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Estimation of residential water demand: a state-of-the-art review

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Abstract

This paper surveys the main issues in the literature on residential water demand. Several tariff types and their objectives are analyzed. Then, the main contributions to the literature on residential water demand estimation are reviewed, with particular attention to variables, specification model, data set, and the most common econometric problems. The paper concludes with comments on future trends and a summary of the contents of the study.

JEL classification: Q21; Q25

Keywords: Water demand; Water resources management; Demand estimation

1. Introduction

This paper surveys the main issues in the literature on residential water demand. Water has been identified as one of the most important natural resources and somewhat different from the rest, because it is viewed as a key to prosperity and wealth. As Marshall (1879) remarked, water has played a crucial role in the location, function, and growth of communities.

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Conflicts over water have always involved competition among alternative uses or among geographical regions, and water has become the source of increasing controversy, as supplies fail to meet demand in many areas. This calls for the careful analysis of decisions pertaining to the allocation of water resources.

Lately, there has been a change of approach to water management, which traditionally focused on supply-side policies. The character of water as a scarce good and the need to efficiently price its consumption have gained increasing recognition. This article focuses on the pricing of water for domestic consumption, because it is usually the most important use in an urban context (OECD, 1999) and its management results in the most controversial decisions from a socioeconomic viewpoint. Its study is crucial for guiding future policies.

Water price is the main instrument to control demand, so we will analyze several tariff types and their objectives. We will then focus on residential water demand estimation, with especial attention to variables, model specification, data sets, and the most common econometric problems. Finally, we will comment on future trends and summarize.

2. The pricing of water services: typology and objectives

Designing a tariff is often complex. Pricing is aimed at pursuing not only greater allocative efficiency but also objectives of equity, public health, environmental efficiency, financial stability, simplicity, public acceptability, and transparency (OECD, 1987, p. 14, 1999).

In this multiobjective context, a mixture of fixed and variable elements is common. The fixed part entitles to consume the good, while subsequently consumers pay an additional smaller amount per unit. The latter can be non-linear itself, if the cost per additional unit varies when consumption reaches certain thresholds, in such a way that the tariff consists of a sequence of marginal prices for different consumption blocks. These block prices could be increasing, if prices rise with each successive block of water use, or decreasing, in the opposite case. From the viewpoint of efficiency, a decreasing tariff scheme might seem preferable,[1] while an increasing one would be more effective in moderating water use. On the other hand, a decreasing tariff could promote overuse, since additional units eventually become marginally cheaper, while it is not clear that the marginal cost of supply decreases for large users. On the other hand, increasing-block tariffs would be considered more equitable and explicitly redistributive (Maddock and Castaño, 1991).[2] However, they do not necessarily guarantee equity, for example, in developing countries, where it is usual to find dwellings with a high population density (Whittington, 1992). Increasing block tariffs might also adversely affect vulnerable groups, such as users who, for health reasons, need to use great amounts of water.

Water demand fluctuates with the seasons of the year (due to weather effects), the day of the week, or the hour of the day, so a seasonal or peak-price tariff may be used to promote conservation and efficiency. Peak pricing is regarded as fair, since peak period

[1] If each block is assumed to represent a different good and it is expected that demand is more inelastic within the first block than in the higher blocks, optimal pricing would imply higher prices in the first block (Ramsey, 1927).

[2] This tariff may also be aimed at promoting conservation or revenue generation.

users, responsible for capacity additions, should bear the capacity costs and the operating and maintenance costs, while off-peak consumers pay only the latter (Munasinghe, 1992, p. 267).[3] The final effect of a seasonal pricing scheme is not certain, though, since it might reduce average but not peak demands (Beecher et al., 1994, p. 63).

In general, the complexity of tariffs is a direct consequence of a multiobjective context. This will affect the demand specification process. Non-linear prices and fixed elements will complicate the tariffs and the choice of variable price. These and other problems will be analyzed in the following paragraphs.

3. The methodology of water demand estimation

3.1. Introduction

The use of price to manage water demand has been an issue of growing concern among decision-makers during the last decades. Economists have tried to shed some light on the effects of different types of tariffs estimating demand functions and normally focusing on the calculation of price-elasticities. To this end, some type of econometric model is derived of the form $Qd = f(P, Z)$, which relates water consumption to some measure of price (P) and other factors (Z) such as income, household type, or household composition. However, there is no general consensus on the methodology to analyze water demand.

Since the 1960s (Gottlieb, 1963; Howe and Linaweaver, 1967), water demand has been extensively studied, with the focus on either aggregate municipal demand or residential demand (see OECD, 1987; Baumann et al., 1997, p. 67, for compilations of early studies). The estimated values of price-elasticity of water demand vary widely. Espey et al. (1997) used meta-analysis[4] to show differences in estimated price-elasticities due to the inclusion or not of explanatory variables other than price in the demand function, the choice of functional form of estimation technique, and type of data.

However, the meta-analysis obscures important qualitative information. Using study findings as the units of analysis produces non-independent data and gives greater weight to studies with many comparisons. Averaging across constructs and including studies with obvious methodological flaws can confuse the reliability of findings. Also, the study by Espey et al. (1997) is not recent enough to include many interesting developments in water demand estimation, which, as described below, have only appeared during the last 5 years.

This section discusses the relative merits of the statistical procedures for estimating elasticities of water demand. First, the main variables that determine water demand will be discussed, with particular attention to price selection. Differences in the data sets and different models of demand specification employed will then be evaluated. Finally, some estimation problems and suggested solutions will be presented.

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[3] Moreover, to the extent that most peak demands are associated with luxury consumption by wealthier users, equity considerations also support peak pricing.

[4] A meta-analysis consists of a set of statistical procedures designed to accumulate experimental and correlational results across independent studies. Meta-analysts translate results from different studies to a common measure and statistically explore relations between study characteristics and findings.

3.2. Variables

The economic approach to water demand estimation uses econometric techniques to relate water consumption to some measure of the price of water and a set of explanatory variables. A selection of these independent variables is described next.

3.2.1. Water price

Water demand in most cases is estimated as rather inelastic. This is because water has no substitutes for basic uses and because the customer exhibits a low level of perception of the rate structure, since water bills typically represent a small proportion of income (Chicoine and Ramamurthy, 1986; Arbués et al., 2000). However, prices can play a crucial role in demand management as long as the elasticities are different from zero.

Under block rate tariffs, it is difficult to analyze the effect of changes in the intramarginal rates, that is, rates that do not correspond to the current level of consumption. As shown in Taylor (1975), given that the marginal price is not affected by a change in the intramarginal rate, the latter will only affect demand through an income effect. Most early studies employed the marginal price corresponding to the block where the user (or, with aggregate data, the typical user) consumes. However, following Taylor (1975) and Nordin (1976), a difference variable is added. Specific to the case of multiple tariffs (and those cases where a fixed quota and/or a free allowance is used), Nordin (1976) defined the difference variable as the difference between the total bill and what the user would have paid if all units were charged at the marginal price. This variable should represent the income effect imposed by the tariff structure.

In models in linear form, the difference variable should be equal in magnitude and opposite in sign to the income effect variable. This theoretical expectation has been tested in the empirical literature but with little success, as shown in Table 2. This finding has led to different reactions. First, lack of consumer information about the tariff structure and the fact that the difference variable amounts to such a small fraction of the household income have been suggested as explanations (Nieswiadomy and Molina, 1989). Others argue that the effect of the intramarginal changes in price is not estimated correctly, which biases the results. The use of aggregate data has been blamed as a major source of incorrect specification (Schefter and David, 1985).

Nordin's specification has been the subject of great controversy (Billings and Agthe, 1980; Foster and Beattie, 1981a,b; Houston, 1982, 1983). While a perfectly informed consumer should react to marginal price and the rate premium (as defined by Nordin, 1976), most consumers will not devote much time or effort to study the structure or changes in intramarginal rates (Billings and Agthe, 1980; Bachrach and Vaughan, 1994, p. 9) because of information costs. An alternative specification applied in several studies is the average price. Other authors applied both average and marginal (or Nordin) price in the same or different models.

Opaluch (1982, 1984) proposed a model (also developed by Chicoine and Ramamurthy, 1986) to empirically test which price reaction is supported by the data. Shin (1985) introduced a price-perception parameter to test whether users react to average or marginal price. Different values of this parameter, combined with different rate structures, yield different theoretical results about the ordering of perceived, marginal, and average price values (Nieswiadomy and Molina, 1991; Nieswiadomy, 1992; Nieswiadomy and Cobb, 1993).

Table 1 shows the main price alternatives. Some elasticity values (or value ranges) show that the choice of variable did not greatly affect the results, while some suggest that demand is more responsive to average price.

Another potential consequence of the lack of information by the consumers is that these could respond to lagged rather current average prices (Charney and Woodard, 1984; Opaluch, 1984). Since water bills are received after a period, the issue arises of whether to use a current or lagged price specification (Arbués et al., 2000). It has been shown (Young et al., 1983; Nieswiadomy and Molina, 1991) that consumers are not always aware of current price schedules, although the choice of the appropriate price remains controversial (Charney and Woodard, 1984; Opaluch, 1984; Nieswiadomy and Molina, 1991).

3.2.2. Other variables

3.2.2.1. Income. In studies that use aggregate data, the income measure is normally total money income for the area divided per household or per capita. In household-based studies, the variable *assessed value of the property* is sometimes used (Howe and Linaweaver, 1967; Hewitt and Hanemann, 1995; Dandy et al., 1997; Arbués et al., 2000). This variable could be introduced in addition to income, acting as a proxy for wealth and household preferences for home life-style. However, it is normally too correlated with income and other variables to be useful in practice (Lyman, 1992; Barkatullah, 1996). To circumvent this problem, Jones and Morris (1984) developed a proxy for family income based on the educational level of the head of the household, car ownership, and the assessed property value and age of the residence.

Richer users present a lower level of perception of the rate structure, since the total bill represents a lower proportion of their income. Thus, several works (Hanke and de Maré, 1982; Agthe and Billings, 1987, 1997; Saleth and Dinar, 2000) analyze these income effects, estimating different demand functions for different income levels.

Table 2 includes examples of income elasticities. Some studies provide also estimates of the elasticity with respect to Nordin's (1976) difference variable.

3.2.2.2. Weather variables. Climatic effects have been introduced in different ways. Foster and Beattie (1979, 1981a) used precipitation during the growing season. Billings and Agthe (1980), Billings (1982), Agthe et al. (1986), Nieswiadomy and Molina (1988), and Hewitt and Hanemann (1995) used evapotranspiration from Bermuda grass minus rainfall. Al-Quanibet and Johnston (1985) used a variable function of temperature, minutes of sunshine, and wind speed. Billings (1987) and Griffin and Chang (1990) used average monthly temperatures, summer rain, and the °F by which mean temperature exceeded 58 °F. Stevens et al. (1992) and Agthe and Billings (1997) used temperature together with annual rainfall.

Maidment and Miaou (1986) criticized the common assumption that the effect of the weather variables is linear. They suggested that rainfall has a dynamic effect: it reduces water demand initially, but the effect diminishes over time. Its effect is also state-dependent, the higher the water use before a rainfall, the stronger the effect (Miaou, 1990).

Table 1
Different price specifications

Price specification	Study	Price elasticity
Nordin specification (marginal price and difference)	Agthe and Billings (1980)	−0.179 to −0.705
	Billings and Agthe (1980)	−0.267 to −0.49
	Billings (1982)	−0.56 to −0.66
	Howe (1982)	−0.06 to −0.57
	Agthe et al. (1986)	−0.26 to −0.62
	Deller et al. (1986)	−0.36 to −1.12
	Billings (1987)	−0.06 to −0.5
	Billings and Day (1989)	−0.52
	Nieswiadomy and Molina (1989)	−0.09 to −0.86
	Hewitt and Hanemann (1995)	−1.57 to −1.63
	Barkatullah (1996)	−0.23 to −0.28
	Agthe and Billings (1997)	−0.39 to −0.57
	Dandy et al. (1997)	−0.12 to −0.86
	Corral et al. (1998)	−0.11 to −0.17
	Renwick and Archibald (1998)	−0.33 to −0.53
	Renwick and Green (2000)	−0.16
	Martínez-Espiñeira (2002b)	−0.12 to −0.28
Marginal price	Howe and Linaweaver (1967)	−0.21 to −1.57
	Gibbs (1978)	−0.51
	Carver and Boland (1980)	−0.02 to −0.70
	Jones and Morris (1984)	−0.07 to −0.21
	Martin et al. (1984)	−0.256
	Williams (1985)	−0.263 to −0.539
	Martin and Thomas (1986)	−0.50
	Williams and Suh (1986)	−0.25
	Moncur (1987)	−0.03 to −0.68
	Schneider and Whitlatch (1991)	−0.11 to −0.262
	Lyman (1992)	−0.39 to −3.33
	Martin and Wilder (1992)	−0.32 to −0.60
	Nieswiadomy (1992)	−0.02 to −0.17
	Nieswiadomy and Cobb (1993)	−0.17 to −0.29
	Hansen (1996)	−0.003 to −0.1
	Kulshreshtha (1996)	−0.23 to −0.78
	Höglund (1999)	−0.10
	Pint (1999)	−0.04 to −1.24
Average price	Sewell and Roueche (1974)	−0.067 to −0.568
	Gibbs (1978)	−0.62
	Foster and Beattie (1979)	−0.27 to −0.76
	Hanke and de Maré (1982)	−0.15
	Jones and Morris (1984)	−0.18 to −0.34
	Williams (1985)	−0.619 to +0.332
	Williams and Suh (1986)	−0.484
	Billings and Day (1989)	−0.70
	Griffin and Chang (1990)	−0.16 to −0.38
	Rizaiza (1991)	−0.78 to +0.18
	Martin and Wilder (1992)	−0.49 to −0.70
	Nieswiadomy (1992)	−0.22 to −0.60
	Stevens et al. (1992)	−0.10 to −0.69

Table 1 (*Continued*)

Price specification	Study	Price elasticity
	Nieswiadomy and Cobb (1993)	−0.45 to −0.64
	Point (1993)	−0.167
	Kulshreshtha (1996)	−0.34 to −0.96
	Höglund (1999)	−0.20
	Nauges and Thomas (2000)	−0.22
Other specifications	Cochran and Cotton (1985)	−0.4
	Williams (1985)	−0.22 to −0.49
	Chicoine and Ramamurthy (1986)	−0.47
	Williams and Suh (1986)	−0.179 to −0.315
	Griffin and Chang (1990)	−0.01 to +0.035
	Nieswiadomy (1992)	−0.29 to −0.45
	Renzetti (1992)	−0.01 to −0.65
	Nieswiadomy and Cobb (1993)	−0.319 to −0.637
	Bachrach and Vaughan (1994)	−0.03 to −0.47
	Arbués et al. (2000)	−0.002 to −0.655

Table 2
Difference vs. income elasticities

Study	Difference elasticity	Income elasticity
Agthe and Billings (1980)	−0.112 to −0.412	1.33–7.829
Billings and Agthe (1980)	−0.123	
Billings (1982)	−0.075 to −0.14	1.68–2.14
Agthe et al. (1986)	−0.14 to −0.25	
Nieswiadomy and Molina (1989)		0.10–0.14
Billings and Day (1989)	−0.21	0.36
Hewitt and Hanemann (1995)		0.15
Kulshreshtha (1996)	−0.069 to +0.435	0.051–0.123
Renwick and Green (2000)	−0.01	0.25

Sometimes water users appear to respond more to the mere occurrence of rainfall than to its amount: the effect is mainly psychological. Therefore, the number of rainy days should be a better explanatory variable than the amount of rain in any given period (Martínez-Espiñeira, 2002b). It is also important to investigate the thresholds beyond which precipitation or temperature no longer affect on water use (Miaou, 1990).

Few studies of water demand in Europe use intra-annual data.[5] Only comparisons between annual water demand in a rainy year and annual water demand in another (more or less rainy, dry) year have been made (Nauges and Thomas, 2000). Therefore, weather effects have not been so well-analyzed as in areas of the US. One exception is Martínez-Espiñeira (2002b), who matches use data from each intra-annual billing period with monthly weather data.

3.2.2.3. Resident population per account/household composition. If the dependent variable is water use per household, household size should positively affect use. However, due

[5] For example, Hanke and de Maré (1982).

to economies of scale in the use of water, the increase in water use is less than proportional to the increase in household size (Höglund, 1999). However, as Arbués et al. (2000) show, there is an optimum household size beyond which these economies of scale vanish.

Families with children could be expected to use more water. Outdoors use by children and teenagers might be higher too. Youngsters might use water less carefully, have more showers, and demand more frequent laundering, while retired people might be thriftier. These expectations are confirmed by studies like Nauges and Thomas (2000). On the other hand, retired people tend to spend more time at home and do more gardening (Lyman, 1992).

3.2.2.4. Housing characteristics. Distinguishing houses used only for a part of the year, or as a secondary residence, from principal residences might help identify those communities where seasonal use can have a greater impact. The proportion of individual households might also be helpful to proxy the average size of gardens, and sometimes the level of penetration of individual (rather than collective) metering (Nauges and Thomas, 2000). The effect of this variable is uncertain, though, and it is correlated with many others (Schneider and Whitlatch, 1991).

Other housing features, such as the number of bathrooms, may be relevant. The stock of appliances could help show the difference between short-run and long-run reactions, as suggested by the literature on electricity demand.

3.2.2.5. Frequency of billing and rate design. Users who are more frequently billed might be expected to understand better the tariff structure and the relation between use and size of the bill. More billing periods would then mean less water use. However, less but bigger bills could create some kind of shock effect on the consumer. This could explain why Stevens et al. (1992) found positive estimated coefficients for the frequency of billing. Kulshreshtha (1996) analyzed the differences in price-elasticities according to the frequency of billing although his results were not too conclusive.

Having different rates available make it possible to specify different demand models. Young et al. (1983) found that an increasing step rate (which applies the higher rate to all the water used, not just the excess over the first block) was very useful to reduce water use. However, Stevens et al. (1992), using an average price variable, found that price elasticities were not significantly affected by the choice of a uniform, increasing, or decreasing rate. Nieswiadomy and Molina (1989) divided their data set into two sub-periods with different tariffs, finding a higher price-elasticity value for increasing blocks.

3.2.2.6. Indoor versus outdoor use: seasonal demands and peak-load pricing. Residential demand consists of two components, indoor usage and outdoor usage. The demand function can be estimated using variables that reflect outside characteristics, such as irrigable area per dwelling unit (Howe and Linaweaver, 1967), garden size (Nieswiadomy and Molina, 1989; Lyman, 1992; Hewitt and Hanemann, 1995), sprinkler system (Lyman, 1992), or pool ownership (Dandy et al., 1997). Renwick and Archibald (1998) proposed a model of household water demand that explicitly incorporates measures of domestic and landscape irrigation technologies. Outdoor use is usually assumed to exhibit higher price sensitivity (Howe and Linaweaver, 1967; Morgan and Smolen, 1976; Foster and Beattie, 1979; Renwick and Green, 2000).

Indoor and outdoor usage differences might require seasonal-demand and peak-load pricing. Several studies have found winter demand less sensitive to price changes (Carver and Boland, 1980; Howe, 1982; Griffin and Chang, 1990; Renzetti, 1992; Dandy et al., 1997). Lyman (1992) found peak demand more elastic than off-peak demand and showed that the elasticity of peak-demand affects off-peak demand when consumers purchase more water-efficient appliances. In general, seasonal differences have been found under lagged-response specifications (Young et al., 1983; Nieswiadomy and Molina, 1991).

3.3. Data set

The problems associated with the use of aggregate data under block pricing have been acknowledged from an early stage. However, many empirical studies have simply ignored them, mainly because the use of a correct specification would require information beyond that commonly available to the researcher. For this reason, demand functions are normally estimated using the marginal price and the difference value faced by the *typical* household.

Schefter and David (1985) suggested that the use of aggregate data explained one of the main points of controversy in the water demand estimation literature. They pointed out for the first time that, if the rest of variables are averages, mean marginal price and mean difference are more appropriate measures. However, these averages must be properly weighted by the distribution of users per block. Lacking this information, they resorted to simulated data to show that increasingly realistic assumptions on the distribution progressively led to the equality of the sizes of the estimates of difference and income.

An important question is how the distribution of the quantity demanded across households can be estimated. Schefter and David (1985) could mention only one previous study that offered the variance of quantity demanded across households: Hanke and de Maré (1982), using individual data. Recently, Corral et al. (1998) and Martínez-Espiñeira (2002a) have used actual (rather than simulated) data on the proportions of consumers per block in studies based on the methodology proposed by Schefter and David (1985).

In theory, the estimation of residential water demand functions within a micro setting using household level data is the preferred approach (Schefter and David, 1985; Young, 1996; Saleth and Dinar, 2000). However, attempts at the micro level are rather few, since they require a great volume of information. This fact and the characteristics of several variables included in the demand function (especially personal income) make it difficult to obtain a good sample of micro data. Studies estimating micro-level water demand are among others: Hanke and de Maré (1982), Jones and Morris (1984), Nieswiadomy and Molina (1989), Schneider and Whitlatch (1991), Hewitt and Hanemann (1995), Maresca et al. (1997), and Arbués et al. (2000).

On the temporal dimension, some water demand studies use time-series. However, few use a pure time-series approach (Schneider and Whitlatch, 1991; Billings and Agthe, 1998). These studies should be viewed with some caution, since they are based on a relatively short time-series, often containing few changes in the nominal price of water (Hanke and de Maré, 1982).

A different approach consists of only using a cross-section of consumers or communities. In cross-section analysis, the socioeconomic characteristics of the different groups analyzed are very relevant and the elasticities estimated are supposed to represent their long-term value.

A third option is to combine cross-section with time-series data in a panel-data approach. This increases the number of observations, resulting in more reliable parameters and enabling the researcher to specify and test more sophisticated models that incorporate less restrictive assumptions about the data. Panel-data models help overcome problems of multicollinearity, and make it possible to control for unobservable heterogeneity of the cross-sectional units.

From a theoretical point of view, several static and dynamic panel-data models have been proposed (Baltagi, 1995; Arellano and Honoré, 2001). Dynamic models incorporate both the advantages of panel data and the insight of the dynamic approach, allowing for lag-response specifications.

Many studies use only pure cross-sectional analysis. Thus, the demand model is estimated with ordinary least squares (OLS) for the entire cross-section and time-series data sample (Hanke and de Maré, 1982). To our knowledge, only a few studies have applied panel-data methodologies (see Table 3). None of them has employed “random coefficient models”, which allow for the variation in time or across cross-sectional units not only of the parameter of the intercept but also of the slope regressors in the demand function. The use of dynamic panels is still rare and very recent in the field of water demand (Höglund, 1999; Arbués et al., 2000; Nauges and Thomas, 2001; Martínez-Espiñeira and Nauges, 2001).

4. Estimation problems

We will analyze some difficulties that could appear in demand estimation. Some of them are related to the use of non-uniform prices. The choice of functional form, the problem of simultaneity, and the presence of demand discontinuities are also presented in this section. Table 3 classifies the main studies according to the method applied.

4.1. Choice of functional form

Linear water demand functions are often chosen because of their ease of estimation. These can be derived from a quadratic utility function, but are most often presented with no formal derivation (Al-Quanibet and Johnston, 1985). The linear functional form is often criticized, because it implies that the change in quantity demanded in response to a price change is the same at every price level. On the other hand, it also implies that consumers are less sensitive to price the lower the price is. This is intuitively appealing and has been, to some extent, supported by empirical evidence (Billings and Day, 1989).

If the linear shape is assumed to apply to the whole range of the demand curve, a *choke* price is found at which consumers do not demand any water. This is somewhat at odds with the idea that water is essential. On the other hand, the linear shape also accounts for a level of user satiation for very low prices, which agrees with the intuitive expectation.

Another very popular functional form is the double-log, which yields direct estimates of elasticities (Williams, 1985; Dandy et al., 1997). It also leads to a constant-elasticity form

Table 3
Different econometric techniques

Econometric technique	Study
OLS	Howe and Linaweaver (1967)
	Gibbs (1978)
	Foster and Beattie (1979)
	Carver and Boland (1980)
	Hanke and de Maré (1982)
	Cochran and Cotton (1985)
	Schefter and David (1985)
	Williams (1985)
	Agthe et al. (1986)
	Chicoine and Ramamurthy (1986)
	Chicoine et al. (1986)
	Deller et al. (1986)
	Williams and Suh (1986)
	Billings (1987)
	Moncur (1987)
	Nieswiadomy and Molina (1989)
	Griffin and Chang (1990)
	Rizaiza (1991)
	Lyman (1992)
	Martin and Wilder (1992)
	Nieswiadomy (1992)
	Nieswiadomy and Cobb (1993)
	Bachrach and Vaughan (1994)
	Hewitt and Hanemann (1995)
	Hansen (1996)
	Saleth and Dinar (2000)
	Höglund (1999)
	Pint (1999)
Instrumental variables	Agthe and Billings (1980)
	Billings (1982)
	Jones and Morris (1984)
	Agthe et al. (1986)
	Chicoine et al. (1986)
	Deller et al. (1986)
	Billings (1987)
	Nieswiadomy and Molina (1989)
	Martin and Wilder (1992)
	Nieswiadomy (1992)
	Renzetti (1992)
	Bachrach and Vaughan (1994)
	Hewitt and Hanemann (1995)
	Barkatullah (1996)
	Agthe and Billings (1987)
	Renwick and Archibald (1998)
Free allowances (1)/blocks (2)	(1) Gibbs (1978)
	(2) Nieswiadomy and Molina (1989)
	(2) Nieswiadomy and Cobb (1993)
	(1) Bachrach and Vaughan (1994)

Table 3 (*Continued*)

Econometric technique	Study
	(2) Hewitt and Hanemann (1995) (1) Dandy et al. (1997) (2) Martínez-Espiñeira (2002b)
Panel-data techniques	Moncur (1987) Schneider and Whitlatch (1991) Höglund (1999) Pint (1999) Arbués et al. (2000) Nauges and Thomas (2000) Martínez-Espiñeira (2002b)
Time-series techniques	Sewell and Roueche (1974) Martin et al. (1984) Chicoine and Ramamurthy (1986) Martínez-Espiñeira and Nauges (2001)

of demand. This implies that the proportional sensitivity of use to price changes is the same for low and for high prices. The use of this functional form has been criticized because of its lack of consistency with utility theory (Al-Quanibet and Johnston, 1985).

The LOG–LINear specification could be convenient too. The Stone–Geary form (Al-Quanibet and Johnston, 1985; Gaudin et al., 2001) accounts for the fact that a minimum amount of water demanded should be expected even for very high prices. This subsistence level may also be made dependent on the evolution of consumer habits and the stock of water-using equipment, in such a way that its size varies in time (Nauges and Martínez-Espiñeira, 2001).

Some authors (Woo, 1992; Höglund, 1999) use the Box–Cox specification to find the correct functional form (Greene, 2000, pp. 444–453). A test developed by Ramsey (1974) can be used to check for incorrect functional forms (see, for example, Williams, 1985). Table 4 shows examples of data set types and functional forms used.

4.2. Simultaneity: instrumental variables

A necessary condition for unbiased and consistent parameter estimation under OLS is that there is no correlation between the error term and any of the explanatory variables. However, with multipart block rates, this condition is not fulfilled, since prices are endogenously determined by quantity demanded. Unless price is infinitely elastic, a simultaneous-equations problem theoretically exists, even if the parameters of the rate schedule are known a priori.

The simultaneity problem is normally considered an empirical issue, dependent on the particular context and data set. Thus, Foster and Beattie (1979) acknowledged the problem but, due to the nature of their data, had to ignore it. Similarly, Taylor (1975) considered the simultaneity problem not relevant because in the short-run the tariff structure is independent of consumption. Formal tests of its presence are even scarcer (an exception is Nieswiadomy and Molina, 1991). A Hausman (1978) test can detect the presence of simultaneity and the

Table 4
Data set types and functional form

Type of data set used	Study
Cross-section	Jones and Morris (1984) LIN/LOG/SLOG
	Schefter and David (1985) LIN
	Williams and Suh (1986) LIN/LOG
	Stevens et al. (1992) LIN
	Nieswiadomy and Cobb (1993) LOG
	Point (1993) SLOG
	Bachrach and Vaughan (1994) LIN
	Kulshreshtha (1996) SLOG
	Saleth and Dinar (2000) LOG
Time-series	Sewell and Roueche (1974) LIN/LOG
	Agthe and Billings (1980) LIN/LOG
	Billings and Agthe (1980) LIN/LOG
	Billings (1982) LIN/LOG
	Al-Quanibet and Johnston (1985) SG/LIN/SLOG
	Cochran and Cotton (1985) LOG
	Agthe et al. (1986) LIN
	Hansen (1996) LIN/SLOG
Panel data or CS–TS	Howe and Linaweaver (1967) LIN/CD
	Carver and Boland (1980) LIN
	Hanke and de Maré (1982) LIN
	Chicoine and Ramamurthy (1986) LIN
	Deller et al. (1986) LIN
	Billings (1987) LIN
	Moncur (1987) LIN
	Nieswiadomy and Molina (1989) LIN
	Griffin and Chang (1990) LIN
	Schneider and Whitlatch (1991) LIN
	Lyman (1992) LOG–LIN
	Martin and Wilder (1992) LOG
	Nieswiadomy (1992) LOG
	Renzetti (1992) SLOG
	Hewitt and Hanemann (1995) LOG
	Agthe and Billings (1997) LIN/LOG/SLOG
	Dandy et al. (1997) LIN
	Corral et al. (1998) LIN
	Renwick and Archibald (1998) LIN
	Höglund (1999)
	Pint (1999) LIN
	Arbués et al. (2000) SLOG
	Nauges and Thomas (2000) LOG
	Renwick and Green (2000) LOG
	Martínez-Espiñeira (2002b) LIN

LIN: linear, CD: Cobb–Douglas, LOG: logarithmic, SLOG: semilogarithmic, SG: Stone–Geary.

need to use "instrumental variables" estimation (Agthe et al., 1986).[6] Also a Ramsey-type test checks for, among other misspecifications, simultaneity (see, for instance, Williams, 1985[7]). If simultaneity is present, OLS under a declining block tariff will underestimate or overestimate demand elasticity depending on whether the supply schedule is steeper than the demand schedule or otherwise (Griffin and Martin, 1981; Terza and Welch, 1982).

Some authors argue that OLS estimation can be more reliable even when the potential for simultaneity is substantial, since the use of the difference variable will suffice (Saleth and Dinar, 2000, pp. 25–26). The similarity of OLS and "instrumental variables" estimates (2SLS and 3SLS) obtained by Jones and Morris (1984), Chicoine et al. (1986), or Saleth and Dinar (2000), suggests that simple OLS may be appropriate for studying demand for block-rate priced goods. However, once the choice of technique has been discussed on the basis of economic considerations, it is ultimately the econometrician's task to shed light on the technical issues surrounding that choice.[8]

Under simultaneity, "instrumental variables" techniques, such as two-stage least square (2SLS) or three-stage least square (3SLS) are preferable to OLS estimation. Thus, the problem of simultaneity in the presence of a block rate structure has been dealt with in three different ways:

(1) McFadden et al. (1977) suggest an instrument obtained in two steps. First, a predicted consumption level is estimated by regressing average consumption on the typical bill and a set of explanatory variables (excluding average price). Then, this predicted consumption is used to interpolate the typical bills to obtain a predicted average price that is used to instrument measured average price. Agthe and Billings (1987) used this model considering in that set of variables the tariff changes. Jones and Morris (1984) and Renzetti (1992) regressed the average price against several characteristics of tariffs such as fixed charges, the first block price, or the differentials of other blocks with respect to the first one (see also Nieswiadomy and Molina, 1989; Deller et al., 1986).

(2) Taylor et al. (1981), for the case of electricity demand, created a linear approximation to the total bill (B_i) and derived from it instrumental variables for the marginal price and the difference. Billings (1982) and Agthe and Billings (1997) successfully applied this approach to the study of water demand. To create a constant marginal price and difference parameter for each rate structure, first the total revenue function or total bill function is calculated, using only the rate schedule, over the range of demanded quantities found in the sample. These values of the total bill are then regressed against their associated Q values (where Q is the amount of water purchased).

[6] For instance, Henson (1984) implements the Hausman test in an electricity demand model. In all cases tested, the null hypothesis of price exogeneity is rejected.

[7] The RESET test consists of a standard F test on the coefficient vector $\boldsymbol{\theta} = 0$ in the augmented regression $q = \boldsymbol{X}\beta + Z\boldsymbol{\theta} + u$, where $\boldsymbol{X}$ is a matrix of test variables. Ramsey proposed a particular choice of Z, with his basic premise being that the mean of the ith disturbance (the Nth element of δ, where $\delta = Z\boldsymbol{\theta}$) can be made a function of $(\boldsymbol{X}\beta)_i$. This implies the use of $\boldsymbol{X}\beta$ raised to different powers as test variables. β is not observable, so Ramsey suggests the use of $\hat{q} = \boldsymbol{X}\hat{\beta}$ raised to three powers (where $\hat{\beta}$ is the OLS estimate). Williams augmented regression uses test variables $Z = [\hat{q}^2, \hat{q}^2, \hat{q}^3]$, where the ith element of $\hat{q}^j$ is simply $(\boldsymbol{X}\beta)_i$.

[8] These technical issues are beyond the scope of this survey, but works like Sawa (1969) constitute a useful point of reference.

This results in the estimation, for each rate schedule, of a linear approximation to total bill function $TR = a + bQ + u$ (where u is the residual error term). Values of marginal price are derived from its slope $\partial TR/\partial Q = b = \hat{P}$, while the intercept a is $\hat{D}$, the difference between what consumers actually pay and what they would pay if all units were sold at $\hat{P}$. Billings argued that, since $\hat{P}$ and $\hat{D}$ do not vary with observed quantities, this technique avoided the systematic biases due to measuring Q with error and using its values to determine $\hat{P}$ and $\hat{D}$. Oshfeldt (1983) replied, after applying Hausman-type tests for errors in variables, that Billings (1982) procedure would not solve completely the errors-in-variables problem for a generality of cases and suggested alternative techniques to OLS (such as "maximum likelihood" techniques).

A variant of the method above uses an approximation to the average price schedule, instead of the bill schedule, to find an instrumental variable for the average price. For example, let $b(k) = B(k)/Q_k$, where $b(k)$ represents the average price of the k interval.[9] $b(k) = a_k^z$, so taking logarithms $\ln[b(k)] = \ln(x) + z\ln(Q_k) + u$, which represents the logarithmic transformation of the average price, and u is an error term.

(3) Finally, Fair (1970) proposed the iterative least squares (ISLS) method.[10] This technique, similar to 2SLS, estimates the demand equation and the equation relating the price to consumption independently. This method employs a three-stages regression. First, instrumental variables uncorrelated with the error term are chosen, including at least the endogenous variables vector ($\boldsymbol{y}$) lagged and the explanatory variables vector ($\boldsymbol{x}$) lagged and not lagged. Each component of vector $\boldsymbol{y}$ must be regressed on these instrumental variables to calculate the predicted values of $\boldsymbol{y}$ ($\hat{\boldsymbol{y}}$). The second stage consists of estimating by OLS, for an arbitrary value of coefficients vector ($\boldsymbol{r}$), the equation objective using $\hat{\boldsymbol{y}}$, and calculating the sum of squared residuals of the regression. Finally, the previous OLS estimation is iterated for various values of $\boldsymbol{r}$ between minus one and one to find the $\boldsymbol{r}$ and the corresponding estimates of the others parameters that minimize the sum of squared residuals of the second-stage regression.

Hewitt and Hanemann (1995), Rietveld et al. (1997), and Pint (1999), having available costly individual data, can be counted among the few exceptions who apply "maximum likelihood" methods to the analysis of water demand.

4.3. Demand discontinuity, modeling the choice of consumption block

Another problem in specification and estimation is related to possible shifts in the distribution of consumers among price blocks. The instrumental variable methods involve a linearization of the rate schedule, which produces a spurious negative correlation between the price variable and the random error term (Terza, 1986). Consequently, some kind of modeling is needed to capture the discrete and discontinuous nature of household responses to block pricing.

[9] The tags k are normally referred to the lower limit the block in such a way that the indeterminacy of the highest block is avoided.

[10] As Fair (1970) indicates, this can be considered to be a special case of the iterative method developed by Nagar and discussed in Theil (1965, pp. 354–355).

A Probit model is often used to examine the probability that the consumer be in a particular block as a function of a set of variables (including block prices). Houston (1982) applied the Probit model to individual household data on electricity use. He found that the assumption that price plays a nonsignificant role in block positioning was tenable because, given the width of blocks, other factors were much more relevant. The result can be extrapolated to the case of water, most of all because its prices are normally much lower.

Users whose marginal willingness to pay falls close to block borders might not be able to choose a price that accurately reflects it, since the lower block could be too cheap and the higher one could be too expensive. That idea also helps understand why in many studies with individual data the researcher observes clustering around the borders of the blocks (Castro et al., 2002). This supports the advisability of modeling block choices.

The contributions from labor supply modeling are an important reference to the modeling of block membership. Burtless and Hausman (1978) developed a technique to model labor supply choices in the case of a negative income tax. This technique, based on the concept of consumer surplus, was later used, in addition to a specification based on Probit analysis, by Terza and Welch (1982) to study of electricity and water demand. They suggested a two-stage Probit (TSP) similar to one previously developed by Heckman (1978), parting from the following demand specification:

$$Q_i = P_i\alpha_1 + m_i\alpha_2 + \boldsymbol{X}_i\beta + e_i, \quad i = 1, \dots, I$$

where i is the consumption block, Q_i the consumption observed when the user falls in block i, P_i the marginal price in block i, m_i the income adjusted for the income effect created by the block tariff in block i, $\boldsymbol{X}_i$ a row vector of exogenous household characteristics, α_1, α_2, and β the unknown parameters and e_i is i.i.d $N(0, \sigma^2)$.

Under a declining tariff, the appropriate regression would be

$$Q_i^* = P_i\alpha_1 + m_i\alpha_2 + \boldsymbol{X}_i\beta + v_i \quad (1)$$

where $Q_i^* = Q_i - \hat{h}$, $\hat{h}$ is the correction factor to account for the declining block structure, and v_i is the random error term. The correction factor purges the correlation between the price and the error term (Terza, 1986, p. 1135). First, an ordinal Probit model of the observed rate blocks outcomes is estimated. The Probit results are then used to compute the correction factor $\hat{h}$ for each member of the sample.[11] Finally, one must apply OLS to Eq. (1). The TSP estimator is consistent and asymptotically normal.

Recently, other authors have followed the labor supply tradition (summarized by Moffitt, 1986, 1990) using two-step techniques to correctly specify consumer demand under multiple blocks. They propose a two-stage model in which first the block is selected in a discrete-choice fashion and then the quantity within that block is chosen in a continuous way. Hewitt and Hanemann (1995), Corral et al. (1998), Pint (1999), and Martínez-Espiñeira (2002a) belong to the very few who applied the method to estimate water demand. The technique requires "maximum likelihood" methods and, again, an estimation of the distribution of users per block, so Probit analysis is normally applied.

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[11] Heckman (1978) and Terza and Welch (1982) describe the exact form of h.

4.4. Unobservable variables: modeling free allowances

When free allowances are used, whereby, after having paid an initial connection fee, the consumer is entitled to a free number of units of water, a sample selection problem arises because for some consumers it is not possible to identify willingness to pay for marginal amounts of water. They pay an effective zero marginal price if they consume within the block covered by the fixed minimum fee. However, allocating a zero marginal price to these consumers would not be adequate, since their marginal price is simply not observed. Attaching an average marginal price (the minimum fee divided by the amount consumed) to the observations concerned would not be appropriate either.

Another option would be to exclude these problematic observations from the sample. Unfortunately, this may lead to biased and inconsistent OLS and IV estimates. The suggested solutions involve again the use of information on the underlying distribution of consumers per block and Probit analysis. Dandy et al. (1997) specifically address the issue distinguishing between use within the free allowance (where price at the margin is zero) and use beyond the free allowance border. Castro et al. (2002) show the distortions caused by free allowances by hiding the real consumer preferences distribution. The effect of free allowances is also explicitly analyzed by Martínez-Espiñeira (2002b).

5. Conclusions and future trends

Residential water demand has been an important topic research for a long time. We have reviewed the main variables that can affect demand. Water price, income, or household composition are crucial determinants of residential consumption. When analyzing the effect of water price, most studies have shown that demand is inelastic. This conclusion allows policymakers to use prices to achieve water savings.

Most water tariffs have complex structures that combine fixed and variable charges. The presence of non-uniform prices has originated several problems in demand model specification and estimation. On one hand, the choice of the price measure needs to be empirically tested. Consumers lack perfect information, so it is necessary to choose the better response index. Nordin (1976) price specification and average price are the main alternatives. On the other hand, demand simultaneity and discontinuity invalidate the OLS method. In this respect a controversy remains concerning the econometric issue of simultaneity bias. Instrumental variables and multi-stage least square procedures, or “maximum likelihood” techniques are frequently used to solve those problems. However, some demand estimates presented in this survey show that instrumental estimates of prices are almost identical to those obtained by simpler OLS approaches. This question may be an area for further research in *Econometrics*.

When designing demand-control policies, pricing could be complemented by other instruments. Future residential demand models are expected to analyze alternative demand programs, such as the promotion of low-consumption technologies. Renwick and Archibald (1998) modeled households’ decisions about the adoption of these technologies, showing that the effect on conservation of this type of instrument seems to be substantial.

Another line of future research would deal with panel-data methods, which only a few studies have applied. Many extensions to the basic panel techniques remain unexplored, such as the use of "random coefficients models", or underexplored, such as dynamic specifications. In this sense, the availability of intra-annual data, still scarce, would make it possible to specify lag-response of seasonal demand models within a dynamic framework.

Further work should also be expected on the modeling of the choice of consumption block under block tariffs. This requires very detailed data and the use of relatively sophisticated modeling techniques. However, it would shed more light not only on one of the main controversies found in the academic literature but also on the effects of an increasingly popular management tool. Careful analysis of the effects of block-pricing policies on the distribution of users per block will also be crucial for the estimation of the distributive effects of these policies. This is an essential ingredient in the study of the welfare and socioeconomic impacts of water conservation policies, which is another line of research that will probably receive further attention in the near future.

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References

Agthe, D.E., Billings, R.B., 1980. Dynamic models of residential water demand. Water Resources Research 16 (3), 476–480.

Agthe, D.E., Billings, R.B., 1987. Equity, price elasticity, and household income under increasing block rates for water. American Journal of Economics and Sociology 46 (3), 273–286.

Agthe, D.E., Billings, R.B., 1997. Equity and conservation pricing policy for a government-run water utility. Journal of Water Supply Research and Technology. AQUA 46 (5), 252–260.

Agthe, D.E., Billings, R.B., Dobra, J.L., Rafiee, K., 1986. A simultaneous equation demand model for block rates. Water Resources Research 22 (1), 1–4.

Al-Quanibet, M.H., Johnston, R.S., 1985. Municipal demand for water in Kuwait: methodological issues and empirical results. Water Resources Research 2 (4), 433–438.

Arbués, F., Barberán, R., Villanúa, I., 2000. Water price impact on residential water demand in the city of Zaragoza. A dynamic panel data approach. Paper presented at the 40th European Congress of the European Regional Studies Association (ERSA) in Barcelona, Spain, 30–31 August.

Arellano, M., Honoré, B., 2001. Panel data models: some recent developments. In: Heckman, J.J., Learner, E.E. (Eds.), Handbook of Econometrics, vol. 5. Elsevier/North Holland, New York, Chapter 53, pp. 3229–3296.

Bachrach, M., Vaughan, W.J., 1994. Household water demand estimation. Tech. Rep. Working Paper ENP 106, Inter-American Development Bank Productive Sectors and Environment Subdepartment Environment Protection Division.

Baltagi, B.H., 1995. Econometric Analysis of Panel Data. Wiley, New York.

Barkatullah, N., 1996. OLS and instrumental variable price elasticity estimates for water in mixed-effects model under multiple tariff structure. Working Papers in Economics, Department of Economics, University of Sydney.

Baumann, D.D., Boland, J.J., Hanemann, W.M., 1997. Urban Water Demand Management and Planning. McGraw-Hill, New York.

Beecher, J.A., Mann, P.C., Hegazy, Y., Stanford, J.D., 1994. Revenue Effects of Water Conservation and Conservation Pricing: Issues and Practices. National Regulatory Research Institute, Ohio State University, USA.

Billings, R.B., 1982. Specification of block rate price variables in demand models. Land Economics 58 (3), 386–393.

Billings, R.B., 1987. Alternative demand model estimations for block rate pricing. Water Resources Bulletin 23 (2), 341–345.

Billings, R.B., Agthe, D.E., 1980. Price elasticities for water: a case of increasing block rates. Land Economics 56 (1), 73–84.

Billings, R.B., Agthe, D.E., 1998. State-space versus multiple regression for forecasting urban water demand. Journal of Water Resources Planning and Management—ASCE 124 (2), 113–117.

Billings, R.B., Day, W.M., 1989. Demand management factors in residential water use: the Southern Arizona experience. Journal of the American Water Works Association 81 (3), 58–64.

Burtless, G., Hausman, J.A., 1978. The effect of taxation on labor supply: evaluating the Gary negative income tax experiment. Journal of Political Economy 86 (6), 1103–1130.

Carver, P.H., Boland, J.J., 1980. Short-run and long-run effects of price on municipal water use. Water Resources Research 16 (4), 609–616.

Castro, F., Da-Rocha, J.M., Delicado, P., 2002. Seeking θ's desperately: estimating the distribution of consumers under increasing block rates. Journal of Regulatory Economics 22 (1), 29–58.

Charney, A.H., Woodard, G.C., 1984. A test of consumer demand response to water prices: comment. Land Economics 60 (4), 414–416.

Chicoine, D.L., Ramamurthy, G., 1986. Evidence on the specification of price in the study of domestic water demand. Land Economics 62 (1), 26–32.

Chicoine, D.L., Deller, S.C., Ramamurthy, G., 1986. Water demand estimation under block rate pricing: a simultaneous equation approach. Water Resources Research 22 (6), 859–863.

Cochran, R., Cotton, A.W., 1985. Municipal water demand study, Oklahoma City and Tulsa, Oklahoma. Water Resources Research 21 (7), 941–943.

Corral, L., Fisher, A.C., Hatch, N., 1998. Price and non-price influences on water conservation: an econometric model of aggregate demand under nonlinear budget constraint. Working Paper No. 881, Department of Agricultural and Resource Economics and Policy, University of California at Berkeley.

Dandy, G., Nguyen, T., Davies, C., 1997. Estimating residential water demand in the presence of free allowances. Land Economics 73 (1), 125–139.

Deller, S., Chicoine, D., Ramamurthy, G., 1986. Instrumental variables approach to rural water service demand. Southern Economic Journal 53 (2), 333–346.

Espey, M., Espey, J., Shaw, W.D., 1997. Price elasticity of residential demand for water: a meta-analysis. Water Resources Research 33 (6), 1369–1374.

Fair, R.C., 1970. The estimation of simultaneous equation models with lagged endogenous variables and first order serially correlated errors. Econometrica 38 (3), 507–516.

Foster, H.S.J., Beattie, B.R., 1979. Urban residential demand for water in the United States. Land Economics 55 (1), 43–58.

Foster, H.S.J., Beattie, B.R., 1981a. On the specification of price in studies of consumer demand under block price scheduling. Land Economics 57 (2), 624–629.

Foster, H.S.J., Beattie, B.R., 1981b. Urban residential demand for water in the United States: reply. Land Economics 57 (2), 257–265.

Gaudin, S., Griffin, R.C., Sickles, R.C., 2001. Demand specification for municipal water management: evaluation of the Stone–Geary form. Land Economics 77 (3), 399–422.

Gibbs, K.C., 1978. Price variable in residential demand models. Water Resources Research 14 (2), 15–18.

Gottlieb, M., 1963. Urban domestic demand or water in the United States. Land Economics 39 (2), 204–210.

Greene, W.H., 2000. Econometric Analysis, 4th ed. Prentice-Hall, Englewood Cliffs, NJ.

Griffin, R.C., Chang, C., 1990. Pretest analysis of water demand in thirty communities. Water Resources Research 26 (10), 2251–2255.

Griffin, A.H., Martin, W.E., 1981. Price elasticities for water: a case of increasing block rates: comment. Land Economics 57 (2), 266–275.

Hanke, S.H., de Maré, L., 1982. Residential water demand: a pooled time-series cross-section study of Malmö, Sweden. Water Resources Bulletin 18 (4), 621-625.

Hansen, L.G., 1996. Water and energy price impacts on residential water demand in Copenhagen. Land Economics 72 (1), 66–79.

Hausman, J., 1978. Specification tests in Econometrics. Econometrica 46 (6), 1251–1270.
Heckman, J.J., 1978. Dummy endogenous variables in a simultaneous equation system. Econometrica 46 (4), 931–959.
Henson, S.E., 1984. Electricity demand estimates under increasing-block rates. Southern Economic Journal 51 (1), 147–156.
Hewitt, J.A., Hanemann, W.M., 1995. A discrete/continuous choice approach to residential water demand under block rate pricing. Land Economics 71 (2), 173–192.
Höglund, L., 1999. Household demand for water in Sweden with implications of a potential tax on water use. Water Resources Research 35 (12), 3853–3863.
Houston, D., 1982. Revenue effects from changes in a declining block pricing structure. Land Economics 58 (3), 351–363.
Houston, D., 1983. Revenue effects from changes in a declining block pricing structure: reply. Land Economics 59 (3), 360–364.
Howe, C.W., 1982. The impact of price on residential water demand: some new insights. Water Resources Research 18 (4), 713–716.
Howe, C.W., Linaweaver, F.P., 1967. The impact of price on residential water demand and its relationship to system design and price structure. Water Resources Research 3 (1), 13–32.
Jones, C.V., Morris, J.R., 1984. Instrumental price estimates and residential water demand. Water Resources Research 20 (2), 197–202.
Kulshreshtha, S.N., 1996. Residential water demand in Saskatchewan communities: role played by block pricing system in water conservation. Canadian Water Resources Journal 21 (2), 139–155.
Lyman, R.A., 1992. Peak and off-peak residential water demand. Water Resources Research 28 (9), 2159–2167.
Maddock, R., Castaño, E., 1991. The welfare impact of rising block pricing: electricity in Colombia. Energy Journal 12 (4), 65–77.
Maidment, D.R., Miaou, S.P., 1986. Daily water use in nine cities. Water Resources Research 22 (6), 845–885.
Maresca, B., Poquet, G., Pouquet, L., Ragot, K., 1997. LÉau et les usages domestiques. Comportements de consommation de lÉau dans les ménages. CREDOC Cahier de Recherche C104 200 F.
Marshall, A., 1879. Water as an element of national wealth. In: Pigou, A. (Ed.), Memorials of Alfred Marshall. Kelley & Millman, New York, reprinted in 1956, pp. 134–141.
Martin, W.E., Thomas, J.F., 1986. Policy relevance in studies of residential water demand. Water Resources Research 22 (13), 1735–1741.
Martin, R.C., Wilder, R.P., 1992. Residential demand for water and the pricing of municipal water services. Public Finance Quarterly 20 (1), 93–102.
Martin, W.E., Ingram, H.M., Laney, N.K., Griffin, A.H., 1984. Saving Water in a Desert City. Resources for the Future. Johns Hopkins University Press, Baltimore, MD.
Martínez-Espiñeira, R., 2002a. Estimating water demand under increasing block tariffs using aggregate data and proportions of users per block. In: Pashardes, P., Swanson, T., Xepapadeas, A. (Eds.), Current Issues in the Economics of Water Resource Management: Theory and Policy. Kluwer Academic Publishers, Amsterdam, Chapter 2, pp. 27–46.
Martínez-Espiñeira, R., 2002b. Residential water demand in the Northwest of Spain. Environmental and Resource Economics 21 (2), 161–187.
Martínez-Espiñeira, R., Nauges, C., 2001. Residential water demand: an empirical analysis using co-integration and error correction techniques. Paper presented at the 35th Meetings of the Canadian Economic Association, Montreal, June 1–3, 2001.
McFadden, D., Puig, C., Kirschner, D., 1977. Determinants of the long-run demand for electricity. American Statistical Association Proceedings of the Business and Economics Section 72 (358), 109–113.
Miaou, S.P., 1990. A class of time-series urban water demand models nonlinear climatic effects. Water Resources Research 26 (2), 169–178.
Moffitt, R., 1986. The econometrics of piecewise-linear budget constraints. Journal of Business and Economic Statistics 4 (3), 317–328.
Moffitt, R., 1990. The econometrics of kinked budget constraints. Journal of Economic Perspectives 4 (2), 119–139.
Moncur, J., 1987. Urban water pricing and drought management. Water Resources Research 23 (3), 393–398.
Morgan, W.D., Smolen, J., 1976. Climatic indicators in the estimation of municipal water demand. Water Resources Bulletin 12 (3), 511–518.

Munasinghe, M., 1992. Water Supply and Environmental Management: Developing World Applications. Studies in Water Policy and Management. Westview Press, Boulder and Oxford.
Nauges, C., Martínez-Espiñeira, R., 2001. Identifying fixed and variable shares of residential water consumption using the Stone–Geary utility function. Working Paper, Economics, St. Francis Xavier University.
Nauges, C., Thomas, A., 2000. Privately-operated water utilities, municipal price negotiation, and estimation of residential water demand: the case of France. Land Economics 76 (1), 68–85.
Nauges, C., Thomas, A., 2001. Dynamique de la consommation d'Eau potable des ménages: une étude sur un panel de communes franc,aises. Economie et Prevision Numéro spécial 'Economie de l'Environnement et des Resources Naturelles'.
Nieswiadomy, M.L., 1992. Estimating urban residential demand: effects of price structure, conservation and education. Water Resources Research 28 (3), 609–615.
Nieswiadomy, M.L., Cobb, S.L., 1993. Impact of pricing structure selectivity on urban water demand. Contemporary Policy Issues 11 (6), 101–113.
Nieswiadomy, M.L., Molina, D.J., 1988. Urban water demand estimates under increasing block rates. Growth and Change 19 (1), 1–12.
Nieswiadomy, M.L., Molina, D.J., 1989. Comparing residential water estimates under decreasing and increasing block rates using household data. Land Economics 65 (3), 280–289.
Nieswiadomy, M.L., Molina, D.J., 1991. A note on price perception in water demand models. Land Economics 67 (3), 352–359.
Nordin, J.A., 1976. A proposed modification on Taylor's demand–supply analysis: comment. The Bell Journal of Economics 7 (2), 719–721.
OECD, 1987. Pricing of Water Services. OECD, Paris.
OECD, 1999. Household Water Pricing in OECD Countries. OECD, Paris, unclassified document ENV/EPOC/GEEI(98)12/FINAL.
Opaluch, J., 1982. Urban residential demand for water in the United States: further discussion. Land Economics 58 (2), 225–227.
Opaluch, J., 1984. A test of consumer demand response to water prices: reply. Land Economics 60 (4), 417–421.
Oshfeldt, R.L., 1983. Specification of block rate price variables in demand models: comment. Land Economics 59 (3), 365–369.
Pint, E., 1999. Household responses to increased water rates during the California drought. Land Economics 75 (2), 246–266.
Point, P., 1993. Partage de la ressource en eau et demande d'Alimentacion en eau potable. Revue Economique 44 (4), 849–862.
Ramsey, F., 1927. A contribution to the theory of taxation. Economic Journal 37 (1), 47–61.
Ramsey, J.B., 1974. Classical model selection through specification error tests. In: Zarembka, P. (Ed.), Frontiers in Econometrics. Academic Press, New York, Chapter 1, pp. 13–47.
Renwick, M.E., Archibald, S.O., 1998. Demand side management policies for residential water use: who bears the conservation burden? Land Economics 74 (3), 343–359.
Renwick, M.E., Green, R., 2000. Do 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.
Renzetti, S., 1992. Evaluating the welfare effects of reforming municipal water prices. Journal of Environmental Economics and Management 22 (1), 147–163.
Rietveld, P., Rowendal, J., Zwart, B., 1997. Estimating water demand in urban Indonesia: a maximum likelihood approach to block rate pricing data. Tinbergen Institute Discussion Papers, TI 97-072/3.
Rizaiza, O.S.A., 1991. Residential water usage: a case study of the major cities of the western region of Saudi Arabia. Water Resources Research 27 (5), 667–671.
Saleth, R.M., Dinar, A., 2000. Urban thirst: water supply augmentation and pricing policy in Hyderabad city, India. The World Bank. Technical Paper No. 395.
Sawa, T., 1969. The exact sampling distribution of ordinary least squares and two-stage least squares estimators. Journal of the American Statistical Association 64 (327), 923–937.
Schefter, J.E., David, E.L., 1985. Estimating residential water demand under multi-tariffs using aggregate data. Land Economics 61 (3), 272–280.
Schneider, M.L., Whitlatch, E.E., 1991. User-specific water demand elasticities. Journal of Water Resources Planning and Management—ASCE 117 (1), 52–73.

Sewell, W.R.D., Roueche, L., 1974. Peak load pricing and urban water management: Victoria, BC, a case study. Natural Resources Journal 14 (3), 383–400.

Shin, J.S., 1985. Perception of price when information is costly: evidence from residential electricity demand. Review of Economics and Statistics 67 (4), 591–598.

Stevens, T.H., Miller, J., Willis, C., 1992. Effect of price structure on residential water demand. Water Resources Bulletin 28 (4), 681–685.

Taylor, L.D., 1975. The demand for electricity: a survey. The Bell Journal of Economics 6 (1), 74–110.

Taylor, L.D., Blattenberger, G.R., Rennhack, R.K., 1981. Residential energy demand in the United States. Tech. Rep., Report to the Electric Power Research Institute, Data Resource, Inc.

Terza, J.V., 1986. Determinants of household electricity demand: a two-stage Probit approach. Southern Economic Journal 53 (2), 1131–1139.

Terza, J.V., Welch, W.P., 1982. Estimating demand under block rates: electricity and water. Land Economics 58 (2), 181–188.

Theil, H., 1965. Economic Forecast and Policy. North-Holland, Amsterdam.

Whittington, D., 1992. Possible adverse effects of increasing block water tariffs in developing countries. Economic Development and Cultural Change 41 (1), 75–87.

Williams, M., 1985. Estimating urban residential water demand for water under alternative price measures. Journal of Urban Economics 18 (2), 213–225.

Williams, M., Suh, B., 1986. The demand for urban water by customer class. Applied Economics 18 (2), 1275–1289.

Woo, C.K., 1992. Drought management, service interruption and water pricing: evidence from Hong Kong. Water Resources Research 28 (10), 2591–2595.

Young, R., 1996. Measuring economic benefits for water investment and policies. The World Bank. Technical Paper No. 338.

Young, C.E., Kingsley, K.R., Sharpe, W.E., 1983. Impact on residential water consumption of an increasing rate structure. Water Resources Bulletin 19 (1), 81–86.