6. Residential Water Use

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1. Introduction

Although 72% of the earth surface is covered by water, less than 1% of the world's fresh water is directly accessible for human uses. Given humans' water consumption patterns and the world population growth rate, these fresh water reserves have been shrinking all over the world at an alarming rate. There are currently more than 800 million people facing water scarcity and the United Nations project that approximately 2 to 7 billion people will be left without water by 2050; moreover, in the next 20 years, the average global supply of water per person will drop by one-third (see United Nations, 2003 and 2006).

There are essentially two broad issues of concern for policy makers in the analysis of residential water consumption. The first issue relates to water pricing in the absence of environmental considerations, and whether existing prices are reflective of water scarcity as well as marginal costs of production and supply. The second issue relates to water pollution or degrading uses of water (Khan, 2005). Socially optimal pricing of water entails a per-unit price that encompasses the opportunity (or user) cost of water as generated by its scarcity, the marginal cost of producing/supplying water, and the marginal environmental cost of water use. In instances in which water is an exhaustible resource, water pricing requires adjustments over time to reflect the increased water scarcity and thus increased opportunity cost of water use. Socially optimal pricing of water also requires that the social costs and benefits associated with water use be properly measured. And even if an accurate assessment of these costs and benefits is possible, there are often political considerations that prevent water use from being appropriately priced. One such consideration is equity.

The effectiveness of water pricing depends on household responsiveness to price changes. The impact of a price increase on the demand for any good can be decomposed into an income effect and a substitution effect. The income effect results from a decrease in purchasing power (or decrease in real income) following the price increase; the substitution effect results from substitution possibilities which enable consumers to switch from more expensive goods to cheaper alternatives. At low price levels, the income effect of a given percentage change in price will be minimal. However, when the price of water is high, the income effect can be important. In response to a price change, individuals may start using more water-saving technologies or repairing leaks and replacing water-using laws with other paving materials. Appropriate estimation of the demand for water thus entails that consumers' responses to high price levels (or to significant price increases or price increases at high price levels) be taken into account.

In addition, studies on residential water use conclude that the demand for water at low levels of consumption is inelastic as water has no close substitutes so that the substitution effect is practically next to zero for basic needs. However, when this minimal level of consumption is satisfied, the marginal use of water may be more readily substitutable. As such, price elasticities may increase with consumption levels.

Households' response to water pricing depends not only on the initial price level but also on the pricing structure. In most countries, water supply services are typically financed through a two-part tariff involving a fixed fee and a variable (per-unit) charge. Consumers pay a fixed fee to be connected to water services which is charged, in most cases, to recover the investment cost and to ensure equity. Additionally, consumers pay a charge per unit of water consumed. This additional amount can be non-linear, that is, the cost per additional unit varies when consumption reaches certain thresholds. Thus, in different consumption blocks, the tariff structure has different marginal prices. These block rates can be either increasing or decreasing. In the increasing block-rate scheme, the price goes up for each successive block of water usage; in the decreasing block scheme, the opposite applies. Under the decreasing price structure, consumers tend to use more water; under the increasing block rate, they pay a penalty (in the form of higher price) for overusing water.

When estimating the price elasticity of demand, using only average prices in the presence of a block-rate system produces upward biased estimates. In increasing block-pricing schemes, a quantity of water (first block) is supplied with a fixed nominal fee, beyond which (the second block) the price level goes up. Once consumers move into the second block, they face a higher marginal price (MP) and a higher average price (AP). The increase in AP is however smaller than that in MP as AP includes the lower rate charged for units in the first block.

Concerns over the accuracy of estimates of price effects also exist when only marginal prices are considered and a block-rate system is in place (Howe and Linaweaver, 1967) as the income effects of a change in intra-marginal rates cannot be properly accounted for with constant marginal prices (within each block). The empirical formulation employed in Howe and Linaweaver (1967) allows for the estimation of a price elasticity of demand that includes both the income and substitution effects resulting from a change in the marginal price and a second elasticity measuring the income effect of changes in intra-marginal rates. This second price variable is referred to as the Nordin's difference variable (Nordin, 1976) and is defined as the difference between consumers' actual water bill and the water bill that would result if each unit of water were purchased at the marginal price.[1]

The relationship between marginal and unit prices depends on the level of consumption, whether it is below or above the allowance level (if there is one), and

1. This "difference" variable and the income variable both measure income effects only. Therefore, in a linear demand equation, their coefficients are expected to be equal in magnitude but opposite in sign.

whether the rate structure is increasing, uniform, or decreasing. The marginal price is zero for consumption up to the allowance level; for the first unit beyond the allowance level (and any additional unit in the first block), the marginal price is equal to the unit price for the first block. For units of consumption above the allowance, the marginal price exceeds, equals, or falls short of the average price, depending on whether the block rate is increasing, uniform, or decreasing.

Besides measures relying on water price increases, other instruments can be used by governments to induce a reduction in residential water use, which are particularly useful when changes are needed in very short periods of time. These non-price policy measures include: restrictions on certain water usages, rationing, public information campaigns, labeling and metering, and subsidies for using water-efficient technology. In several studies that consider these non-price demand management policies, the empirical evidence points to their being highly effective at reducing water demand.

In addition to policy variables, the demand for water use is likely to depend on a host of other factors, including socio-demographic (*e.g.* age, income, type and size of house) and attitudinal characteristics, and responses to a given policy are likely to vary with these characteristics. In light of the increased awareness of the environmental problems associated with water usage and the alarming projections of water scarcity over the next few decades, water-related conservation issues are bound to be high on the policy agenda. For policies to be efficiently and effectively designed, it is then necessary for those involved in policy-making to have an accurate understanding of the factors influencing households' water consumption decisions, the direction and magnitude of influence of each of these factors, and whether the effects of policy incentives tend to be independent of socio-demographic and attitudinal characteristics or are more pronounced in particular segments of the population.

Section 2 provides a review of the empirical literature on residential water use structured around two themes: (2.1) factors determining the demand for water and (2.2) willingness-to-pay for water, which is essential to the estimation of the benefits of water use. In section 3, the policy implications that arise from the discussion of the empirical literature are presented.[2]

2. Literature review

Firstly, the main findings on the determinants of residential water use are presented. Four types of explanatory variables are considered: socio-demographic characteristics, attitudinal factors, pricing policy measures, and non-pricing policy measures. The sub-section on socio-demographic characteristics also includes a discussion about weather variables, whenever applicable. Secondly, the results of the literature reviewed on the willingness-to-pay for water services are summarized.

2. The results of the studies are summarized in the three tables presented in the related online report, "Household Water Consumption: Summary of Empirical Results", at *http://dx.doi.org/10.1787/482525215830*. Table A.1 gives a summary of the evidence on the policy instruments considered in the literature. Table A.2 summarizes the effects of socio-demographic, weather, attitudinal, and policy variables. Table A.3 provides the price elasticity and income elasticity estimates available to date.

2.1 Determinants of the demand for water use

In the majority of the studies reviewed, the estimation of a water demand function almost always includes some socio-demographic factors and policy variables (either pricing or non-pricing, or both). Questions about the role of attitudes are less frequently examined; this is clearly an area where more research is needed, especially in consideration of the difficulties with relying on incentive-based initiatives (either because of low price elasticities or because of equity concerns).

2.1.1 Socio-demographic characteristics and weather variables

In Headley (1963), the impact of family income on residential water demand is studied on the basis of data from 14 cities in the San Francisco-Oakland metropolitan area. Income is the only variable included in the model as it is thought to be a good proxy for all those factors that induce consumers to demand more water (*e.g.* dishwasher ownership, number of bathrooms). The relationship between the average percentage change in water purchase associated with a given percentage change in the median family income is estimated for 1950 and 1959. The results translate into income elasticity estimates of 1.49 and 1.24, respectively, suggesting that water consumption is very responsive to changes in income. In the analysis of the data over the ten-year period (1950 to 1959), the income elasticity estimate is much lower, although more plausible, with a weighted elasticity for the entire population reported at 0.19, suggesting that a 10% increase in income results in a 2% increase in water use. The study concludes that there is a significant positive relationship between family income and residential water consumption.

In Wong (1972), the demand for municipal water is estimated with data from Chicago and nearby communities over the period from 1951 to 1961. Two analyses are carried out: a time-series analysis involving Chicago and 59 neighboring communities; a cross-sectional analysis involving 103 public water supply systems. In the former analysis, average per-capita municipal water demand is expressed as a function of price per 1 000 gallons, average household income, and average summer temperature; in the latter analysis, temperature is excluded and sample communities are divided into four groups according to size. In both cases, income is found to be a statistically significant variable for Chicago (in the time-series analysis) and for the two largest groups of communities (in the cross-sectional analysis). The time-series model provides a lower estimate of the income elasticity (0.2 for Chicago versus 0.48 in the cross-sectional model); however, income does not seem to have any significant impact on per-capita water consumption in suburban or small communities. Average summer temperature is significant in both suburban and urban centers.

In Nieswiadomy and Molina (1989), the demand for water use is estimated based on microdata time-series (monthly) observations for the same group of consumers facing a decreasing block-rate pricing for the first half of the time series and an increasing block-rate schedule for the second half of the time series. Out of the 60 000 households living in the city of Denton, Texas, 101 consumers are randomly sampled, with their monthly water billing records obtained from the city's water department from 1976 to 1980, under a decreasing block-rate system, and from 1981 to 1985, under an increasing block-rate system. Only summer months are considered; furthermore, the sample data are screened in such a way that the sample only includes houses with lawns and without swimming pools and owned/occupied by the same families over the entire time period. The model also includes income and weather as explanatory variables. Independently of the type of block-rate pricing scheme in place or of the estimation technique employed, households with higher incomes, bigger houses, and/or bigger lots are found to demand more water; furthermore, the effect of hotter temperatures on water consumption is significant and, as expected, positive.

In Renwick and Archibald (1998), data are collected through various sources (households' monthly utility bills and telephone interviews) to estimate the demand for residential water in two Californian communities, Santa Barbara and Goleta. Aside from policy variables, other variables covered in the study include the size of the household and household income. Results suggest that household size, as expected, has a positive effect on water consumption and that a 10% increase in income leads to a 3.6% increase in water use. The income elasticity estimate is similar to that in Howe and Linaweaver (1967), Jones and Morris (1984), Nieswiadomy (1992), and Renwick *et al.* (1998).[3] Furthermore, income is found to negatively affect households' responsiveness to price changes; in particular, a 10% increase in the price of water leads to a 5.3% reduction in water use for the low-income group, a 2.2% reduction for the moderate- to high-income group, and a 1.1% reduction for the wealthy people. The fact that low-income households are almost 5 times more responsive to price increases than the high-income households suggests a shifting of the financial burden of conservation through higher prices onto low-income households, and thus poses a serious concern for policy makers from an equity point of view.

In Espineira (2000), data are gathered from 132 towns in north-west Spain[4] for the period from 1993 to 1999 to estimate a water demand function that includes average number of members in the household, per-capita disposable income, average monthly temperature, number of days with precipitation in a month, number of water units charged regardless of actual use (in m^3), number of billing periods in a year, percentage of population over age 64, percentage of dwellings regarded as main residence, and a variable, referred to as the Nordin difference, that measures the difference between the total water bill and the water bill that would result from pricing total water use at the marginal price. The estimated coefficient of the "difference" variable used in the model is highly significant and has the expected negative sign, which implies that water is a normal good as confirmed by a positive and statistically significant income elasticity estimate. The estimates of the coefficients of the weather variables (average monthly temperature and number of rainy days in the month) are statistically significant with negative signs, although the magnitude of the estimates is rather low, implying that climatic effects do not play a significant role in determining the demand for water, particularly in the north-west area of Spain. Consistent with *a priori* considerations, a higher ratio of the population above age 64 is found to lead to a lower level of water use whereas the number of houses regarded as main residence is found to have a positive effect. The latter variable captures the impact of tourism, which is particularly relevant in

3. The income elasticity estimate is 0.32 in Howe and Linaweaver, between 0.40 and 0.55, for three different marginal prices, in Jones and Morris, ranging from 0.28 and 0.44 in Nieswiadomy, and 0.25 in Renwick *et al.*

4. Most of these towns employ a tariff schedule consisting of a fixed fee for a minimum allowable quantity and a second block charged at a single rate, or several blocks charged at increasing rates.

the area of interest. The larger the number of holiday residences is, the more water is expected to be consumed during the summer and relatively less in the other seasons. However, this seasonal impact is not detected.

In Nauges and Thomas (2000), data are collected from 116 eastern France communities over the period 1988 to 1993. Water consumption is estimated as a function of average water price, proportion of inhabitants over 60 years old, proportion of households composed of one or two members, average income before tax, population density, proportion of single house units in the community, proportion of houses equipped with a bath, proportion of houses in which the owner owns one or more cars, proportion of housings built before 1949 in the total stock of housings, proportion of housings built after 1982 in the total stock of housings, local community economic activity, and average annual rainfall. In France, 85% of the population is supplied water by private operators; furthermore, residential water users face a two-part tariff scheme whereby they pay a fixed fee for access to the supply of water and a variable fee which depends on water consumption. In determining the price of water, the local authority (municipality) negotiates with private operators for the entire contracting term, and the price depends largely on the expected amount that is to be used by the community, socio-demographic characteristics of the community, and possible pressures by lobbying groups. The price of water is thus not only the result of profit-maximizing considerations by the private operators, but also of negotiations between private operators and the local authority. Based on the estimated coefficients of the various non-policy variables included in the analysis, house age has a positive effect on water consumption as older houses are more prone to leakages, a 10% increase in average taxable income leads to a 1% increase in water use, and communities with more seniors (over 60) and/or with more new (built after 1982) houses require less water.

In Domene and Sauri (2005), a sample of 532 households, from 22 municipalities in the metropolitan region of Barcelona, is utilized to investigate the effects of urbanization and demographic, behavioral, and housing characteristics on water consumption patterns. In Spain, the demand for housing in the suburbs of the main cities has been increasing significantly as a result of a number of social and economic factors such as preferences for single condominium units, prevalence of many single-member families, rising affluence levels, and low interest rates. The urban sprawl experienced by Spain and, in general, southern Europe over the last decade gives rise to important concerns over the environment, as low-density urbanization leads to inefficient use of land and energy, and rapid urbanization causes substantial increases in water consumption.[5] In this study, a telephone survey is administered to collect information from each of the 532 households on water use for both indoor and outdoor activities, socio-economic variables, household characteristics, water fixtures, and total water consumption from their water bills for 2003. Three types of housing are used in the analysis: *i)* high-density housing (apartments in a multistory building), *ii)* mid-density housing (apartment blocks with shared garden

5. Two important transitions witnessed in MRB are: a declining household size (based on the 2001 census, more than 25% of households are single-member households and more than 50% have two persons or less) and the migration of young couples with children to suburbs.

and swimming pool), and *iii)* low-density housing (condominiums and detached housing).[6]

A descriptive analysis of the data reveals that households differing in income do not exhibit significantly different personal habits of water usage (*e.g.* washing hands, brushing teeth, and flushing toilets). The few cases in which significance can be established include showers, which low-income groups tend to have fewer per week, and water use in general, which tends to be higher among women and lower among older people. In terms of water consumption across the three housing types, high-density households are found to use the least amount of water per household and per capita, with an annual average of 120 litres per person per day, possibly because they have fewer indoor water fixtures and fewer members (households are smaller in size), although there is no statistical difference in water usage between low- and mid-density households; furthermore, 72% of water consumed in high-density households is for personal hygiene (shower, bath, and toilet) and 36% of water consumed in low-density households is for irrigating gardens. As for the results of the estimation of the per-capita demand for daily water consumption, housing type, garden necessities, household size, presence of a swimming pool, income, and consumer attitudes towards water conservation are all significant determinants of water usage. Households living in single-family dwellings tend to consume approximately 36 litres more per day, on average, than those living in multistory buildings because of outdoor use of water; households with fewer members and/or without swimming pools tend to consume less water while those with higher income levels consume more through the use of more water-based appliances. Garden size is not significant but garden design is important.

In Mazzanti and Montini (2006), a municipal panel data set from Emilia-Romagna, Italy, covering the period 1998 to 2001, is used to examine the determinants of the demand for residential water. In addition to the price of water, several socio-economic factors are considered, including income, household size, population age, altitude, and share of rural area. Income and altitude are the only variables found to be significant. Results suggest that water consumption decreases with altitude (as temperature drops) but increases with income. According to estimates, a 10% increase in income causes water use to drop by 5.3 to 6.2%.

2.1.2 Attitudinal characteristics

In Domene and Sauri (2005), a telephone survey is administered to 532 households in the metropolitan region of Barcelona to examine, among other factors, the impact of consumers' attitudes towards water conservation on water consumption. A consumer behaviour index is constructed based upon six conservation practices: installing water-saving devices in taps, toilets, and showers (each of them counted individually), turning off running water while brushing teeth, purchasing water-efficient appliances, and comparing water consumption between periods. The descriptive analysis of the data

6. Of all the houses in the region, 60% are high-density, 30% are detached or semi-detached, and the rest are apartment blocks with communal garden and swimming pool. In MRB, from 1985 to 2000, 35% of new houses are detached or semi-detached, which means that most of those houses have a garden (considered a symbol of social status). Furthermore, smaller households, with one or two members, are usually found in the metropolitan centers while larger households are more common in the suburban areas.

shows that consumer behaviour does not tend to depend on income, with only one exception being shower use, which high-income groups have more frequently. Attitudes towards water conservation are found to have an effect on water consumption.

In Gilg and Barr (2005), a sample of 1 600 households from Devon, UK, is employed to examine how the behavioral patterns of households affect water demand. The data are gathered through a questionnaire in which consumers are asked about their attitudes towards water consumption and their socio-demographic characteristics. More than half of the sample reports having undertaken water-saving actions (such as turning off the tap while brushing teeth, using shower rather than a bath, waiting until there is a full load before using a washing machine). Based on the data collected, four clusters of individuals are identified: *i)* committed environmentalists, *ii)* mainstream environmentalists, *iii)* occasional environmentalists, and *iv)* non-environmentalists. Committed and mainstream environmentalists have a strong commitment to water-saving behaviour, while occasional environmentalists are much less committed and non-environmentalists never undertake water-conserving behaviour. Results indicate that the mean age of committed environmentalists in the highest while the mean age of non-environmentalists is the lowest. Non-environmentalists have significantly lower income levels while committed and mainstream environmentalists tend to have smaller households.

In Hurd (2006), households' landscape choices are examined based on data from a mail survey implemented in 2004 in three New Mexico cities (Albuquerque, Las Cruces and Santa Fe). Four types of landscapes are identified according to the extent to which water conservation considerations have been incorporated. Households' landscape choice is then expressed as a function of water cost, number of children in the household, level of education, and degree of responsibility towards water conservation, all of which but the number of children have effects that are both significant and consistent with *a priori* expectations. In particular, a sense of moral responsibility towards water conservation is found to significantly induce people to choose water-conserving landscape types.

2.1.3 Pricing policy measures

In Wong (1972), the demand for municipal water is estimated for Chicago and nearby communities with data from 1951 to 1961. The price coefficient estimate is found to be statistically significant for the suburban communities outside Chicago in a time-series model, and for all communities but those in the small-size group in a cross-sectional model. In general, the estimates from the cross-sectional analysis (ranging from -0.26 to -0.82) is higher than that in the time-series analysis (ranging from -0.02 to -0.28). In the latter case, the estimated price coefficient for Chicago is insignificant, which is likely attributable to the extremely low water price (22 cents per 1 000 gallons in 1961); water prices tend to be higher in suburban areas (from 25 cents to USD 1.25 per 1 000 gallons) due to greater distance from water supply and, as such, consumers tend to be more price-sensitive. In the cross-sectional analysis, the higher price elasticity detected in larger and more urbanized communities may also be related to the higher water prices consumers face when they use groundwater as opposed to surface water, which is less expensive to supply.[7] In sum, households living in communities outside Chicago tend to be more

7. The cross-sectional analysis includes 103 municipal systems all supplied by groundwater; the time-series analysis includes Chicago and 59 nearby communities all supplied by the surface water of Lake Michigan.

price-sensitive and, although the proportion of the total variation in water consumption explained by variation in the explanatory variables included in the model (price, income and, in the time-series analysis, temperature) is low, there is some evidence in support of a differential pricing system as an effective tool for reducing water usage.

In Billings and Agthe (1980), the marginal price elasticity of water demand is estimated for increasing block-rate schemes, based on monthly data from Tucson, Arizona, from January 1974 to September 1977, with different model specifications. The empirical formulation employed in the study allows for the estimation of a price elasticity of demand that includes both the income and substitution effects resulting from a change in the marginal price and a second elasticity (difference elasticity) measuring the income effect of changes in intra-marginal rates. Results indicate that price elasticities range from -0.45 (at 21 cents per 100 cubic feet) to -0.61 (at 42 cents per 100 cubic feet) in a linear specification, consistently with findings in Wong (1972) and Young (1973) for the same geographical area. The difference elasticity of demand is instead estimated to be between -0.12 and -0.14, depending on specification. The estimate of the coefficient of the difference variable has the expected sign but is much larger in magnitude than the estimate of the coefficient of the income variable. Possible explanations for this deviation include: *i)* the difference variable absorbs less than 0.15% of income and may be too small to have any significant impact on consumers' perceptions of income; *ii)* the use of aggregate rather than individual data; *iii)* the use of state-level income data. Finally, a comparison of the results with nominal and real figures for prices and incomes reveals that consumers are more responsive to real changes than to nominal changes.

In Chicoine and Ramamurthy (1986), the appropriateness of including either only marginal prices or average prices in the estimation of the demand for water is tested. The data are gathered from a telephone survey conducted in 1983 and involving 100 households living in 59 rural water districts in Illinois which rely on decreasing block-rate systems. As noted, under a block-pricing schedule, price effects can be accurately captured through the inclusion of a marginal price and a difference variable (also referred to as Nordin difference) that measures the lump-sum income effects embedded in a block-rate system. However, consumers are often unaware of the complexities of block-pricing mechanisms and do not have a clear notion about marginal rates; as a result, they tend to respond to average prices rather than to marginal prices. To test this hypothesis, the demand model employed in this study is an average price model with price decomposed into marginal price and a second variable that is equivalent to the difference between average price and marginal price. Monthly water consumption is estimated as a function of the two price components, number of people in the household, number of bathrooms in the household, and monthly income of the household minus the (Nordin) difference variable. The results suggest that the second price variable has a negative impact on water consumption which implies that consumers tend to respond to average water prices when taking decisions about water usage. At the same time, the hypothesis that the average price model with no marginal price is correctly specified is rejected, so that marginal price is necessary to explain consumers' behaviour towards water usage. Furthermore, a model with marginal price but without average price is unable to explain consumers' decisions concerning water consumption, possibly because water expenses represent a small proportion (around 1.3%) of households' income. The analysis thus points to the importance of including both marginal and average prices in the estimation of water demand.

In Nieswiadomy and Molina (1989), a panel of 101 consumers in the city of Denton, Texas, is observed from 1976 to 1985. A decreasing block-rate pricing in place during the first period to 1980 and an increasing block-rate pricing in place during the second period from 1981. Different estimation procedures are employed and each results into a significant and negative price effect for both pricing schemes; in other words, higher water prices induce lower water usage.[8] When the endogeneity of the price variable is accounted for with the use of appropriate estimation procedures, the estimate of the price coefficient is shown to have the expected sign and to be statistically significant, ranging from -0.36 to -0.86, with the only exception being the decreasing block-rate scheme in one of the models estimated. Consistent with other studies which include the Nordin difference variable, such as Schefter and David (1985)[9] and Chicoine and Ramamurthy (1986), no evidence is detected in support of the proposition in Nordin (1976) that the difference variable capturing the income effects of intra-marginal rates has a negative effect on water consumption, corresponding in magnitude to the effect of an income increase. This insignificance may result from the opaque signal provided by complicated pricing structures and confusing billing procedures or, as proposed in Henson (1984), from the small size of water expenditures relative to consumers' monthly budgets.

In Dandy *et al.* (1997), data from 400 households living in the metropolitan area of Adelaide, South Australia, covering the period 1978 to 1992 are employed in the estimation of water demand. In the area of interest, water is priced on the basis of a two-part tariff system consisting of a fixed charge and a uniform fee for each unit above a free allowance of water usage. The period of study includes the 1991-1992 introduction of a constant allowance of 136 kl of water; prior to 1991-1992, water allocation is computed as a percentage of property value. When consumers use less than the free allowance level, they only pay the fixed charge; their marginal price is zero, so that their water consumption depends on their needs which vary only with climate, household size, and other non-price factors. However, when households consume more than the allowance level, they pay the fixed fee plus the uniform unit rate for each unit of water consumed above the allowance level; their water demand becomes sensitive to the marginal price. Consistent with the utility maximizing framework of decision making (Griffin and Chang, 1990), the results suggest that consumption is influenced by marginal prices and not unit (average) prices.

Because of the presence of the free allowance level, marginal prices and average prices do not coincide in spite of the rate uniformity. Marginal prices are used, together with real property value as a proxy for real income, socio-economic characteristics, and physical variables, in both a static model and a dynamic model of water demand. In the static model, the average household is found to reduce its water usage by 21% in response to the introduction of the constant allowance of 136 kl of water. Furthermore,

8. The IV and 2SLS price effect estimates are argued to be improvements over the ordinary least square estimates which tend to be understated (negative bias) in the presence of decreasing block-rate pricing and overstated (positive bias) in the presence of increasing block-rate pricing because of simultaneity in the relationship between water consumption and water price (under a block-rate system, the price of water both determines and is determined by consumption) or endogeneity of the price level (the price of water is an endogenous variable as it is a function of consumption).

9. In Schefter and David (1985), estimation results are based on aggregate data from 131 Wisconsin communities which rely on multi-part tariff schedules for water pricing.

consumption above the allowance level is more sensitive to income, climatic variables, and swimming pool ownership than consumption below the allowance level, but as sensitive to household size, number of rooms, and plot size. In general, however, free allowance induces people to consume more water. In the dynamic model, lagged annual consumption of water is added as an explanatory variable and its effect found to be statistically significant, suggesting that consumers tend to respond slowly to changes as substitution possibilities are less immediate when water-using durables (*e.g.* washing machines and dishwashers) are involved. The long-run price elasticity of annual water demand is estimated to be between -0.63 and -0.77, which is higher relative to estimates in other studies possibly because of the fact that almost 50% of water used in Adelaide is for outdoor activities (to water lawns and gardens); correspondingly, outdoor use of water is found to be more price-sensitive than indoor use. A 10% increase in real marginal price thus leads to as much as an 8% decrease in water demand and a 1% increase in revenues.

An interesting result within the dynamic model is that consumers above the allowance level adjust their consumption as the price level increases (and other variables change) more slowly than those below the allowance level. The mean lags for consumption above and below the allowance are 1.710 and 0.923 years, respectively; this makes sense as consumers using more water (that is, above the allowance level) tend to have a larger stock of water-using appliances, the use of which requires more time for adjustment.

In the study by Renwick and Archibald (1998) presented earlier which relies on data from two communities in southern California (Santa Barbara and Goleta), evidence is also provided on the effects of the pricing measures introduced during a period a severe water shortage. In June 1989, Santa Barbara implemented its first pricing policy, moving from a fixed per-unit uniform rate to a moderately increasing block-price schedule and, less than a year later, to a steeply increasing price schedule. In July 1990, the city of Goleta moved from a moderately increasing block-pricing schedule to a relatively high uniform rate. Given the context, the short-run price elasticity of water demand is found to be significant (-0.33), which is consistent with the -0.29 estimate in Berk *et al. (*1980) based on data from three communities in the South Coast of Santa Barbara County,[10] and households' responsiveness to price changes is shown to depend on income.

In Renwick *et al.* (1998), residential water demand is estimated based on data from 8 urban communities in California. The estimation incorporates non-price demand-side management (DSM) policies (such as public education campaigns, rationing, restrictions on certain uses of water like landscape irrigation, and subsidies to promote more water-efficient technologies), in addition to block-pricing schedules, weather variables, and selected socio-economic characteristics. The results suggest that a 10% increase in price reduces water demand by 1.6%, but by up to 2% during the summer months. These estimates are smaller than those in Berk *et al.* (1980), Renwick (1996), and Renwick and Archibald (1998), which range from 2.2% to 3.7%. The reasons for the discrepancy may be the exclusion of DSM policy variables in Berk *et al.* (1980) and the significantly larger ranges of marginal prices in Renwick (1996) and Renwick and Archibald (1998).

10. This estimate is also comparable to the estimates in Agthe *et al.* (1986), Billings (1987), Moncur (1987), and Nieswiadomy and Molina (1989), which range from -0.27 to -0.52.

In Pint (1999), the empirical analysis entails the estimation of consumers' responses to the substantial water price increases experienced during the California drought from 1987 to 1992. The data set used in the study includes a sample of 599 single-family households from the Alameda County Water District. The pricing system is based on increasing block rates. Different models (heterogeneous-preferences and two-error models) are used to estimate price elasticities[11] and the results suggest that the price elasticity ranges in the summer from -0.04 to -0.20 (at a price of USD 0.60 per cubic feet) to -0.47 (at a price of USD 2.00). In the winter, price elasticities range from -0.07 to -0.33 (for USD 0.60 per cubic feet) to -1.24 (at a price of USD 2.20 per cubic feet). Even though the estimated demand elasticities are low (particularly, within the heterogeneous-preferences model which is considered to predict single-family water use more accurately), the relatively large price increases across the blocks did result in a 16% reduction in residential water demand from 1990 to 1991. These price increases also resulted in an increase in revenue, unlike other Californian water systems that relied upon quantity restrictions to reduce water use and suffered from severe loss in revenue, which ultimately forced them to increase water prices in later periods. One interesting conclusion of this study is that, while previous analyses produce low price elasticity estimates for California (possibly because of small price variations), excessive price hikes render water demand relatively elastic. Thus, people who are relatively irresponsive to price changes can become quite responsive when subjected to large price hikes (beyond the usual pattern).

In Espiñeira (2000), data are collected from 1993 to 1999 in 132 north-west Spain towns to estimate water demand as a function of household size, income, temperature, precipitation in a month, Nordin difference, number of water units charged regardless of actual use (in m^3), number of billing periods in a year, percentage of population over age 64, and percentage of dwellings regarded as main residence. Most communities in the sample rely upon a tariff schedule that consists of a fixed quota with a minimum free allowable quantity and a second block charged at a single rate or several blocks charged at increasing rates. Independently of the estimation procedure employed,[12] the marginal price elasticity is found to be quite small, ranging from -0.12 to -0.16, with statistical significance only in one model. For water usage up to the minimum level, consumers effectively face a marginal price of zero so that water consumption decisions are not affected by price changes. At high levels of water use (beyond the minimum level), the demand for water is however expected to be responsive to price changes as consumers are beyond the free allocation. This is indeed confirmed by the estimates; in fact, when only data on monthly average water use beyond the minimum level are used, the price elasticity of demand is estimated to be approximately double, that is, -0.33. Hence, the study concludes that *i)* over and above the minimum level of water consumption, the demand for water becomes elastic; *ii)* the larger the minimum amount of water that is sold for a given fixed fee, the higher the average use is; *iii)* the more water consumers use, the more responsive to price changes they are; *iv)* at lower tariff rates, consumers are less interested in finding out about the true marginal water price that results from the tariff system; *v)* within the minimum water use level, the average price of water clearly explains the quantity of water demanded; *vi)* beyond the minimum water use level,

11. The heterogeneous-preferences model results in much less elastic water demand curve than the two-error model.

12. Ordinary least squares, Hausman-Taylor, fixed effects, random effects, and between group estimation.

consumers find it worthwhile to invest time in understanding the tariff system and respond to price signals.

In Dalhuisen (2003), a meta-analysis is carried out in an attempt to explain the empirical variation in the price and income elasticities of residential water demand. The meta-analysis sample consists of 296 price- and 162 income-elasticity estimates of residential water demand from 64 studies over the period 1963 to 2001. An important conclusion of this study is that variation in price and income elasticities is due to differences in the underlying tariff structures. Under an increasing block-rate system, price elasticity estimates tend to be relatively high and income elasticity estimates relatively low. On the other hand, the presence of a decreasing block-rate system does not seem to affect price elasticity but does increase income elasticity. Using average prices, as opposed to marginal prices, inflates both price and income elasticities; the inclusion of the Nordin-difference variable only matters for income elasticity while the adoption of a discrete-choice specification only affects price elasticity. Finally, consumers in higher-income areas have relatively higher price and income elasticities (in absolute terms) and, as also found in OECD (1999), price elasticity estimates tend to be larger (in absolute terms) in Europe than in the United States.

In Nauges and Thomas (2003), water demand is estimated with a time-series (1988 to 1993) data set from 116 French communities in which water services are financed by means of a two-part tariff system involving a fixed connection fee and a price per unit of water consumed. A dynamic model is applied to determine whether current water usage is influenced by past water usage and whether households' adjustments in water consumption in response to price changes are immediate or manifest themselves in the long run. In addition to confirming the positive and significant effect that income has on water consumption, with an income elasticity of 0.51, the study concludes that the long-run price elasticity is about 1.5 times larger than the short-run price elasticity (-0.40 versus -0.26) and, accordingly, that consumers start reducing water usage when they believe that the increase in the price of water is persistent (that is, after a permanent increase in the price). Based on the results, it takes more than one year for consumers to respond to price increases as it takes time to identify the sources of excess water usage and, even when these sources are easily identifiable, it takes time to eliminate them as they relate to the use of durable goods such as dishwashers and swimming pools.

In Espiñeira and Nauges (2004), data from Seville, Spain, covering the 1991 to 1999 period during which a severe drought was experienced, are used to estimate a water demand function and obtain an estimate of the minimum consumption level below which water demand becomes insensitive to price changes.[13] The water price schedule examined in the study consists of a fixed fee and an increasing three-block rate. In addition to the marginal price of water, monthly household water consumption is regressed on virtual income per month,[14] precipitation per month, number of daily hours of supply restrictions applied during the worst drought periods, banned outdoor water usage, and population density. Results suggest that, above the minimum threshold consumption level, water

13. The minimum consumption level can be thought of as the minimum amount necessary to fulfill essential needs such as drinking, cooking, and personal hygiene.

14. Virtual income is the difference between the average salary and the (Nordin) difference variable. Average salary is used as a proxy for household income.

demand, although inelastic, is responsive to price changes: a 10% price increase reduces water use by 1% (a 10% increase in income has exactly the opposite effect, that is, a 1% increase in water use) and a 9% price increase is equivalent, in terms of its impact on water use, to a daily supply restriction of one hour. Hence, as long as water consumption is above this threshold, both pricing and non-pricing measures can be effective policies; however, once the threshold level is achieved, policy makers should focus more on non-pricing tools.

In Taylor *et al.* (2004), data from 34 Colorado municipal water utilities over a two-year period (1984 to 1985) are employed to determine whether marginal price and/or average price should be used to estimate the demand for water. Water demand is defined on a per-connection basis instead of total sales and assessed according to a number of variables: marginal price and/or average revenue, higher annual temperature, monthly precipitation, annual income, water conservation program, water rate schedules (flat-rate pricing, increasing block pricing, decreasing block pricing, and non-metered fixed monthly fees). Different estimations procedures are used, accounting for the fact that the price level depends on the water consumption level under block-rate systems.[15] With a marginal price specification, the elasticity of water demand is found to vary between -0.3 and -0.2. When average revenue is included in the analysis instead of marginal price, the price elasticity reaches -0.4 because of the fixed monthly fee that is embedded in the average revenue but not in the marginal price.[16] When this fee is removed, the average revenue variable fails to have any significant impact on water demand or its coefficient is estimated to have the wrong sign. Hence, in the presence of fixed fees, a marginal price specification is more appropriate. In general, results suggest that, relative to constant rates, increasing block rates result in less water use, and both decreasing block rates and non-metered fixed monthly fees result in more water use; specifically, the consumption of water is 16% lower, 31% higher, and 83% higher under increasing block, decreasing block, and non-metered fixed rates, respectively, when compared to the water use under constant rates. Independently of the type, a pricing mechanism is, however, more efficient than conservation programs which are found to have no significant impact.

In Cummings *et al.* (2005), 50 public water systems across 28 coastal Georgia counties, each with its own water pricing scheme (mostly, based on a block-rate system), are considered over the period 2003 to 2005. Data for residential water use are obtained through a mail questionnaire that includes questions regarding the physical facility of the water system and the amount of water billed per household in the months of January and July 2002. Based on the data, average monthly use of water per household, price paid by the average household per month, and marginal quantity of water used by the average household are derived for the months of January and July.[17] In the water demand model, marginal water quantity is expressed in terms of three variables: median household income, marginal price (per thousand gallons), and a variable referred to as Nordin

15. A 2SLS estimation procedure is employed, with both a log-log form and a linear form, and its results compared to and contrasted with the OLS estimation results.

16. When fixed monthly fees represent a substantial component of the total water bill, a specification that includes average revenue creates a bias toward unitary price elasticity.

17. The marginal quantity is the extra amount of water beyond the range of the last block.

difference.[18] While income and the difference variable do not seem to be relevant determinants of water consumption,[19] marginal prices do have some impact which tends to increase as prices increase. Consistent with findings in other studies, water demand is inelastic at low prices and elastic at high prices; specifically, water demand becomes elastic in January for marginal prices above USD 2.33, which applies to only 7% of the sampled water systems, and in July for marginal prices above USD 4.00, which does not apply to any of the sampled water systems. Even if the demand for water is inelastic, at least for a certain price range, pricing mechanisms do affect people's conservation behaviour at the margin while having the additional benefit of increasing the flow of funds going into communal activities, including the management of water systems.

In Domene and Sauri (2005), a sample of 532 households from 22 municipalities in the metropolitan region of Barcelona is observed to examine the effects of urbanization and demographic, behavioral, and housing characteristics on water consumption. Through the inclusion of average price, the analysis also allows for an assessment of the effectiveness of pricing schemes. Although the water pricing mechanism in MRB commonly consists of a fixed service fee plus several increasing blocks, average price is used as opposed to marginal price in light of a number of considerations: *i)* almost half of the interviewed households do not look at the water bill or compare it with previous bills, *ii)* most of customers admit that they do not understand the tariff schedule of their municipality, and *iii)* heterogeneous pricing structures exist in the sample area. Hence, based on the estimation results, average price does not seem to play a significant role in households' decisions over water consumption, a finding that is likely attributable to the fact that expenditures on water represent a negligible proportion (around 1% on average) of the total household budget.

In Olmstead *et al.* (2005), 1 082 households in 11 urban areas covering 16 water utilities across North America (Canada and the United States) are considered in an empirical analysis of the effectiveness of increasing block-rate schedules relative to that of uniform rate structures. With 26 price systems included in the study (8 two-tier increasing block-rate structures, 10 four-tier increasing block-rate schedules, and 8 uniform structures), the price elasticity for households facing an increasing block-rate schedule is estimated to be -0.64 in the context of a discrete choice model; the price elasticity for households facing uniform marginal prices is instead computed to be -0.33 in the context of a panel random effects model. These figures, both of which are statistically significant, suggest that increasing block-rate systems are more effective at reducing residential water demand relative to uniform rate systems.

In the study by Hurd (2006) presented earlier, landscape choices of home-owners are analysed in terms of their impact on residential water demand. The data is based on a mail survey carried out in 2004 in three cities in New Mexico. In cities with high per-capita water use, residential areas are dominated by traditional turf grass landscapes and

18. Variable that measures the difference between the total water bill and the water bill that would result from pricing total water use at the marginal price and that is introduced as a way of accounting for income effects.

19. The estimated coefficient of the difference variable is insignificant for both January and July. The estimated coefficient of medium income is significant for January but, contrary to theory and most of the empirical evidence, it is negative.

hydrophilic landscapes; however, 35% to 70% of current per-capita water can be saved if a traditional bluegrass type landscape is adopted, along with improved outdoor water usage. The results suggest that water costs highly affect landscape choice: the use of traditional water-intensive turf grass increases water use, and thus costs, substantially; therefore, increases in water prices induce households to choose water-saving landscapes. It is estimated that a 1% increase in the water rates will result into a reduction of 2.8% in the likelihood for households to choose a landscape with 100% turf grass. Therefore, it is evident from the study that higher water costs influence the landscape choices of households toward water-saving activities.

In Mazzanti and Montini (2006), the demand for residential water in Emilia-Romagna, northern Italy, is estimated with municipal panel data covering the period 1998 to 2001. In 1994, the region of interest, which enjoys a relatively high per-capita GDP, witnessed the implementation of water reform policies amounting to two basic principles: *i)* that water prices be reflective of long-run costs of water provision and *ii)* that water provision be gradually privatized. One of the immediate results of the water reform was a rise in water prices; for the 125 municipalities considered in the study, the nominal increase in water prices was 8.9% from 1998 to 2001. The basic price structure of water in Emilia-Romagna is an increasing block-rate schedule; however, because of lack of data on marginal prices, the price pertaining to the medium block of the tariff structure is instead used in the analysis. Residential water demand is then expressed as a function of water price, municipal income, and several socio-economic variables (such as household size, population age, density of commercial enterprise, altitude, and share of rural area). Based on the results about the price elasticity of demand, water consumption is very responsive to price changes; in particular, a 10% increase in the price leads to an 11% decrease in water consumption when only income is included in the model and up to a 13% decrease when the other socio-economic variables are controlled for in the analysis. The high (and significant) price elasticity of demand is likely the result of the relatively high water pricing structure in Emilia-Romagna.

2.1.4 Non-pricing policy measures

In Creedy *et al.* (1998), the effect of group metering is examined with household data from Western Australia where most households are metered under a group system. Because of free-riding incentives, group metering is expected to result in more water use than single metering, other things being equal. Free-riding occurs as a result of an inconsistency in how the costs and benefits of an increase in water use are shared among households in the same group; specifically, while the benefits of an increase in water use accrue only to the household using the additional water, the costs are borne by every household in the same group, independently of its water use. This problem causes households to use more water than they would otherwise as, effectively, they face a lower marginal price of water. The evidence gathered in the study does not, however, support the notion of excess water consumption or free-riding under group metering; a possible explanation for this discrepancy between theoretical predictions and empirical findings is that water prices are quite low in the sample and it is therefore difficult to identify the variation in water consumption that is attributable to the effect of free-riding.

In Renwick and Archibald (1998), non-price Demand-Side Management (DSM) (*e.g.* low-flow toilets and showerheads, water-efficient irrigation measures) are examined, together with socio-economic factors and pricing measures, within a residential water demand model with data from southern California covering the 1985 to 1990 period.[20] For each of the water-efficient technologies considered (low-flow toilets and showerheads, water-efficient irrigation measures), households are found to respond positively, thus adopting the technology, to an increase in the price of water and the presence of more non-price DSM policies. Each of the DSM policies considered is found to be relevant. In response to the allocation and irrigation restriction policies in Goleta and Santa Barbara, the average household is shown to consume 28% and 16% less water, respectively. The use of one low-flow toilet induces households to reduce water use by 10% while the use of one low-flow showerhead results in a decrease in household water consumption of 8%. Water-efficient irrigation technologies reduce water use by 11%; traditional irrigation techniques, on the other hand, increase water usage by 9%. It is evident from the study that DSM policies can be as effective as pricing measures at encouraging households to engage in water conservation. The impact of non-price DSM policies is also found to be linked to density, with stronger negative effects among low-density households with larger landscaped areas or in suburban areas.[21] Consistent with this result, adoption of water-efficient irrigation technologies causes a larger reduction in water consumption among low-density households (31% versus 10% among high-density households). An important conclusion of this study is that the effectiveness of policy instruments, both pricing and non-pricing, is not independent of households' characteristics.

In the study by Renwick *et al.* (1998) presented earlier, data gathered from the 8 urban Californian communities, representing 7.1 million people, are used to examine the impact of demand-side management (DSM) programs. The study considers six types of programmes used during the severe drought from 1985 to 1992 to encourage people to save water: *i)* public information campaigns, *ii)* subsidies for adopting more water-efficient technologies, *iii)* distribution of free retrofit kits, which include a low-flow showerhead, tank displacement devices, and dye tablets for leak detection, *iv)* rationing of water among households, *v)* restriction on certain types of water usage, such as ban on landscape irrigation during peak hours, and *vi)* ensuring compliance with the local water department to certain water conservation steps. In addition to incorporating non-price DSM policies, the econometric model employed in the analysis allows for variables commonly covered in empirical studies of residential water demand, namely, price variables, weather factors, socio-economic characteristics, and lot size.

20. During the period under consideration, California experienced a severe drought which forced policy makers to experiment with various pricing and non-pricing policies. In 1988, Santa Barbara relied on DSM policies and offered free low-flow showerheads and rebates for the adoption of low-flow toilets. In 1989, the city adopted a moderately increasing block-price schedule and, a year later, a steeply increasing block-price schedule. Furthermore, in 1990, the local authority imposed a strict ban on specific water uses, including landscape irrigation. The City of Goleta also adopted several DSM policies such as rebates for low-flow toilets and free low-flow showerheads. In 1989, it introduced an exceptional "mandatory water allocation" policy whereby water usage was to be allocated across households according to their historical patterns of usage, and excessive usage of water was to be penalized with significant marginal prices. In addition, the District moved from a moderately increasing block-pricing schedule to relatively high uniform rates in 1990.

21. Low-density households own large landscaped areas and thus tend to demand more water so that there is more room for DSM policies to affect their water consumption patterns.

The results suggest that the implementation of public information campaigns and retrofit subsidies is likely to reduce the average monthly household water demand by 8% and 9%, respectively. The use of water rationing and restrictions could reduce the average household water demand by 19% and 29%, respectively (from the mean monthly use). The coefficients associated with stringent policies are larger (in absolute values) than those associated with voluntary measures, implying that restrictions on water usage are more effective at reducing water demand than public information campaigns. On the other hand, rebates for adopting water-efficient technologies and compliance policies are found to be insignificant; most probably because of the problem of aggregating water policies over several heterogeneous water systems, it is difficult to detect any measurable impact of these policies on water use. Non-price DSM policies thus provide a very accessible alternative to price policies, which are also found to be effective. In sum, to achieve moderate reductions in water demand (5% to 15%), modest price increases or voluntary DSM policy mechanisms, such as public information campaigns, can be implemented; for a larger reduction in water demand (above 15%), modest price increases and voluntary DSM policy mechanisms, such as public information campaigns, can be introduced. However, to achieve larger reductions in water demand (greater than 15%), large price increases or more stringent compulsory policy measures (*e.g.* water use restrictions) are better instruments.

In Nauges and Thomas (2000), the demand for water is estimated based on time-series (1988-1993) data from 116 municipalities in eastern France. The study points to a very low price elasticity of demand; specifically, a 10% increase in prices is found to result in a 2.2% decrease in water consumption. Because of this poor responsiveness, non-price policies (such as low-flow equipment promotion, awareness campaigns, and education programs about water conservation) are suggested as better means for inducing consumers to use less water. Furthermore, as those living in individual houses, and thus with access to their own meters, are found to consume less water, generalization of water meters to every household is argued to likely induce more awareness about water use and therefore a more effective management of water bills. This is consistent with the conclusion that individual metering is highly effective at reducing household water consumption by providing consumers with proper signals of increased water prices. Other studies that analyze individual metering report a reduction in water use anywhere from 7% to 35% (Herrington, 1997; Edwards, 1996; Mid-Kent, 1997).

In Espiñeira and Nauges (2004), a water demand function is estimated with data from Seville, Spain, during the period 1991 to 1999, which includes the 1992-1995 drought. One of the main results of the study is that water demand becomes insensitive to price changes below a certain water consumption level (this level can be thought of as the minimum amount necessary to fulfill essential needs such as drinking, cooking, and personal hygiene) so that non-price policies are to be considered whenever this level is reached for further reductions in water use. Two non-price policies are considered in the analysis (bans and supply restrictions), in addition to other commonly included determinants of water use such as the marginal price of water, income, precipitation per month and population density. Bans on outdoor uses are not found to have any significant explanatory power while supply restrictions[22] are significant with a daily supply

22. Water restrictions of the type applied in Seville as part of emergency measures during the worst drought periods.

restriction of one hour amounting to a reduction in water consumption equivalent to that resulting from a 9% increase in the price of water. The substantial influence that supply restrictions can have on water consumption is an important policy result in light of the fact that, below a certain consumption level, estimated to be around 3 cubic meters per month, households become irresponsive to price increases.

In Gaudin (2006), the question about the relevance of providing clear-cut price information to consumers is explored in a study based on data gathered from the American Water Works Association (AWWA) and household interviews. Per-capita annual water consumption is expressed as a function of average water price, income, average household size, population density, and temperature. To identify the presence of different types of information, two types of variables are used. The first type includes billing features that may influence water demand through price responses (*e.g.* price information variables, quantity information variables, and variables related to other billing aspects). The second type includes billing features that may affect water demand by changing consumer preferences through non-pricing measures (*e.g.* water conservation aspect of water usage, which is not related to prices). Aside from confirming the significance of a number of variables included in most of the empirical analyses of residential water use (income, size, density, rainfall, and temperature), this study finds that the inclusion of information variables has a positive impact on household response to water price increases. Specifically, the presence of information about the marginal price on the bill (next to the consumed quantity) serves to increase (in absolute terms) the price elasticity from -0.37 to -0.51, so that, for a given target reduction in quantity, the required price increase can be 30% lower if price information is appropriately included on the bill (assuming constant elasticity).

In Hurd (2006), the impact of consumer awareness about water conservation is studied in relation to households' choice among four types of landscape differing in their mix between turf grass and water-conserving patterns. Based on the evidence gathered from the analysis of a 2004 mail survey conducted in three New Mexico cities, awareness among the population about water conservation is found to be a powerful tool for reducing residential water demand. A 10% increase in awareness is in fact estimated to increase the likelihood of adopting a landscape fully incorporating water conservation considerations by 13%.

2.2 Welfare impacts

In Woo (1994), the welfare implications of various policies aiming at addressing an extreme water supply shortage are compared. Over the period 1973 to 1990, the Hong Kong Water Supplies Department resorted to three service interruptions to cope with severe droughts. Prior to these interruptions, which applied to all residential and commercial buildings, information was widely advertised in order to mitigate their adverse effects. The welfare loss associated with the water service interruptions is computed[23] based on the results of the estimation of a water consumption model. This model has monthly per-capita water usage expressed as a function of temperature and

23. The welfare loss computed in this study is based on the Hicksian compensating variation notion which gives the additional income that is necessary after the policy change to restore the level of satisfaction of an individual to its pre-change level.

monthly average price of water, per-capita income and water supply in hours. For the same water use reduction, the welfare loss ensuing from a price increase is also computed. The results suggest that the per-capita welfare loss from a service interruption falls in the range from USD 221 to USD 1 607 per month while the per-capita welfare loss from a price increase, and given the same reduction in water use as under the service interruption, is less than USD 1 per month. It is clear from these figures that service interruptions are very inefficient ways of dealing with water supply shortages. In the presence of water scarcity, pricing instruments seem to allocate resources more efficiently, with a minimal welfare loss.

Of all for the studies on residential water consumption reviewed, that by Hensher *et al.* (2005) is one of the very few concerned with willingness to pay (WTP) for water services. In Hensher *et al.* (2005), households' willingness to pay for assurance that water services are not interrupted is estimated with data gathered through an experiment conducted in 2002 in Canberra, Australia. Based upon the results, consumers are found to be willing to pay for a reduction in the number of water service interruptions and length of interruption experienced each year. The marginal willingness to pay for a reduction in the frequency of interruptions does, however, tend to decrease as the number of interruptions per year increases. If, for example, water supply interruptions usually occur twice a year, the average consumer's marginal willingness to pay for a frequency reduction is 41.5 Australian dollars (AUD) while, with monthly interruptions, the marginal willingness to pay drops to AUD 9.6. Consumers seem to be willing to pay for a reduction in the length of interruption and, interestingly, customers are willing to pay an average of 19% of their current bill to receive advance notice for each interruption.

3. Policy implications

A very important feature of residential water use that most of the articles reviewed share is the estimation of households' responsiveness to increases in water charges as captured by the own-price elasticity of demand. Understanding the extent to which water demand responds to price increases has a fundamental policy dimension that is often not fully explored by policy makers because of equity considerations. Although non-pricing mechanisms do exist for inducing a reduction in water use such as restrictions on certain water usage, rationing, public information campaigns, and subsidies for using water-efficient technologies, pricing structures are viewed as being amongst the most effective means of affecting behaviour. The effectiveness of pricing schemes depends upon the own-price elasticity of demand: the higher the elasticity, the more sensitive consumption is to price changes.

In general, water demand is found to be relatively price inelastic; the lowest estimate of the own-price elasticity in the available literature, from Renwick *et al.* (1998), Pint (1999), Espiñeira (2000), Espiñeira and Nauges (2004), and Strand and Walker (2005), averages -0.10, which implies that a 10 percent increase in water prices yields only a 1 percent decrease in water consumption. There are however studies (Wong, 1972; Nieswiadomy and Molina, 1989; Dandy *et al.* 1997; Pint, 1999; Gaudin, 2006; Mazzanti and Montini, 2006) in which higher estimates averaging at -0.91 are obtained. In Pint (1999) and Mazzanti and Montini (2006), water demand is actually reported to be elastic or very responsive, with a price-elasticity of -1.24 in the former and of -1.33 in the latter.

Although the available evidence seems to point to a relatively price inelastic water demand, the existence of elasticity estimates that suggest otherwise highlights the relevance of the reference price range, that is, the range of prices in the data set being analyzed. In other words, the own-price elasticity of residential water demand is likely to be price-dependent with low figures (in absolute terms) corresponding to low prices and high figures (in absolute terms) correspondingly to high prices. This dependence seems to be confirmed in the study by Cummings *et al.* (2005), in which water demand becomes elastic for marginal prices above $2.33 in January and above $4.00 in July, but warrants further investigation within a framework that allows for much greater price variation than has so far been possible. In Brookshire *et al.* (2002), for example, the difficulty of obtaining an appropriate estimate for the own-price elasticity of residential water demand in a comparative analysis of US cities is attributed to the lack of price variation over the previous 40 years.

Understanding whether and how the own-price elasticity of water demand depends on the price of water has important implications for the design of effective and efficient pricing schemes. For most of the data sets considered in the literature, the pricing structure consists of either a two-part tariff or a block system or both (multi-part tariff). A two-part tariff typically includes a fixed fee, intended for cost recovery and to ensure equity, and some variable fee which may be constant (two-part) or vary across blocks (multi-part). Each block corresponds to a certain range of water consumption and the variable fee may increase or decrease from one block to another. In the absence of the fixed fee, the pricing scheme is more accurately labeled as a block system which can be increasing, decreasing, or uniform depending on whether the variable fee increases, decreases, or remains unchanged from one block to another, respectively.

The effects of different pricing structures on water consumption depend upon household responsiveness to price changes at different levels of consumption. If water demand becomes increasingly more price elastic as consumption increases, increasingly smaller price increases are needed, as households reduce their water consumption moving from one block to another, to induce further reduction in water consumption. An increasing block price system may indeed be the price scheme that is most consistent with the features of the relationship between the price of water and the quantity of water demanded.

In general, increasing block rates are found to be effective at reducing water consumption (Billings and Agthe, 1980; Nieswiadomy and Molina, 1989; Renwick and Archibald, 1998; Pint, 1999; Espiñeira, 2000; Cummings *et al.*, 2005; Strand and Walker, 2005; Mazzanti and Montini, 2006) and, based on the evidence from the one study that permits the comparison (Taylor *et al.*, 2004), appear to perform better than decreasing block rates and non-metered fixed monthly fees by resulting in less water use. Increasing block rates may however be more conducive to inequities as water substitution possibilities may involve, once a certain consumption level is achieved, the adoption of water-saving technologies which are likely to be less accessible to low-income households, unless subsidizing programs are in place. It is indeed out of equity concerns, coupled with the fact that water is an essential commodity, that water prices are typically kept at low levels causing households to overuse and misuse water.

Independently of the pricing scheme adopted, pricing mechanisms to regulate water consumption are deemed to be crucial to ensuring the achievement of environmental, economic, and social goals which, in turn, help achieve "sustainable development" goals (OECD, 1987; OECD, 1999). Accordingly, in many OECD countries, water reforms have been initiated in support of efficient water pricing based on long-run marginal cost considerations, with annual water prices increasing from 1% to 22% (OECD, 2003). These stark price increases have also triggered questions about "affordability" of water, particularly among low-income households, in response to which many OECD countries, including the United Kingdom, France, Australia, Japan, and Poland, have introduced several support measures (such as direct income assistance from the government, capped tariff rebates and discounts, and payment assistance in the form of easier payment plans). To cite some specific examples, funds are in place at local levels to help write off water debts in France; a social fund, financed through a small levy on water charges, is available for needy households in the Belgian region of Wallonia; discount tariffs are provided in Australia and the United States; charitable trusts are set up by private water utilities to pay off water debts in England and Wales.

As emphasized in OECD (2003), subsidizing water services, thus keeping water prices at low levels (and certainly below the marginal social cost of water provision), may not be the best way of addressing the problems of affordability and equity, which are particularly relevant for water given its essential nature. Water prices do seem to provide households with proper signals and should thus reflect water provision costs. At the same time, however, support measures should be devised to assist needy households. Alternatively, or in conjunction with these measures, free (or low-priced) water allowance levels could be established, as they often are, to ensure that households have access to the amount of water necessary to satisfy basic needs (*e.g.* drinking, cooking, and personal hygiene). Up to this threshold level, households would be quite insensitive to price changes so that pricing mechanisms would not be effective and would have significant welfare implications.

Although some attempt is made in the literature to estimate the minimum threshold level of water consumption (Espiñeira and Nauges, 2004),[24] it is not clear how such a level should be determined and whether factors such as persistent characteristics of the environment and historical water use levels should be considered. One of the first challenges of policy makers is to be able to identify, through a better understanding of households' behaviour in a comparative framework of analysis, the elements that are essential to the setting of the minimum threshold level. As pointed out in Dandy *et al.* (1997), OECD (1999), and Espiñeira (2000), the free (or low-priced) allowance level should be set as low as possible to avoid encouraging consumers to use more water than they would have to fulfill their basic needs.

For water consumption above the minimum threshold level of water consumption, that is, at levels where households become price-sensitive, a pricing mechanism could be devised and supplementary programs could be introduced to alleviate inequality problems resulting from the pricing scheme. In order for both the pricing mechanism and the supplementary programs to be properly designed, it is important to have a good grasp of the effects that income has on water use decisions and of how different households, where differences are identified on the basis of any observable economic or socio-demographic characteristic, respond to water price changes.

24. The estimate is 2.6 cubic meters per capita per month.

The empirical evidence to date suggests that income is a quite significant determinant of residential water use, with income elasticity estimates ranging from 0.10 to 0.71. As wealthier households tend to rely more heavily upon water-consuming durables (such as dishwashers, washing machines, and swimming pools), they are reasonably expected to consume more water.

A better understanding of the sources of differences in water consumption between low- and high-income households may help identify the particular water uses to target with restrictive instruments. Aside from income, of which the effect on own-price elasticity of water demand deserves further exploration, there are other individual characteristics (*e.g.* household age and size, type of dwelling) that may have an impact on price responsiveness but the available literature does not permit any conclusive statement to be made about this impact. Based on the findings to date, there is some indication, for example, that older households, those living in high-density areas, and those living in multistory buildings tend to use less water but whether these groups are less or more responsive to price changes remains an open, still very relevant, question.

In sum, there seems to be support for pricing instruments as constituting an effective means of encouraging households to reduce their water consumption but, as different households may respond differently to a given price change and these differences are still to be carefully scrutinized, it is not clear what the optimal pricing scheme design would or should look like and which other (non-pricing) policy instruments could be introduced, alongside with the pricing program, to realign any inequality in the distribution of the burden of conservation resulting from the pricing program because of income differences and/or differences in responsiveness to price changes.

Furthermore, for any policy to be effective, households need be fully informed about the policy; in the presence of a block pricing schedule, consumers do not seem to have a clear idea about the different blocks and their corresponding prices so that they often fail to realise the price differences across blocks (Chicoine and Ramamurthy, 1986; Nieswiadomy, 1992; OECD, 1999; Nauges and Thomas, 2000; Taylor *et al.*, 2004; Strand and Walker, 2005; Gaudin, 2006). In Gaudin (2006), the presence of marginal price information on the water bill, next to the water consumption figure, is estimated to result into a price elasticity increase (in absolute terms) from -0.37 to -0.51; correspondingly, for a given water use reduction target, the required price increase, under a constant price elasticity assumption, can be 30% lower when proper price information is included on the water bill. For this same reason, that is, to ensure that households see differences in water prices and act accordingly, individual metering can be quite beneficial; several studies do indeed point to the conclusion that individual metering can induce substantial reduction in water consumption, anywhere from 7% to 35%, by allowing households to fully realize the price signal for reducing their water demand (*e.g.* Edwards, 1996; Herrington, 1997; Mid-Kent, 1997; OECD, 1999; Nauges and Thomas, 2000). Many OECD countries (including Germany, Belgium, France, and the United Kingdom) have moved to individual metering systems to ensure that households have access to their own water bills, which, in turn, allow them to more accurately decide about their water usage levels.

Among the various non-pricing policies that are considered in the empirical residential water use literature (public information campaigns, subsidies for households to adopt water–efficient technologies, free distribution of water-saving devices such as low flow showerheads and toilets, rationing of water among households, restrictions on certain types of water usage such as a ban on landscape irrigation during peak hours, and mandatory installation of several water-saving systems) and that policy makers are becoming increasingly interested in, particularly in the presence of stark water scarcity and when substantial water demand reductions are required in short periods of time, restrictive measures (water rationing and water use restrictions) are shown to be more effective at reducing water consumption than voluntary measures (public information campaigns). Restrictive measures are also found to be quite effective relative to pricing measures: in Espiñeira and Nauges (2004), for example, a one-hour restriction of water supply per day has an impact on water consumption equivalent to that of a 9% increase in the price of water; in Renwick *et al.* (1998), restrictive policies perform better than pricing policies for reductions in water use above 15%. While, on the benefit side, there may be valid arguments for supporting either pricing or restrictive measures, it is not clear that the two types of policies compare in terms of welfare loss. In Woo (1994), in fact, which is the only study to date that attempts to derive the welfare implications of various policies, the welfare loss, which is computed as the additional income necessary to restore an individual's level of satisfaction to its pre-policy level, is estimated to be, in the presence of restrictive water supply policies, approximately 900 times larger than that under pricing policies. With such a large welfare loss gap, restrictive policies may not be reasonable substitutes for pricing instruments, although they may be opted for in conjunction with pricing instruments to alleviate the potential side-effects of higher water prices or when immediate water use reductions are sought as, based on findings in a couple of studies (Dandy *et al.,* 1997; Nauges and Thomas, 2003), it takes households time to adjust their consumption decisions in response to price changes (long-run own-price elasticity tends to be larger, in absolute terms, than its short-run counterpart).

Of other non-pricing policies considered in the literature, low flow showerheads and low flow toilets can have a substantial impact on water use; the adoption of one of each of the two systems translates, in Renwick and Archibald (1998), into a water use reduction of 8% and 10%, respectively, thus suggesting that free distribution of water-saving technologies or programs that provide rebates to households investing in water-saving technologies can be quite effective. Furthermore, as owning lawns increases residential water consumption (Nieswiadomy and Molina, 1989; Dandy *et al.*, 1997; Renwick *et al.*, 1998; Domene and Sauri, 2005), landscape irrigation restriction policies can have significant effects on water demand in low-density areas where households tend to have bigger landscaped areas (Renwick *et al.*, 1998; Renwick and Archibald, 1998). The type of landscape can also affect households' water consumption (Domene and Sauri, 2005; Hurd, 2006): the "Atlantic garden," planted with turf grass, is, for example, more water-demanding than other landscaping techniques and city planners can rely upon public campaigns to ensure that households are made fully aware of the negative effects of turf grass landscape (in Hurd, 2006, a 10% increase in awareness is found to lead to a substantial increase in the likelihood of adopting landscape types with less turf grass).

REFERENCES

Agthe, D. E., B. R. Billings, J. L. Dobra and K. Raffiee (1986), "A Simultaneous Equation Demand Model for Block Rates", *Water Resources Research*, 22(1), 1-4.

Berk, R. A., T. F. Cooley, C. J. LaCivita, S. Parker, K. Sredl and M. Brewer (1980), "Reducing Consumption in Periods of Acute Scarcity: The Case of Water", *Social Science Research,* 9(2), 99-120.

Billings, R. B. (1987), "Alternative Demand Model Estimators for Block Rate Pricing", *Water Resources Bulletin,* 23(2), 341-345.

Billings, R. B. and D. E. Agthe (1980), "Price Elasticites for Water: A Case of Increasing Block Rates", *Land Economics,* 56 (February), 73-84.

Brookshire, D. S., H. S. Burness, J. M. Chermak and K. Krause (2002), "Western Urban Water Demand", *Natural Resources Journal*, 42(4), 873-989.

Chicoine, D. L. and G. Ramamurthy (1986), "Evidence on the Specification of Price in the Study of Domestic Water Demand", *Land Economics,* 62 (February), 26-32.

Creedy, J., J. van de Ven and Kirsty E. McKenzie (1998), "The Demand for Water by Single-metered and Group-metered Households", *Australian Economic Review*, 31(3), 203-210.

Cummings, R., J. Hill, B. Thompson and D. Wilson (2005), "Conservation Pricing of Household Water Use in Public Water Systems in Georgia's Coastal Communities: A Preliminary Exploration", Working Paper # 2005-007.

Dalhuisen, J. M. (2003), "Price and Income Elasticities of Residential Water Demand: A Meta-analysis", *Land Economics*, 79(2), 292-308.

Dandy, G., T. Nguyen and C. Davies (1997), "Estimating Residential Water Demand in the Presence of Free Allowances", *Land Economics*, 73(1), 125-139.

Domene, E., and D. Sauri (2005), "Urbanisation and Water Consumption: Influencing Factors in the Metropolitan Region of Barcelona", *Urban Studies*, 43(9), 1605-1623.

Edwards, K. (1996), "The Role of Leakage Control and Metering in Effective Demand Management", paper delivered at Conference on Water 96: Investing in the Future, London.

Espey, M., J. Espey and W. D. Shaw (1997), "Price Elasticity of Residential Demand for Water: A Meta-Analysis", *Water Resources Research,* 33(6), 1369-74.

Espiñeira, R. Martĩnez (2000), "Residential Water Demand in the Northwest of Spain", Environment Department, University of York, UK.

Espiñeira, R. Martínez and C. Nauges (2004), "Is All Domestic Water Consumption Sensitive to Price Control?", *Applied Economics*, 36(15), 1697-1703.

Gaudin, S. (2006), "Effect of Price Information on Residential Water Demand", *Applied Economics*, 38(4), 383-393.

Gilg, A. and S. Barr (2005), "Behavioral Attitudes Towards Water Saving? Evidence from a Study of Environmental Actions", *Ecological Economics,* 57, 400-414.

Griffin, R. C. and C. Chang (1990), "Pretest Analyses of Water Demand in Thirty Communities", *Water Resources Research,* 26(10), 2251-55.

Headley, J. Ch. (1963), "The Relation of Family Income and Use of Water for Residential and Commercial Purposes in the San Francisco-Oakland Metropolitan Area", *Land Economics*, 39(4) (November), 441-449.

Hensher, D., N. Shore and K. Train (2005), "Households' Willingness to Pay for Water Service Attributes", *Environmental and Resource Economics*, 32(4), 509-531.

Henson, S. (1984), "Elasticity Demand Estimates under Increasing Block Rates", *Southern Economic Journal,* 51 (July), 147-56.

Herrington, P. R. (1997), "Pricing Water Properly", in O'Riordan, *Ecotaxation*, Earthscan, London.

Howe, Ch. W. and F. P. Linaweaver Jr. (1967), "The Impact of Price on Residential Water Demand and Its Relation to System Design and Price Structure", *Water Resources Research*, 3(1), 13-31.

Hurd, H. B. (2006), "Water Conservation and Residential Landscapes: Household Preferences, Household Choices", *Journal of Agricultural and Resource Economics*, 31(2), 173-192.

Jones, C. V. and John Morris (1984), "Instrumental Price Estimates of Residential Water Demand", *Water Resources Research,* 20(2), 197-202.

Khan, J.R (2005), *The Economic Approach to Environmental and Natural Resources* (Thomson South-Western, third edition, U.S.A.).

Krause, K., J. M. Chermak, and David S. Brookshire (2003), "The Demand for Water: Consumer Response to Scarcity", *Journal of Regulatory Economics*, 23(2), 167-191.

Mazzanti, M. and A. Montini (2006), "The Determinants of Residential Water Demand: Empirical Evidence for a Panel of Italian Municipalities", *Applied Economics Letters*, 13(2), 107-111.

Mid-Kent (1997), “Meter Pilot Project Report 1”, *Mid-Kent Water Plc.,* Snodland, UK.

Moncur, J. (1987), “Urban Water Pricing and Drought Management”, *Water Resources Research*, 23(3), 393-398.

Nauges, C. and A. Thomas (2000), “Privately Operated Water Utilities, Municipal Price Negotiation, and Estimation of Residential Water Demand: The Case of France”, *Land Economics,* 76(1) (February), 68-85.

Nauges, C.and A. Thomas (2003), “Long-run Study of Residential Water Consumption”, *Environmental and Resource Economics,* 26(1), 25-43.

Nieswiadomy, M. L. (1992), “Estimating Urban Residential Water Demand: Effects of Price Structure, Conservation, and Public Education”, *Water Resources Research*, 28(3), 609-615.

Nieswiadomy, M. L. and D. J. Molina (1989), “Comparing Residential Water Demand Estimates Under Decreasing and Increasing Block Rates Using Household Demand Data”, *Land Economics,* 65(3), 280-289.

Nordin, J. A. (1976), “A proposed modification on Taylor’s demand-supply analysis: comment”, *The Bell Journal of Economics*, 7(2), 719-721.

Olmstead, S., M. Hanemann and R. Stavins (2005), “Do Consumers React to the Shape of Supply? Water Demand under Heterogeneous Price Structures”, KSG Faculty Research Working Paper Series, Harvard University.

OECD (1987), *Pricing of Water Services*, Organisation for Economic Co-operation and Development, Paris.

OECD (1999), *The Price of Water: Trends in OECD Countries*, Organisation for Economic Co-operation and Development, , Paris.

OECD (2003), *Social Issues in the Provision and Pricing of Water Services,* Organisation for Economic Co-operation and Development, Paris.

Pint, M. E. (1999), “Household Responses to Increased Water Rates during the California Drought”, *Land Economics*, 75(2) (May), 246–266.

Renwick, M. E. (1996), “An Econometric Model of Household Water Demand With Endogenous Technological Change under Demand Side Management Policies”, Ph.D. Dissertation, Stanford University.

Renwick, E. M. and S. O. Archibald (1998), “Demand Side Management Policies for Residential Water Use: Who Bears the Conservation Burden”, *Land Economics,* 74(3), August, 343-359.

Renwick, E. M. and R. D. Green (2000), “Does Residential Water Demand Side Management Policies Measure up? An Analysis of Eight California Water Agencies”, *Journal of Environmental Economics and Management*, 40(1), 37-55.

Renwick, M., R. Green and Ch. McCorkle (1998), "Measuring the Price Responsiveness of Residential Water Demand in California's Urban Area", California Department of Water Resources, May.,

Schefter, J. E. and E. L. David (1985), "Estimating Residential Water Demand Under Multi-part Tariffs Using Aggregate Data", *Land Economics*, 61(3), 272-280.

Strand, J. and I. Walker (2005), "Water Markets and Demand in Central American Cities", *Environment and Development Economics*, 10(3), 313-335.

Taylor, L. D. (1975), "The Demand for Electricity: A Survey", *The Bell Journal of Economics,* 6(1), 74-110.

Taylor, R. G., J. R. McKean and A. Robert (2004), "Alternate Price Specifications for Estimating Residential Water Demand with Fixed Fees", *Land Economics*, 80(3), 463-475.

United Nations (2003), "World Water Development Report – Water for People, water for Life", World Water Assessment Programme, UN.

United Nations (2006), "World Water Development Report 2 – Water, a Shared Responsibility", World Water Assessment Programme, UN.

Whittington, D., J. Briscoe, Xinming Mu and W. Barron (1990), "Estimating the Willingness to Pay for Water Services in Developing Countries: A Case Study of the Use of Contingent Valuation Surveys in Southern Haiti", *Economic Development and Cultural Change*, 38(2), 293-311.

Wong, S. T. (1972), "A Model on Municipal Water Demand: A Case Study of Northeastern Illinois", *Land Economics,* 48 (February), 34-44.

Woo, C. (1994), "Managing Water Supply Shortage: Interruption *vs.* Pricing", *Journal of Public Economics*, 54(1), 145-160.

Young, R. A. (1973), "Price Elasticity of Demand for Municipal Water: Case Study of Tucson, Arizona", *Water Resources Research,* 9 (August), 1068-72.

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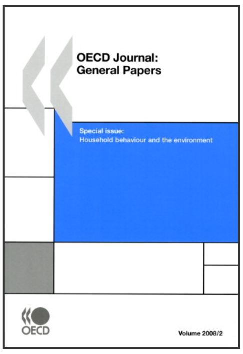

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