Literature Review of Water Demand

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Abstract— ***The field of water demand analysis is becoming increasingly important, due to the problems that water utilities are faced with, when supplying the constantly increasing water quantities. This review paper starts with an introduction to water demand modeling and continues with the specification of the demand models and variables used. Also, effects of non-price policies and technology changes are reviewed.***

1. *Introduction: Demand Modeling*

With the increase in worldwide water demand over the last few decades, water utilities face problems of supplying the quantity of demanded water. Water pricing, together with other options, showed to be an efficient tool in controlling water consumption. Many studies have researched the influence of pricing. The journals "Land Economics" and "Water Resources Research" have dedicated much space to this study.

A number of the studies were influenced by or used previous research developed in the study of electricity demand (i.e. Taylor 1975, Nordin 1976). Most of the studies are regression models based on data collected during various surveys, in regions where water prices increased.

In a large number of water demand studies, there are many different approaches. There is no consensus on the correct method to predict the demand for water. This is in part influenced by the fact that every region has its own characteristics regarding water use and socio-economic influences. Most studies find that household characteristics, water prices, climate and seasonal changes and conservation campaigns influence price elasticity.

Water demand studies started in the 1960 and 70s mainly in the USA. In the 1980s, the number of studies increased significantly, mostly encountering regression models based on various data sets in water scarce areas of the US. In the 1990s, conservation methods and water efficient technologies received more attention. Also, a number of studies were done in European and other countries. In addition, some new methods were investigated in order to predict the water demand.

This literature review presents specifications of the models, variables used, technology changes, non-price policies, and some new studies in this field that differ from earlier research.

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2. *Models Specification*

2.1 Form

Most of the demand models are regression models. They typically use the form Q = f (P, Z) where P are the price variables and Z are factors such as income, household characteristics, weather, etc (Arbues et al. 2003). The most common forms are linear and logarithmic. There is no agreement about which functional form gives better results. Some researchers specify the form by seeing which model better fits their data set. Billing and Agthe (1980) cite that the elasticity in the log model is more useful if the demand is a rectangular parabola, while the elasticity in the linear form is more useful if water demand is linear over a relevant range.

The main flaw that researchers attribute to the linear model is that at some price, the demand for water will be zero, which is not logical as a minimum level of water consumption is needed to survive (Arbues et al, 2003).

2.2 Estimation methods

Different estimation methods are used in the studies. The most common are Ordinary Least Squares (OLS), Two and Three -Stage Least Squares (2SLS, 3SLS), and Maximum Likelihood. The choice of the method is somewhat influenced by the data set that the researcher possesses.

2.3 Data sets

A number of different datasets have been used, ranging from individual household data to aggregate data. A number of the studies used surveys conducted on a sample of households (Rizaiza 1991, Dandy et al. 1997, Renwick and Archibald 1998), other researchers used surveys conducted by the American Waterworks Association (Nieswiadomy - 1984 survey, Foster and Beattie – 1960 survey).

Researches used cross-sectional data (Foster and Beattie 1979, Chicione and Ramammurthy 1986, etc.), times- series data (Billings 1982), and most commonly cross-sectional-times series data (Nieswiadomy and Molina 1989, Renwick and Archibald 1998, Chicione and Ramamurthy 1986, etc.). Some models include lagged consumption in their models (Dandy et al. 1997, Nieswiadomy and Molina 1991). The Dynamic model, with an included lagged consumption, is used because water use tends to respond slowly to changes in price and other variables, because water-using durables, like washing machines, swimming pools, etc. tend to change only steadily (Dandy et al. 1997).

3. VARIABLES

3.1. Household characteristics

Household characteristics are an important factor influencing water demand. All studies include monthly household income as a significant variable that increases water demand. In the deficiency of income data, some demand models use property value as an alternative (Dandy et al 1997).

A number of researchers include lot size as a significant variable (Renwick et al 1998; Dandy et al 1997; Lyman 1992, etc.). Houses with larger lot sizes are expected to have larger outdoor water use (Renwick and Green 1998). Also, household size was frequently used in the demand equation (Nieswiadomy 1992, Renwick et al 1998, Dandy 1997 etc.) as having significant influence on demand. Density of households (Foster, Renwick 1998; Nauges 2000), the number of faucets and age distribution of household members (Lyman1992) are used in some studies too. Table 1 presents income and household size elasticities found in some water demand studies.

3.2. Price Variables

The most common question in the water demand literature is whether the average price or the marginal price combined with the difference variable should be used as the price variable in the demand equation. Although it has been the subject of a thorough debate in the literature, a consensus has not been reached yet.

The Debate: Howe and Linawever (1967) cited that using the marginal price alone will have invalid results in the presence of block tariffs. Taylor (1975) suggested an alternative method by including two price-related variables in the estimating model, when block rates are applied. Nordin (1976) modified it, citing that the second price variable should be the difference between the consumers actual bill and what would be paid if all units were purchased at the marginal price (in the case of a declining block tariffs for electricity). Billings and Agthe (1980) implement the difference variable under increasing block tariffs for water demand, showing that it is correct and statistically significant. Economic theory suggests that the coefficients in front of the difference variable and income variables should be the same magnitude, but with opposite signs. However, empirical evidence shows that the coefficient on income and difference should have different signs, but with a bigger coefficient in front of the income variable.

Billings and Agthe (1980, 1982) argue that the use of the average price will generate bigger elasticities when a block pricing schedule is implied, especially when the marginal price increases, while the intra-marginal rates remain the same. In this case the change in marginal price is greater than the change in average price. A possible situation is that with an increase in MP, the AP remains constant or even decreases. Billings and Agthe (1980, 1982) also cite that the effect of a change in rates may have different effects on water use; the use of average price alone ignores this, and produces less accurate results

In many recent studies on water demand, the MP combined with the difference variable is used to show price elasticities (Renwick and Archibald (1998); Renwick, Green, and McCorkle (1998); Dandy, Nguyen, and Davies (1997); Nieswiadomy and Molina (1989)).

However, many earlier studies use the average price (Wong 1972, Young 1973, Foster and Beattie 1979). In their studies Foster and Beattie (1981) recognize that the Nordin specification (the use of MP and difference variable) was not significantly different that the average price specification. They also emphasize questions regarding the knowledge that consumers have on their MP and the way of block pricing and if their reaction is actually set according to the average price.

Shin (1985) constructed a price perception model for electricity demand that describes the response of consumers to MP or AP. He cited that the average consumer does not know the actual rate schedule. Nieswiadomy (1992) gives reasons supporting the average price variable because of the difficulty of determining the actual water usage during the month, as water meters are difficult to read. In addition he cites the difficulty of knowing when blocks have been switched and the fact sewer charges can confuse the consumer.

Shin (1985) defines the price perception parameter as $P^* = MP\ (AP/MP)\ k$, where k is the price perception parameter. Thus, if $k = 0$ the consumer responds only to the MP, if $k = 1$ then the consumer responds only to the average price. If $0 < k < 1$ then the price perceived is between AP and MP. Shin finds that electricity consumers react to average prices in his study. Nieswiadomy (1992) tests the Shin model for water demand. His results indicate that consumers react more to average prices than to marginal prices; k is approximately equal to 1 (although in his 1991 study he found that consumers react to marginal prices)

Opaluch (1982) also suggests a test concerning the measure of the price to which consumers respond, for a two block tariff schedule. The hypothesis was conducted through a thorough utility theoretical framework by Opaluch (1981). He suggests a demand equation:

$$Q = B_3 + B_1 \cdot P_x + B_2 \cdot P_2 + B_3 \cdot \left(\frac{(P_1 - P_2) \cdot Q_1}{Q} \right) + B_4 \cdot \left(Y - (P_1 - P_2) \cdot Q_1 \right)$$

where:

Q – total purchases of the goods subject to block pricing

Px – price index for other relevant goods

P1 – price of Q in the first block

Q1 – quantity of the good which is subject to the initial block pricing (P1)

Y – total income of the consumer

The average price is

$$AP = \frac{P_1 \cdot Q_1 + P_2 \cdot (Q - Q_1)}{Q} = P_2 + \frac{(P_1 - P_2) \cdot Q_1}{Q}$$

If the consumers react to the block tariff schedule, then B3 = 0, and the demand equation reduces to Nordin's specification. If the consumers react to the average price, B2 = B3 the equation uses average price as a variable.

The Conclusion: A number of studies accept the idea that the preferences between different price specifications are influenced by empirical rather then theoretical factors. Foster and Beattie (1979, 1981) state that the price schedule that consumers react to should be a subject for testing with available data. Basically, if the consumers think the water bill is significant, they will put in the effort to learn about the pricing schedule and their exact consumption and marginal price. Otherwise, where the water bill represents a small percentage of income, the consumer will react to the average price (Nieswiadomy 1992, Shin 1985)

A review of accounted price elasticities and price variables used in various studies are presented on Table 2.

Most researchers found that seasonal changes and climates influence water consumption. However, they used different variables. Billings et al. (1980,1982) use evapotranspiration from Bermuda grass minus rainfall, Dandy et al. (1997) use moisture deficit (MD = PE-0.6R, where 0.6R = effective rainfall, MD = moisture deficit, but only for the summer demand), Foster and Beattie (1981) use precipitation during growing season, Ajadi et al (2003) used rainfall, while Nieswiadomy and Molina (1991) used weather as a variable.

A Number of studies also use temperature in their models (Nieswiadomy, Renwick et al., Riaza, etc.). Renwick et al. (1998) included the influence of temperature and rainfall in their water demand model. Following Chesnutt and Mcspadden, they present two equations for influences that temperature and climate have on demand. To include the influence of seasonality these equations used sine and cosine Fourier series for the maximum daily air temp (eq. 1) and cumulative monthly precipitation (eq. 2). These values are then included into the demand equation.

(1)

$$\ln(DTEMP) = \gamma_0 + \sum_{1}^{6} \left\{ \gamma_{1,j}^{tp} \cdot \sin\left(\frac{2\pi jt}{12}\right) + \gamma_{2,j} \cdot \cos\left(\frac{2\pi jt}{12}\right) \right\} + e_{it}^{tp}$$

(2)

$$\ln(DPREC) = \gamma_0 + \sum_{1}^{6} \left\{ \gamma_{1,j}^{pr} \cdot \sin\left(\frac{2\pi jt}{12}\right) + \gamma_{2,j} \cdot \cos\left(\frac{2\pi jt}{12}\right) \right\} + e_{it}^{pr}$$

A number of studies found that summer demand is more elastic to price increase than is winter demand (Lyman 1992, Dandy et al. 1997, Griffin and Chang, etc.). Dandy used seasonal models (winter and summer) in his studies. Also studies have found that outdoor water use is more elastic than indoor.

Nieswiadomy cites that in a log-log model temperature has a nonlinear relationship with demand; the marginal impact of temperature goes up with increases of temperature; he also cites that variations of temperature below 18C have no impact on water demand.

4. *Effects of Non-Price Policy on Household Demand*

Previous studies have shown that non-price policies reduce demand. Renwick and Green (1998) showed that non-price Demand side Management (DSM) policy instrumnets have influence on demand. In their demand equation they included six variables: Public information campaigns (INFO), distribution of free retrofit kits (RETRO), low-flow toilet rebate programs (REBATE), water rationing policies (RATION), water use restrictions (RESTRICT), compliance affirmation policy (COMPLY).

In their study of California Water agencies they find that policies reduce water demand by the percentage presented in table 3.

Table 1: Influence of non-price policies

Variable	% or reduction
INFO	8%
RETRO	9%
RATION	19%
RESTRICT	29%
COMPLY	Not significant
REBATE	Not significant

Logically, more obligatory policies reduce demand for water more than voluntary policies. As the authors conclude, the outcome is influenced by the quality of the implementation of these policies.

Nieswiadomy (1992), using experience in Tucson cites that a campaign is successful in decreasing demand only for a few years. Yet, after a few years use increases back to its previous level. He cites that only a major public campaign accompanied with a price increase will have success in the long run. Nieswiadomy also suggests that education programs will probably have more effect in water scarce regions, because of the awareness of water scarcity.

5. INFLUENCE OF TECHNOLOGICAL CHANGE ON THE DEMAND FOR WATER

Influence of technology changes only recently became evident. Renwick and Archibald (1998) found that increasing the number of low flow toilets in a household by one would decreases household demand by 10%, while Chesnutt et al. (1992) found that it would decrease the demand by 11%.

Regarding the efficiency of low flow showerheads, the next elasticities were perceived:

Table 1: Elasticities of low-flow showerheads

Renwick and Archibald	Whitcomb	Chesnutt and McSpadden
8%	6.4 -9.7 %	2%

Low flow toilets and showerheads reduce water by having more efficient technologies and insure significant long term demand reduction with no required changes in the behavior of consumers (Renwick and Archibald 1998). In the same study, they perceive that the elasticity for adoptions of water efficient irrigation technologies for low and high density households is 31 and 10 percent, respectively.

Nieswiadomy warns that even if a water efficient device is installed, the consumer may react by using more water knowing about the conservation effect of the device, therefore offsetting the conservation impact of the device.

Agthe and Billings studied effects that would make consumers install water efficient technologies in individual households and apartments. They found that obligations to save money, income, household size and summer marginal prices effected the decision.

6. RECENT STUDIES

6.1. Maximum-Likelihood Models

Recently, maximum-likelihood models were used to predict price elasticity (Hewitt and Hanemann (1995), Pint (1999), etc.). Maximum-likehood models were previously applied in the labor supply literature. These two models are specified in a two-stage framework, they are based on likelihood functions that show the probability that a household will choose a particular block, in a discrete way, combined with the probability of its particular level of use in the chosen block, in a continuous way. Hewitt (1993) presented three different maximum-likelihood models: the heterogeneous-preference model, the error perception model and the two-error model. The models are structured based on the assumed source of error in estimating household demand. These errors can be errors in data, missing variables or errors in the household's actual consumption relative to its intended consumption. The models directly allow both economic and non-economic influences, they cite that variation in behavior is due to both price and income and influences represented by various socio-demographic variables (Pint 1999).

However, Hewitt and Hanemann using the two-error model got higher elasticities than in previous studies (-1.6), while Pint pointed out that elasticity is bigger in the two-error model (-0.2 to -1.24) than in the heterogeneous - preferences model (-0.04 to -0.29), concluding that the two models might be upper and lower bounds on the estimates for elasticity of demand for water. Also, they mention that these models are very costly to estimate, since they require a large number of socio-demographic observations and have complex non-linear functions.

6.2. Stone–Geary Form

A few authors used the Stone-Geary form to predict water demand and price elasticity (Matinez-Espineira and Nauges 2004, Gaudin et al 2001, Al-Qunaibet et al 1985). The function has already been used for food products, durable goods, transportation, and energy. Gaudin et al.(2001) propose this form because it includes a quantity of water that does not respond to price, allows elasticity to decrease as the price increases, and uses only two parameters (□ and □) for each good. □ is defined as a threshold below which water consumption is not affected by prices, while □ is the preference variable. Basically, "The consumer is faced with a given level of income and set of prices. The consumers first purchases a minimum acceptable level of each good (the $□_i$'s) and then portions of each good, for their leftover income, according to their preference parameter (the $□_i$'s)" (Gaudin et al. 2001) Gaudin present the next form:

$$Q_w = \gamma_w + \beta \cdot \frac{I^* - P_w \cdot \gamma_w - \gamma_z}{P_w}$$

where I and P are income and price. SGE (γ,β) are linear combinations of exogenous variables. So, the equation for non-constant γ and β in the Gaudin et al (2001) study is:

$\beta_w = (\beta_0+\beta_1 C+\beta_2 SP+\beta_3 APP)$ and

$\gamma_w = \alpha o+\alpha_1 C+\alpha_2 SP+\alpha_3 AAP$

(γ_z was excluded from the model, as insignificant to the study)

Where C – days with rainfall; SP – Spanish population; AAP –average annual precipitation)

Gaudin et al (2001) found summer elasticities bigger than winter elasticities, and that more than half of the water demand does not respond to price increase.

Table 2: Elasticities in studies that use the Stone-Geary Form

Author	Study area	Price elasticity	Income Elasticity
Gaudin et al. (2001)	Texas	0.19-0.28	
Martinez-Espineira and Nauges (2004)	Spain	-0.1	0.1
Al-Quinaibet and Johnston (1985)	Kuwait	-0.77	0.211

6.3. Meta-analysis

Meta-analysis is the use of statistical techniques in a systematic review with a purpose of integrating the results of the included studies. Espey et al. (1997) using meta-analysis studied the factors that affect price elasticity estimates in recent studies in the USA. They tried to explain differences in elasticity using differences in inclusion of variables in the regression models. They found that long-run estimates are more elastic to than short-run estimates; that the inclusion of income, population density, household size, temperature, and seasonable variable do not influence the price elasticity even though they influence the demand; also that evapotranspiration rates, pricing structure (increasing block rates were found to be much more elastic), rainfall and the season influence the elasticity. Also, summer elasticity was found to be bigger than winter elasticity.

Dalhuisen et al. (2003) in their meta-analysis study found that moderately high price elasticities and reasonably low income elasticities are found in studies with increasing block rates. Also, they find that the absolute magnitudes of price and income elasticities are greater for areas with high income, that price elasticities in Europe are bigger than in the US and that elasticities do not change with the date of the study, in other words they did not find differences in elasticities of earlier and more recent studies.

CONCLUSION

Studies in water demand prediction and elasticity have come up with a wide range of results. These studies have been conducted using different datasets, regression methods, price increases and variables, that alter the results. Consequently, some correlation parameters have been empirically proven. However, water demand and price elasticity are, no doubt, influenced by local conditions and socio- economic variables. A consensus has not been reached regarding the best methods to predict demand and elasticity. Most researches conclude that more studies have to be done in water demand.

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Author	Study area	Model	Income elasticity	Household size
Hewitt and Hanemann	Texas	D/C	0.15	
Renwick, Archibald 1998	California	Linear	0.36	
Dandy et al 1997*	Australia	Linear	SR: 0.14 | LR: 0.32-0.38	SR 0.04; LR 0.19
Griffin et al(1990)	Texas	Linear	0.3-0.48	

*Dandy et al. in his annual model used property value as an indicator of income (SR –short range; LR – Long range)

Table 3: Income and household size elasticity from various studies

Authors		Study area	Price variable	Price Elasticity
Howe and Linaweaver (1967)		USA	AP	-0.23
Gibbs (1978)		Miami, Florida		-0.51
Foster and Beattie (1980)	Exponential	USA	AP	-0.35 to -0.76
Billings (1982)	Lin/Log	Tucson, Arizona	MP & D	-0.66/-0.56
Schefter and David (1985)		Wisconsin		-0.12
Chicoine et al. (1986)		Illinois		-0.71
Chicoine and Ramamurthy (1986)	Linear	Illinois	MP (AP)	-0.6 on MP
Nieswiadomy and Molina (1989)	Linear	Denton, Texas	MP & D	-0.86
Griffin and Chang (1990)	Linear	USA	AP	-0.16 to -0.37
Riazaiza (1991)	Logarithmic	Saudi Arabia	AP	-0.4 to -0.78
Hansen (1996)		Copenhagen, Denmark		-0.10
Renwick and Archibald (1997)	Linear	California	MP & D	-0.33
Hoglund (1997)	Linear	Sweden	MP & AP	-0.20 on AP
Dandi et al. (1997)	Linear	Australia	MP & D	-0.63 to -0.77
Renwick, Green, McCorkle (1998)	Logarithmic	California	MP & D	-0.16 to -0.21
Nauges and Thomas (2000)	Linear	France	AP (&MP)	-0.22
Ayadi et al.(2003)	Logarithmic	Tunisia	AP	-0.17

Table 4: Summary of price elasticities in some studies of residential water demand