Determinants of residential water consumption: Evidence and analysis from a 10-country household survey

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[1] Household survey data for 10 countries are used to quantify and test the importance of price and nonprice factors on residential water demand and investigate complementarities between household water-saving behaviors and the average volumetric price of water. Results show (1) the average volumetric price of water is an important predictor of differences in residential consumption in models that include household characteristics, water-saving devices, attitudinal characteristics and environmental concerns as explanatory variables; (2) of all water-saving devices, only a low volume/dual-flush toilet has a statistically significant and negative effect on water consumption; and (3) environmental concerns have a statistically significant effect on some self-reported water-saving behaviors. While price-based approaches are espoused to promote economic efficiency, our findings stress that volumetric water pricing is also one of the most effective policy levers available to regulate household water consumption.

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1. Introduction

[2] An increasing number of countries face concerns over maintaining water security in response to climate variability and rising populations. In response to these challenges, governments are developing strategies to restrain water demand, particularly with residential consumers. Three important policy levers to reduce water consumption are (1) volumetric water prices; (2) subsidies for, and/or a requirement to use, water-saving devices; and (3) promotion of conservationist attitudes about water through, for example, public information campaigns. To quantify the absolute and relative importance of these factors on household water consumption, we use a unique household-level data set collected from 10 countries by the Organization for Economic Cooperation and Development (OECD) Secretariat in 2008.

[3] The common survey instrument used by the OECD permits us to make valid cross-country comparisons on household water consumption while simultaneously accounting for household characteristics, climate, attitudinal characteristics and environmental concerns, environmental behaviors and actions, water efficiency devices, and differences in water prices. The survey provides evidence on several policy levers available to water authorities: volumetric price, water conservation campaigns, and promotion of water-saving devices. While theory suggests that price-based approaches are economically efficient [*Griffin*, 2001] in that they allow water to be allocated to its highest value in use, the present analysis shows that price-based approaches are also likely to be the most effective in that they significantly affect water consumption relative to voluntary instruments in terms of controlling long-run residential water demand.

[4] Our results are important because, in general, water utilities and water pricing regulatory authorities have eschewed the use of price as the primary method of controlling residential water demand and have, instead, opted for a variety of nonprice approaches [*Olmstead and Stavins*, 2009]. Our unique data set allows us to also investigate complementarities between household water-saving behaviors and the average volumetric price of water. We show that a higher average price increases the likelihood that households will undertake some self-reported water-saving behaviors. We also find that attitudinal characteristics and environmental concerns, as measured in the survey, do increase the likelihood of undertaking some specific and self-reported water-saving behaviors some attitudinal characteristics and environmental concerns also increase the rate of adoption of a low volume/dual-flush toilet that reduces household water consumption.

[5] Section 2 provides a brief review of the literature on water pricing and residential water demand while section 3 presents a summary and corroboration of the OECD survey data. Section 4 presents the residential water demand analysis and section 5 describes the results of the factors that affect water-saving behaviors. Section 6 summarizes the key findings and offers concluding remarks.

2. Review of the Literature

[6] The large literature on residential water demand is summarized and reviewed by several authors, including *Dalhuisen et al.* [2000], *Ferrara* [2008], *Hanemann* [1998], *Olmstead* [2010], *Renzetti* [2002, pp. 17–34], *Shaw* [2005, pp. 100–135], *Schleich and Hillenbrand* [2009], and *Young and Haveman* [1985], among others. We summarize key

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past findings in terms of (1) the water price variable, (2) the elasticity of demand, and (3) nonprice factors.

2.1. Water Price

[7] A long-standing controversy in residential demand studies is whether consumers, faced with block-rate tariffs, respond to the average water price, to the marginal price corresponding to the last unit of water consumed, or to a combination of average and marginal price. *Arbues et al.* [2003] provide a comprehensive survey of residential water demand studies and observe that, in many cases, the choice of a marginal or average price variable in models does not substantially affect estimated price elasticities. They also note that the choice of the price variable (marginal or average) remains an unresolved issue in empirical work.

[8] One of the earliest studies by *Howe and Linaweaver* [1967] argues that consumers should respond to the marginal price corresponding to the current level of consumption. By contrast, *Foster and Beattie* [1981] provide evidence in favor of an average price specification in residential water demand estimation because of (1) the complexity of water tariff under block rate structures and (2) the inclusion of sewer charge and fixed service charge in the water bill that, together, impair consumers' ability to identify and respond to a marginal price.

[9] *Taylor* [1975] posits that with block-rate pricing structures the effect of the marginal price on consumption represents only the behavior of the consumer in terms of the last block of consumption but does not determine the response to intramarginal changes. He proposes including in an estimated model both the marginal price corresponding to the last block of consumption and either (1) the total cost or (2) the average price of all units consumed prior to the last block. In an extension of Taylor's work, *Nordin* [1976] proposes a water demand model that includes both the marginal price and an "expenditure difference" variable that represents the total water bill less the total cost that the consumer would have to pay if all units of water consumed were charged at the marginal price. More recently, discrete/continuous choice models have also been developed to account for multiple prices and the potential endogeneity associated with block tariff structures [*Hewitt and Hanemann*, 1995; *Olmstead et al.*, 2007].

2.2. Price Elasticity of Demand

[10] Two meta-analysis studies of water demand find that residential consumption does respond to price changes, but is price inelastic. In particular, *Espey et al.* [1997] used 124 elasticity estimates to obtain a median short-run price elasticity of demand of –0.38 and a median long-run price elasticity of demand of –0.64. *Dalhuisen et al.* [2003] combined 296 price elasticity estimates to derive an overall mean price elasticity of –0.41. *Dalhusien et al.* [2000] also find that households are more responsive to price changes the more time they have to adapt to price increases. The finding that the price elasticity of demand can be greater in the long run is especially important for water authorities and utilities when they evaluate the effectiveness of raising the volumetric price of water on water consumption [*Nauges and Thomas*, 2003; *Arbues et al.*, 2004].

[11] High-income households appear to be less price elastic in terms of their water consumption than low-income households. *Renwick and Archibald* [1998] used data from two communities in California and found that higher income households have a statistically significant smaller consumption response to water price changes than lower income households.

[12] For the volumetric price to influence water consumption, consumers must be metered. *Nauges and Thomas* [2000] calculate that a one per cent increase in the proportion of single housing units (all of which have water meters) in 116 French communities would, all else equal, result in a 0.44% reduction in residential water demand. *Gaudin* [2006], using U.S. data, shows that if consumers are informed about the volumetric price that they pay on their water bill, this can increase the price elasticity of demand by 30–40%.

2.3. Nonprice Factors

[13] Household water demand depends on preferences, as well as prices and income. Preferences may vary across households, and much of the variation in household consumption has been shown in the literature to be explained by variation due to observable household and demographic characteristics. The nonprice factors in demand regressions attempt to attribute variation in preferences to specific factors. In this analysis, we focus on two household characteristics that are especially relevant: conservation attitudes and the presence of water-saving devices.

[14] Many water authorities promote installation of water-saving devices, such as efficient toilets and showerheads. While it seems intuitive that water-saving devices should reduce household consumption, this may not necessarily be true in all cases. This is because an increase in water efficiency of a device effectively reduces the unit cost of the produced service and, thus, could theoretically cause an increase in consumption. *Olmstead and Stavins* [2009] provide a review and summary of studies on water saving devices. The empirical evidence is mixed. For example, a study of low-flow showerhead retrofits in Colorado found no significant influence on consumption, while studies in California and Florida found modest savings. Similarly, several studies of efficient toilets find associated water savings, while *Renwick and Green* [2000] report that rebates for water-efficient toilets had no significant impacts. Determining the impact of a change in water-saving devices is statistically complicated by the fact that the presence of such devices in a household may be endogenous.

[15] The connection between attitudinal characteristics and environmental concerns and water consumption is policy relevant because advertising campaigns have frequently been attempted to reduce consumption by promoting water conservationist attitudes. *Domene and Sauri*'s [2005] study of Spanish water consumption is one of the very few to examine the influence of attitudinal variables on water consumption, and finds a significant association. In a study that uses household data from England, *Gilg and Barr* [2006] also find that water-saving behaviors are positively associated with respondents' status as owner occupiers, whether they have a tertiary education (e.g., university or polytechnic), are members of community groups and are "committed environmentalists."

3. International Household Survey Data

[16] The survey data for our analysis came from an environmentally related questionnaire, "2008 OECD Household Survey on Environmental Attitudes and Behavior," developed by the OECD Secretariat and obtained from a web-based access panel. These data include responses from approximately 10,000 households in 10 OECD countries (Australia, Canada, Czech Republic, France, Italy, South Korea, Mexico, Netherlands, Norway, and Sweden). Respondents were asked a series of questions in terms of their household and residential characteristics (age, income, household size and composition, employment status, residence size, type of residence, etc.), attitudinal characteristics and environmental concerns, and general activities (membership of an environmental organization, supporting/participating in activities of an environmental organization, participation in civil society, etc.), and their consumption and investment behaviors in terms of waste, transport, energy, organic food, and water. A copy of the full survey questions is available from the authors upon request while key water-related questions are replicated in Appendix B.

[17] In the introduction to the survey, respondents were specifically asked to ensure their water bills were accessible. In the water issues section of the survey instrument, an optional question requested water consumption and water expenditures for the past year. Sewage charges were not asked for in the survey instrument and, thus, are not part of our analysis. Households also provided data on their water-saving behaviors (turning off water while brushing teeth, taking a shower instead of a bath to save water, plugging in the sink when washing dishes, etc.), the adoption of water-saving devices (low-flow shower heads, low volume or dual-flush toilets, etc.), and whether/how they were charged for water use.

[18] The survey methodology is described in detail by *OECD* [2008]. The survey was conducted for the OECD by Lightspeed Research, which was chosen following scrutiny of the provider's panel size, recruitment, management, and representativeness. Lightspeed recruited a panel of potential survey participants through newsletters and advertisements with partner sites. Participants from the overall panel were then chosen and invited to participate in specific surveys based on stratification and panel-management rules. To obtain a representative sample, the participants were stratified with respect to income, age, gender, and region within each country. Approximately 1000 households were interviewed in each of the 10 survey countries, with the exception of the Czech Republic, where only about 700 participating panel members matched the stratification requirements. The 10 countries were selected, in part, based on which OECD member countries provided funding for the research. While the response rate is not available for France, it is available for the following locations: Canada (77%), Australia (72%), Italy (60%), Netherlands (49%), Sweden (65%), Norway (55%), Czech Republic (53%), Mexico (47%), and South Korea (57%).

3.1. Summary Statistics

[19] Of the 10,251 households in the general survey, 1993 respondents provided details about their water consumption. As a proportion of the households responding to the question whether they face water charges, 80% stated that they were subject to such charges, and as a proportion of these households, 84% incurred water charges based on their level of consumption. In total, 1660 households reported water consumption in the range 40–4,000 kL yr^{-1}. There is reason to be skeptical about reported household consumption outside that range. This is because in a sample of actual water bills for over 5000 detached houses in Canberra, Australia for the year 2000 only two households had consumption in excess of 4000 kL and 15 households had less than 40 kL [see *Troy et al.*, 2006]. Those residences with water consumption less than 40 kL yr^{-1} were almost certainly unoccupied as their water consumption in other periods was much larger. Accordingly, the analysis presents results for both the full sample, and the sample truncated to include only consumption between 40–4,000 kL yr^{-1}. The main qualitative findings are similar. Overall, 17% of respondents who reported their household water consumption were considered to have provided unreasonably small values (12%) or large values (5%). The various summary statistics presented are based on the truncated sample. Descriptions for the survey variables used in the analysis are provided in Table 1. The responses to selected qualitative variables calculated from samples used in the analysis are provided in Table 2 while Table 3 gives the frequency of the self-reported water-saving behaviors from the subset of households used in our models of water-saving behaviors.

[20] Table 4 is a summary of the observations per country and the mean and median values for water consumption by household (kL household^{-1}), average water price (€ kL^{-1}), household income (€), household size (number of people) and size of residence (m^2) in a sample of 1369 households that was used to model water consumption. Among the 10 countries surveyed, Mexico has the highest median level of annual water consumption (250 kL yr^{-1}) and also has the lowest median of average water price (0.31 € kL^{-1}) where this price is constructed as the ratio of household water expenditures to household water consumption. France has the lowest median level of water consumption (100 kL yr^{-1}) and the highest median of average water price (2.82 € kL^{-1}). Figure 1 illustrates the striking and negative relationship between the mean of volumetric price of water (€ kL^{-1}) and the mean of per capita residential water consumption (kL yr^{-1}) among the 10 countries.

[21] Measures of household income by country reflect the relative rankings of per capita income in the 10 countries such that Norway has the highest average household income and Mexico the lowest. The overall proportion of household income spent on residential water consumption is a little less than 1% and varies from a low of 0.45% in South Korea to a high of 1.74% for the Czech Republic. The data also indicate that households in the two lowest income deciles in all countries as a whole spend, as a percentage of income, between 2 and 3 times as much on their water bill than households in the highest-income decile.

3.2. Online Surveys and Data Comparisons

[22] Online surveys offer the advantages of lower costs and quicker return time than mail surveys and are widely used in marketing research. Despite these benefits, a concern with the use of online surveys is that the quality of the responses and the representativeness of the online sample to the population may be inferior relative to more

Table 1. Description of Key Survey Variables

Variables	Description
Household water consumption	Water consumption of the household (kL yr^{-1})
Average water price	Is the average water price (€ kL^{-1}). It is constructed as the ratio of household water expenditures to household water consumption
Volumetric water charge	Dummy = 1 if a household is charged according to how much water they use, =0 if otherwise
Higher education	Dummy = 1 for having completed post-2ndary school or university-level education, =0 if otherwise
Household income	Is the household income after tax (thousands of EUR/year)
Adults	Is the number of adults (age $\geq$ 18) in the household
Children	Number of children (age < 18) in the household
Size of residence	Size of residence (m^2)
Rooms	Number of rooms in the residence
Age of respondent	Is the age of the respondent (years)
Urban location	Dummy = 1 if the residence is best described as being located in an urban area, =0 if otherwise
House dummy	Dummy = 1 if the residence is a detached or semidetached house, =0 if otherwise
Garden dummy	Dummy = 1 if the residence has a garden, terrace or balcony, =0 if otherwise
Dual-flush/efficient toilet	Dummy = 1 for having low volume or dual flush toilet, =0 if otherwise
Efficient shower	Dummy = 1 for having water flow restrictor taps/low flow shower head, =0 if otherwise
Rainwater tank	Dummy = 1 for having water tank to collect rainwater, =0 if otherwise
Enviro-concerns	Reflect concerns about environmental issues, values from 1 to 4. Higher values mean more concerns about environment
Enviro-group member	Dummy = 1 if being member of/or contributor to an environmental organization, =0 if otherwise
Enviro-group supporter	Dummy = 1 if contributing personal time to support the activities of an environmental organization over the past 24 months, =0 if otherwise
Voter dummy	Dummy = 1 if the respondent had voted in local or national elections in the previous six years, =0 if otherwise
High income	Dummy variable for high income group, =1 for households in the two highest income deciles in the survey, =0 if otherwise
Low income	Dummy variable for low income group, =1 for households in the two lowest income deciles in the survey, =0 if otherwise
Turn off the water while brushing teeth	Reflect the frequencies of doing this behavior. Take values from 1 to 4 for "never," "occasionally," "often" and "always"
Take shower instead of bath specifically to save water	Reflect the frequencies of doing this behavior. Take values from 1 to 4 for "never,""occasionally," "often" and "always"
Water the garden in the coolest part of the day to save water	Reflect the frequencies of doing this behavior. Take values from 1 to 4 for "never," "occasionally," "often," and "always"
Collect rainwater/recycle waste water	Reflect the frequencies of doing this behavior. Take values from 1 to 4 for "never," "occasionally," "often," and "always"
Precipitation	Annual rainfall in meters
Summer temperature	Average summer temperature in °C

Table 2. Responses to Selected Qualitative Variables[a]

	Sample Used in Water Consumption Model (N = 1369)		Sample Used in Model of "Turning Off Water While Brushing Teeth" (N = 8374)	
	Yes (%)	No (%)	Yes (%)	No (%)
Higher education	56.39	43.61	62.47	37.53
Enviro-group member	16.73	83.27	14.63	85.37
Enviro-group supporter	11.98	88.02	10.33	89.67
Voter dummy	92.84	7.16	89.83	10.17
House dummy	69.17	30.83	54.71	45.29
Urban location	72.46	27.54	76.08	23.92
Dual-flush/efficient toilet	65.52	34.48		
Efficient shower	62.24	37.76		
Rainwater tank	26.66	73.34		
Volumetric water charge			66.35	33.65

[a]Descriptive statistics calculated from other subsamples used in models of other water-saving behaviors are similar to the descriptive statistics detailed above.

traditional survey methods. A summary of comparisons between mail and web-based surveys and an empirical test of their equivalence by *Deutskens et al.* [2006], however, provide evidence that in terms of response characteristics, accuracy and composite reliability the two methods are indistinguishable. Recent evidence, at least in terms of medical research, also supports the hypothesis that the reliability between web-based and telephone interviews are similar [*Rankin et al.*, 2008] although this may not necessarily be true in general population surveys.

[23] While internet surveys may not be the most reliable method of data collection, at least relative to properly conducted face-to-face interviews [*Fricker and Schonau*, 2002], the pertinent question is, whether the data collected by the OECD with its internet survey provide an extractable, albeit noisy, signal in terms of the household determinants of water demand? Data comparisons on key water variables suggests that, at least for the countries where corroboration has been undertaken (such as Canada), the data do provide an extractable signal. For instance, the survey

Table 3. Frequency of Self-Reported Water-Saving Behaviors in Samples Used in Models of Water-Saving Behaviors

Behaviors	Never	Occasionally	Often	Always	N[a]
Turn off the water while brushing teeth	11.49	19.97	20.32	48.22	8374
Take shower instead of bath to save water	5.77	9.18	21.57	63.49	8082
Plug the sink when washing dishes	17.52	19.24	19.22	44.02	7753
Water the garden in the coolest part of the day	12.45	14.75	23.42	49.38	5727
Collect rainwater or recycle waste water	44.41	14.63	14.63	26.33	6248

[a]N, number of observations used in the model.

results indicate 40% of Canadian households have dual-flush or low volume toilets and 56% have low-flow showerheads while [*Statistics Canada*, 2009] reports for 2007 that 39% of households have dual-flush toilets and 54% have low-flow showerheads.

[24] Summary data that compare key socio-economic characteristics from census and other sources with those from the OECD sample are available for a selection of the countries. A comparison of the data indicates that the online OECD sample is representative of the overall population in terms of key variables such as household size, residence size, etc. [*OECD*, 2008]. The demographics of the subset that is used in our water consumption model are also similar in median and in both mean and standard deviation to the demographics of the full set of respondents (see Appendix A). Overall, the *OECD* [2008, p. 33] concludes that the survey data compares well with other data sources, with the exception of Mexico where the sample of respondents may represent a higher income demographic. Our main findings with all 10 OECD countries are not significantly changed if Mexican households are excluded.

[25] Another way to compare the survey responses is to use the burden of water charges as a percentage of income or household expenditures. Unlike cross-country comparisons using water prices, there is no need to make conversions into a common currency and over time as the water burdens are already directly comparable. A comparison from two published data sources of the average water burden [*OECD*, 1999, 2003] to those calculated from this survey is provided in Table 5 where our data is calculated from the subsample that is used in the analysis of water consumption. The comparison reveals a general similarity despite some specific differences.

4. Analysis of OECD Residential Water Demand

[26] The analysis is grouped into two categories. In this section, we regress the natural logarithm of household water consumption in thousands of liters (kL) against a range of socio-economic and residential characteristics, attitudinal characteristics and environmental concerns of respondents, and the average water price (€ kL^{-1}). In section 5, we undertake ordered probit estimation to regress self-reported water-saving behaviors against a wide range of continuous and categorical variables. Combined, the two types of estimation seek to answer the following questions:

[27] 1. How does household water consumption vary with differences in the average water price?

[28] 2. How much is household water consumption influenced by water-saving devices, such as dual-flush toilets?

[29] 3. How do attitudinal characteristics and environmental concerns (such as membership of or support for an environmental organization, concern about environmental issues) influence water consumption and water-saving behaviors?

[30] In the analysis, we are mindful of the statistical pitfalls of working with potentially noisy self-reported data from a very diverse sample and emphasize that we neither collected the data nor devised the survey questionnaire. Our goal is not to show that the data is "acceptable," but rather to demonstrate how to overcome the statistical challenges of using noisy data to identify a robust signal in terms of the effects of the average water price on household water consumption while accounting for relevant socio-economic, attitudinal, and bio-physical variables. We employ a battery of methods to correct for and to test for the reporting errors in the survey data. These include instrumental variables based on responses by neighbors, a Heckman selectivity-

Table 4. Mean and Median Values for Key Variables by Country and OECD (10) Calculated From the Sample Used in Water Consumption Model

	Household Water Consumption (kL yr^{-1})		Average Water Price (€ kL^{-1})		Household Income (€ yr^{-1})		Household Size (Number of Persons)		Residence Size (m^2)		
	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Obs
Australia	445	196	1.170	0.737	36,976	31,138	2.961	3	113	125	128
Canada	535	200	1.391	1.223	47,538	45,166	2.744	2	138	125	39
Czech R.	200	107	1.727	1.440	12,004	10,211	3.075	3	97	75	161
France	129	100	3.000	2.818	34,453	34,650	2.656	2	109	125	282
Italy	403	200	1.127	0.943	30,607	26,000	3.099	3	112	125	223
Korea	515	220	0.522	0.428	25,344	24,798	3.721	4	91	75	104
Mexico	375	250	0.563	0.309	7458	6584	3.715	4	114	125	165
Netherlands	171	102	2.089	1.765	32,228	29,750	2.252	2	96	75	159
Norway	137	120	2.369	1.698	61,461	58,060	2.833	2	152	150	30
Sweden	221	125	2.588	2.357	37,110	34,146	2.564	2	144	125	78
OECD (10)	**292**	**140**	**1.703**	**1.333**	**28,334**	**25,239**	**2.969**	**3**	**110**	**125**	**1369**

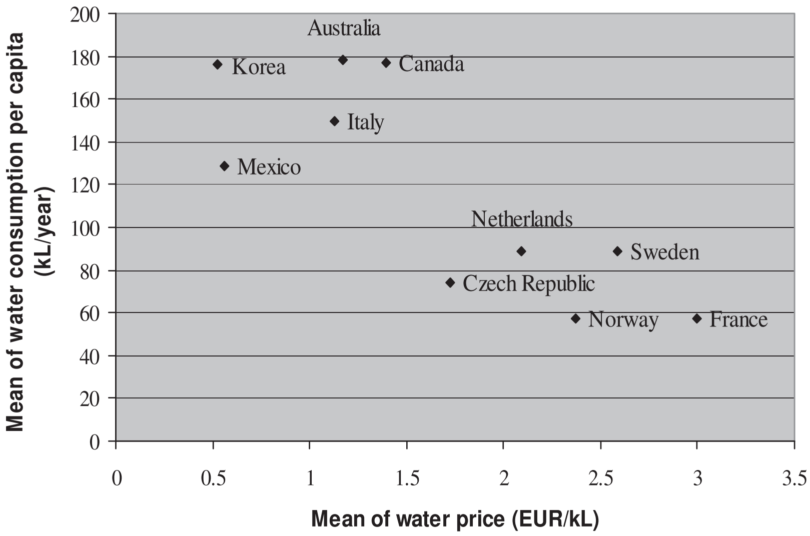

Figure 1. Residential water consumption per capita plotted against the calculated mean water price in OECD (10). Data from OECD 2008 survey (calculated from the sample of 1369 observations used in the reported water consumption model).

bias test based on overall survey completion, and a test based on whether the final digit of reported consumption is 0/5 or some more "random" number.

4.1. Explanatory Variables

[31] To determine the effect of water charges on household water use, we construct an average price of water (€ kL^{-1}) based on water expenditures and quantities consumed by households, defined as "Average water price." Ideally, a marginal price as well an average price should be included in the analysis, but marginal price data or the type of water tariff (increasing block, decreasing block, fixed price) faced by consumers are not available from the OECD survey. Despite this limitation, the effects of different average water prices on household water consumption, while also accounting for other relevant socio-economic variables, can still provide important information about the effectiveness of price and nonprice approaches as methods to regulate water demand.

[32] Respondents provided information about their concerns to eight environmental issues: waste generation, air pollution, climate change, water pollution, natural resource depletion, genetically modified organisms, endangered species and biodiversity, and noise. The question is replicated in Appendix B as question 5. Respondents indicated for each issue whether they are "not concerned," "fairly concerned," "concerned," "very concerned," or have "no opinion." We coded the levels of concern numerically from 1 (not concerned) to 4 (very concerned). The index variable "enviro-concerns" was constructed as the mean response for those categories where the respondent expressed an opinion, so that higher values of this index indicate that respondents have "greener" views. In addition, respondents were asked if they had voted in local or national elections in the previous 6 years (voter dummy), if they were a member of an environmental organization (enviro-group member) replicated as question 6 in Appendix B, and whether they had contributed any personal time

Table 5. Comparison of the Burden of Water Charges as Percentage of Income or Expenditures

Country	Year	OECD Denominator	OECD (%)	*Productivity Commission* [2008, p. 21][a,b] (%)	OECD 2008 Survey (N = 1369)[c] (%)
Australia	1996	income	0.79[d]	0.65	0.60
Canada	1996	income	1.05[d]		0.66
Czech Republic	1996	income	2.2[d]		1.74
France	1995	income	0.9[e]		0.90
Italy	1997	expenditures	0.7[e]		0.78
Korea	1997–98	expenditures	0.6[e]		0.45
Mexico	2000	income	1.3[e]		1.40
Netherlands	1999	income	0.6[e]		0.71
Norway	1996	income	0.45[d]		0.51
Sweden	1996	income	0.59[d]		1.00

[a]Based on New South Wales and as a percentage of total expenditure on goods and services in 2003–2004.
[b]Blank cells indicate data not available.
[c]Data of *OECD* [2008] survey is calculated from the sample used in water consumption model as shown in Table 6.
[d]Refers to public water supply. Data was obtained from *OECD* [1999, Table 22].
[e]Refers to public water supply. Data was obtained from *OECD* [2003, Table 2.2].

over the past 24 months to support the activities of an environmental organization (enviro-group supporter). The survey did not specify particular environmental groups, so membership or support does not necessarily imply concern over water use. We note with caution that these environmental attitudes/concerns questions used by the OECD have not been formally "validated," as have alternatives such as the New Environmental Paradigm (NEP) questions. To the extent possible, we checked whether the questions and answers were consistent with the various criteria described by *Dunlap et al.* [2000] in their validation of the revised NEP scale. While these checks were satisfactory, we note that there may be important aspects of environmental attitudes not reflected by these specific questions.

[33] Key household data provided by respondents included the age of respondent in years (age of respondent), number of adults (adults) and children (children) in the household, whether they had completed postsecondary school or university-level education (higher education), and after-tax household income (in thousands of Euros). Characteristics such as size of residence in square meters (size of residence), number of rooms in the residence (rooms), presence of a garden, terrace or balcony (garden dummy), whether the residence is best described as being located in an urban area (urban location), and if the residence was a detached or semidetached house (house dummy) were also obtained from respondents. In addition, information about the presence of water-saving devices at the residence such as dual-flush or efficient toilets (dual-flush/efficient toilet), water restrictors on taps/low-flow shower head (efficiency shower) and a rain water tank (rainwater tank) was provided. Climate data in terms of annual precipitation (precipitation) and average summer temperature (summer temp) come from an analysis by *New et al.* [2002] and were obtained in electronic form from http://www.gaisma.com. We use the climate estimates for the largest city of the recorded region (state, province, etc.) in the survey in which each respondent resides.

[34] The demand relationship can be written symbolically in terms of categories of explanatory variables as Ln Consumption = *f*(average price, conservation devices, attitudes, demographics, climate) + error, where *f* stands for a generic function, and the goal of estimation is to identify the parameters of this relationship.

4.2. Estimation

[35] Our analysis used an instrumental variables (IV) approach to estimate the effect of average price on household water consumption. IV estimation was undertaken because of two reasons: first, if there are block rate structures in terms of household water tariff the average water price variable is endogenously determined by household consumption, hence a potential endogeneity problem exists; and second, if there were reporting errors, the errors-in-variable problem might induce correlation between explanatory variables and the error term. To avoid these problems, a valid instrument was used for the average price in the preferred regression model.

[36] To generate a valid instrument for price, we used a jackknife grouping approach [*Angrist et al.*, 1999]. For each price response, we used as an instrument the average of the price variable for other households in the same administrative region (e.g., state or province) of the country. By construction, the regional price is uncorrelated with any reporting noise or endogenous choices by the particular household. Thus, if we define $\bar{p} = \sum_{i=1}^{N} p_i/N$ as the mean of the price variable p defined over all N households in a particular region then the jackknife price instrument for respondent j in that region is $(N\bar{p} - p_j)/(N-1)$.

[37] A possible concern is that investments in efficient toilets and other water-saving devices are simultaneously determined with water consumption. If so, these investments could be correlated with the error term in the household's demand equation, through unexplained variations in preferences. Accordingly, we constructed an instrument for these investments, using three pieces of information. First, the survey instrument asked whether such water devices were preexisting or if they could not be uninstalled, and if so, these cannot be considered as explicit investment decisions by the household. It is possible that the presence of water-saving devices could be a significant factor in the household's choice of residence or in the cost of the residence. However, given the relatively small fraction of household budgets spent on water, and the complexity of house-hunting, any endogeneity is likely to be modest. Second, as with the price variable, we applied a jackknife grouping instrument that was based on all the other households in the same administrative region of each respondent. Third, we used the variable "ownership of the residence" because house owners have more incentive than renters to make physical investments in a property. Symbolically, the model for presence of water-saving devices can be written in terms of categories: Devices = *g*(regional penetration, ownership, pre-existence, water consumption determinants) + error, where *g*(.) stands for a generic function with unknown parameters. We define "regional penetration" as the jackknife instrument that is a "catch-all" for factors other than household-specific tastes, such as regulations, device prices, or building styles which may influence regional levels of conservation device adoption.

[38] Regression 1 of Table 6 presents the results of the preferred regression specification. In this model, the natural logarithm of annual water consumption by households is regressed against a range of explanatory variables including the natural logarithm of average water price. Instruments are used for price, raintank, and water saving devices for shower and toilet. The estimation technique for the instruments is two stage least squares. The second stage accounts for country-level random effects in the correlation structure. The regression was implemented using the "xtivreg" command in the Stata statistical package. The F statistic for the instrument in the first stage regression exceeds 170 where *Staiger and Stock* [1997] suggest a first-stage F statistic greater than 10 is sufficient to avoid weak instrument issues. For comparison, regression 4 of Table 6 shows the same regression without using the instrument for the average price variable or the water-saving devices. A Durbin-Wu-Hausman specification test strongly rejects (p value = 0.001) the version without instruments in regression 4.

4.3. Results

[39] A key finding of regression 1 of Table 6 is that the central elasticity estimate for the average price is −0.429, and it is statistically significant at the 1% level as shown by the reported p values. This particular result emphasizes that

Table 6. Residential Water Consumption Results

Variable	Regression 1: Baseline IV		Regression 2: With Price-Income		Regression 3: With Outliers		Regression 4: With No Instruments	
	Coefficient	*p* Value	Coefficient	*p* Value	Coefficient	*p* Value	Coefficient	*p* Value
Average price (ln)[a]	−0.429[b]	0.000	−0.473[b]	0.000	−0.515[b]	0.000	−0.557[b]	0.000
Dual-flush/efficient toilet	−0.249[b]	0.004	−0.229[b]	0.007	−0.149[b]	0.003	−0.094[c]	0.011
Efficient shower	0.110	0.227	0.114	0.207	0.024	0.622	−0.024	0.503
Rainwater tank	−0.089	0.305	−0.069	0.422	0.011	0.838	0.017	0.680
Household income	0.003[b]	0.008	0.003[c]	0.038	0.005[b]	0.000	0.005[b]	0.000
Adults	0.133[b]	0.000	0.136[b]	0.000	0.160[b]	0.000	0.123[b]	0.000
Children	0.059[b]	0.003	0.063[b]	0.001	0.091[b]	0.000	0.053[b]	0.005
Rooms	0.039[b]	0.000	0.039[b]	0.000	0.042[b]	0.004	0.042[b]	0.000
Age of respondent	0.002	0.160	0.002	0.105	0.002	0.233	0.003[d]	0.075
Urban location	−0.019	0.667	−0.012	0.765	−0.036	0.534	−0.022	0.586
House dummy	−0.001	0.982	−0.019	0.689	−0.031	0.609	−0.041	0.364
Size of residence	0.001	0.122	0.001	0.124	0.001[c]	0.042	0.001	0.161
Garden dummy	0.032	0.494	0.049	0.298	0.042	0.498	0.038	0.404
Enviro-concerns	−0.017	0.515	−0.022	0.406	−0.039	0.260	−0.010	0.705
Enviro-group member	0.035	0.494	0.031	0.536	0.141[c]	0.038	0.015	0.759
Enviro-group supporter	−0.050	0.413	−0.053	0.383	−0.203[b]	0.009	−0.063	0.274
Higher education	0.003	0.932	0.009	0.809	−0.021	0.695	−0.037	0.310
Voter dummy	−0.069	0.315	−0.064	0.350	−0.062	0.503	−0.083	0.213
Precipitation	−0.161[c]	0.039	−0.133[d]	0.090	−0.195[d]	0.054	−0.215[b]	0.003
Summer temp	0.015[c]	0.035	0.015[c]	0.044	0.023[c]	0.022	0.003	0.609
Constant	4.312[b]	0.000	4.273[b]	0.000	3.995[b]	0.000	4.560[b]	0.000
High income/price interaction			0.228[b]	0.001				
Low income/price interaction			0.045	0.478				
Residual SD[e]								
Observations in regression[f]								

[a]Dependent variable is natural logarithm of annual household water consumption (kL).
[b]Significantly different from 0 at the 1% level of significance.
[c]Significantly different from 0 at the 5% level of significance.
[d]Significantly different from 0 at the 10% level of significance.
[e]Regression 1, 0.62; regression 2, 0.62; regression 3, 1.14; regression 4, 0.60.
[f]Regression 1, 1369; regression 2, 1369; regression 3, 1551; regression 4, 1369.

differences in the average price of water across households are important in explaining variation in household water consumption across the OECD (10) countries. For comparison, note that the meta-analysis by *Dalhuisen et al.* [2003] found a mean price elasticity of −0.41 and a median of −0.35.

[40] Socio-economic variables that have statistically significant coefficients at the 1% level include household income (+), the number of adults (+), and the number of children (+). The implied income elasticity at the mean income is 0.11. For comparison, the meta-analysis of *Dalhuisen et al.* [2003] reports an average income elasticity of 0.43 and a median of 0.24. The only residential variable that has a statistically significant coefficient is the number of rooms (+). The coefficient on the size of the residence has the hypothesized sign (+) with a *p* value of 0.122. The coefficient on the dual-flush/efficient toilet dummy variable is −0.249 which is negative and statistically significant at the 1% level. This indicates that the presence of a water efficient toilet reduces household water consumption by about 25%. By contrast, neither efficient shower heads nor rainwater tanks have a statistically significant effect on household water consumption.

[41] The estimated coefficients of the two climate variables, that include precipitation (−) and average summer temperature (+), are statistically significant at the 5% level. It suggests that climate factors also help to explain differences in household water consumption.

[42] The estimated coefficients of a number of explanatory variables hypothesized to affect household water consumption in Table 6, conditional on existing household water infrastructure, are not statistically significant at the standard levels of significance. These include all the attitudinal characteristics and environmental concerns variables, age of respondent, urban location, and dummies for whether the respondent had voted in the past 6 years, has a higher education, and if the residence is a house or has a garden.

[43] The environmental concerns and behavior variables, and also voting behavior, were not individually and also were not jointly significant at conventional levels of significance. To investigate this finding more fully, supplementary regressions were undertaken. First, we used a principal components orthogonal decomposition. The primary component explains more than 50% of the variation. None of the components are statistically significant, with the largest t statistic being 0.91. Second, we used a factor-analysis decomposition of the attitudinal variables. Again, none of the four identified factors was statistically significant, with the largest t statistic being 0.68. Given that these decompositions are orthogonal, no subset of the terms will be jointly significant either. Similarly insignificant results hold whether or not the "voter," "enviro-group member," and "enviro-group supporter" are included in the decompositions, or are included separately. In addition, we ran the regression with each attitudinal variable included alone, to avoid multicollinearity issues while preserving a simple variable interpretation and none of the attitudinal variables was statistically significant from 0.

[44] To better understand the impact of the average water price on household water consumption, we also estimated a model that allows price elasticities to be different between different income groups. This was implemented by estimating a model with an interaction term between a dummy variable for two income categories with the natural logarithm of price. The income categories were low income (lower quartile), high income (upper quartile), and middle income. These results are presented in regression 2 of Table 6. The estimated coefficient for the interaction term between high income and average price is positive and statistically significant at the 1% level, while the interaction term between low income and average price is insignificant. We also estimated the model where the interaction between low-income group and average water price is dropped from the model such that the base group is the low- and medium-income group. In this particular model, the coefficient of the interaction between high-income group and average water price is still positively significant. In short, the results indicate that water consumption for upper quartile income households is *less* responsive to changes in the average water price than for middle- and low-income households, and this difference is statistically significant.

[45] The results reported regressions 1, 2, and 4 in Table 6 only include households with self-reported household water consumption levels between 40 and 4000 kL yr^{-1}. To evaluate the robustness of the results to removing outliers, column 3 of Table 6 presents the results with all possible observations included in the regression, but with the price instruments calculated from the truncated data set. The results in regressions 1 and 3 are comparable. This suggests that reporting noise in the outlier observations is not correlated with the exogenous variables.

[46] The estimated coefficients on the key explanatory variables (average price, dual-flush toilet, income, adults, children, number of rooms at the residence, precipitation, and summer temperature) all remain statistically significant with outliers included and the coefficients on all of these variables have the same sign in the two samples. When outliers are included, the coefficient on the size of the residence (+) becomes statistically significant at the 5% level, as does the coefficient for membership in an environmental organization (+) and the coefficient for support of an environmental organization (−). Overall, the results suggest that, although the data are noisy, especially when outliers are included in the estimation, there is a strong signal between some key socio-economic explanatory variables and household water consumption.

4.4. Robustness Checks

[47] Various tests were performed to evaluate the robustness of the results. We used the *MacKinnon et al.* [1983] extended *P* test, based on an artificially nested model, to choose between a standard linear and log linear specification. The results indicate that the log linear model is preferred to the linear one. Using the Ramsey test [*Ramsey*, 1969], we failed to reject the null hypothesis of no functional-form misspecification in the log linear model.

[48] A frequent concern with random effects models is that the average level of a key explanatory variable may be correlated with some important omitted country-specific variable that appear as country-level random effects. For example, in countries with unusually high water consumption it is possible that the average price might also be set higher in response. To test for this effect, we followed *Hausman and Taylor* [1981] and formed a new instrument by taking deviations from the country mean of the main jackknife instrument for price. This uses only within-country variation so it is uncorrelated, by construction, with any country-level random effect. The coefficient on price is still highly significant (p value = 0.001), and the point estimate (−0.53) is similar to estimates using the original instrument. An overidentification test also failed to reject (p value = 0.19) the null hypothesis that the original instrument is uncorrelated with any country-level random effects.

[49] We calculated deviations from country mean to account for possible correlation with the random effect. The first stage F statistics were all above 60, indicating sufficiently strong instruments. Point estimates are similar to the preferred specification, and a Durbin-Wu-Hausman test fails to reject (p value = 0.87) the null hypothesis that water-saving investments are uncorrelated with the regression error term.

[50] Another issue is the possibility that there may be sample selection bias such that there is a difference in terms of those households that reported their water consumption and those that did not. In particular, if unexplained variation in respondent's decision to report water consumption is correlated with unexplained variation in the water consumption itself, our estimates would be biased. To test for this possibility, a Heckman two-step test [*Heckman*, 1979] was undertaken for the preferred model, which failed to reject the null hypothesis of no bias. For the Heckman test to be robust and powerful, instruments are needed that predict whether the respondent provided data on the water bill but also have no direct bearing on water consumption. We suspect that respondents who chose not to answer similar questions in other parts of the survey instrument, such as the questions on expenditures on food, would also be less likely to report expenditures on water. Such a correlation might arise due to (1) impatience or laziness; (2) personal record-keeping habits; or (3) the respondent was not the primary homemaker or bill payer. Thus, we chose as instruments the set of specific questions which satisfied three properties: First, they provide for a "do not know" option; second, are plausibly related to household knowledge or record keeping; and, third, are posed to every respondent (no skip patterns). Some sort of answer to all questions posed to everyone was obligatory, so complete nonresponse was not an option. The six questions chosen were on the topics of expenditures on food, role of energy cost in choice of housing, time-varying electricity charges, amount of waste produced, and available recycling facilities. In the first stage, probit regression predicted response as a function of all exogenous variables, and each of these instruments was strongly significant, with all individual p values less than 0.003, a joint p value of 0 to at least 4 decimal places, a pseudo-R^2 of 0.11, and all coefficients negative as expected. In the second step, we tested whether the inverse-Mills ratio from the first step belongs in the water-consumption regression. This ratio is statistically insignificant, with a p value of 0.95, and the inclusion of the ratio produces almost no change in the regression results. Details on this test are available on request from the authors.

[51] Although our study finds no statistically significant direct effect of the attitudinal characteristics on household water consumption, conditional on existing household water infrastructure, it is possible that general environmental concerns and behaviors may influence household investment decisions. For instance, attitudinal characteristics and environmental concerns may help determine the purchase of dual-flush toilets that, in turn, could have a significant effect on reducing household water consumption [*Beaumais et al.*, 2009]. To examine this issue, we estimated a probit model of the adoption of a low volume/dual flush toilet. Our results show that some of the variables presenting attitudinal characteristics and environmental concerns, as measured in the survey, have a statistically significant and positive effect on the adoption of a low volume/dual flush toilet. Statistically significant variables include enviro-group supporter ($p = 0.027$), enviro-concerns ($p = 0.001$) and enviro-group member ($p = 0.035$). The positive effect of attitudinal characteristics/environmental concerns on the adoption of a low volume/dual flush toilet, combined with a significant and negative effect of a low volume/dual flush toilet on household water consumption, indicates there is an indirect effect of attitudes and environmental concerns on household water consumption.

[52] A final concern with our survey data is the possibility of reporting error. While instrumental variables estimation is designed to handle this issue, we provide a further check based on the last digit of reported quantity and expenditure data. We presume that individuals who provided their "best guess" in terms of the size of their water bill or water consumption were likely to provide their estimates ending with the "rounding" digits 0 or 5. By contrast, individuals providing data directly from their water bills, as they were instructed, would form a group of responses with a much more uniform pattern in terms of the last digit of their expenditures or consumption. To test for these possible differences, we created a dummy variable that equals one if both expenditures (in the local currency) and quantity ended in either a 0 or 5. We included this reporting dummy variable with the average price and estimated a model that allowed the estimated price elasticity to differ based on this last-digit pattern (0 or 5). The estimated price elasticity differed by only 0.03, and the difference was statistically insignificant (p value $= 0.63$).

5. Analysis of Water-Saving Behaviors

[53] A key policy lever in managing water demand is campaigns to conserve water use through a change in water-use practices. In the survey, respondents were asked to provide an indication of what water saving practices they undertook and their frequency (never, occasionally, often, always and not applicable). Using these responses, a series of ordered probit models were estimated to test whether a range of right-hand side variables increase the probability of undertaking self-reported water-savings behaviors. Key results are presented in Table 7 where the explanatory variable "volumetric water charge" is a dummy variable that equals 1 for households who are charged according to how much water they use. We use this dummy variable specification so that respondents who provided information about how they were charged for their water, but not the quantity consumed, can be included in the ordered probit analysis.

[54] Table 7 indicates that the largest overall effect on increasing the probability of respondents undertaking water-saving behaviors is whether households incur a volumetric water charge. Volumetric water charges increase the probability of (1) turning off the water while brushing teeth, (2) taking a shower instead of a bath, (3) watering the garden in the coolest part of the day, and (4) collecting rainwater and recycling wastewater. By contrast to the estimates with household water consumption as the dependent variable, environmental concerns and behaviors do affect some self-reported water-saving behaviors. For instance, being a member of an environmental organization or a supporter of an

Table 7. Summary of the Marginal Effects on Probability of "Often" or "Always" (Combined) Undertaking Water-Saving Behaviors

	Turn Off the Water While Brushing Teeth	Take Shower Instead of Bath Specifically to Save Water	Plug the Sink When Washing Dishes	Water the Garden in the Coolest Part of the Day to Save Water	Collect Rainwater/Recycle Waste Water
Volumetric water charge	0.157[a]	0.058[a]	0.018	0.073[a]	0.156[a]
Household income	−0.071[a]	0.001	−0.015[b]	−0.017[a]	−0.018[a]
Enviro-concerns	0.045[a]	0.010[c]	0.011	0.023[a]	−0.030[a]
Enviro-group member	0.026[c]	0.004	0.029[c]	0.015	0.045[b]
Enviro-group supporter	0.056[a]	0.021	0.110[a]	0.075[a]	0.107[a]
Higher education	0.039[a]	0.007	−0.020	−0.020[c]	−0.150[a]
Voter dummy	0.044[b]	0.015	0.085[a]	0.035[c]	0.045[b]
Adults	0.014[a]	−0.009[b]	0.016[a]	−0.015[a]	0.035[a]
Children	0.021[a]	−0.008[c]	0.018[a]	0.002	−0.001
Rooms	0.004	0.0003	0.0004	0.025[a]	0.012[a]
Age of respondent	−0.001[c]	0.001[b]	0.004[a]	0.004[a]	.004[a]
Urban location	0.033[a]	0.0004	−0.070[a]	−0.034[b]	−0.116[a]
House dummy	0.055[a]	0.014	0.036[a]	0.083[a]	−0.114[a]
Size of residence	−0.001[a]	−0.0001	−0.0003[b]	−0.0003[b]	−0.0004[a]
Number of Observations	8374	8082	7753	5727	6248
LR-chi2 test for overall significance of the model	LR = 758 (P = 0.000)	LR = 87.4 (P = 0.000)	LR = 1029 (P = 0.000)	LR = 503 (P = 0.000)	LR = 648 (P = 0.000)

[a]Significantly different from 0 at the 1% level of significance.
[b]Significantly different from 0 at the 5% level of significance.
[c]Significantly different from 0 at the 10% level of significance.

Table 8. Effect of Facing Volumetric Water Charges on Probability of Undertaking Water-Saving Behaviors

Water Saving Behavior	Marginal Change in Probability			
	Never	Occasionally	Often	Always
Turning off water while brushing teeth	−0.0689[a]	−0.0619[a]	−0.0132[a]	0.1440[a]
Taking shower instead of bath	−0.0183[a]	−0.0186[a]	−0.0225[a]	0.0594[a]
Plugging the sink when washing dishes	−0.0049	−0.0029	−0.0005	0.0083
Watering gardens in the coolest part of the day	−0.0486[a]	−0.0327[a]	−0.0151[a]	0.0964[a]
Collecting rainwater/recycling waste water	−0.1616[a]	0.0082[a]	0.0320[a]	0.1214[a]

[a]Significantly different from 0 at the 1% level of significance.

environmental organization increases the probability of "turning off water while brushing teeth," "plugging the sink when washing dishes," "watering the garden in coolest part of the day," (statistically significant only for "enviro-group supporter") and "collect rainwater/recycle waste-water." Greater environmental concerns are also statistically significant at increasing the probability of undertaking most of the self-reported water-saving behaviors. The social norm of the respondents, represented by whether they had voted in local or national elections in the past 6 years, was also found to significantly increase the probability of undertaking 4 out of the 5 water-saving behaviors.

[55] It is important to emphasize that the results in Table 7 are self-reported behaviors. Based on the regression results in section 4, however, the increased probability of undertaking water-saving behaviors is insufficient to show a statistically significant effect of the attitudinal characteristics on household water consumption conditional on existing household water infrastructure. However, as indicated earlier, attitudinal characteristics and environmental concerns do have an indirect effect on reducing household water consumption through the adoption of a low volume/dual flush toilet.

[56] Table 8 provides the marginal changes in the probability of undertaking water-saving behaviors from facing volumetric charges. Table 9 provides the marginal changes in probability from an increase in the average water price, where the ordered probit model is estimated for the sample which includes sufficient information to calculate average price. These marginal effects were calculated using the command "mfx" in Stata. In Table 8 and Table 9, the changes in probability of "always" engaging in water-saving behavior are positive in all cases, this is necessarily matched by negative changes in less-frequent categories. Both sets of results consistently indicate that volumetric water charge and a higher average price for water tend to increase the frequency of undertaking water-saving behaviors. Table 10 transforms the statistically significant marginal changes in probability from Table 8 for those households facing volumetric charges into actual water savings based on average water savings associated with each behavior. These calculated water savings, presented for illustrative purposes only, indicate that the overall effect of facing volumetric water charges is to reduce household water consumption by about 40 kL yr^{-1}, or about one quarter of median household water consumption in the OECD (10), provided that all the water-saving behaviors are applicable to the household.

6. Concluding Remarks

[57] Using a common survey instrument that collected household survey data from 10 OECD countries on environmental concerns and behaviors, water consumption and expenditures and socio-economic characteristics, we find that there is a robust, statistically significant and negative relationship between the average price of water and household water consumption. Among the possible water-saving devices included in the survey instrument, only a low volume/dual-flush toilet is found to have a statistically significant and negative effect on water consumption. After controlling for water-saving devices and other household and residential characteristics, we do not find significant evidence on the influence of environmental concerns and behaviors on household water consumption. However, attitudinal characteristics and environmental concerns do increase the adoption of a low volume/dual-flush toilet, which significantly reduces water consumption. Some environmental behaviors such as membership and support for an environmental organization, and also environmental concerns, do have a statistically significant and positive effect on the probability of undertaking self-reported water-saving

Table 9. Effect of Average Water Price on Probability of Undertaking Water-Saving Behaviors

Water Saving Behavior	Marginal Change in Probability			
	Never	Occasionally	Often	Always
Turning off water while brushing teeth	−.0014	−.0023	−.0011	.0048
Taking shower instead of bath	−.0034[a]	−.0040[a]	−.0073[a]	.0147[a]
Plugging the sink when washing dishes	−.0115[b]	−.0093[b]	−.0024[b]	.0232[b]
Watering gardens in the coolest part of the day	−.0107[b]	−.0126[b]	−.0107[b]	.0340[b]
Collecting rainwater/recycling waste water	−.0177[a]	−.0016[c]	.0012[c]	.0181[a]

[a]Significantly different from zero at the 5% level of significance.
[b]Significantly different from zero at the 1% level of significance.
[c]Significantly different from zero at the 10% level of significance.

Table 10. Water Consumption Effect of Volumetric Water Charges by Water-Saving Behaviors[a]

	Turn Off the Water While Brushing Teeth[b]	Take Shower Instead of Bath Specifically to Save Water[c]	Water the Garden in the Coolest Part of the Day to Save Water[d]	Collect Rainwater[e]	Recycle Waste Water[f]	Total
Measurement	Per person	Per person	Per household	Per household	Per person	Per household
Value	−0.858 kL	−1.148 kL	−5.660 kL	−8.441 kL	−6.652 kL	−40.07 kL

[a]Water consumption effect is measured in kL per year. Water-saving behaviors is measured for a three person household for 1 year. The effect of volumetric water charge on "plugging the sink when washing dishes" is insignificant as reported in Table 8, thus we do not include behavior "plugging the sink when washing dishes" in Table 10 above.

[b]Turning off the tap while brushing your teeth (assume 2 min per time) in the morning and at bedtime can save up to 20 L d^{-1} or 7.3 kL yr^{-1} based on average tap flows at a rate of 15–30 L min^{-1} and assumption that brushing of teeth would take 5 L/min (Water Wise Household, Available from South Australia Water at http://www.sawater.com.au/NR/rdonlyres/9E796BFF-7A3D-46A7-8E90-DF9F054AB4F4/0/WWHouse.pdf).

[c]Showers of 8 min duration using water efficiency shower head will use takes 72 L of water while, on average a bath tub, will hold about 150 L for a normal bath. Assuming a household member takes a shower instead of bath can, thus, save 78 L d^{-1} or 28.47 kL per person per year [*Madden and Carmichael*, 2007].

[d]Watering the garden consume around 400 L d^{-1} depending on aspect, vegetation type, soil type and residence size. Watering the garden in the early morning or evening can save up to 50% of water from evaporation (200 L d^{-1}). Assuming the garden is watered every day this will save up to 73 kL yr^{-1} [*Edwards*, 2004].

[e]A 5000 L water tank connected to 100 m^2 of roof when the water is only used for garden watering can provide around 59 kL of water per year depending on the total rainfall and pattern of rainfall and if used for toilet flushing and for the washing machine (see Think Water, ACT Water Fact Sheets, available at http://www.thinkwater.act.gov.au/more_information/publications.shtml).

[f]Recycling gray water from kitchen and bathroom can collect 33.5 kL per capita per year while recycling water from laundry can save up to 13 kL per person per year [*Troy et al.*, 2005, pp. 59–62].

behaviors, as does charging households volumetrically for their water use or increasing water price.

[58] Overall, the results suggest that despite the fact that water expenditures account for only about 1% of household income, charging households volumetrically for the water they use and the average price charged for water are the most important variables explaining differences in household water consumption in the 10 OECD countries surveyed. These findings imply that the average volumetric water price is an effective instrument to manage residential water demand in the surveyed countries. The analyses also suggest that water demand management policies that include campaigns to promote water-saving behaviors (such as taking a shower instead of a bath) and use water-saving devices (such as dual-flush toilet) would be more effective if households faced a volumetric charge for water, and a higher average water price.

Appendix A

[59] Here we present a comparison of descriptive statistics between samples (Table A1).

Table A1. Descriptive Statistics Calculated From the Sample Used in Water Consumption Model in Comparison to the Descriptive Statistics Calculated From the Full Sample of All Respondents

Variable	Full Sample (N = 10,251)			Subsample Used in Model of Water Consumption (N = 1369)		
	Median	Mean	SD	Median	Mean	SD
Age	43	43.15	14.30	44	44.02	14.22
Adult	2	2.24	1.02	2	2.38	1.04
Children	1	1.65	0.96	1	1.65	0.99
Income	25,800	30,258	21,633	25,239	28,334	18,877
Rooms	4	4.88	2.31	5	5.22	2.06
Urban	1	0.762	0.426	1	0.725	0.447
House_dummy	1	0.554	0.497	1	0.692	0.462
Size of residence	100	101.2	50.70	125	109.9	49.39
Garden dummy	1	0.856	0.351	1	0.922	0.269
Enviro-concerns	0.4	0.414	0.683	0.4	0.434	0.675
Enviro-group member	0	0.141	0.348	0	0.167	0.373
Enviro-group supporter	0	0.097	0.296	0	0.120	0.325
Higher education	1	0.614	0.487	1	0.564	0.496
Voter dummy	1	0.882	0.323	1	0.928	0.258
Dual-flush/efficient toilet	1	0.509	0.500	1	0.655	0.475
Efficient shower	1	0.544	0.498	1	0.622	0.485
Rainwater tank	0	0.169	0.374	0	0.267	0.442
Turning off water while brushing teeth	3	3.05	1.07	3	3.23	0.962
Taking shower instead of bath	4	3.41	0.899	4	3.54	0.796
Plugging the sink when washing dishes	3	2.92	1.15	3	3.02	1.09
Watering gardens in coolest part of day	4	3.11	1.07	4	3.34	0.946
Collecting rainwater/recycling waste water	2	2.23	1.26	3	2.55	1.29

Appendix B: Selected Questions From the OECD Survey Instrument

[60] Here we show selected questions from the OECD survey (Figure B1).

Q1. Is your household charged for water consumption in your primary residence?

1. Yes
2. No
3. Not sure

If Q1 =1, Ask Q2

Q2. How is your household charged for water consumption?

1. Charged according to how much water is used (e.g. via a water meter)
2. Flat fee (e.g. lump sum included in charges or rent)
3. Don't know

If Q2=1, Ask Q3

Q3. Approximately how much was the total annual cost for water consumption for your primary residence?
Please indicate if possible amount in $ and corresponding annual consumption in kL

Amount in $ per year *Please provide answer to the nearest dollar*	Volume of water consumed in kL
NOT OBLIGATORY	NOT OBLIGATORY

Q4. How often do you do the following in your daily life?
Please select one answer per row

	Never	Occasionally	Often	Always	Not applicable
Turn off the water while brushing teeth					
Take showers instead of bath specifically to save water					
Plug the sink when washing the dishes					
Water your garden in the coolest part of the day to reduce evaporation and save water					
Collect rainwater (e.g in water tanks) or recycle waste water					

Q5. How concerned are you about the following environmental issues?
Please select one answer per row

	Not concerned	Fairly concerned	Concerned	Very concerned	No opinion
Waste generation					
Air pollution					
Climate change (global warming)					
Water pollution					
Natural resource depletion (forest, water, energy)					
Genetically modified organisms (GMO)					
Endangered species and biodiversity					
Noise					

Q6. Are you currently a member of, or contributor/donator to, any environmental organisations?

1. Yes
2. No

Figure B1. Water use, water saving behaviors and attitudinal characteristics.

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