

Commercial and Industrial Water Demand Estimation: Theoretical and Methodological Guidelines for Applied Economics Research

ANDREW C. WORTHINGTON

Department of Accounting, Finance and Economics

GRIFFITH UNIVERSITY, AUSTRALIA

e-mail: .worthington@griffith.edu.au

ABSTRACT

Unlike the modelling of residential water demand, very little recent empirical work has concerned the estimation of commercial and industrial water demand. This is an important omission, not only because these activities are subject to the same water-related challenges found elsewhere, including the need for a reliable water supply, rising water prices and seasonal water scarcity, but because they also account for substantial water use as a key input into productive activities and hence employment and value-added. Moreover, commercial and industrial water demand and its management are inherently complex, involving among other things the potential for recycling, the impact of discharge regulations, the possibilities of substituting for other inputs and the potential for self-supply, and the role of large scale workplace practices and technology. As a means of redressing this imbalance, this paper provides a discussion of the theory and practice of commercial and industrial water demand estimation. Both model specification and estimation and the outcomes of past analyses are discussed. Particular focus is placed on providing useful guidance to future researchers in this important area.

Keywords: Commercial and Industrial Water Demand, Derived Demand, Factor Inputs, Price and Output Elasticity of Demand.

Estimación de la demanda de agua comercial e industrial: pautas teóricas y metodológicas para la investigación en Economía Aplicada

RESUMEN

A diferencia de lo que ocurre con la modelización de la demanda de agua residencial, existen muy pocos trabajos empíricos recientes sobre la estimación de la demanda de agua comercial e industrial. Esta es una omisión importante, no sólo porque estas actividades están sujetas a los mismos desafíos relacionados con el agua en otros lugares, incluida la necesidad de un suministro fiable de agua, el aumento de precios y la escasez estacional de recursos, sino porque también se considera relevante para el uso del agua como un insumo clave en las actividades productivas y, por tanto, en el empleo y valor añadido. Además, tanto la demanda como la gestión de recursos hídricos para usos comerciales e industriales son inherentemente complejos, implicando entre otros aspectos, el potencial de reciclado, el impacto de las regulaciones sobre extracciones, las posibilidades de sustitución de otros insumos y el potencial de auto-abastecimiento, y el papel jugado por la tecnología. Como un medio para corregir dicho desequilibrio, este documento ofrece un análisis teórico y práctico de la estimación de la demanda de agua comercial e industrial, tratando tanto la especificación del modelo como la estimación y los resultados de los análisis anteriores. Se hace especial hincapié en proporcionar una orientación útil a los futuros investigadores en esta importante área.

Palabras clave: Demanda de agua comercial e industrial, demanda derivada, inputs, outputs, precio y elasticidad de la demanda.

Clasificación JEL: C51, D21, L23, Q31.

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1. INTRODUCTION

Traditionally, water demand has been distinguished according to broad usage: namely, residential, agricultural, commercial, industrial and recreational and environmental. Residential water demand covers uses of water by households, both inside and outside the confines of the residence and typically includes washing, cooking, bathing, laundry and gardening. Agricultural demand is taken to cover all irrigation and livestock purposes. Commercial use consists of water used by warehouses, stores and shopping centres, restaurants, hotels and related activities, cinemas, offices, and educational, entertainment and health establishments. Industrial water demand is focused on cooling, processing and manufacturing operations, power generation, sewerage, cleanup and sanitation, and fire protection. Finally recreational and environmental relates to all end-uses other than residential that have value derived from utility provision direct to the consumer.

Despite these enormously dissimilar uses for water, a common area of interest for policymakers and hence researchers is the estimation of water demand and with it the price elasticity of demand. This is essential work as it allows water providers, often in highly regulated sectors, to better understand and manage the needs of their customers. Moreover, it is especially important in the face of declining rainfall associated with climate change, pressing needs for maintaining and expanding expensive water supply infrastructure, jurisdictional, sectoral and environmental conflicts over existing surface and groundwater supplies, and sometimes rapid population growth and urbanisation.

Nevertheless, we choose to focus on commercial and industrial water demand. The main reason is that very little work on water demand modelling has been undertaken outside the residential water sector, primarily because commercial and industrial use traditionally accounts for a smaller proportion of urban water use, which in turn is substantially less than rural (agricultural) use. This is not to say that commercial and industrial water use is insignificant. For example, across Europe, 42% of total water use is for agriculture, 23% for industry, 18% for urban purposes (including commercial uses) and 18% for energy production (United Nations Environment Programme, 2004). However, the breakdown of water consumption between the sectors varies considerably from one country to another. For instance, in France (64%), Germany (64%) and the Netherlands (55%) relatively more water is used for the production of electricity (share in brackets), while in Finland (66%) and Sweden (28%) water is mostly used for other industrial purposes (including cellulose and paper production).

Likewise, in the US, publicly supplied commercial and industrial purposes accounted for about 10% of water use, a further 4% for self-supplied industrial use, 3% for aquaculture and mining and 49% for thermoelectric power generation (Kenny *et al.*, 2005). Finally, in Australia, overall water consumption was 21,703 gigalitres in 2000/01, of which 70% was for agriculture, 10% for households and 20% for commercial and industrial uses (including water supply, sewerage and

drainage services). By 2004/05, water consumption had fallen to 18,767 gegalitres, with agriculture falling to 65%, households increasing to 11% and commercial and industrial increasing to 24% (Australian Bureau of Statistics, 2006). One final consideration is while residential and agricultural uses have accounted for much water use in the past, the shift from agriculture-orientated activities to commercial-orientated activities in many developed economies and to industrial-orientated activities in many developing economies means that these sectors will play an increasingly greater role in water consumption and a closer examination of commercial and industrial water demand is clearly warranted.

The paper itself is structured as follows. Section 2 briefly reviews the theory of commercial and industrial water demand. Section 3 discusses past empirical research into commercial and industrial water demand with reference to the larger body of work on residential water demand. Section 4 provides some recommendations for a way forward in estimating commercial and industrial water demand consistent with both theory and past practice. Section 5 concludes.

2. COMMERCIAL AND INDUSTRIAL WATER DEMAND THEORY

The neoclassical economic theory of production provides a useful framework for examining firm's use of water and the sensitivity of commercial and industrial water use to market prices (Spulber and Sabbahi, 1994; Merrett, 1997; Renzetti, 2002). Unlike consumer demand, where a household has a set of preferences for goods and services (including water) that may be represented by a utility function, for commercial and industrial firms the demand for water is derived along with other inputs as part of a production function. Accordingly, the demand for water, and hence the price elasticity of demand, is a function of not only the price of water but also the price of the firm's outputs, the prices of complementary and substitutable inputs, and the level of available technology, amongst others. Moreover, at least some commercial firms may have substantially more choice over some aspects of water use than typical households, and may have ready availability to different qualities of water, including intake water, water recycling, treatment of water prior to use and water discharge. These and other theoretical considerations considerably complicate the empirical modelling of water demand by commercial and industrial firms.

2.1. Production and input demand

Assume that a competitive firm's production technology is characterised by the following production function:

$$y = f(x_1, x_s, \dots, x_N) \quad (1)$$

where y is the firm's output (measured in physical units) and x_i are the quantities of various inputs (typically capital and labour but also water). One natural approach to modelling water use in firm production is to only include the quantity of water intake. However, a more developed approach is to include four facets of water use as separate inputs: namely, water intake, water recycling, treatment of water prior to use, and water discharge. This is relatively common in the small number of theoretical and empirical studies of industrial water demand. Of course, this behaviour varies substantially across firms with water recycling, treatment of water prior to use, and water discharge normally confined to only the larger industrial users.

Implicit in the neoclassical production function is the assumption that some substitution possibilities exist among inputs. This is clearly possible with the alternative water input specifications in industrial use where recycled water may substitute for intake water and where the efficiency of water recycling substitutes for the quantity of water discharged. In commercial use, these opportunities are once again more limited though the firm may, for example, substitute water efficient technology for water use. Under the assumption that the firm is perfectly competitive in its input markets, it will take the prices of the inputs in (1) as exogenously given. For any given level of output, the cost-minimising input combination can be derived:

$$\min_{\{x_i\}} \sum_{i=1}^N w_i \cdot x_i \text{ subject to } f(x_1, x_2, \dots, x_N) \geq \bar{y} \quad (2)$$

Solving (2) yields the firm's conditional input demands as a function of input prices and the level of output:

$$x_i^* = h(w_1, w_2, \dots, w_N, \bar{y}) \quad i = 1, \dots, N. \quad (3)$$

This conditional demand equation is structurally equivalent to the consumer's Hicksian demand curve concept except that it is conditioned on the level of output rather than the level of consumer utility. Substituting the optimal input quantities into the objective function yields the firm's cost function:

$$C(w_1, w_2, \dots, w_N, \bar{y}) = \sum_{i=1}^N w_i \cdot x_i^* \quad (4)$$

The cost function indicates the minimum cost of producing the target level of output at the specified vector of market input prices. It also contains all of the economically relevant information that is contained in the production function. The conditional input demands may be recovered from the cost function by applying Shephard's lemma:

$$\partial C(w_1, w_2, \dots, w_N, \bar{y}) / \partial w_i = x_i^* = h(w_1, w_2, \dots, w_N, \bar{y}) \quad i = 1, \dots, N. \quad (5)$$

If the firm is also operating in a competitive output market, then it also takes its output price, p , as given. The firms' profit is then given by the difference between revenue and costs:

$$\pi = p \cdot y - \sum_{i=1}^N w_i \cdot x_i = p \cdot f(x_1, x_2, \dots, x_N) - \sum_{i=1}^N w_i \cdot x_i \quad (6)$$

Under the assumption of profit-maximising behaviour, the firm's optimal input demands and output supply may be characterised as:

$$\begin{aligned} x_i^* &= m(w_1, w_2, \dots, w_N, p) \quad i=1, \dots, N. \\ y_* &= f(x_1^*, x_2^*, \dots, x_N^*) = n(w_1, w_2, \dots, w_N, p) \end{aligned} \quad (7)$$

Substituting these expressions into the profit equation yields the profit function. This indicates the maximal profits the firm can earn when constrained by existing market prices and technology.

$$\pi(w_1, w_2, \dots, w_N, p) = p \cdot y_* - \sum_{i=1}^N w_i \cdot x_i^* \quad (8)$$

The optimal input demands and output supply may be retrieved from the profit function by applying Hotelling's lemma:

$$\begin{aligned} \partial \pi(w_1, w_2, \dots, w_N, p) / \partial w_i &= m(w_1, w_2, \dots, w_N, p) \quad i=1, \dots, N. \\ \partial \pi(w_1, w_2, \dots, w_N, p) / \partial p &= n(w_1, w_2, \dots, w_N, p) \end{aligned} \quad (9)$$

The input demand functions have several features relevant to the following discussion. First, it is clear that the demand for any input (including water) is dependent on all input and output prices. Thus, any empirical effort to characterise the demand for water (and any resulting price elasticities of demand) with only a single price included among the explanatory variables either assumes that demands are separable or runs the risk of specification error. Second, the input demand equation is homogeneous of degree zero. This means that only changes in relative prices will induce changes in input use. Third, the demand for any input is decreasing in its own price. Fourth, the demands for any two inputs, i and j , are characterised by the following symmetry property:

$$\frac{\partial x_i^*}{\partial p_j} = \frac{\partial x_j^*}{\partial p_i} \quad i, j=1, \dots, N. \quad (10)$$

Putting this aside and assuming that the level of output and all water and non-water input prices (and their qualities if applicable) are given as parameters in the

model, we can see some interesting outcomes. For example, while the derived demand for water is normally considered inelastic, in some production processes it may be elastic in the sense that an increase in the water price may lead to technological changes which reduce the quantity or quality of water used or which make it possible to recycle water. Quality characteristics and the output level will also (positively) affect water demand exogenously and shift the demand curve. For instance, an improvement in the quality of water without a change in price would increase productivity and shift the demand curve to the right. An increase in the price of a non-water input would, depending on the degree of complementarity or substitutability with water, shift the derived demand for water to the left or right. Finally, an increase in rent for commercial premises may decrease the demand for water and shift demand to the left.

Technological factors are also generally expected to have a larger impact on water demand in commercial activities than in, say, the residential sector. Commercial firms, like hotels and entertainment precincts, may increase their use of water-based displays or undertake extensive landscaping to attract customers. Lower-quality or recycled water may be potentially used for some of these uses. Commercial firms may also undertake efforts to capture natural rainfall or undertake the recycling of water. Moreover, factors such as regulations, pricing policy, educational campaigns, housing trends, supply costs, and changes in the technology of demand, which could influence residential, also potentially influence commercial demand. However, it is also sometimes argued that commercial demand for water is less price-sensitive as employees as agents are not directly responsible for water costs.

Finally, there are several ways to represent these relationships in elasticity form. The most straightforward of these are the price η_p and output η_y elasticity of input demand:

$$\begin{aligned}\eta_p &= \left(\frac{\partial x_i^*}{\partial p_j} \right) \cdot \left(\frac{p_j}{x_i^*} \right) \quad i, j = 1, \dots, N. \\ \eta_y &= \left(\frac{\partial x_i^*}{\partial y} \right) \cdot \left(\frac{y}{x_i^*} \right)\end{aligned}\tag{11}$$

It may be that in the short run, the firm's decisions regarding water are constrained by the quantity of an input whose quantity it is unable to alter (such as the existing stock of capital). In these circumstances, the optimisation is carried out with an additional constraint. Short-run or restricted cost and profit functions result:

$$C(w_1, w_2, \dots, w_{N-1}, \bar{x}, \bar{y}) \text{ and } \pi(w_1, w_2, \dots, w_{N-1}, \bar{x}, p)\tag{12}$$

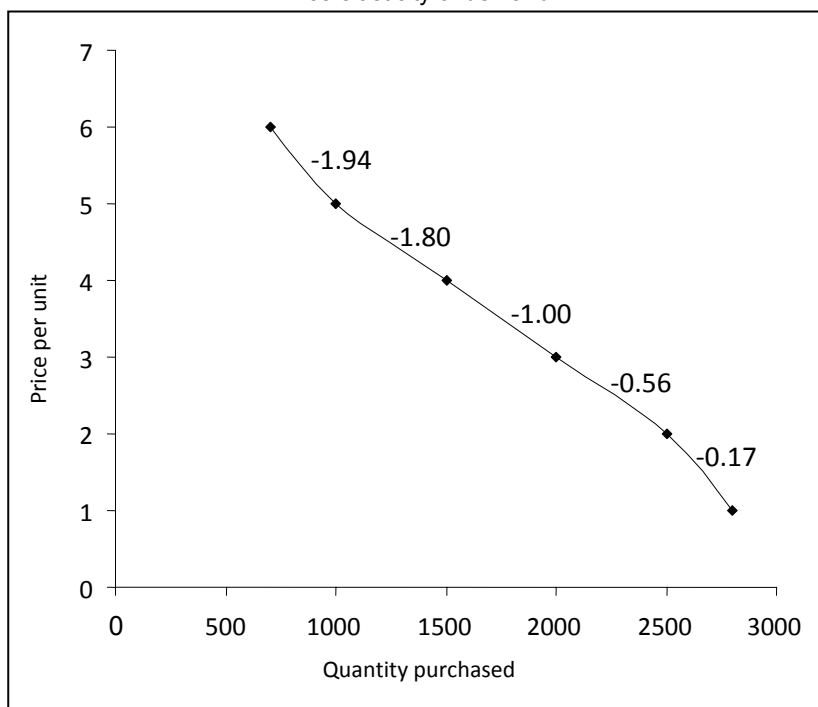
2.2. Price elasticity of estimated demand

Unfortunately, the real-world derivation and interpretation of the price elasticity of commercial water demand can be problematic. To be of most use, demand modelling should produce the relationship between the price per unit of water and the quantity that commercial and industrial firms are willing to purchase at each price. As shown in Figure 1, demand is conventionally represented graphically with price on the vertical (y -axis) and quantity on the horizontal (x -axis). The graph is constructed using a hypothetical demand schedule with the price elasticities of demand for each segment (arc) of the curve using the midpoint calculation:

$$\eta_p = (Q_2 - Q_1) / [(Q_1 + Q_2) / 2] / (P_2 - P_1) / [(P_1 + P_2) / 2] \quad (13)$$

As is well known, price elasticity will vary along the length of any particular demand function (with the exception of perfectly inelastic, unitary and perfectly elastic curves) with relatively more elastic values at higher prices (though not necessarily elastic in absolute terms) and relatively less elastic values at lower prices (though not necessarily inelastic in absolute terms). If the demand function is mathematically continuous, the price elasticity could be measured for each and every point, however, these essential observations remain.

FIGURE 1
Price elasticity of demand.



Accordingly, one problem that arises with estimating the commercial and industrial demand for water, as with all demand functions, is that the observed (or actual) sample data will only ever correspond to a relatively small set of values along the demand curve and there is no way of knowing how representative this is of the entire demand function. For example, an empirically estimated demand curve may yield relatively low price elasticities at low prices and these will necessarily be higher at higher prices. With commercial water demand, at low quantities purchased, a higher price brings little reduction in the absolute quantity purchased because of the intensity of need for water (much the same as the subsistence or nondiscretionary level of water found in households). In the middle range, a price change potentially brings about a change in the quantity purchased, while with higher quantities purchased a lower price brings about no change in the quantity purchased because the demands by the commercial user are fully satiated. Ideally, the full price schedule should be included in the demand function. To some extent, this problem can be addressed by sampling actual data across time where a wider range of prices and quantities are sampled, though with the additional complication that many other demand conditions, especially technology, are no longer held constant.

Nonetheless, as with the theory of consumer demand, the economic theory of firm behaviour provides at least some direction to empirical researchers seeking to model commercial water use. The most important observation is that the demand for any input (including water) is a function of its own price, the prices of all other inputs, and either the quantity or price of output depending on the behavioural assumption made. In addition, input demands should satisfy basic homogeneity and symmetry conditions.

3. ESTIMATING COMMERCIAL AND INDUSTRIAL WATER DEMAND

For the most part, empirical research on urban (non-agricultural) water demand has overwhelmingly focused on residential demand. Despite this, water demand modelling for commercial and industrial uses can benefit from the insights gathered from the extant residential water demand literature. In brief, residential water demand is normally modelled by including the price of water, income and other explanatory factors thought to influence discretionary and nondiscretionary demand. This reflects consumer theory and the role of water in providing utility for final end-use. Accordingly, for studies of residential water demand, this would typically take the form $Q = f(P, Z)$ where Q 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; Hoffmann and Worthington, 2008). Indeed, many studies ostensibly focusing on

residential water demand often include variables to avoid the confounding effects of a significant proportion of commercial/industrial users.

In contrast, in commercial and industrial applications, the demand for water is a derived demand and should accordingly depend on the price and cost shares of water and other factor inputs and the level of output. For most commercial and industrial demand equations, the typical form is $Q = f(P, S, Y, Z)$ where Q is the quantity of water as a derived demand (once again, likely consumed), P is a measure of all factor prices (including water), S are factor cost shares, Y is the level of output, and Z are other independent variables. Regardless, there is a heavy emphasis with both residential and commercial and industrial studies on calculating the price and income/output elasticities of water demand and these generally indicate that the price elasticity of water demand for commercial users is lower than residential users and substantially lower than that for industrial users.

3.1. Scope of empirical survey

At least two studies, Arbues *et al.* (2003) and Hoffmann and Worthington (2008), have surveyed the estimation of residential water demand while another, de Gispert (2004), has reviewed industrial water demand. However, the former focuses almost exclusively on residential water demand, while few papers in the latter were published after the late 1990s. Other possibilities include the meta-analyses by Espey *et al.* (1997) and Dalhuisen *et al.* (2003). Unfortunately, these focus on providing indicative measures of price and income/output elasticity, and are not particularly useful for researchers undertaking new work. This review concentrates on studies published since 1980. EconLit, the *Journal of Economic Literature* electronic database, was searched to identify articles concerned with commercial and industrial water demand estimation. References from these studies were used to identify other articles not included in the database.

3.2. Tariff structure

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 as the observations used for deriving demand are drawn from this context, a good knowledge of the existing tariff structure is essential for model specification.

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) 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 Syme (1988), Barkatulla (1996), Dandy *et al.* (1997), Higgs and Worthington (2001) and Hoffman *et al.* (2006)].

In terms of the few commercial and industrial water demand studies, with the exception of Williams and Suh (1986), flat rate pricing structures dominate (Babib *et al.* 1982; Renzetti, 1988, 1992, 2002; Reynaud, 2003; Garcia and Reynaud, 2003). This is fortunate in that there are fewer complications, as discussed below, involved in interpreting and specifying the impact of pricing structure on the price elasticities than with residential water demand estimation.

3.3. Determinants of demand

3.3.1. Pricing

By the law of demand, 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 easily classic econometric modelling techniques.

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.

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 Martínez-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.

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-Españeira (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 Scheffer and David (1985) and Martínez-Españeira (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 Martínez-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), Martínez-Españeira (2003a).

Similar variations in the price elasticity of demand are found in studies of commercial users. Lynn *et al.* (1993) used a mail survey of commercial firms in

Miami to study the impact of prices on water use. Price elasticities for intake water by sub-sector were -1.33 (department stores), -0.76 (grocery stores), -0.12 to -0.24 (motels and hotels), -0.174 (restaurants) and -0.48 other establishments). Williams and Suh (1986) instead used aggregate water demand equations for commercial and industrial sectors. The price elasticities ranged between -0.141 to -0.360 for commercial uses, with output elasticities of about 0.99 . In another study, Schneider and Whitlatch (1991) used account-specific data for 16 Ohio communities and found short and long-run price elasticities of commercial demand of -0.234 and -0.918 , respectively. Both elasticities were higher than either the residential or industrial sector suggesting commercial users are substantially more price sensitive, while substantial lags in price adjustment were found in both the commercial and industrial sectors. Finally, Malla and Gopalakrishnan (1993) estimated price elasticities of -0.074 to -0.106 and output elasticities (as measured by the number of employees) of 0.058 to 0.606 for commercial water demand in Hawaii.

In terms of industrial water, Babin *et al.* (1982) estimated translog cost functions for US industries using state-level cross-sectional observations. Water (average price) was included as an input—together with labour, capital and materials—and this indicated price elasticities in the broad range of 0.00 to -0.81 . Ziegler and Bell (1984) considered water use in chemical firms only using both average and marginal prices. The estimated price elasticities were found to be -0.078 and -0.0001 , respectively. Williams and Suh (1986) employed an aggregate analysis of residential, commercial and industrial users and found that price elasticities were higher than residential uses (which were again higher than commercial uses) at -0.44 to -0.74 .

In a series of studies, Renzetti (1988; 1992; 2001) used Canadian data to model uses of four different kinds of water qualities—water intake, water treatment, water recirculation and water discharge. To a certain extent, this is equivalent to regarding water not as a single input, rather as sub inputs representing different purposes within the firm, for which firms are able to make choices about the level of intensity. The results for water intake ranged widely: -0.1186 and -0.5368 (Renzetti 1988), -0.1534 to -0.5885 (Renzetti 1992) and -0.8098 (Renzetti 2001). In a study of self and publicly supplied manufacturing firms, Renzetti (1993) found that the demand for water by self-supplied firms was relatively less price elastic, especially in food and textiles. In other work, Dupont and Renzetti (2001) concluded that water intake and recirculation are sensitive to input prices and that water intake is a substitute for water recirculation, energy, labour and capital. Lastly, Mitchell *et al.* (2002) that there was a clear interrelationship between water demand and waste minimisation in industrial users with reductions in water demand of potentially 31% just from manufacturing industries in Yorkshire, while Liaw *et al.* (2006) concluded price elasticity varies with water price in cases involving water reuse in a study of the integrated circuit industry in Taiwan.

3.3.2. *Income and output*

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). 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 Syme (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.

For commercial and industrial studies, output rather than income elasticity is the correct measure, though water demand should likewise increase with the level of output. A variety of ways of measuring output in commercial and industrial uses are found, including value-added (Williams and Suh, 1986), the number of employees (Malla and Gopalakrishnan, 1993) or employee hours (Renzetti, 1988), revenue (Renzetti, 2001), however, some studies also do not even attempt to measure output (Babin *et al.*, 1982). In a comparison of the residential, commercial and industrial sectors, Williams and Suh (1986) found that the output elasticity of water was substantially higher (and closer to unity) than either residential or industrial users. Renzetti (1988) concluded that the elasticity of industrial users in petrochemical, heavy, forestry and light sectors was actually output elastic, indicating that water use increases more than proportionately with increases in output. In fact, while residential water demand is almost universally small (if not insignificant) in terms of income elasticity, in the very small number of studies where it is considered output elasticity is close to if not more than unitarily elastic. Finally, Renzetti (1993) found in a comparison of self and publicly-supplied manufacturing firms that water demand was output inelastic.

3.3.3. *Weather and seasonal factors*

As a rule, residential water use is usually shown to be highly sensitive to seasonal fluctuations. 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). 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-Espíñeira (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-España 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-analyses, 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.

The only known commercial/industrial study to include weather and seasonal factors is Williams and Suh (1986). Citing that water demand for commercial and industrial classes was both similar in many regards and unlike residential demand, Williams and Suh (1986) posited that aggregate residential demand was variously a function of marginal and average prices, the size of the customer class, per capita income, total rainfall during summer, average temperature during summer, population per square middle, value-added (industrial only), and receipts in establishments of selected services. The commercial specification included the average summer temperature. However, while no justification was made by Williams and Suh (1986) for its inclusion, it did turn out to be significant in the final estimation results.

3.4. Data and sampling frequency

The availability (or rather acute lack) of accurate data at an appropriate frequency has plagued attempts at modelling both residential and commercial and industrial water demand. In theory, estimating water demand functions with unit level data would be the most valuable, especially over time. But while many researchers advocate the use of, say, 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, Renwick and Archibald (1998) used stratified random sampling of surveys.

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)]. This is especially the case with the small number of studies on commercial and industrial water demand [see, Babin *et al.* (1982), Williams and Suh (1986), Renzetti (1988; 1992; 2001) and Reynaud (2003)]. 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 firm output, size, industry, 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)].

3.5. 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-Espineira (2003b). Lastly, many techniques normally reserved for cross-sections 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-Espineira 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.

4. A PROPOSED RESEARCH APPROACH

In terms of the small number of studies concerned with commercial and industrial water demand there are three main findings. First, the price elasticities of demand for commercial water are substantially higher than either residential or industrial uses. This suggests that the commercial demand for water is potentially more price responsive and may thereby indicate opportunities for substitutability between differing qualities of water, including recycling. Second, the output elasticity of both industrial and commercial uses is close to elastic, suggesting that a substantial factor accounting for increases in water usage is the growth of output with water demand increasing proportionately with output. Finally, the most significant challenge to existing studies of commercial and industrial price elasticities of water demand is the continued reliance on aggregate data compiled at the jurisdictional or utility level. For the most part, this has meant that studies have not strictly followed the position of water as a factor input and have therefore not considered the important role of output and output prices and the relative prices of complementary and substitutable factor inputs, including recycling and water efficiency improving technology.

A major decision to be made is whether focus will lie solely on water intake by commercial and industrial users, or a broader conceptualisation of water using technology by including trade waste (wastewater discharged from commercial and industrial activities) and sewerage services. Including these services (and their prices) will provide a more accurate description of the water technology used in commercial enterprises and the interrelationships between intake, discharge and recycling, etc. However, the data requirements are much more demanding.

Two possible alternatives for commercial and industrial water demand modelling are then available. The first approach is closest to the notion of commercial water use as a derived demand as presented in Section 2. The basic assumption is that commercial firms seek to minimise their costs (including the cost of water) at some chosen level of output subject to the relative prices of their factor inputs (including water). Accordingly, the following information for each commercial user is required to estimate the cost function:

- Total costs —this would include all water and non-water costs (typically labour and capital).

- Input prices —price of water, being the tabled marginal or average water usage charge per kilolitre. The price of labour and capital could be obtained from industry averages or for labour, wage and salary expenditures divided by total costs, and for capital, capital-related expenditures divided by total assets.
- Outputs —user output could be potentially specified in a number of ways, including physical output, number of customers, value-added, revenue, production units, etc.
- Other characteristics —a number of additional explanatory parameters could be added, and these potentially include year identifiers for use in balanced and unbalanced panel data models, location identifiers, industry type and so on.

While it is obvious that that this approach would yield the most accurate price elasticity estimates, the data requirements are demanding and unlikely to be satisfied with the information available from most water providers. For example, the basic user information would need to be supplemented by questionnaires direct to commercial and industrial businesses and an expectedly low response rate and/or incomplete or misleading responses would substantially reduce the accuracy of the specification.

The second alternative is to specify the demand equation directly using, say, a Cobb-Douglas production function. The following information would be required:

- Quantity of water consumed —in kilolitres per quarter or year.
- Price of water —being the tabled marginal or average water usage charge per kilolitre.
- Other characteristics —additional explanatory parameters could again be added, and these potentially include year identifiers for use in balanced and unbalanced panel data models, location identifiers, industry type and so on.

While this form is much less demanding it suffers from several restrictions. First, as no variable representative of the prices of the other inputs is included, they are assumed constant in the short run. However, this may not be an unreasonable assumption with the use of quarterly data or where it is believed that the cross-elasticities of substitution between water and other inputs is very low (as with residential water demand). Second, it is not clear what measure could be used to scale water usage that varies according to the size of a commercial/industrial user. In the cost function approach, this is achieved through the inclusion of output in the forms of the dollar value of revenue or value-added, the quantity of output, or the number of employees or customers. In residential demand modelling, this is often done on a household basis (where the range of household sizes is relatively small) or on a per capita basis. On a commercial and industrial basis, there are two possibilities using the available data. One is to allow the constant term to account for misspecification; the second is to divide users in groups according to the volume of use.

Starting with the dependent variable, the quantity of water demanded (in point of fact, consumed) can be measured at the commercial user level via user metering. The first independent variable specified is the marginal price of water. A key feature of commercial water demand modelling is the pricing structure and a variety of alternative forms have been employed. As discussed, different pricing structures and pipe sizes can complicate the calculation of a marginal price, as reflected by the variation in pricing specification in the literature. Where a flat rate pricing structure is not in place, the simplest approach would be to use the charge on water usage as the marginal price, however, a Nordin-style price adjustment is also possible.

The second independent variable is lagged consumption for each commercial user. In the case of water consumption, it is reasonable to assume that the current period's water use will be related to the previous period. Therefore, the inclusion of the previous quarter's consumption should capture any unobservable determinants, including past changes in water-saving behaviour and technology. By including a lagged term for consumption, the model is effectively estimating the long-run price elasticity. Several other independent variables can then potentially be included. Depending on the scope of the project required these could include variables identifying water restrictions and the presence of a Water Management Action Plan, weather and seasonal factors, geographic and industry identifiers, etc.

5. CONCLUSION

The aim of this paper was to review the theory and practice of commercial and industrial water demand estimation, of which the principal purpose is to obtain price and output elasticities of demand for a range of important business and policy purposes. To start with, and as discussed, the major theoretical complication arising with the estimation of commercial and industrial price elasticities of water demand is that it is a derived demand arising from the production process of the user and therefore intrinsically tied with cost minimisation and factor input substitutability. Accordingly, while residential water demand estimation can provide some insights, the approach needed fundamentally differs and has substantially more demanding informational and modelling requirements. This at least partly accounts for the very small number of studies worldwide that have modelled commercial and industrial water demand.

In terms of the small number of empirical studies concerned with industrial and commercial water demand estimation there are two main findings. First, the price elasticities of demand for commercial and industrial water are substantially higher than residential uses. This suggests that the commercial and industrial demand for water is potentially more price responsive and may thereby indicate opportunities for substitutability between differing qualities of water, including recycling. Second, the output elasticity of both industrial and commercial uses is close to

elastic suggesting that a substantial factor accounting for increases in water usage is the growth of output with water demand increasing proportionately with output.

However, the most significant challenge to existing studies of commercial and industrial price elasticities of water demand is the continued reliance on aggregate data compiled at the utility level. For the most part, this has meant that studies have not strictly followed the position of water as a factor input and have therefore not considered the important role of output and output prices and the relative prices of complementary and substitutable factor inputs, including recycling and water efficiency-improving technology. As a means of resolving this deficit, this paper proposes two alternative modelling approaches each with different informational and modelling requirements that may assist future researchers in designing the most theoretically and empirically appropriate framework for estimating commercial and industrial water demand.

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