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Nondiscretionary residential water use: the impact of habits and water-efficient technologies

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Several studies published in the last few decades have demonstrated a low price-elasticity for residential water use. In particular, it has been shown that there is a quantity of water demanded that remains constant regardless of prices and other economic factors. In this research, we characterise residential water demand based on a Stone-Geary utility function. This specification is not only *theory-compatible* but can also explicitly model a minimum level of consumption not dependent on prices or income. This is described as minimum threshold or nondiscretionary water use. Additionally, the Stone-Geary framework is used to model the subsistence level of water consumption that is dependent on the temporal evolution of consumer habits and stock of physical capital. The main aim of this study is to analyse the impact of water-saving habits and water-efficient technologies on residential water demand, while additionally focusing attention on nondiscretionary uses. This is informed by an empirical application using data from a survey conducted among residents of Brisbane City Council, Australia. The results will be especially useful in the design of water tariffs and other water-saving policies.

Key words: conservation economics, demand analysis, water management and policy.

1. Introduction

Australia is the second driest continent and is also the hottest in terms of the duration and intensity of heat (Dillon 2000). Water is scarce, and hence appropriate demand side management (DSM) policies to manage and conserve water supplies are an important policy tool. DSM policies can not only reduce water consumption, but may also encourage the sustainable use of water. DSM can also achieve other objectives such as improving the environmental benefits, achieving ecological sustainability and addressing equity concerns (OECD 2003, 2010).

Effective management and conservation of Australia's dwindling urban water supplies are some of the country's most pressing needs. In order to encourage and enable the public to reduce urban water consumption, it is

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imperative to undertake a critical examination of DSM policies in Australia and determine how these policies can be improved or changed in order to achieve publically acceptable, cost-effective reductions in water consumption. The DSM policies that can be adopted or have been adopted to reduce water consumption have been classified into several categories. On the one hand, there are a number of market-based water-saving strategies including pricing, incentives and subsidies. On the other hand, there are regulatory instruments such as restrictions on water use, quotas, education, persuasive messages or moral suasion measures which have been widely used to produce a similar outcome.

If we look at pricing policies, the majority of studies on residential water demand have found demand to be price-inelastic. One reason is the special character of water supply at the residential level. It is a well-known fact that a householder's water consumption habits tend to be deeply entrenched. Some studies show that there is a minimum amount of water demanded, which is not affected by economic variables (García-Valiñas *et al.* 2010) and is insensitive to change by means of price (or income) variations. This compounds the difficulty of improving the effectiveness and efficiency of water-pricing policies.

Some of the aforementioned measures designed to lower water consumption (basically regulatory initiatives, but also subsidies) have led households to adopt a number of pro-water-saving habits and investments. Despite efforts to promote these kinds of policies,[1] few economists have used cross-sectional household data (see, for example, Renwick and Archibald, 1998; Millock and Nauges 2010) to study residential water consumption.

Therefore, the aim of this study is to address a shortcoming in the literature by characterising residential water demand within the Brisbane City Council (BCC, Queensland, Australia). The analysis is conducted using a cross-sectional household database and focusing on the nondiscretionary quantity of water, that is insensitive to prices and income. We then estimate a demand function based on a Stone-Geary utility function. We seek to establish whether several pro-water-saving habits and investments adopted by households impact on the nondiscretionary amount of water used.

The article is structured as follows. Section 2 deals with a brief survey of the literature on residential water demand, especially those studies which have focused on the Stone-Geary utility framework. Section 3 explains the theoretical fundamentals of the model and our contribution in terms of its

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[1] As Millock and Nauges pointed out (2010, p. 541), 'several state governments in Australia (including Northern Territory, South Australia, Victoria) currently offer rebates for a series of labelled water-efficient products, including rainwater tanks, dual flush toilets and water-efficient shower heads. The rebates vary from Australian dollar (AUD) 10–20 for a water-efficient showerhead to AUD 1000 for a rainwater tank connected to toilet and laundry (for further details, see http://www.smartwatermark.org/home/rebates.asp). Installation of water-efficient devices is seen as an effective manner of inducing water conservation for several reasons'.

empirical specification. Section 4 includes a description of the data set and variables used. The results are discussed in Section 5. Section 6 concludes by summarising the main results and proposing some future guidelines for formulating water use and management policies.

2. Stone-Geary framework: a review

In recent years, the Stone-Geary specification has been widely used in studies relating to residential water use (Al-Quanibet and Johnston 1985; Gaudin *et al*. 2001; Martínez-Espiñeira and Nauges, 2004; Madhoo 2009; Meran and Von Hirschhausen 2009; Nauges *et al*. 2009; Schleich 2009; García-Valiñas *et al*. 2010; Monteiro and Roseta-Palma 2011). One reason for its popularity might be in its empirical foundations. The main focus of earlier studies was the estimation of price elasticities; however, when researchers noticed that estimates of price elasticities were normally very low, they started to wonder whether a basic amount of water use would actually be unresponsive to changes in price in the short run (Arbués *et al*. 2003; Worthington and Hoffman 2008). As we explain in the next section, this specification is not only *theory-compatible,* but can also explicitly model a minimum level of consumption that does not depend on prices.

Al-Quanibet and Johnston (1985) chose the Stone-Geary utility function, whose associated demand curves asymptotically approach nonzero levels of consumption, to show that there might be a role for the minimum level of water demand that is required for subsistence. Utilising an ordinary least squares (OLS) estimation for Kuwait, they obtained a nondiscretionary quantity of water demanded of around 42 L per capita per day. Price elasticity estimated was around −0.77.

Gaudin *et al*. (2001) compared the performance of the Stone-Geary and the generalised Cobb-Douglas functional forms in modelling water demand using US data. Their study had to rely on water *production* data for the dependent variable rather than water *consumption*. As correctly acknowledged by the authors of the study, this resulted in two problems: first, the presence of storage tanks allowed for monthly variations in production that may not reflect monthly variation in consumption, and second, losses to the system were included. Additionally, the authors had only time-invariant census data on population available to derive measures of water consumption per capita during the 5 years analysed. They estimated values of the threshold parameter that ranged between 9.8 m^3/month and 13.4 m^3/month in January and between 17.6 m^3/month and 20.0 m^3/month in July. The elasticity values they derived from the Stone-Geary specification (evaluated at the appropriate means) were lower than those from the generalised Cobb-Douglas production function. The range of price elasticities using the Stone-Geary form, which allowed significant seasonal variation in elasticities, were −0.19 to −0.28, compared with −0.35 to −0.47 using the generalised Cobb-Douglas production function.

Martínez-Espiñeira and Nauges (2004) used the Stone-Geary function to model water demand in Seville, Spain. They proposed two approaches in their empirical application of this functional form. In the first approach, the basic level of water use was assumed constant, while in the second approach, it was allowed to vary according to past levels of consumption, a proxy for households' water-using equipment, and habits. Hence, the study analysed the dynamic evolution of the threshold for the first time in the water-demand literature. They obtained a price elasticity (estimated at the sample mean) of demand equal to −0.10 and an income elasticity of demand equal to 0.10. This value is smaller than the price elasticities previously obtained in other European countries. However, apart from using a different model specification (the Stone-Geary functional form instead of log-log models), their analysis was based on a time-series data set, whereas most other previous European studies have dealt with cross-sectional data. Further, Martínez-Espiñeira and Nauges (2004) estimated a volume of about six cubic metres per month as the amount of water demanded by consumers that is highly insensitive to changes in price. In the conclusion to their paper, the authors suggested that the design of water-management policies should consider that once the threshold is approached as a result of conservation and pricing policies, price policies would barely affect demand below such a level.

In a similar way, Schleich (2009) characterised residential water demand in Germany. Using a database of 593 German communities in 2003, he applied the Stone-Geary framework to detect regional differences in both total and nondiscretionary water demand. Using OLS estimation techniques, he obtained an average minimum threshold oscillating between 66 and 116 L per capita per day. Price elasticities ranked from −0.11 to −0.36. Madhoo (2009) obtained similar results for Mauritius Island using a linear expenditure system, estimating a minimum threshold of around 60 L per capita per day, with an average price elasticity of around −0.06. A similar price-elasticity value was found by García-Valiñas *et al.* (2010). Under the framework of an affordability analysis, they estimated a 'lifeline' of residential water consumption of around 112 L per capita per day for Andalusia, Spain.

Additionally, two other studies have applied panel data methods. Nauges *et al.* (2009) considered a database of 2329 French municipalities in 1998 for the period 2001 and 2004. This analysis was especially interesting because France had encouraged both municipalities and water suppliers to develop social tariffs for water because some households experienced difficulty in paying their water bills. Nauges *et al.* (2009) estimated a regional minimum threshold ranging between 99 and 200 L per capita per day. The average nondiscretionary consumption in the country is estimated at 108 cubic metres per household per year, which represents 77 per cent of the average total per household consumption. Regional price-elasticity oscillates between −0.05 and −1.04. Panel data methodologies have been also applied by Monteiro and Roseta-Palma (2011), with aggregate data related to 278 municipalities in mainland Portugal for the years 1998, 2000, 2002 and 2005. They estimated a minimum threshold by 209 L per household per day, and a price elasticity close to -0.05.

In summary, several studies have considered the Stone-Geary framework, with the majority obtaining similar results. In general, nondiscretionary residential water consumption ranges between 65 per cent and 85 per cent of the global household's water consumption. However, none of these studies have focused attention on the role of habits or investments in reducing residential water consumption, especially those involving nondiscretionary uses. Hence, this study will make a useful contribution to the existing literature in this area of research.

3. Methods

The main objective of this study is to calculate which portion of water use is price and income inelastic and to observe how this level of usage and the total residential water demand changes in response to habits and investments. Accordingly, we estimate a water-demand function derived from the Stone-Geary utility function. This specification conveniently makes it possible to model the proportion of consumption that is not responsive to price changes and to model the proportion that easily responds to price variations. The basic model can be explained as follows. The average household in the municipality is assumed to enjoy a given level of income and face a set of prices for water supply and other goods and services. We assume that the household solves its utility maximisation problem by first purchasing a *subsistence* level (γ_i) of each good and service i and then allocates the leftover income (labelled *supernumerary* income) in fixed proportions to each good or service according to their respective preference parameter (β's). Q^w and Q^z denote the demands for water and for all other goods/services, respectively, while P^w and P^z are unit prices, γ^w and γ^z are the minimum amounts (or subsistence level(s) or threshold(s)), and I is income. The Stone-Geary utility function would then read as follows:

$$U = \beta^w ln(Q^w - \gamma^w) + \beta^z ln(Q^z - \gamma^z) \tag{1}$$

$$\text{where } \beta^w > 0, \beta^z > 0, \beta^w + \beta^z = 1, (Q^w - \gamma^w) > 0 \text{ and } (Q^z - \gamma^z) > 0$$

β^w and β^z denote the fixed proportions of the supernumerary income (the income left over after the household purchased the minimum amounts of water and all other goods, γ^w and γ^z respectively) that the household will allocate to each water (β^w) and numerary good (β^z). The household will then maximise its utility, subject to the relevant budget constraint and after considering several simplifying assumptions (see, for example, Gaudin *et al.* 2001; Martínez-Espiñeira and Nauges, 2004). The household water-demand equation therefore becomes:

$$Q^{w} = (1 - \beta^{w})\gamma^{w} + \beta^{w}(I/P^{w}) \tag{2}$$

The Stone-Geary function enjoys the advantage of being theoretically consistent and uses only two parameters for each type of good while allowing for nonconstant elasticities that may increase with price. Additionally, both parameters have an intuitive economic meaning: γ can be seen as a threshold below which consumption is not affected by changes in prices or income, while β represents the marginal budget-share allocated to the good considered.

However, the Stone-Geary utility function imposes some important theoretical restrictions. It assumes that there is a strong separability among goods: that is, the marginal propensity to consume (and by extension, income elasticity) is positive for all relevant goods and services and that for a positive γ, the demand for the good in question is inelastic (less than one in absolute value). The two latter assumptions are not too severe given water demand has routinely been found to exhibit such properties in previous empirical studies. That is, water use in urban areas is usually found to be a normal good. The bulk of water-demand studies also estimate a value of the price elasticity of demand lower than one (see, for example, Arbués *et al.* 2003; Worthington and Hoffman 2008).

According to the first assumption, all goods are then assumed to be gross complements to water consumption. However, water for municipal use is normally assumed to show negligible complementarity and substitution relationships with respect to other goods (Al-Quanibet and Johnston 1985). This assumption of strong separability between water and other goods is common, being implicit in all studies estimating a single water-demand equation.

Despite the limitations and constraints of this methodology, a residential water-demand function based on this approach has particular utility because it allows greater accuracy in estimating a clear-cut minimum threshold of consumption within which users have no ability to adjust consumption in the short run. Another advantage is that the Stone-Geary specification can be used to model the dependence of the subsistence level on the consumer habits and stock of physical capital (Martínez-Espiñeira and Nauges, 2004; Worthington and Hoffman 2008). Thus, the Stone-Geary demand empirical model that we propose to estimate is the following:

$$cpc_{it} = \alpha_i + \beta_i \left(\frac{I}{P}\right)_{it} + u_{it} \tag{3}$$

where i and t are the indices for households and years, respectively, cpc_{it} is average water consumption per head and per quarter, I_i denotes income, P_{it} is the price of water, and u_{it} is the usual idiosyncratic error term. In equation (4), we allow for some heterogeneity in the parameters as follows:

$$\alpha_i = \alpha_0 + WS_i'\phi + \delta sub_i + \gamma q_t \tag{4}$$

$$\beta_i = \beta_0 + Z_i'\phi$$

where WS_i represents a set of households' water-saving habits and/or investments, sub_i is a variable that identifies the suburb group where household i is located, q_t identifies the quarter, and vector Z_i gathers another set of household i's characteristics not included in the vector WS_i.

4. Database and variables

In this section, we describe the database used to estimate the Stone-Geary model specified in the previous section. Data for this study were obtained from a survey conducted among residents of BCC to assess their water use, as well as attitudes to water use management and conservation. The study, which commenced in 2009, employed a multistage sampling procedure in order to select a random sample covering residents of BCC. In the first stage, we ranked the 189 suburbs in BCC (the largest in Australia) based on the 2006 census median Australian Bureau of Statistics fortnightly income from highest to lowest. From this list, we selected every 2nd suburb, resulting in a sample of 83 suburbs. We then obtained a list (from BCC) of owner occupied households who pay water rates. From that list, we selected every 3rd household and sought their consent for the study. As mentioned earlier, we took into account only surveyed owner-occupied households rather than the entire population. From the list of addresses provided by the BCC, we selected 37 341 addresses from whom we sought consent to participate in a 3-year study. We received 3475 responses volunteering participation. A detailed questionnaire was then sent out to the recruited sample in 2010, from which we received 2142 useable responses.[2] The participants were given the opportunity to respond either using a paper-based or an Internet-based survey.

The survey questionnaire consisted of nine main sections. Section 1 covered general information on household water conservation measures such as domestic fixtures, domestic appliances, garden and lawn maintenance, pool, rainwater tanks, and grey-water use, household water consumption, and water conservation habits and strategies. Section 2 sought details of future water-saving strategies. Section 3 dealt with water-demand strategies that could be used by water-management authorities such as restricting the supply of water, water pricing, provision of incentives, buying back surplus water, education, moral persuasion, promotion of low-consumption technologies and increasing the supply of water to residents. Section 4 collected information on the household's attitudes towards water conservation. Section 5 sought information about households' awareness and knowledge of water

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[2] The initial sample was significantly reduced, due to outliers and missing values. Thus, the final number of observations ranges from 1879 to 2748 (see Table 3).

Table 1 Variables: definitions and descriptions

Variable	Name	Definition
Dependent variable	*cpc*	Water consumption per capita per quarter (m^3)
Independent variables		
I/P	*incopr_1*	Income per capita divided by one-period lagged marginal price (Thousand AUS$)
Z	*agema65*	Percentage of older people (%)
	titeduc	Dummy variable which takes value 1 if the interviewee has at least a trade certificate, 0 otherwise
	immigrant	Dummy variable which takes value 1 if the interviewee was born in Australia, 0 otherwise
	sgarden	Categorical variable which takes the following values: = 1 if household's garden is smaller than 50 m^2; = 2 if household's garden is between 51 m^2 and 250 m^2; = 3 if household's garden is bigger than 250 m^2
	swim	Dummy variable which takes value 1 if the household has a swimming pool, 0 otherwise
	tankcap	Categorical variable which takes the following values: = 0 if there is not rainwater tank in the property; = 1 if there is a rainwater tank and its capacity is lower than 5 m^3; = 2 if there is a rainwater tank and its capacity is between 5 m^3 and 10 m^3, = 3 if there is a rainwater tank and its capacity is bigger than 10 m^3
WS	*habindoor*	Index of habits related to water indoor uses (mean score)
	haboutdoor	Index of habits related to water outdoor uses (mean score)
	showeref	Percentage of efficient showers
	toiletef	Percentage of efficient toilets
Other variables	*q_2, q_3,q_4*	Quarter dummy variables
	sg_2, sg_3, sg_4, sg_5	Suburb group dummy variables

pricing. Section 6 covered questions on barriers to water conservation, while Sections 7 and 8 dealt with environmental and social attitudes and other general questions. The final section (9) collected socio-economic and demographic features of the household, including age, gender, level of education, household size and income.

Table 2 Descriptive statistics

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
cpc	2754	12.36	5.90	4.13	35.50
incopr_1	2748	4.04	2.31	0.76	14.68
agema65	2754	0.24	0.38	0.00	1.00
titeduc	2754	0.78	0.41	0.00	1.00
nimmigrant	2754	0.79	0.40	0.00	1.00
sgarden	2754	2.31	0.64	1.00	3.00
swim	2746	0.28	0.45	0.00	1.00
tankcap	2746	1.21	1.00	0.00	3.00
toiletef	2754	0.87	0.31	0.00	1.00
showeref	2734	0.80	0.36	0.00	1.00
habindoor	2754	0.68	0.18	0.14	1.00
haboutdoor	2754	0.83	0.26	0.00	1.00

Tables 1 and 2 report the variables and the data set used. Table 1 shows the main variables considered in the estimation. Table 2 includes some descriptive statistics. Water consumption per head is the dependent variable (*cpc*). We use data on households' water consumption from the second quarter of 2009 to the first quarter of 2010.[3]

In the vector of water-saving habits and investments (*WS*), we consider two indexes of water-saving habits and two variables related to investments. To build the water-saving indexes, we asked households to what extent they use the following water-saving practices:

a) Turning off the tap when soaping up in the shower
b) Turning off the tap when washing dishes
c) Reducing the number of baths/showers
d) Reducing the length of baths/showers
e) Reducing toilet flushes
f) Turning off the tap when cleaning teeth
g) Use of a shower rather than a bath
h) Using less water in the garden
i) Washing the car without using domestic tap water

The respondents were given an opportunity to answer within a scale between 1 = never to 5 = always. Those variables have been rescaled, giving the value 1 when the household *usually* or *always* adopts this particular behaviour and 0 otherwise. For example, if the household regularly turns off the tap when washing dishes, that fact would mean that it has adopted the habit and is given a value of 1. Thus, we create a variable representative of indoor habits (*habindoor*) by summing up the values of the rescaled questions from a) to g). A further variable for outdoor habits (*haboutdoor*) was also

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[3] Since the survey was conducted in 2010, variables related to habits, investments and households' characteristics refer to that year. However, since we only have information on the first quarter of that year, we also consider three more periods in order to obtain more consistent estimates.

created, which sums up the values of the rescaled questions h) and i). In both cases, and after summing up, the result is divided by the number of habits in each case, which allows obtaining a mean score for each household. Thus, the indexes were ranked from 0 to 1, showing the percentage of habits adopted by each household. Higher values in the indexes indicate a higher degree of water conservation commitment (Millock and Nauges 2010). For investments, we have used the proportion of all appliances in the house that are 'water-efficient' showers and toilets (*showeref, toiletef*). These variables are included in the vector *WS*.

The main economic variable included (*incopr_1*) is created dividing per capita income[4] by the one-period lagged marginal price.[5] With this lag, we assume that households obtain information about prices once they receive the bill at the end of the quarter.[6] Additionally, we examine a group of household characteristics, which could impact households' total water consumption. These variables are included in the vector Z. In the estimations, these variables are denoted by the prefix *in_*, indicating their interaction with the variable *incopr_1*. The selection of variables was based on their correlations and also on previous studies on residential water demand (Arbués *et al*. 2003; Worthington and Hoffman 2008). The variables are the percentage of people in the household older than 65 (*agema65*), education level (*titeduc*), born in Australia or not (*nimmigrant*), the size of garden (*sgarden*), the existence of a swimming pool on the property (*swim*) and the capacity of rainwater tanks (*tankcap*). Finally, temporal and suburb group dummy variables have also been included. With respect to the former, we have considered quarterly dummy variables in order to capture seasonal effects (*q_2 q_3 q_4*). In the latter case, we have reduced the high number of suburbs[7] by clustering them into five groups,[8] including four dummy variables (*sg_2 sg_3 sg_4 sg_5*).

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[4] Household income has been adjusted by the *difference* variable (Nordin, 1976).

[5] Thus, water tariffs are not linear and are non-uniform. They depend on the level of water consumption, which means that the technical relationship could bias the economic relationship between prices and consumption and consequently, price-elasticity estimates (Arbués *et al.* 2003). However, by considering a one-period lagged variable, we are able to reduce such an endogeneity problem.

[6] If we look at some of the data included in the survey, this is a very realistic hypothesis. Around 30 per cent of the surveyed households were not aware of the existing water tariffs. Furthermore, despite the rest (70 per cent) knowing that there is a block tariff, only 22 per cent knew how many tiers the tariff had. Hence, it is reasonable to hypothesise that households obtain information about consumption and water prices through water bills. In general, it could be argued that there is a lag in obtaining the information. This means that residents obtain the relevant information in the period after consumption.

[7] Although 83 suburbs were covered initially in the survey, there were insufficient data for 16 of the suburbs. Consequently, we have observations related to 67 Brisbane suburbs.

[8] In this respect, we consider a K-means clustering based on Euclidean distance. The suburb-level variables included in the analysis are the following: average household income, average household size, percentage of residents who were born in Australia and percentage of female residents. The information was taken from Australian Bureau of Statistics (ABS) 2006 Census (http://www.abs.gov.au/). Table A2 (Appendix) shows the main statistical values for each group.

The evidence is mixed regarding the impact of different variables included in the empirical specification on water use. Beginning with household composition, Gilg and Barr (2006) showed that those most committed to water saving in the home were older residents. Similarly, some studies have found that families with children use more water. Outdoor use by households with children and teenagers could also be higher. Furthermore, young people may use water less carefully, have more showers and demand more frequent laundering, while retired people might be thriftier. These expectations are confirmed by studies such as that by Nauges and Thomas (2000). On the other hand, retired people tend to have more free time, so that they could spend more time at home and do more gardening (Lyman 1992). Hence, the expected sign of *agema65* is not totally clear.

With respect to the influence of education level on water saving, some studies have shown that it is positively related to pro-environmental behaviour and attitudes (see, for example, Torgler *et al.* 2010). Furthermore, the costs of environmental activism might be lower for better-educated people because they have more civic skills (Lubell 2002). Hence, we expect to find a negative relationship between educational level and water consumption.

There is no consensus in the literature about the effect of immigration and ethnicity status on pro-environmental behaviours (Mohai 1990); thus, it is difficult to make a prediction regarding water saving. On one hand, the literature on environmental justice has showed that ethnic minorities are more engaged with environmental activism. On the other hand, minorities could also be less environmentally active because they experience greater difficulty in accessing political and cultural resources (Musick *et al.* 2000). Moreover, it has been found that people from different cultural backgrounds may be more or less reactive to the price of water (Worthington and Hoffman 2008).

Additionally, housing equipment and characteristics have also been mentioned in the literature (Arbués *et al.* 2003). Thus, the demand function can be estimated using variables that reflect outside features such as garden size (Nieswiadomy and Molina 1989; Lyman 1992; Hewitt and Hanemann 1995), or swimming pool ownership (Dandy *et al.* 1997). In general, we expect to find a positive relationship between these characteristics and residential water consumption. Finally, as an important contribution in this article, we have also considered a variable which shows the total capacity of rainwater tanks in the house (*tankcap*). Our expectations propose the hypothesis that households with rainwater tanks could substitute tap water with rainwater for some water uses (especially outdoor usage).[9]

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[9] The Queensland Water Commission requires (in the Queensland Development Code – MP 4.2 Water Savings Targets) that all new domestic dwellings in SEQ connected to town water supply should achieve a water-saving target of 70 kl/annum via the use of a rainwater tank, grey water treatment/other alternative water substitution measures or through a combination of measures.

Table 2 shows the main characteristics of the households in the sample. The representative household reports a per head consumption of around 12 m^3 per quarter. In general, the population is young, with the average percentage of people older than 65 being 24 per cent. The majority of people interviewed (79 per cent) were born in Australia, and around 78 per cent of them have at least a trade certificate. The size of the garden is medium–big, and around 30 per cent of the households own a swimming pool. Around 70 per cent of the households have rainwater tanks in their property, and the majority of them have a capacity ranging between 5 to 10 m^3. A high percentage of the households have installed low-consumption appliances in toilets and showers, and on average, they demonstrate a high level of pro-environmental behaviour in terms of habits. Table A1 (Appendix) shows the correlation matrix of the variables included in the analysis.

5. Results

In this section, we present the most important findings relating to the empirical model estimation. We have used mainly OLS, including dummy variables by period and suburb group in the majority of cases. The variables included in the sets *WS* and *Z* are time invariant. As a consequence, a slight temporal variability is registered among periods.

We present the estimates of five models. The models introduce variables sequentially or in a different specification in order to allow sensitivity analysis, which informs us of the robustness of the specification. Model 0 (m0) is a basic specification, which considers only the *incopr_1* variable. Model 1 (m1) includes suburb group and temporal dummy variables. Model 2 (m2) includes WS and Z_1 set of variables (socio-demographic and habits). Model 3 (m3) includes Z_2 set of variables (efficient investments). Finally, Model 4 (m4) allows moving some of the variables from the vector *WS* to *Z*, to check the sensitivity of the estimates. With this procedure, we also check the hypothesis that some of the technologies and/or habits (especially those which could be related to outdoor uses) could also have an impact on discretionary water consumption. Table 3 summarises the estimates for the main parameters corresponding to the five models.

The table shows a number of interesting and intuitive findings. Firstly, the coefficient corresponding to *incopr_1* is positive and significant in all cases. This result is according to our expectations, consistent with the Stone-Geary theoretical framework and in line with previous studies' results. Moreover, we observe that some of the variables related to water-saving habits and investments are significant and in general have the expected signs. Thus, a higher degree of water conservation commitment in terms of habits leads to lower water consumption levels. The habits adopted by households relating to indoor water uses (*habindoor*) present a negative and significant sign in all the cases. This finding indicates that those households developing a pro-saving culture in daily behaviour are able to reduce their nondiscretionary

Table 3 Stone-Geary residential water demand: estimates

Variable	m0	m1	m2	m3	m4
incopr_1	0.771***	0.833***	0.617**	0.694***	0.935***
in_agema65	—	—	−0.128	−0.081	−0.055
in_titeduc	—	—	−0.271***	−0.269***	−0.258***
in_nimmigrant	—	—	0.379***	0.400***	0.419***
in_sgarden	—	—	0.168***	0.185***	0.197***
in_swim	—	—	0.416***	0.396***	0.368***
in_tankcap	—	—	−0.102	−0.171*	−0.069
in_haboutdoor	—	—	—	—	−0.245
in_toiletef	—	—	—	—	0.118
in_showeref	—	—	—	—	−0.466***
toiletef	—	—	—	0.459	—
showeref	—	—	—	−1.948***	—
habindoor	—	—	−3.072***	−2.794***	−2.983***
haboutdoor	—	—	−1.656***	−1.683***	—
q_2	—	−1.841***	−1.863***	−1.878***	−1.865***
q_3	—	−1.886***	−2.047***	−2.061***	−2.041***
q_4	—	−0.857***	−0.854**	−0.856**	−0.854**
sg_2	—	1.527***	2.205***	2.014***	2.042***
sg_3	—	0.558	1.679***	1.586***	1.591***
sg_4	—	1.005**	2.275***	2.023***	2.060***
sg_5	—	1.944***	2.431***	2.186***	2.243***
_cons	9.243***	8.916***	10.464***	11.187***	9.746***
N	2748	2748	1891	1879	1879
Adj. R^2	0.091	0.115	0.141	0.159	0.159

Note: $^{*}P < 0.1$; $^{**}P < 0.05$; $^{***}P < 0.01$.
*in_*: denotes the interaction of the independent variable with *incopr_1*.

water threshold. Additionally, as Model 3 shows, outdoor habits (*haboutdoor*) also have an impact on per capita consumption.

We also observe that, overall, there is a strong significant and negative relationship between per capita water threshold consumption and the adoption of some water-efficient technologies (*showeref*). Finally, the signs related to the variables that interact with *incopr*_1 are generally in accordance with our expectations and the results of previous studies (Worthington and Hoffman 2008). It appears that Australians consume more water than immigrants, in per capita terms. Education levels show a negative and significant relationship with per capita water consumption. The results also indicate that a larger garden and a swimming pool in the property have a positive effect on per capita water consumption. Finally, it is worth mentioning that rainwater tanks' capacity reduces tap water demand. This finding is representative of a substitution effect between tap water and water from rainwater tanks. We estimate that rainwater is mainly allocated to outdoor use because only 20 per cent of the households interviewed declared that their rainwater tanks are connected to the house. Finally, higher levels of per capita water consumption are registered during the first quarter of the year (control group) when higher temperatures are recorded in Australia.

Tables 4 and 5 show the main figures relating to the threshold, the weight that this threshold has on total per capita consumption (*thresh; per_thresh*) and own-price elasticity(η). In Tables A2, A3 and A4 (see Appendix), we provide additional information on some of these variables, reporting the figures by suburb group. The results show that the average water threshold lies between 8.31 and 9.25 cubic metres per quarter per person, depending on the empirical modelling. This is equivalent to 92–103 L per capita per day, or between 69 per cent and 76 per cent of total consumption. As explained earlier, these results are in accordance with the findings of other studies. The average own-price elasticities are in line with the previous literature, with values below one (Worthington and Hoffman 2008). Moreover, it is also interesting to observe that the higher the minimum threshold and the weight of nondiscretionary water use on total water consumption, the lower the own-price elasticity of Australian households. This is a very intuitive finding. As long as the high percentage of residential water use does not change when the main economic variables change, it is expected that demand remains inelastic.

Table 4 Threshold and price elasticities

	m0	m1	m2	m3	m4
η	−0.4104	−0.4435	−0.5726	−0.6118	−0.5587
thresh	9.25	9.02	8.31	8.26	8.33
per_thresh	0.7626	0.7423	0.6967	0.6911	0.7004

Table 5 Estimated residential nondiscretionary water use: indoor habits and investments (m^3 per quarter per capita)

	m0	m1	m2	m3	m4
toiletef					
≤0.5 (a)	9.25	8.95	8.25	8.08	8.29
>0.5 (b)	9.25	9.03	8.32	8.28	8.34
Diff = mean(a) − mean(b) (*t*-value)		(−1.54)	(−0.82)	(−2.15)**	(−0.68)
showeref					
≤0.5 (a)	9.25	9.04	8.34	9.45	8.38
>0.5 (b)	9.25	9.01	8.30	7.93	8.32
Diff = mean(a) − mean(b) (*t*-value)		(0.58)	(0.66)	(21.37)***	(0.94)
habindoor					
≤0.5 (a)	9.25	8.98	9.24	9.24	9.15
>0.5 (b)	9.25	9.03	8.16	8.10	8.20
Diff = mean(a) − mean(b) (t-value)		(−0.92)	(13.37)***	(12.36)***	(12.85)***
haboutdoor					
≤0.5 (a)	9.25	9.00	8.98	8.93	8.34
>0.5 (b)	9.25	9.03	8.11	8.06	8.33
Diff = mean(a) − mean(b) (t-value)		(−0.81)	(13.08)***	(11.45)***	(0.17)

Note: *$P < 0.1$; **$P < 0.05$; ***$P < 0.01$.

Table 5 shows the estimated average water threshold, which takes into account the kind of habits and investments that have been adopted by households. This demonstrates how the level of water conservation commitment, in terms of both habits and investments, impacts on nondiscretionary water consumption. We use the bound of 50 per cent, to distinguish between those households that present a higher percentage with those whose percentage is lower or equal to 50 per cent. Finally, the results of several mean-comparison tests are provided.

Except in the case of the Model 1 (m1) where the threshold is constant, we observe that in some cases, pro-saving habits and investments have a significant impact on the water threshold. For example, those households that usually or always adopt pro-water-saving behaviours, and those who have installed efficient showers in more than 50 per cent of the total appliances, register a lower water threshold. In the case of efficient toilets, no clear results are obtained. In fact, we have found a negative correlation between the installation of those appliances and the habits related to the use of toilets, detecting some kind of rebound effect.[10] Depending on the case, the significant water savings related to threshold ranks between 10 and 17 litres per capita per day.

Finally, Table 6 shows the estimated global water consumption (per head and per quarter), considering the same scenarios as in the previous table.

Table 6 Estimated residential total water use: indoor habits and investments (m^3 per quarter per capita)

	m0	m1	m2	m3	m4
toiletef					
≤0.5 (a)	12.72	12.70	12.50	12.47	12.49
>0.5 (b)	12.29	12.31	12.12	12.16	12.15
Diff = mean(a) − mean(b) (*t*-value)		(3.68)***	(2.51) **	(1.96)**	(2.15)**
showeref					
≤0.5 (a)	12.59	12.65	12.35	13.57	13.54
>0.5 (b)	12.29	12.29	12.13	11.82	11.83
Diff = mean(a) − mean(b) (*t*-value)		(3.81)***	(1.77)*	(13.55)***	(13.23)***
habindoor					
≤0.5 (a)	11.95	11.89	12.91	12.97	12.97
>0.5 (b)	12.43	12.46	12.06	12.08	12.08
Diff = mean(a) − mean(b) (*t*-value)		(−5.32)***	(5.59)***	(5.57)***	(5.54)***
haboutdoor					
≤0.5 (a)	12.33	12.31	12.92	12.96	12.67
>0.5 (b)	12.36	12.39	11.96	11.98	12.07
Diff = mean(a) − mean(b) (*t*-value)		(−0.98)	(7.79)***	(7.44)***	(4.53)***

Note: $*P < 0.1$; $**P < 0.05$; $***P < 0.01$.

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[10] This phenomenon would lead to an increase in water use after the installation of water-efficient equipment (Campbell *et al.* 2004).

Again we observe that both habits and efficient investments are bringing about reductions in water used, especially in the case of indoor habits and water-saving showers. In the case of global water demand, significant water savings range between 2 and 20 litres per capita per day.

6. Conclusions

This study reports the impact of pro-saving habits and investments on residential water consumption. Previous literature has shown that these nonmarket initiatives are effective in producing significant water consumption savings (Millock and Nauges 2010). We have sought to isolate and measure the influence of those behaviours and appliances, which explain the quantity of water consumption that is nonsensitive to prices or income changes.

To achieve this, we specified a water-demand model based on a Stone-Geary utility function. This functional form explicitly considers that water consumption includes two components: a *fixed* quantity that cannot be easily adjusted in the short run after a price change and an additional quantity that can adapt almost instantaneously to price changes. This makes it possible to estimate *a lifeline* or nondiscretionary amount of water. In addition, we extend the basic model in order to include some pro-saving habits and investments. This is the most important contribution of this study.

We tested our empirical model using a microdata set of households from BCC. Our empirical findings on the scope of measures to save water are in accordance with our expectations and previous literature on Stone-Geary demand model. Specifically, this analysis shows that it is possible for households to save a significant amount of water-adopting pro-environmental habits and investments. As expected, some behaviours that households adopt relating to indoor uses (that is daily tasks such as house cleaning or personal hygiene) have a higher impact on the minimum threshold. With respect to investment, the installation of efficient showers is shown to be positive in terms of saving water for nondiscretionary uses.

Hence, the findings indicate some important considerations regarding public polices in conserving and managing the demand for urban water. Adopting efficient appliances could lead to reductions in residential water consumption. However, the benefits that are linked to water savings would not be sufficient to compensate the costs related to the application of such policies (Barrett 2004). Promoting certain pro-saving habits emerge as a low-cost alternative to bring about a reduction in water consumption. The effect of habits on water demand is a key finding, since it could explain a good proportion of the differences between short-run and long-run elasticities of water demand (Arbués *et al.* 2003; Worthington and Hoffman 2008). In fact, the persistence of habits related to water use has been identified as a potential reason why, below a certain level of use, households might fail to respond altogether in the short run to water price changes (Gaudin *et al.* 2001;

Martínez-Espiñeira and Nauges 2004). Thus, our results are in line with Domene and Saurí (2006) who found that households with strong indoor water conservation habits reduce their consumption between 4.3 and 4.6 litres per capita per day during the winter season. Hence, in order to change water consumption habits, some strategies such as educational or moral suasion campaigns could be developed.

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Appendix

Table A1 Correlations matrix

	cpc	*incopr_1*	*agema65*	*titeduc*	*nimmigrant*	*sgarden*	*swim*	*tankcap*	*toiletef*	*showeref*	*habindoor*	*haboutdoor*
cpc	1.0000	—	—	—	—	—	—	—	—	—	—	—
incopr_1	0.3074	1.0000	—	—	—	—	—	—	—	—	—	—
agema65	0.0960	0.3223	1.0000	—	—	—	—	—	—	—	—	—
titeduc	−0.0021	0.0598	−0.0210	1.0000	—	—	—	—	—	—	—	—
nimmigrant	0.0781	0.0403	0.0011	−0.0575	1.0000	—	—	—	—	—	—	—
sgarden	0.0319	−0.0678	−0.0157	0.0364	−0.0675	1.0000	—	—	—	—	—	—
swim	0.0587	−0.1912	−0.0552	0.0582	−0.0752	0.0918	1.0000	—	—	—	—	—
tankcap	−0.0408	−0.1119	−0.0557	−0.0166	0.0284	0.1804	0.2172	1.0000	—	—	—	—
toiletef	−0.0146	−0.0885	−0.0664	0.0588	0.0153	−0.0433	0.0713	0.0733	1.0000	—	—	—
showeref	−0.1405	−0.0721	−0.0357	−0.0738	0.0128	−0.0032	0.0187	0.0294	0.1191	1.0000	—	—
habindoor	−0.0527	0.1356	0.1630	−0.0335	0.0380	−0.0532	−0.0917	0.0867	−0.0410	0.1002	1.0000	—
haboutdoor	−0.0570	−0.0354	−0.0205	−0.0302	0.0040	0.0626	0.0568	0.2855	0.0548	0.0609	0.1684	1.0000

Table A2 Suburb groups

Suburb group	Household income	Average household size	Born in Australia (%)	Females (%)	Observations (%)
1	2434.90	2.99	71	51	7
2	1401.09	2.46	73	52	38
3	1093.43	2.53	67	51	12
4	1680.01	2.58	73	52	26
5	1985.29	2.76	75	51	17

Table A3 Residential water threshold by suburb group (m^3 per quarter per capita)

Suburb group	m0	m1	m2	m3	m4
1	9.25	7.75	6.45	6.76	6.51
2	9.25	9.32	8.50	8.41	8.52
3	9.25	8.34	8.00	7.96	8.12
4	9.25	8.78	8.49	8.40	8.46
5	9.25	9.71	8.73	8.62	8.73

Table A4 Percentage of threshold on total water consumption, by suburb group (%)

Suburb group	m0	m1	m2	m3	m4
1	73.30	68.23	60.48	62.14	60.82
2	77.18	75.83	71.73	71.06	72.13
3	77.87	74.59	71.39	70.54	72.19
4	75.59	73.07	68.84	68.05	68.92
5	75.34	74.70	69.54	68.66	69.91