in equation (1) below.

$$(1) \quad \begin{aligned} Y_i &= b_0 + b_1 \mathrm{Pr}optoil_i + b_2 Pool_i + b_3 Spa_i + b_4 Dish_i + b_5 BMount_i + b_6 Illawarra_i \\ &+ b_7 HrsGard_i + b_8 Small_i + b_9 Medium_i + b_{10} L\arg e_i + e_i \end{aligned}$$

where:
Y_i is total annual water demand for customer *i*; *Proptoil* is the proportion of single flush toilets out of total toilets; *Pool* is a (0, 1) dummy variable indicating whether a pool is owned; *Spa* is a (0, 1) dummy variable indicating whether a spa is owned, *Dish* is a (0, 1) dummy variable indicating whether a dishwasher is owned; *BMount* is a (0, 1) dummy variable indicating if the household is in the Blue Mountains; *Illawarra* is a (0, 1) dummy variable indicating if the household is in the Illawarra region; *HrsGard* is the number of hours per week a garden is watered; *Small, Medium* and *Large* are (0, 1) dummy variables associated with houses located on small, medium and large land areas; $ß_0$ is the estimated water use relating to other end uses not specifically identified such as drinking use, showering, toilet flushing amongst others; $ß_2$, represents the additional water use associated with having only single flush toilets in the household; $ß_2$, through to $ß_4$, reflect the estimated average annual water use associated with each appliance; $ß_4$ and $ß_5$ represent the difference in water use attributable to living in the Blue Mountains and Illawarra, relative to Sydney; $ß_7$ reflects the estimated average annual water use applied to a garden for each hour of watering, and $ß_8$ through to $ß_{10}$ reflects the additional garden water use attributable to block size; and *e* is the error term with independently and identically distributed properties.

By having dummy variables associated with different land sizes of each household it allows these effects to be captured in addition to the length of watering captured in the variable of the number of hours of summer garden watering on average per week.

4 Alternative functional forms can also be considered, for example linear or exponential. So long as f′(p) < 0 holds, then these functional forms could be equally valid.

To capture the potential impacts of variable climatic impacts on water demand, regional dummy variables associated with the Blue Mountains and Illawarra are also included.

If we were simply interested in the direct and indirect average contribution of each item to total water demand, then equation (1) could be directly estimated.

To consider the interactions of income, household size and payment of water usage charges, the end uses were split into discretionary and non-discretionary uses. Discretionary uses included predominately garden watering while non-discretionary uses included in the model were mainly toilet flushing. The constant variable relating to those end uses not explicitly included in the model such as showering, manual dish washing and hosing of driveways and car washing were also considered as having both discretionary and non-discretionary characteristics.

Discretionary uses were considered as having a linear interaction with household income and payment of water usage charges. The interaction was presumed to be different for the constant term, but constant across all the garden watering variables. Non-discretionary water uses were considered as having a logarithmic interaction with household size. This means that as household size increases, the marginal impact on water use decreases. This assumption is consistent with other literature in the area.

Water use associated with dishwashers, spas and swimming pools were considered independent of income, payment of water usage charges and household size. Estimation of more general functional forms confirmed the appropriateness of this assumption.

Given these additional assumptions, the model was modified as expressed in equation (2) below:

$$
\begin{aligned}
(2)\quad & Y_i = b_0 + b_1 \Pr optoil_i + b_2 Pool_i + b_3 Spa_i + b_4 Dish_i + b_5 BMount_i + b_6 Illawarra_i \\
& + a_1 Income_i + a_2 Nopay + a_3 \ln(HHsize_i) + \\
& \left(b_7 HrsGard_i + b_8 Small_i + b_9 Medium_i + b_{10} L\arg e_i\right) \times \left(1 + g_1 Income_i + g_3 Nopay_i\right) \\
& + \left(g_3 \Pr optoil_i \ln(HHsize_i)\right) + e_i
\end{aligned}
$$

where: *Income* is a discrete variable indicating what income category the household is in compared with the modal income category of 1; *Nopay* is a (0, 1) dummy variable if the household is an apartment which does not pay a usage component, or is a tenant who is not required to pay their water usage bill; and *HHsize* is the number of persons in the household compared with the modal household size of 2; and $?_1$ through to $?_3$ reflect the incremental impact on the constant water use associated with income, payment of water usage charges and household size; $?_1$ through to $?_3$ reflects the impact of income, payment of water usage charges and household size on garden water use.

4 THE DATA USED AND MODEL RESULTS

The model described in equation (2) was estimated using data from the IPART 2003 household survey. A summary of the data used is contained in Table 2 below.

Equation (2) was estimated using SPSS version 12.0. The results of the estimations are contained in Table 3 below.

Table 2 Summary of the data

Sample size	**No.**	**2443**			
		Mean		**Minimum**	**Maximum**
Average water use per year	kL	270	*1.3*	1	2612
Proportion of households with:					
- dishwasher	%	35.9	*2.7*	0	1
- washing machine	%	97.8	*0.3*	0	1
- swimming pool	%	11.6	*5.6*	0	1
- spa	%	2.9	*11.8*	0	1
Average number of:					
- Toilets	No.	1.7	*1.0*	0	13
- Single flush toilets	No.	0.8	*2.2*	0.0	6
- Dual flush toilets	No.	1.0	*2.2*	0.0	11
Average hours watering garden in summer	Hrs	1.7	*2.9*	0	25
Proportion with					
- small land size	%	14.4	*4.9*	0	1
- medium land size	%	52.6	*1.9*	0	1
- large land size	%	10.1	*6.0*	0	1
Average number of people living in the house	No.	2.9	*1.0*	1	12
Proportion of households with:					
- concession card	%	39.1	*2.5*	0	1
Proportion living in:					
- Sydney	%	84.8	*0.9*	0	1
- Blue Mountains	%	3.3	*11.0*	0	1
- Illawarra	%	11.9	*5.5*	0	1

Note: Figures in italics represent relative standard errors expressed as a percentage of the estimate.

By using average characteristics for each of the variables, the contribution of each end use to total water consumption was estimated. The constant represented the largest contribution to average water use, almost 66 per cent, or an average of 172kL per household per year. Unfortunately, due to limitations with the survey data collected, we were unable to gain better insights into the composition of this constant amount.

Garden water appears to have made the next largest contribution to water use. The results indicate that for each hour that a household waters the garden in summer, it accounts for almost 7kL of water per year. However, this amount was found to increase with land size. A household on a large block was estimated as using almost 64kL more per annum compared with a household without a garden. Similarly a house on a medium block used 41kL more per annum and a house on a small block only 20kL more.

By considering average hours of summer watering and the incidence of small, medium and large land sizes it is possible to estimate the contribution of garden watering implied in the model to overall water use. Garden watering in 2003 contributed to approximately 23 per cent of average overall water use.

Table 3 Results from equation estimations

	Base		Income		Household size		Payment of water usage	
CONST	164.3	*17.1*	-16.0	*-2.9*	122.8	*14.0*	25.6	*2.1*
PROPTOIL	20.5	*2.9*			22.8	*2.0*		
DSHWASH	25.4	*3.6*						
HRSWARM	6.6	*5.6*						
SMALL	19.5	*2.1*						
MEDIUM	41.4	*4.8*	0.5	*3.6*			0.6	*1.8*
LARGE	63.6	*5.3*						
POOL	52.2	*5.4*						
SPA	38.2	*2.2*						
BMOUNT	-47.0	*2.8*						
ILLAWARRA	-40.0	*4.3*						
R^2	0.32							
F statistic	65.6							

NB: Figures in italics are estimated t-statistics.

The additional contribution of single flush toilets made the third largest contribution, accounting for around 5 per cent of total residential water use. On average, single flush toilets accounted for an additional 21kL per year on average for a household, compared with households with dual flush toilets.

Of the remaining amenities included in the model, dishwashers made the next largest contribution (over 3 per cent of total residential water use, or 25kL per dishwasher), then swimming pools (accounting for over 2 per cent of total residential water use, or 52kL per swimming pool), and finally spas (accounting for less than half a per cent of total water use or 38kL per spa).

The results indicate that household size and the payment of water usage charges are the two most important factors influencing residential water demand. On average a two person household is estimated to use 67 per cent more water than a one person household, and a three person household uses on average 23 per cent more than a two person household.

A household who does not receive a water usage bill is estimated to use an additional 19 per cent more water compared with households which do pay their water usage bill. It is unclear the underlying reason for this difference. The answer is likely to be partly related to these households not receiving an appropriate pricing signal to influence their water using decisions. The difference might also be because people residing in tenanted properties are not responsible for the maintenance and upkeep of water infrastructure within the home.

Finally, the results show that household income has a positive and significant impact on a household's garden water use, but does not have a large impact on total household water demand. The analysis indicates that as a household's income increases from one income category to the next, it uses around 29 per cent more garden water.

However, this increased garden water use is offset in part by reduced water use from other areas as income increases. The negative and significant relationship between income and the constant may reflect that higher income households are more likely to have adopted water saving devices such as water efficient shower heads, and water efficient washing machines or have newer appliances which are in general more water efficient. This result might also suggest that the costs associated with purchasing and maintaining these systems mean that higher income households are more likely to have lower water use in non-discretionary uses.

Finally, the results demonstrate that water use is lower in the Blue Mountains and Illawarra regions relative to Sydney for all residential water users. This might be due to different climatic conditions between the two regions.[5]

5 CONCLUSIONS

This paper adds to the debate about water demand in Sydney by providing estimates of the contribution of appliances, and outdoor water use on average annual water demand. By explicitly considering the impacts of household size, income and payment of water usage bills on average annual demand, it provides some insight into the contribution each has on water demand.

The results show that household size and whether the household receives a water usage bill are the most significant contributors to a household's average annual water use.

Income was found to have a small but significant effect on water demand. Part of the reason why this study has found the impact to be smaller than other studies could be because individual appliances are being specifically included in the model. Large water using factors like swimming pool ownership may be more prevalent amongst higher income households, such that the income effect found in other studies could be masking the contribution of the individual components of water demand.

The model results indicate that outdoor water use represented approximately 23 per cent of total household water demand. If this water use is considered discretionary, it only represents a small component of overall average water demand.

5 An examination of Bureau of Meteorology data comparing Katoomba and Wollongong with Sydney City and Parramatta indicate that mean average rainfall is lower in Sydney compared with Katoomba, and the mean number of rain days is lower in Wollongong compared with Sydney.

The results also demonstrate that whilst an individual end use may make a large contribution to total household water demand, such as for swimming pools, the low incidence of swimming pools in the community results in it only representing 2 per cent of total water use.

Finally, the results in this paper demonstrate the practical applicability of using household survey data to estimate the components of water demand rather than more expensive traditional approaches associated with monitoring actual water use by individual households. The relative importance of components of demand can then be calculated.

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