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A state of the art review of residential water demand modelling

A. C. Worthington
University of Wollongong, a.worthington@griffith.edu.au

M. Hoffmann
Queensland University of Technology

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Keywords

Water demand; Demand side management; Price and income elasticity

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A STATE OF THE ART REVIEW OF RESIDENTIAL WATER DEMAND MODELLING

University of Wollongong
School of Accounting & Finance

Working Papers Series

Andrew C. Worthington

Mark Hoffman

School of Accounting & Finance
University of Wollongong
Wollongong NSW 2522
Australia

Tel +61 (2) 4221 3718
Fax +61 (2) 4221 4297
eMail george@uow.edu.au
www.uow.edu.au/commerce/accy/

A STATE OF THE ART REVIEW OF RESIDENTIAL WATER DEMAND MODELLING

Andrew C. Worthington

School of Accounting and Finance, University of Wollongong

Mark Hoffman

School of Economics and Finance, Queensland University of Technology

Abstract. The increased reliance on demand-side management policies as an urban water consumption management tool has stimulated considerable debate among economists, water utility managers, regulators, consumer interest groups and policymakers. In turn, this has fostered an increasing volume of literature aimed at providing best-practice estimates of price and income elasticities, quantifying the impact of non-price water restrictions and gauging the impact of nondiscretionary environmental factors affecting residential water demand. This paper provides a synoptic survey of empirical residential water demand analyses conducted in the last twenty-five years. Both model specification and estimation and the outcomes of the analyses are discussed.

Keywords. Water demand; Demand side management; Price and income elasticity

1. Introduction

Water supply efficiency and demand management are increasingly important issues for residential water supply authorities throughout the world. Population growth, coupled with the reduction in freshwater supplies and the increasing cost of infrastructure, has prompted suppliers to place renewed emphasis on demand management through pricing structures and other strategies to control consumption. At the same time, the impact of global warming with potentially higher demands and lower supplies, and the higher values placed by the citizenry on environmental protection and sustainability have also had a role to play. Clearly, there is the need for better demand forecasting: given the real cost and value of water is now significantly higher, so too is the possible loss from under- or over-prediction of demand.

Concurrently, there is ongoing debate about the competing demands of consumers and other stakeholders. Klawitter (2003), for example, argues that sustainable urban water pricing must be designed to meet, amongst others, the needs of current and future generations, resource use efficiency, full cost recovery (including supply costs, opportunity costs and economic externalities), economic viability of the water utility, and equity and fairness for different users. Dalhuisen *et al*. (2001) agree that the pricing structure should cover costs, be fair, induce economically efficient usage (i.e. meet the long run marginal social cost), and be administratively feasible. One important outcome of this debate has been a reorientation of public policy in that agricultural, industrial and commercial water use is not the only focus of attention. With households accounting for a substantial proportion of total water supply use in most developed economies, residential water demand has become a principal concern of policymakers.

In response, an extensive body of literature around the world has concerned itself with the estimation of residential water demand functions. In a multiplicity of contexts, these studies have analyzed a range of market and non-market systems with different tariff structures with an assortment of samples. Nevertheless, they share a common focus; namely, providing best-practice estimates of price and income elasticities for designing better charging regimes, quantifying the impact of non-price water restrictions to judge their effectiveness in controlling demand, and gauging the impact of environmental factors to identify the sources and magnitudes of discretionary and non-discretionary water usage. They also have a focus on average rather than peak demand, so the literature is necessarily concerned with using prices to manage overall demand, rather than the different peak demands that arise on an hourly, daily, weekly, monthly or other seasonal basis. The resultant elasticity estimates must, of course, be viewed from this perspective.

The findings from such research are not uncontentious. While economists generally agree that urban water prices that reflect marginal costs is a means of reducing demand during periods of limited water supply availability, others argue that urban water demand is relatively price inelastic, and therefore price is an ineffective tool for regulating demand and consumption. Supporters of this viewpoint suggest that more appropriate mechanisms for regulating water consumption are non-price strategies, encompassing public education campaigns, rationing, water use restrictions and subsidisation of programs aimed at adopting more water efficient technologies. Proponents of the alternative argue that non-price controls, especially water restrictions, decrease consumer welfare, increase deadweight losses, are inequitable and unpopular and place an unnecessary administrative burden on struggling public and private sector water utilities.

2. Scope and Contribution of Survey

At least one study, Arbues *et al*. (2003), has surveyed the estimation of residential water demand. However, few papers included in that survey were published after the late 1990s, and there is an emphasis placed on the earliest modeling approaches. Other possibilities include the meta-analyses by Espey *et al*. (1997) and Dalhuisen *et al* (2003). While these suffer from the usual limitations of meta-analysis – they cannot improve the quality or reporting of the original work, diversity is often ignored or mishandled, and the variability of the sample, the quality of the data, and the potential for underlying biases are not addressed –

they also necessarily focus on providing indicative measures of price and income elasticity, and are not particularly useful for researchers undertaking new work. Apart from discussing the strengths and weaknesses of the different empirical methods, this article examines the steps faced by researchers as they move from a selected approach, to model specification, to the interpretation of results. All of this information is summarized and tabulated on a study-by-study basis. This highlights the empirical problems that have received attention in the literature, and the efforts by researchers to overcome these problems. It therefore provides guidance to those conducting empirical research in residential water demand and is also an aid for policymakers, consumer interest and environmental groups, regulators, water utility managers and industry practitioners interpreting the outcomes of these studies.

This review concentrates on studies published since 1980. EconLit, the *Journal of Economic Literature* electronic database, was searched to identify articles concerned with residential water demand estimation. References from these studies were used to identify other articles not included in the database. Because of this selection process, most of the studies are journal articles, with relatively fewer discussion, conference and project papers. Of the thirty-seven studies presented in Table 1 (recent examples in brackets), fifty-six percent are based on samples in the United States (Renwick and Green 2000; Gaudin *et al*. 2001; Timmins 2002); twenty-four percent are in Europe (Nauges and Thomas 2000; Martinez-Espineira 2002; Nauges and Thomas 2003), sixteen percent are in Australia (Higgs and Worthington 2001; Hoffman *et al*. 2006) and the remainder in other settings. Most employ least squares regression techniques in some way, with the remainder using other techniques, including logit, generalized methods of moments, instrumental variables and cointegration.

However, despite their dissimilar contexts and techniques these studies mostly share a common step-by-step empirical procedure that first determines the choice of estimation method, and second the specification of dependent and independent variables to be used in the selected approach. This usually takes the form: $Q_D = f(P, Z)$ where Q_D is the quantity of residential water demanded (more likely consumed), P is some measure of water price, and Z represents other independent variables thought to impact upon residential water demand. These usually include income, household structure and size, property characteristics, non-price water restrictions and so on (Arbues *et al*. 2003).

This specification is entirely generalisable in that cross-sectional, time-series or pooled cross-sectional and time-series (panel) data can be employed. It can also include data from either a sample of individual households, the whole of the residential sector where consumption from the population of households is summed, and in some cases, whole-of-utility consumption which may include some influence (and possible bias) from the presence of non-residential water consumption (i.e. agricultural, commercial and industrial). The estimated parameters of this model are the key to identifying several important economic relationships likely to assist demand side management policies for urban water consumption. First, the provision of price and income elasticities of demand to evaluate the impact on quantity demanded to changes in price and income. Second, the impact of non-price factors on both discretionary and non-discretionary urban water consumption can be ascertained. Finally, the level of interaction between these factors of demand can also be revealed.

3. Tariff Metering, Structure and Billing

A key feature of demand side management policies is the pricing structure used to apply to water services. Study of the effects of pricing structure can explain how effective price has been in regulating water consumption and thereby how successful price has been in meeting the multiple objectives usually taken into account when designing an optimal pricing policy. For the most part, the empirical researcher is likely to find that a particular tariff structure is already in place, perhaps for some time. And since the observations used for deriving demand are drawn from this context, a good knowledge of the existing tariff structure is essential for the purposes of model specification. Invariably, pricing structures are complex, meeting or attempting to meet, the varying and often competing objectives of equity, financial stability, simplicity, public acceptability and transparency, efficiency, the sustainability of service provision and profitability. For the purposes of demand estimation, three salient features need to be established: (i) the presence of individual household metering; (ii) the structure of prices representing the split between fixed and variable prices and any variance in these prices; and (iii) billing frequency indicating how often bills are issued to paying households for their water consumption.

A variety of alternative charging methods has been employed in the past in an attempt to meet these criteria (Dinar and Subramanian, 1998; Bartoszczuk and Nakamori, 2004). These include a fixed charge invariant to the level of consumption; a fixed charge with a free allowance followed by some excess charge for consumption over a particular level; and, as is common in Australia and elsewhere, a two-part tariff consisting of a fixed component (an access charge) and a usage component based on the actual amount of water consumed (a volumetric charge). The latter can be non-linear if the cost per additional unit varies when consumption reaches certain thresholds. In this way, the tariff consists of a sequence of different marginal prices for different consumption blocks. These prices per kilolitre (or gallon) of water consumed can be constant (a fixed block), increasing with each successive block of water use (an increasing block), or decreasing with each successive block of water use (a decreasing block). By far the most complex block style tariff structure reported is by Arbues *et al* (2001), who sheds light on charging practice in Zaragoza, Spain. Under the local water supply mechanism, there are 140 progressive pricing blocks, with the total bill charged at the highest block price for the period.

Because of the overwhelming dominance of US studies of residential water demand, tariff structures including increasing and decreasing blocks have been well investigated. For example, Billings and Agthe (1980), Agthe *et al*. (1986), Agthe and Billings (1987), Renwick and Archibald (1998), Gaudin *et al*. (2001) have conducted analyses of increasing block structures, Chicoine *et al*. (1986) and Williams and Suh (1986) have examined decreasing blocks, while Foster and Beattie (1981), Schefter and David (1985), Nieswiadomy and Molina (1989) and Timmins (2002) have included both increasing and decreasing block regimes. But outside of the US there is generally less variation in side-by-side tariff structures. For example, increasing block rates dominate studies in Spain [see Martinez-Espineira (2003a; 2003b) and Martinez-Espineira and Nauges (2004)], Indonesia (Rietveld *et al*. (2000) and Cyprus (Hajispyrou *et al*. 2002), while flat rate structures are the primary form in France (Nauges and Thomas 2003) and Australia [see Thomas and Symer (1988), Barkatulla (1996), Dandy *et al*. (1997), Higgs and Worthington (2001) and Hoffman *et al*. (2006)]. This reflects, of course, the permissible and established tariff structures in these economies, rather than any real preference by water researchers.

In general, most of the literature on water management advocates the introduction of household metering (Yepes and Dianderas 1996; Dalhuisen *et al*. 2001; Bartoszczuk and Nakamori 2004; Dalhuisen and Nijkamp 2001). In fact, it has been suggested that the mere introduction of metering, regardless of the pricing structure used, results in a reduction in water use. For example, Yepes and Dianderas (1996) argue that the use of household metering can benefit system maintenance efforts. They found that unaccounted water represents around 10 to 15 percent of the water supply in high income countries, rising to over 50 percent in lower-income countries.

Nevertheless, with metering the incentive to charge large volume users higher prices cannot be ignored. This is the most-common basis for increasing block tariffs, though the incentive differs between large industrial/commercial and household users and the large and small households as found in residential studies. Whittington (1992) argues that increasing block rate tariffs are welfare reducing in developing countries. Two reasons are given: first, many high density apartments have only one meter, so the more families per apartment, the greater the chance of the total metered amount reaching the highest block prices. Second, in some areas of Ghana, unmetered households purchase water from neighbours or street vendors, with the same block rate effect. Obviously, there is little incentive for the water authority to invest in additional metering. Similarly, Dalhuisen and Nijkamp (2001) found that in developing countries household water supply is often not installed due to its high cost, so people buy their water from more expensive street vendors. It should also be said that metering in developed economies is by no means universal (including Norway, Ireland, the United Kingdom and Canada). In Australia, for example, many local councils and water supply authorities still continue to explore the costs and benefits of installing individual household metering, especially in apartment blocks.

The remaining feature relates to the billing cycle. Obviously, for any given household and level of water consumption, billing frequency is inversely related to cost per assessment. While the total water charge per year is unaffected, the difference lies in smaller, more frequent charges as against larger, lower frequency charges. The theoretical argument is that households are more aware of the impact on income of large bills and these can potentially reduce water consumption in subsequent periods. Frequent billing also reminds consumers more frequently of the fact that water costs. On the other hand, less frequent billing does not afford the opportunity for households to quickly adjust consumption in light of these larger bills. In general, billing frequency is little examined because of the low level of cross-sectional and time-series variation. For example, most local government councils in Australia use a 90-day billing cycle corresponding to the quarterly rates assessment and this has changed little in recent years. Stevens *et al*. (1992) is one of the few studies to expressly model billing frequency, but found it to be statistically insignificant influence on water consumption. Griffin and Chang (1990) found a similar result when they attempted to account for rate changes in their model. Realistically, of course, the meaningful analysis of billing frequency can only be made in cross-sectional studies covering a range of utilities, and the overwhelming emphasis of past work on time-series in a single utility indicates why so little is known about this particular impact.

4. Determinants of Demand

4.1 Pricing

By the law of demand, residential water consumption should be inversely related to water price; as a commodity with few substitutes, the price elasticity of demand should also be inelastic. And where there is a single volumetric price (say, dollars per kilolitre), water demand estimation is relatively straightforward. Problematically, discontinuous tariff structures [that is, those that include a fixed access charge, with or without a ‘free’ water allowance, and/or a decreasing or increasing volumetric rate] do not lend themselves to classic econometric modelling techniques.

Consider, for example, a decreasing block rate structure where the price per unit of water falls as consumption increases: it is immaterial whether the price charged is ‘stepped’, with only a small number of decrements, or declines continuously (though the latter is clearly more complex). Since the marginal price varies according to consumption, this structure may introduce multiple price-quantity sets for a consumer tangent to their highest indifference curve, due to the budget line being convex to the origin. Because of this, estimates of price elasticity will vary (Hewitt and Hanemann, 1995). This applies not only to the case of multiple tariffs, but also those pricing schedules where a free allowance is involved. The latter effectively involves a zero price for the first block in an increasing block system. Stevens *et al*. (1992) chose to discard observations in zero price regions, while Dandy *et al*. (1997) used dummy variables to identify the presence of free water allowances. Where no free allowance is involved, empirical evidence indicates water consumption is positively related to the access charge, though its magnitude is very small [see, for instance, Hoglund (1999)]. The logical suggestion is higher water consumption is associated with higher costs of production and, in turn, higher access charges.

To overcome the problem more generally, it was proposed that an additional price variable reflecting the income effect imposed by decreasing or increasing rate block structures be included in water demand estimations. The concept of including a second price along with the marginal price was first introduced by Taylor (1975) (though in the context of electricity pricing). Taylor (1975) suggested that a single price variable, either the average or marginal price, was not sufficient. This approach was further developed by Nordin (1976) who introduced a difference variable referred to as the ‘rate structure premium’ defined as the difference between the total bill less what the bill would have been if the water quantity was consumed at the marginal price. The hypothesis is the rate structure premium should be able to capture the income effects of changes in the intramarginal prices, the fixed price and the quantity breakpoints. Nordin’s (1976) premise was that consumers react not only to marginal prices, but also to the changes in consumer surplus as a result of moving from one block to the other, and that these intramarginal effects should be included in the demand equation. The difference variable in terms of consumer surplus is described as the difference in the consumer surplus under marginal pricing, and the consumer surplus that is actually experienced by a typical consumer. In case of increasing (decreasing) block tariffs the consumer surplus is larger (smaller) then if the units were purchased at the marginal price.

A large number of studies have specified Nordin's difference variable as a measure of price, including Chicoine *et al*. (1986), Chicoine and Ramamurthy (1986), Hewitt and Hanemann (1995), Barkatullah (1996), Renwick and Archibald (1998) and Martinez-Espinera (2003b). Chicoine *et al*. (1986), for example, concluded that the Nordin specification was largely unnecessary, recommending simple ordinary least squares (OLS) with marginal prices, even for block rate structures. Barkatullah (1996) disagreed, finding that OLS and instrumental variable (IV) models under multi-block tariffs are supportive of the Nordin theory. Arbués *et al* (2003), however, found that while the range of elasticity values can vary according to how price is specified, in many cases the difference was not noticeable. Stevens *et al*. (1992) also compared the price elasticity between increasing, flat and decreasing block tariff systems and concluded that calculated elasticities were not statistically different across the various price specifications. Finally, Espey's *et al*. (1997) meta-analysis concluded that studies using Nordin's difference variable yielded significantly higher estimates of elasticity than those specifying the marginal price alone.

Nordin's specification remains the subject of much controversy. This is because it is argued that while a perfectly-informed consumer should react to marginal price and the rate premium (as defined Nordin-style) most consumers do not devote the time or effort to study the structure or the change in intramarginal rates due to information costs (Nieswiadomy and Molina, 1991). Because of this, the Nordin specification (marginal price and difference) is argued to be significant in neither a statistical nor economic sense, though

The essence of this argument is derived from Shin (1985). Shin (1985) suggested that the cause might be price illusion or incomplete information concerning the full budget constraint. Shin (1985) hypothesised that the coefficients of the rate structure premium and income variables should be equal in magnitude but opposite in sign because each measures a pure income effect: their coefficients in a linear demand equation should be equal. Certainly, the expected sign of income is positive, but the derivative of water use with respect to the difference is negative because increasing the intramarginal rates increases the difference and the implicit tax which reduces water use. To capture the pure income effect, Shin (1985) introduced yet another variable, the price perception variable, in addition to the marginal price. Shin's (1985) price perception model showed that consumers respond to average prices rather than marginal prices when faced with decreasing block rate structures. In early work, Nieswiadomy and Molina (1991) used a price perception model to compare increasing and decreasing block tariffs and found that customers react to marginal prices when facing increasing block rates and average prices when faced with decreasing block rates.

Across the remaining literature, there is a wide variation in price specification. Williams and Suh (1986), Moncur (1987), Nieswiadomy (1992) and Garcia and Reynaud (2003) specify marginal prices while Agthe and Billings (1980), Foster and Beattie (1981), Chicoine *et al*. (1986), Barkatullah (1996), Renwick *et al*. (1998) and Martínez-Espiñeira (2003b) adjust the marginal price with Nordin's difference. Carver and Boland (1980) specify the real price (adjusted for changes in the general price level; Gaudin *et al*. (2001) uses the average price, while Chicoine *et al*. (1986) and Griffin and Chang (1990) subtract the marginal price from the average price. Finally, Hajispyrou *et al*. (2002) employ the marginal price in the highest tariff block, while Schefter and David (1985) and Martínez-Espiñeira (2003a) use an average marginal price.

Certainly, the lack of variation in price elasticity estimates belies the substantial variation in price specification. Almost without exception, the estimated price elasticities are negative and inelastic (less than one), signifying the percentage reduction in the quantity of residential water demanded is less than proportionate to the percentage increase in price. While some estimates are very low – see Carver and Boland (1980), Thomas and Syme (1988), Barkatullah (1996), Renwick *et al*. (1998) and Martinez-Espinera and Nauges (2004) for price elasticities less than 0.25 – many more lie in the range of 0.25 to 0.75 – see Agthe and Billings (1980), Chicoine *et al*. (1986), Williams and Suh (1986), Nieswiadomy and Molina (1989), Nieswiadomy (1992), Pint (1999), Gaudin *et al*. (2001), Martinez-Espineira (2003a).

Reasons for the empirical variation in price elasticity estimates remain elusive. Espey's *et al* (1997) rather-dated meta-analysis at least removes some possible contenders: there is no significant difference between estimates from linear and log-linear models or least squares and other estimation techniques; and it appears to matter little if the sample uses household or aggregate (i.e. aggregated households, not aggregated industrial, commercial, agricultural and household users) data or specifies cross-sectional or time-series daily, monthly, quarterly or annual consumption. More likely prospects concern the failure of many studies to take into account market timing. For example, long-run price elasticity estimates are invariably more elastic than short run estimates [Agthe and Billings 1980; Carver and Boland 1980; Agthe *et al* 1986; Moncur 1987; Dandy *et al*. 1997; Martinez-Espinera 2003b; Nauges and Thomas (2003)] and winter price elasticity is less elastic then summer price elasticity (Dandy *et al*. 1997; Pint 1999; Gaudin *et al*. 2001). As justification, Arbués *et al*. (2003) suggest that long-run price responsiveness is likely to be greater due to the capital investment required by consumers to purchase water efficient appliances such as toilets, taps, showers and washing machines. Likewise, an estimate of price elasticity at the means can vary where there is income heterogeneity. For instance, Agthe and Billings (1987), Thomas and Syme (1988), Renwick and Archibald (1998) have concluded that the price elasticity of residential water demand is lower for low income households than middle and high income households. The other possibility is that because non-discretionary (or necessity) demands have a lower price elasticity than discretionary (or luxury) demands, the lower proportion of discretionary demands in low-income households infers lower price elasticities.

4.2. Income

For normal goods, demand should increase proportionately with income. With water, the measurement of income effects on consumption is important, because water bills often represent a lower proportion of income for higher-income households (Arbués *et al*. 2003). In studies based on whole-of-utility data, income is normally per capita or per household, whereas in household-based studies actual household income (or a proxy such as housing value) can be employed. A further consideration is that income, through its correlation with education, may be reflective of water conservation measures taken by the household itself through the purchase of water-conserving appliances and planting of drought-tolerant garden vegetation. In addition, since income can approximate wealth, income (from taxation, census and survey data) can also be used to proxy other normal and luxury goods associated with household water consumption where data may not be as easily obtainable, including swimming pools and spas, in-ground garden irrigation systems, and dishwashing machines.

Estimates of income elasticity in the literature are almost universally income inelastic (less than one) and small in magnitude [see, for instance, Chicoine *et al*. (1986), Moncur (1987), Thomas and Symer (1988), Barkatullah (1996), Dandy *et al*. (1997), Gaudin *et al*. (2001), Garcia and Reynaud (2003). This appears consistent with the strong likelihood that the income elasticity of residential water demand is indeed low. But there is also the possibility that sample or specification bias may have a role to play. For example, few studies sample very income-diverse populations: the income elasticity of water demand would be higher with more variation in household income, say, between households in developing and developed economies. In addition, there is the aforementioned complication that increasing and decreasing block rates potentially encompass income effects. This may also serve to reduce the significance and magnitude of income effects. A final consideration is that the estimated income elasticities are short-run. Income-related activities like buying new appliances, moving house and house extensions, for example, that affect water demand, may only be possible over the longer term, so a more complex model allowing for this longer-run transition may be appropriate.

4.3. Weather and seasonal factors

Household water demand comprises two main components: discretionary and non-discretionary demand. Discretionary water use is normally defined as that used for watering lawns and gardens, swimming pools, washing cars and other forms of outdoor cleaning, but can also include inside use like power showers (where a pump is used to boost the flow rate), spas and other luxury uses. Non-discretionary water use then refers to water used for basic needs such as drinking, cooking and personal hygiene, including laundering, bathing and toilet flushing. For this reason, discretionary water use is regarded as being more price responsive than non-discretionary water use, and as it is largely employed outside, more influenced by weather and other seasonal factors.

As a rule, residential water use is usually shown to be highly sensitive to seasonal fluctuations. For example, Maidment and Miaou (1986) examined daily water use in nine US cities using a physics-type transfer function excluding price and income effects. They found that the response to rainfall depended first on its occurrence, and then on its magnitude, and that there is a non-linear response of water use to temperature changes: with no response for daily maximum air temperatures between 4-21^{o}C and an increase in water use with temperatures above 21^{o}C. Further, water demand was hardly affected as consumption approached a subsistence level.

Weather and other seasonal factors have been specified in a number of ways. These range from temperature (Griffin and Chang 1990), minutes of sunshine, precipitation, rainfall, temperature and rainfall (Stevens *et al*. (1992), the number of rainy days (Hoffman *et al*. (2006), and even the evapo-transpiration rate of Bermuda grass less rainfall (Billings and Agthe 1980, Agthe *et al*. 1986, Nieswiadomy and Molina 1989 and Hewitt and Hanemann 1995). If the data frequency is at least semi-annual, the possibility also exists for seasonal variation, and dummy variables are generally used to control for summer and winter consumption. Without exception, summer price elasticities are lower than winter price elasticities, indicating that it is discretionary water that is most affected by behavioural changes.

Nonetheless, there has been some criticism surrounding the specification of weather parameters. Maidment and Miaou (1986) argue that the linear relationship assumed between the proxy for weather, such as rainfall, and the focus of measurement often breaks down. For example, the impact of rainfall diminishes over time and the effect is greater with higher levels of water use prior to rain. Likewise, Martínez-Espiñeira (2002) suggests that the mere occurrence of rain has a psychological impact, and so the number of rainy days rather than the amount of rain has a greater impact on water demand. Martínez-Espiñeira and Nauges (2004) also found that water demand is minimally affected by weather as consumption approaches some base (non-discretionary) level of use. Finally, in their meta-analysis, Espey *et al* (1997) and Dalhuisen *et al*. (2003) argued that the incorporation of rainfall results in significantly less elastic estimates of the price elasticity of demand. At first sight this would suggest some rainfall and prices are positively related, lying at odds with the notion that prices should be set with scarcity in mind.

4.4 Population and household composition

If the dependent variable is defined as water usage per household, household size should be positively associated with water use. However, not all studies have included household size, even when considering average household water consumption (Agthe and Billings 1980; Nieswiadomy 1992). Accordingly, there is remarkably little empirical evidence on scale economies in water consumption, though the evidence that does exist is very strong. Arbués *et al*. (2000), for example, found that the increase in water use is often less than proportional to the increase in household size or population. They postulated that an increase in the number of households, with population held constant, would lead to an increase in the total water demand in an area. In the same way, an increase in population in inner city and other densely populated areas is unlikely to be associated with an increase in consumption due to smaller housing lots, smaller gardens, and a higher predominance of flats and units. However, in countries where garden-related use is not strong, the extra in-house use (washing, bathing, etc.) would tend to dominate.

A further consideration is household composition. Nauges and Thomas (2000), for example, argued that water consumption in areas with a higher proportion of younger persons is likely to be higher due to more frequent laundering and use of water-intensive outdoor leisure activities. However, communities with a higher proportion of older inhabitants may be more focused on gardening. Martinez-Espineira (2003a), for instance, included variables reflecting both the proportion of the population over 64 years and those under 19 years. In addition, people from different cultural backgrounds may be more or less reactive to the price of water. Griffin and Chang (1990) and Gaudin *et al*. (2001) specified the percentage of the population of Spanish origin as a determinant in their study of water consumption in Texas.

4.5 Non-price consumption controls

In terms of demand-side management policies, a number of non-price controls on consumption are possible. These can include prohibitions and restrictions on the watering of gardens, filling of swimming pools, car washing and path and building cleaning. However, they also include appeals for water conservation and education campaigns aimed at limiting water use. Because of the ubiquitous nature of these policies and their possible interaction with other variables, especially pricing, there is the requirement to include some specification in analyses of water demand and consumption (Syme *et al*. 2000). Renwick, *et al*. (1998), for instance, argue that the clear definition of all relevant policy variables is important for accurate measurement since the nature of the policies used may vary either through time or cross-sectionally.

Syme *et al*. (2000) have argued that the possible interactions of non-price campaigns with other policy instruments make it difficult to evaluate their effectiveness. Statistical studies using regression have problems with multicollinearity among the variables. Interpretation is also a problem, possibly due to unmeasured exogenous variables; for example, a marketing campaign may heighten the motivation to respond to the pricing schedule. Interestingly, while feedback information on usage has been shown to reduce energy consumption, it appears to make little difference to water consumption. Possible causes given are: ineffective conservation methods, water saving is more difficult, water is too cheap to worry about and a lack of motivation to save (Thomas and Syme, 1988).

5. Data and Sampling Frequency

The availability (or rather acute lack) of accurate data at an appropriate frequency has plagued attempts at modelling residential water demand. In theory, estimating residential water demand functions with household level data would be the most valuable, especially consistently over time. But while many researchers advocate the use of household level surveys to specifically identify and measure all relevant household characteristics, only a few have actually been conducted, comprising Foster and Beattie (1981), Nieswiadomy (1992), Nieswiadomy and Cobb (1993), Higgs and Worthington (2001), Arbues *et al*. (2001), and Hajispyrou *et al*. (2002). As an alternative, Rizaiza (1991) and Renwick and Archibald (1998) used stratified random sampling of surveys.

The lack of data availability may help explain the high rate of data re-use from previously published work. For example, the 1974-1980 data for Tucson, Arizona first used in Agthe and Billings (1980) was later specified in Billings and Agthe (1980), Agthe *et al*. (1986) and Agthe and Billings (1987), while a 1976-1985 Denton, Texas dataset was repeatedly employed in Nieswiadomy and Molina (1989; 1991), Griffin and Chang (1990), Hewitt and Hanemann (1995) and Gaudin *et al*. (2001). This is problematic in that much of an apparently broad literature is, in reality, reliant on only a few unique datasets. That said, and as shown in Table 1, the estimates are generally consistent, despite the dissimilar approaches, and this yields some insight into the relatively (low) impact of specification change. At the same time, the cost of gathering information means that many other studies rely on rather-dated information. For example, Carver and Boland (1980) specified a 1969-1974 Washington panel, Foster and Beattie (1981) used a US cross-section from 1960, Moncur (1987) examined a 1975-1981 Hawaiian panel, and Timmins (2002) used a 1970-1993 Californian panel. Given the rapid change in charging regimes and conditions, these studies may not have much to offer contemporary policymakers and utility managers.

Outside of the household-level surveys, most existing research has focused instead on aggregated mains, community or utility-level data [see, for example, Thomas and Syme (1988), Stevens *et al*. (1992), Nieswiadomy and Cobb (1993), Barkatullah (1996), Timmins (2002)]. However, this brings additional complications. One concerns the need for matching average water consumption with the averages of other demand-related characteristics, often from different sources with different frequencies. These potentially include household income, household size, household demographics, etc. The more substantive complication is the apparent inconsistency between non-price demand factors and the quantity demanded being expressed in averages, while water prices are almost always in marginal terms. Schefter and David (1985) argued that on this basis, the more accurate price measures are the *mean* marginal price and the *mean* (Nordin) difference (emphasis added).

Pooled time-series, cross-sectional (or panel data) techniques have dominated the literature [see, for instance, Agthe and Billings (1980), Chicoine and Ramamurthy (1986), Hewitt and Hanemann (1995), Dandy *et al*. (1997), Gaudin *et al*. (2001), Martinez-Espineira (2003a)]. But while the stability of estimates and the increasing degrees of freedom offered by panel data are well known, most of these are unbalanced panels of aggregated communities and utilities, with none following specific households over time. Cross-sectional techniques are the next most popular [see Foster and Beattie (1981), Chicoine *et al*. (1986), Martin and Thomas (1986), Stevens *et al*. (1992), Rietveld *et al*. (2000) and Hajispyrou *et al*. (2002). And not surprisingly given the difficulty in gather accurate and consistent data, time series techniques have not been well used. Further, there is little evidence of application of some of the more advanced time-series techniques [for an exception see Martinez-Espinera (2003)].

The question also arises as to how these studies treat periods when demands exceed supplies, such as droughts, and cannot be completely satisfied. For the most part, the literature includes these periods and relies on factors such as rainfall and water restrictions to quantify these impacts. The alternative, excluding periods when supplies actually meet demands, is not found and the implication is that some misspecification in the estimation of the parameters may result.

6. Estimation Techniques

The existing literature on the estimation of the water demand models involves numerous econometric techniques. For cross-sectional data, the empirical techniques employed include ordinary least squares (OLS), generalised least squares (GLS), two and three-stage least squares (2SLS and 3SLS), logit and instrumental variables (IV). In terms of time series data, vector autoregressive (VAR) models and cointegration techniques could also be potentially used, however the only known water demand study to do so is Martínez-Espiñeira (2003b). Lastly, many techniques normally reserved for cross-sectiosn are equally applicable to pooled time-series, cross-sectional (or panel) data, including OLS, GLS, maximum-likelihood (ML) and 2SLS.

That said ordinary least squares methods dominate the water demand literature (Billings and Agthe 1980; Chicoine *et al* 1986; Hewitt and Hanemann 1995; Higgs and Worthington 2001 and Martínez-Espiñeira 2003a). But one particular problem when using data with block rate pricing is simultaneity: that is, when consumers select the quantity of water to be demanded, they also select the price. Since the price of water both determines and is determined by consumption, OLS estimation of block rate pricing models may yield biased and inconsistent estimates. Since there is a need to find a proxy for the stochastic variable price, several IV techniques have been suggested.

Nieswiadomy and Molina (1991) focus on two common approaches. The first introduces a separate price equation in a two stage least squares (2SLS) procedure. In the first stage, the observed price is regressed against all explanatory variables during the increasing block-pricing period. The predicted price is then specified in the second stage as a regressor. Nieswiadomy and Molina’s (1991) second approach involves the regression of the observed water demand on the actual price that the household faces at different levels of water demand. In the second stage, the predicted quantity demanded and the actual rate schedule is used to obtain a predicted price (Agthe *et al* 1986; Agthe and Billings 1987; Barkatullah 1996; Hewitt and Hanemann 1995 and Higgs and Worthington 2001). Regardless, both techniques are likely to improve the reliability of estimates.

Within the many other techniques, a variety of functional forms have been employed, some with allowance for non-linearity in the underlying consumption technologies. While linear demand functions are easy to estimate, there is the implication that the change in quantity demanded in response to a price change is the same at every price level. Another form, the Cobb-Douglas function, is synonymous with the non-linear log-log (or double-log) model. One of the well-known properties of Cobb-Douglas is that the estimated slope coefficient represents the (partial) elasticity of the dependent variable with respect to the independent variable, holding all other independent variables constant. This removes the necessity of calculating partial elasticities at the means, as with linear functions. Cobb-Douglas water demand equations are widely used in the literature, including Foster and Beattie (1981), Nieswiadomy and Cobb (1993), Hewitt and Hanemann (1995) and Garcia and Reynaud (2004). Alternatively, Gaudin *et al*. (2001) and Martínez-Espiñeira and Nauges (2004) have employed the alternative Stone-Geary utility function, which is also non-linear, though log-lin. The main advantage of this form is that it can incorporate some minimum amount of water demand, irrespective of prices. This subsistence level may be made dependent on the evolution of consumer habits and stock of physical capital, in such a way that its size varies with time.

7. Concluding Remarks

The primary focus of residential water demand modelling has been on obtaining consistent, reliable and useful measures of the price (and to a lesser extent, income) elasticity of demand. Price elasticity estimates are generally found in the range of zero to 0.5 in the short-run and 0.5 to unity in the long-run: income elasticity estimates are of a much smaller magnitude (usually) and positive. The income elasticity of residential water may well be low; sample or specification bias, however, may also be important. For instance, the income effects as measured may be mixed up with price effects in poorly specified models or the elasticities are really only valid in the short term, and may be substantially more elastic over the longer term. Further, price elasticities are higher in the summer than the winter, and this is perhaps a reflection of the differing impact of pricing on discretionary water use that is usually, but not always, related to outside activities. The demand for water has also been shown to vary with seasonal factors, household composition, and the imposition of water restrictions. Aggregate and household level data have been shown to yield similar results and there appears to be no statistically significant difference internationally in the price and income elasticities. These are the least contentious aspects of this area of research.

A more contentious aspect concerns price specification, of which two dimensions have been recognized. First, most water tariffs have complex structures that combine fixed and variable charges. Because of this, there is a division placed between marginal and average prices and consumers' reaction to these prices will then depend on price perception. Second, an additional complication arises where modelling techniques are required to compensate for the (potential) income effect of variable block tariffs. Simultaneity is the basic issue, as consumers choose quantity-price pairs: that is, decisions on quantity determine prices. But specification is only part of the story. The most fundamental limitation in this area is the lack of data concerning households and their demands for water. Only with consistent and specific information collected over relatively long periods of time in a variety of jurisdictions will it be possible to definitively model the many influences on residential water consumption as an input into residential water policy.

Certainly, there is an urgent, even dire, need for empirical work in this area. Consider Australia where there is growing disquiet that the worst drought since 1788 and record high temperatures are not part of some natural cycle, rather the longer realignment in rainfall and temperature caused by global warming. With reservoirs in nearly all state capitals at critically low levels, a lack of essential infrastructure, consideration of desalination plants and effluent recycling plants, and the reallocation of water allocations from agriculture to urban use already taking place, residential water demand management appears the only short-term solution. Patently, good water demand modelling is the key to good water policymaking.

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TABLE 1. Empirical Analyses of Residential Water Demand

Author(s)	Data	Sample	Pricing structure	Dependent variable(s)	Independent variables	Estimation technique(s)	Price elasticity	Income elasticity	Other findings
Agthe and Billings (1980)	Panel.	Tucson, Arizona, 1974-1980.	Increasing block and flat rate	Monthly household water consumption.	Marginal price, difference price, evaporation rate of Bermuda grass less rainfall, household income.	OLS	Short-run 0.18-0.36; long-run 0.27-0.50	Short-run 1.33-2.07; long-run 1.97-2.77	Linear model elasticities greater than log-log model.
Billings and Agthe (1980)	Panel.	Tucson, Arizona, 1974-1977.	Increasing block rate.	Monthly household water consumption.	Marginal price (nominal and real), difference term, implicit marginal sewer charge during winter months, personal income, evapotranspiration less rainfall	OLS	0.27-0.49	n.a.	Real monetary values produce substantially stronger statistical results than unadjusted prices and incomes.
Carver and Boland (1980)	Panel.	Washington, 1969-1974.	Increasing block rate.	Average annual water production divided by the number of connections.	Real income, real price, average number of residences per connection, average number of employees per connection, lagged consumption.	OLS	Short-run 0.10; long-run 0.02-0.70	n.a.	When separated into seasonal and non-seasonal components, elasticities are substantially more inelastic.
Foster and Beattie (1981)	Cross-sectional	United States, 1960.	Increasing and decreasing block rates	Average yearly household water consumption	Marginal price, difference price, median household income, precipitation, average number of residents per meter.	OLS	0.12	0.58	Results of a Nordin-type marginal price model suggest average price is a better specification for yearly data.
Schefter and David (1985)	Cross-sectional	Wisconsin, 1997.	Increasing and decreasing block rates	Quantity of water delivered to residential users	Mean marginal price estimated using the combined water and sewer tariffs, mean difference using the combined water and sewer tariffs, average household income;	OLS	n.a.	n.a.	Given aggregate data, mean marginal price and mean price difference are the most appropriate.
Chicoine, Deller and Ramamurthy (1986)	Cross-sectional	Illinois, 1983.	Decreasing block rate.	Monthly household water consumption.	Price index for other relevant goods, income, Nordin's difference (rate premium), marginal price, average price less marginal price.	OLS, 2SLS and 3SLS	0.22-0.42	0.01-0.14	3SLS estimates slightly more efficient compared to 2SLS estimates and consistent with OLS.
Agthe, Billings, Dobra and Rafiee (1986)	Panel.	Tucson, Arizona, 1974-1980.	Increasing block rate.	Monthly household water consumption.	Marginal price, rate structure premium, evaporation rate of Bermuda grass less rainfall, household income.	OLS, IV and SE	Short-run 0.14; long-run 0.62	n.a.	Demand is significantly more elastic in long run than in short run.

Author(s)	Data	Sample	Pricing structure	Dependent variable(s)	Independent variables	Estimation technique(s)	Price elasticity	Income elasticity	Other findings
Martin and Thomas (1986)	Cross-sectional	Kuwait, South Australia, Western Australia, Arizona, 1978/79 and 1981/82.	Various volumetric charging systems.	Mean daily per capita water consumption.	Marginal price.	Geometric analysis of price and quantity pairs	0.50	n.a.	Precise estimates of demand elasticities may not be necessary for policy purposes. Short-run elasticities give little information for policy purposes.
Williams and Suh (1986)	Cross-sectional.	United States, 1967.	Decreasing block rate	Annual quantity of water demanded by customer class	Marginal price, average revenue price, other price measures, size of customer class, per capita income, total rainfall recorded in the summer months, average temperature in the summer months, population per square mile.	OLS	0.25-0.48	0.64-0.77	Price elasticities larger for average revenue price specifications than for marginal price specifications.
Chicoine and Ramamurthy (1986)	Panel.	Illinois, 1983.	Decreasing block rate	Monthly water consumption by household	Average price decomposed into a marginal price, monthly income less the effects of the block rate structure (Nordin), number of persons in household, number of bath rooms, dummies for month.	OLS	n.a.	n.a.	The marginal price or average price are, by themselves, inadequate in explaining consumption demand for rural domestic water.
Moncur (1987)	Panel.	Honolulu, Hawaii, 1975-1981.	Decreasing block and flat rate	Total bi-monthly household water consumption	Lagged consumption, marginal price, income per household member, rainfall household size, presence of water restrictions	OLS	Short-run 0.03-0.52; long-run 0.10-0.68	0.04-0.08	A conservation program can bolster price elasticity. During a drought, price elasticity decreases in magnitude.
Agthe and Billings (1987)	Panel.	Tucson, Arizona, 1974-1980.	Increasing block rate	Monthly household water consumption.	Marginal price, difference price, evaporation rate of Bermuda grass less rainfall, household income, presence of swimming pool, type of yard vegetation, number of persons in household.	2SLS and IV	Low income 0.56; middle 0.49; upper middle 0.46; high 0.40	n.a.	Substantial increase in water use as household income rises.
Thomas and Syme (1988)	Cross-sectional.	Perth, Western Australia, 1982.	Flat rate.	Annual water consumption from public mains supply.	Marginal price, difference variable, average household income, annual precipitation, restrictions on public water supply use, hours, average household size, percentage of households which use a private underground water bore.	OLS	Overall 0.18; low income 0.19; middle 0.18; high 0.13	0.20-0.22	Contingent valuation approach appears to be reliable and applicable where the available data do not favour regression analysis.

Author(s)	Data	Sample	Pricing structure	Dependent variable(s)	Independent variables	Estimation technique(s)	Price elasticity	Income elasticity	Other findings
Nieswiadomy and Molina (1989)	Panel.	Denton, Texas, 1976-1985.	Increasing and decreasing block rates.	Monthly household consumption.	One-month lagged water consumption, monthly income (based on house value), marginal block price, ratio of lagged average monthly price to current marginal price, irrigable land, weather (based on evapotranspiration of Bermuda grass less precipitation).	OLS, IV and 2SLS	0.36-0.55	0.14-0.15	Significant price effects with decreasing and increasing block rates. Consumers react to average price under decreasing block and marginal price under increasing block.
Stevens, Miller and Willis (1992)	Cross-sectional.	Massachusetts, 1988.	Increasing, decreasing block and flat rates.	Average water consumption per household	Average price of water plus sewerage, average annual income per capita, population density, average annual precipitation, average annual temperature, billing frequency, dummy variable for location of community, dummies for pricing regime.	OLS and 2SLS	Flat rate 0.41; increasing block 0.54; decreasing block 0.69	Flat rate 0.14; increasing block 0.17; decreasing block 0.28	Elasticities are not statistically different between different pricing structures.
Nieswiadomy (1992)	Cross-sectional.	United States, 1984.	Increasing, decreasing block and flat rates.	Average monthly water usage per household	Minimum charge, average price, marginal price, Shin's price (perception price), income, dummies for conservation and education programs, regions, average monthly rainfall and temperature.	OLS	n.a.	n.a.	Conservation does not appear to reduce water use. Consumers react more to average rather than marginal prices in all regions.
Nieswiadomy and Cobb (1993)	Cross-sectional	United States, 1984.	Increasing, decreasing block and flat rates.	Water use per household per month	Marginal price, average price, public education, number of persons per household, percentage of home built before 1939, percentage of homes that are owner-occupied, average rainfall per month and average temperature between last spring freeze and first fall freeze.	OLS and Logit	Increasing block 0.17-0.64; decreasing block 0.28-0.46	Increasing block 0.57-0.63; decreasing block 0.22-0.45	Households react to average prices under both decreasing and increasing block structures. Increasing block structures conservation oriented.
Hewitt and Hanemann (1995)	Panel.	Denton, Texas 1981-1985.	Increasing block rate.	Household monthly water consumption	Lawn size, weather, number of bathrooms, house size, price, income (modified for Nordin's difference), number of days in billing period.	OLS, IV 2SLS	1.57-1.63	0.15-0.16	Comparison of OLS, IV and 2SLS regressions using summer component. Reason for high values may be summer only data.
Barkatullah (1996)	Panel.	Sydney, New South Wales, 1990-1994.	Increasing block and flat rates	Quarterly household water consumption.	Nordin-difference variable, marginal price, average temperature, lagged rainfall, income, property value, peak/off-peak dummy, household size, number of bedrooms and bathrooms, garden condition	OLS, 2SLSand ML	0.21	0.07	OLS provides biased and inefficient estimates. Consumers respond to marginal prices when faced with multi-part tariffs.

Author(s)	Data	Sample	Pricing structure	Dependent variable(s)	Independent variables	Estimation technique(s)	Price elasticity	Income elasticity	Other findings
Dandy, Nguyen and Davies (1997)	Panel.	Adelaide, South Australia 1978- 1992.	Increasing block and flat rates.	Annual household water consumption	Quantity of water consumed in the previous year, annual allowance, dummy variables for consumption in excess of allocation, property value, household size, number of rooms, climate.	OLS	Short-run 0.28; inter 0.12; summer 0.36 Long-run 0.77; winter 0.29; summer 0.86	Short-run 0.14; winter 0.16; summer 0.15 Long-run 0.38; winter 0.33; summer 0.49	Free water allowance results in wastage and that its removal would be an efficient way of reducing water consumption. Little equity impact through removal of allowance
Renwick, Green and McCorkle (1998)	Panel.	California, 1989-1996.	Increasing block and flat rates.	Average monthly household water use	Alternative non-price demand management policies, marginal price, difference term, income, lot size, precipitation (difference from mean), persons per household;	2SLS	0.16-0.20	n.a.	Failure to account for the influence of non-price demand side management policies may result in an overestimate of the price responsiveness of water demand.
Renwick and Archibald (1998)	Panel.	California, 1986-1990.	Increasing block rate.	Total water consumption	Marginal price of water, Nordin difference, policy dummies for restriction, allocation and rebates on water saving technology, adoption of water saving technologies, gross monthly household income, number of household members, housing density, number of faucets, inflation, cumulative monthly rainfall.	2SLSand OLS	Overall 0.33; low income 0.53; middle income 0.21; high income 0.11	0.36	Higher water prices are expected to directly reduce demand in the short run and stimulate the demand for water efficient technologies by increasing the relative benefits associated with adoption in the medium to long run.
Pint (1999)	Panel.	Alameda, Spain, 1982-1992.	Increasing block and flat rates.	Household water use as a deviation from average use	House size, lot size, precipitation, lagged precipitation, temperature and lagged temperature, marginal price and price squared.	OLS and ML	Summer 0.20-0.47; winter 0.33-1.24	n.a.	Maximum likelihood models that explicitly consider the household's response to the rate structure result in plausible estimates of water demand.
Hoglund (1999)	Panel.	Sweden, 1980-1992.	Flat rates and decreasing block rates.	Average household consumption per person per day.	Marginal price of water, fixed price for typical household, average price, gross household income, average household size, regional dummy variables.	OLS, GLS and 2SLS	Marginal 0.08-0.12; average 0.20-0.26; fixed 0.01-0.02.	0.07-0.13	Strong regional variation in household consumption, significant scale economies in household water consumption.

Author(s)	Data	Sample	Pricing structure	Dependent variable(s)	Independent variables	Estimation technique(s)	Price elasticity	Income elasticity	Other findings
Rietveld, Rouwendal and Zwart (2000)	Cross sectional.	Salatiga, Indonesia 1994.	Increasing block rate.	Monthly water consumption.	Marginal price of water, "virtual income" to account for lower infra-marginal price paid for the first allocation of water, household size, and availability of non-piped water.	OLS	1.28-1.16	n.a.	Demand depends on household size and presence of alternative supply.
Gaudin, Griffin and Sickles (2001)	Panel.	Texas, 1981-1985.	Increasing block rate.	Water consumption per capita per month	Average price, per capita income, proportion of population of Spanish origin, climate, average annual precipitation	OLS and GLS	Overall 0.19-0.47 Summer 0.12–0.15; winter 0.24 to 0.27	0.11-0.19	Results suggest that approximately ¾ of total water usage is not responsive to price changes
Higgs and Worthington (2001)	Panel.	Brisbane, Queensland, 1996.	Fixed charge unlimited allowance with simulation of two-part tariff with zero fixed allowance and flat rate.	Household quarterly water consumption.	Household income, value of property, marginal price under the user-pays system, seasonal dummy, number of household members, other house characteristics, and soil characteristic.	IV and Logit	n.a.	n.a.	Because of uncertainty associated with future household water demand, the option to remain on the non-user pays system has value and is incorporated into the appropriate decision-making model.
Martinez-Espineira (2002)	Panel.	Spain, 1993-1999.	Two-part tariff with fixed allowance and increasing block and flat rates.	Average monthly consumption.	Average temperature, population density, household size, fixed component of water and sewerage bill, billing period, income index, marginal price, population over 64 years and under 19 year, precipitation, percentage of housing as main residence dwelling, tourism index, Nordin-difference.	IV	0.12-0.17	n.a.	Significant difference in summer-only elasticities and major impact of climatic variables on monthly consumption.
Timmins (2002)	Panel.	13 cities, San Joaquin Valley, California, 1970-1993.	Increasing, decreasing block and flat rates.	Quantity demanded	Typical rate structure consists of three components: (i) a service charge (ii) some quantity of water and (iii) marginal rate charge for each additional acre foot of water consumed, annual rainfall, number of active residential service connections; dummy for cities.	OLS	n.a.	n.a.	Municipal water administrators charge below marginal cost and in so doing inefficiently exploit aquifer stocks and induce social surplus losses.

Author(s)	Data	Sample	Pricing structure	Dependent variable(s)	Independent variables	Estimation technique(s)	Price elasticity	Income elasticity	Other findings
Hadjispirou, Koundouri and Pashardes (2002)	Cross-sectional.	Cyprus, 1996/97.	Increasing block rate.	Annual water consumption	Marginal price (highest tariff block in cubic meter), income, number of adults, children washing machine, dish washer, square meters of dwelling, toilets outside and inside, running water, household head employed in agriculture, household head retired, sewage system,	ML	n.a.	n.a.	Large families are at a disadvantage under increasing block rates because they face a higher marginal price of water than small families at the same level of utility.
Martinez-Espineira (2003a)	Panel.	Spain, 1995-1999.	Increasing block rate.	Proportion of consumers in each block; average monthly per account water use.	Income index per capita, percentage of population under the age of 19 years, percentage of population over 64 years, the average temperature in each month, mean marginal price difference, average temperature.	IV, Logit, OLS and GLS	0.37-0.67	n.a.	Nordin's specification using aggregate data acompared to average marginal price and average difference. Price elasticity not significantly different.
Garcia and Reynaud (2003)	Panel.	Bordeaux, France, 1995-1998.	Flat rate.	Annual water consumption per water utility	Marginal price, average taxable income per household, number of dependents per household, proportion of housing equipped with a bath or toilet, proportion of industrial users, summer rainfall, proportion of houses built after 1982.	GMM	0.25	0.03	Consistent and efficient econometric method is used to estimate supply-demand system with simultaneous equations.
Martinez-Espinera (2003b)	Time-series.	Seville, Spain 1991-1999.	Increasing block rate.	Average household monthly water consumption	Marginal price of water (adjusted for multi-part tariff structure), virtual income (the difference average salaries and the Nordin-difference), rainfall, average maximum daily temperature, number of daily hours of restrictions, outdoor use bans, information campaigns, summer	Granger causality, cointegration analysis.	Short-run 0.08-0.11; long-run 0.40-0.51.	n.a.	Engle-Granger and Wickens-Breusch ECMs provide similar results.
Nauges and Thomas (2003)	Panel	France, 1988-1993.	Flat rate.	Average annual water consumption	Lagged demand, price (at the beginning of contract with annual updating rule) and income.	GMM	Short-run 0.26; long-run 0.40	0.51	Local authorities should refer to long run elasticities when assessing the impact of tariff changes on consumer welfare.
Martinez-Espinera and Nauges (2004)	Time-series	Seville, Spain 1991-1999.	Increasing block rate.	Average monthly water consumption	Marginal price of water (adjusted for multi-part tariff structure), virtual income (the difference average salaries and the Nordin-difference), rainfall, population, number of daily hours of restrictions, outdoor use bans.	OLS and GLS	0.07–0.13	0.07-0.13	Once price insensitive threshold is reached, information campaigns or promotion of low-water using equipment is more effective in reducing consumption than an increase in price.

Author(s)	Data	Sample	Pricing structure	Dependent variable(s)	Independent variables	Estimation technique(s)	Price elasticity	Income elasticity	Other findings
Hoffman, Worthington and Higgs (2006)	Panel	Brisbane, Queensland, 1998-2003.	Two-part tariff with zero allowance and flat rate.	Quarterly annual water consumption	Marginal price of water, household income and size, number of rainy and warm days in quarter, summer dummy.	OLS	Short-run 0.51; long-run 1.16	0.23	Price and income elasticity higher in owner-occupied households than renter households. Summer and rainy days exert strong influence on residential water consumption.
Gaudin (2006)	Cross-section	United States, 1995.	Uniform, decreasing and increasing block rates.	Per capita residential consumption	Average price of water, per capita income, average number of household members, population density, average annual precipitation, number of high temperature days.	OLS, 2SLS	0.37	0.30	Price information on water bills has a significant positive influence on elasticity.

Notes: OLS – Ordinary Least Squares, 2SLS – Two-stage Least Squares, 3SLS – Three-stage Least Squares, IV – Instrumental Variables, SE – Systems Equations, ML – Maximum Likelihood, GLS – Generalised Least Sqaures, GMM – Generalised Method of Moments, ECM – Error Correction Model, n.a – not applicable or not calculated.