CHAPTER 5: A REVIEW OF STUDIES AND METHODOLOGIES TO ESTIMATE URBAN WATER DEMAND

5.1 Introduction

This chapter introduces the concept of price elasticity of demand for water and reviews a number of domestic water demand studies used to determine the price responsiveness of consumers. Interestingly, the majority of these studies refer to the 'price' of water underpinning, which a number of neoclassical assumptions are made. However, Gildenhuys (1997), states that some services are supplied by the government sector directly to the public sector by means of direct exchange, thereby foregoing the traditional transaction process directed by a price-quantity relationship. This implies that a relationship of "free contracting" exists, whereby the consumer (buyer) purchases a service "according to personal taste, need, preference and wealth", for which, correctly termed, "a user charge, consumer tariff or levy" is paid. Hence, the use of price in this and most of the reviewed studies refers not to a market price, determined under the premises of free trade but rather to the supply charges and tariffs imposed by a service provider, for these purposes, a water utility. Based on the interpretation of the outcomes of the studies reviewed, the methodology for this study is described, including the type of relevant variables and the form of the models to be used to estimate water demand in the case study area.

5.2 Price responsiveness of demand

Price elasticities of demand provide a measure of responsiveness in a standardised unit namely elasticity. The numerical values of elasticities can vary from zero (inelastic) to infinity (elastic). Price elasticities of demand are commonly represented by a negative sign, as demand curves slope downwards, changes in quantity associated with price tend to have the opposite sign to the change in price. However, elasticties can be reported without their respective signs in order to make the interpretation of the effects of price change on behaviour simpler. Without the sign, the interpreter can simply deduce that the larger the elasticity, the greater the responsiveness of quantity demanded to price. When the sign is retained, this interpretation will differ and the smaller the elasticity, the greater the responsiveness will be to changes in price. It is also important to understand that elasticties measure the changes in the quantity *demanded* by a consumer or household to the changes in price and not changes in the quantity of the good as a whole (Begg et al, 1991; Varian, 1996; selected articles on elasticity)

Defined as the ratio of the percentage change in quantity demanded to the percentage change in price, the price elasticity of demand provides an indication of the potential effectiveness of policy changes in price for particular commodities. Formulated in either of two ways:

$$\varepsilon_p = \frac{\Delta q/q}{\Delta p/p} = \frac{\%\Delta q}{\%\Delta p} \quad (5\text{-}1)$$

$$\varepsilon_p = \frac{p}{q} \times \frac{\Delta q}{\Delta p} \quad (5\text{-}2)$$

the value of ε (elasticity) changes along the slope of the demand curve and is usually negative in sign. Functional forms further impact on the nature of the elasticity; a linear demand curve reflects a different elasticity at each point while the cobb-douglas form has a constant elasticity. Elasticity proves to be a valuable measure in evaluating demand projection analysis for water-supply systems that aim to achieve at least some level of financial solvency. Both income and price elasticities may be derived.

Water utilities faced with rapidly growing water demands are looking to water demand management in order to address these pressures. One demand management strategy that is being widely investigated is that of pricing and the implied shifts in water rate structures, although these approaches are frequently implemented within the framework of education and conservation practices (Nieswiadomy, 1992). Due to the mounting emphasis on the role of pricing in water demand management a number of studies are focusing on measures of the responsiveness of demand to these pricing changes as a view to determine whether price could effectively curtail demand for water. The following literature reviews some of these studies and their elasticity results.

5.3 A review of water demand literature

This section reviews twenty water demand studies. These include studies based on cross-sectional data and those based on time-series data. Long-run and short-run elasticities are estimated, with most of the studies indicating that price elasticities for domestic water use become more elastic over time, as consumers have time to adjust their consumption patterns. Domestic demand, industrial demand, commercial demand and water for sprinkling or outdoor use are all reviewed. Income elasticities for many of the studies are also determined. The results and studies are summarised in (table 5-1) below.

Table 5-1: Research results for 20 studies on income and price elasticities for water demand

Study	Region	Year	Price Elasticities	Income Elasticities
Howe et al.	USA, 35 study areas – cross-sectional	1967	D[8]: –0.23 S[9]: -0.7 to – 0.16	D: 0.35 S: 0.4 to 1.5
Turnovsky	US,19 Massachusetts towns – cross-sectional data	1969	D: -0.3 I[10]: -0.5	-
Wong	Chicago: time series (1951-1961) Four community size groups: cross-sectional	1972	D: -0.02 to –0.28 D: -0.26 to –0.82	0.20 to 0.26 0.48 to 1.03
Young	Tucson, Arizona Time series	1973	D: -0.63 to –0.41	-
Dockel & Groenewald	Witwatersrand, RSA Cross-sectional data	1973	D: -0.63 to –0.84	-
Katzman	Penang Island – Malaysia Time series	1977	D: -0.1 to –0.2	0.24 to 0.30 0.32 to 0.39
Lynne et al	Miami, Florida Derived demand model	1978	C[11]: - 0.174	-
Gibbs, K.C.	USA – Miami, Florida	1978	AP[12]: - 0.62 MP[13]: - 0.51	-
Foster & Beattie	USA Generalised model	1979	D: -0.35 to –0.76	-
Billings & Agthe	Tuscon, Arizona	1980	LR: -0.27 to –0.49 Di: -0.12 to –0.14	-
Agthe & Billings	Tuscon, Arizona	1980	SR: -0.12 to –2.22 LR: -0.27 to –0.49 Di[14]: -0.12 to –0.15	-
Carver & Boland	Washington D.C metropolitan, Pooled time series and cross-sectional	1980	SR[15]: < [0.1] LR[16]: -0.2 to –0.7	-
Howe	Hopkins residential water use data	1982	D: -0.52 to –0.86	-
Hanke & De Mare	Malmo, Sweden, Pooled time series cross section	1982	D: -0.15	-
Chicoine & Ramamurthy	Illinois rural water districts, average price model	1986	MP: -0.61 2nd P variable: -1.02	-
Thomas & Syme	Perth, Australia, Contingent valuation	1988	D: -0.2	-
Hewitt & Hanemann	Texas, USA Household level panel data ('81 to '85)	1995	D: -0.57 to –0.63	0.15 to 0.16
Hansen	Copenhagen Pooled time-series data	1996	D: -0.003 to –0.1	CR[17]: -0.2
Nieswiadomy, M.L.	USA – Four regions	1992	AP: –0.22 to –0.6 MP:-0.11 to –0.17 PP[15]: -0.29 to –0.45	0.28-0.44
Veck & Bill	Thokoza, RSA Contingent Valuation Method	2000	D: -0.12 to –0.14 S: -0.19 to –0.47 Average: -0.14 to -0.18	-

Source: Own compilation

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[8] D = Domestic use
[9] S = Sprinkling use
[10] I = Industrial demand for water
[10] C = Commercial demand for water
[12] AP = Average price model
[13] MP = Marginal price model
[13] Di = Difference elasticity
[14] PP = Perceived price model
[15] SR = Short run
[16] LR = Long run
[17] CR = Cross-price elasticity

5.3.1 Demand models using cross-sectional analysis

Gibbs, (1978), reviewed the use of certain price variables in residential water demand models, namely, marginal price and average price. Data was gathered from a large metropolitan area, Miami, Florida and used to form an empirical comparison of the two price formulations. Three hundred and fifty-five households were selected from which 1412 consumption and price observations were pooled. Seasonal residential water demand functions were estimated with the dependent variable in log form. Price and income elasticities were allowed to vary along the demand curve in response to the hypothesis that responses to price 'become more relevant as the price of water approaches a more significant portion of the consumers budget.' A marginal price demand equation was estimated. Further regression equations were also estimated to account for variables such as home value, the number of dishwashers and washing machines, number of bathrooms and residential acreage for income. The results based on the first two equations found that the responsiveness to price was overstated in the average price model, similarly the response to income changes was too. Furthermore, the average price equation was found to understate consumption response to the hot water heat variable and overstate the response on persons per household variable. Gibbs (1978) advised that the marginal price was the more appropriate price to use when defining price variables for estimating water demand models.

Similarly to Gibbs (1978), Nieswiadomy (1992), estimated urban residential water demand for four regions in the United States (the North Central, North East, South and West) based on a national cross sectional data set, by using two models one for average price and one for marginal price. This approach was expanded by including the price perception model by Shin [1985] that accounts for the fact that it is costly and difficult for consumers to determine the actual rate structure to which they are responding. The price perception model includes the perception price (P*) and not average or marginal price. P* is calculated as a function of marginal price and average price adjusted for some price perception parameter k. Such that,

$$P^* = MP\,(AP / MP)^k$$

Nieswiadomy (1992) also included dummy variables for the effects of conservation practices and public education on water demand, recognising the importance of these aspects of water demand management and not just the implications of pricing. The Shin (1985) based model is as follows:

$$\ln Q = \beta_0 + \beta_1 \ln \text{Income} + \beta_2 \ln \text{MarginP} + \beta_2 K \ln (AP/MP) + \beta_3 \ln \text{Rainavg} + \beta_4 \ln \text{Tempavg} + \beta_5 \ln \text{Persons} + \beta_6 \ln \text{Home 1939} + \beta_7 \ln \text{Ownoccupation} + \beta_8 \text{Conservation} + \beta_9 \text{Public awareness}$$

The demand equations were estimated using a Box-Cox transformation indicating that a log-log model was an appropriate form to use. In order to test for heteroskedasticity as cross-sectional data was used, White's [1980] test was applied, indicating no heteroskedasticity. The overall results showed that variations in temperature below 18°c (65°F) had little or no impact on water demand. Analysis of the parameter k indicated that consumers reacted to average prices, however Nieswiadomy and Molina [1991] found that consumers reacted to marginal prices in increasing block structures and to average prices in decreasing block rate structures.

Howe and Linaweaver (1967), estimated the impact of price on residential water demand and its relation to system design and price structures by using cross-sectional data for the United States. The data set was further disaggregated, separating domestic and sprinkling uses, maximum day and peak hour demands, utility revenue and price structures, and economic and climatic characteristics. Thirty-nine study areas were selected and categorised into five areas by climatic conditions. Two functional forms of the water demand equations were estimated based on the premise that theory failed to specify a unique functional form for the purpose of the study. Both linear and cobb-douglas (multiplicative) functions were fitted. The price variable was one of marginal price calculated as the sum of the water price and water-based sewerage charges at the households actual position in the water rate structure, (Howe, 1982). The problem of a spurious demand curve was addressed and it was found that the demand curve for this study was not spurious. The results indicated that separate domestic demand equations should be used for metered and flat-rate areas. Population density appeared to be the only variable significantly affecting demand in the flat-rate and septic tank areas. Billing frequencies and the regional price index did not appear to significantly influence demand or price elasticities. The study was limited in its ability to provide information on the relative frequency or duration of 'extreme demands'. Further information on the cost structures of utilities was recommended before conclusions on optimum price structures are drawn. Information on the factors affecting these costs was limited. Further research (theoretically and empirically) on marginal cost impacts where excess capacity exists, and differences between the nature of short-run and long-run variable costs was recommended.

Turnovsky (1969), estimated demand functions for water where supplies were known to be stochastic. Separate functions were estimated for household and industrial demand. Cross-sectional data was used for 1962 and 1967 from nineteen Massachusetts towns in order to determine whether the response by consumers changed due to the drought that occurred during the intervening years. Ordinary least squares regression was used to estimate the equations. The variables included were supply variance in gal/day squared, included based on the nature of consumer theory where commodities are uncertain in supply, (Turnovsky 1968 and 1969); average price of water (metered revenue / metered gallons used); index of per capita housing space (average number of rooms per dwelling / median number of occupants per dwelling); percentage of population under 18; index of per capita industrial production; regressed against planned per capita consumption in gal/day.

$$\text{Domestic demand, } x_i = \alpha_0 + \alpha_1\sigma_1^2 + \alpha_2 p_i + \alpha_3 h_i + \alpha_4 P_i$$

$$\text{Industrial demand, } x_i = \beta_0 + \beta_1\sigma_1^2 + \beta_2 p_i + \beta_3 Ip_i$$

The models were based on the premise that households tended to use water according to their needs, these needs being derived demands determined by the number of water using appliances within a dwelling unit. Therefore, it was assumed that water use would be a function more closely related to measures of real estate than income flow. The results indicated that price, uncertainty measured by supply variance and dwelling space were significant variables for household demand, whereas dwelling space proved to be insignificant for industrial demand. Furthermore firms appeared to be more responsive to price changes and uncertainty than households as they tended to be more highly influenced by economic factors than households. The price elasticities for the variables were estimated at the mean values of the variables. This study indicated that substantial price and variance changes are required to bring about definite changes in consumption. Government rationing was proposed as a means to reduce domestic water use.

5.3.2 Demand models using time-series analysis

Referred to in a number of studies on demand elasticities, Wong (1972), aimed to solve the question of how price, income and average summer temperature affect water demand. Fifty-nine suburbs in the Chicago area were selected for the study. Two approaches were adopted, the first was a time series analysis of the area over the period 1951 to 1961, the second was a cross-sectional analysis of the 103 municipal supply systems stratified into groups by size: 25,000-over; 10,000-24,999; 5,000-9,999 and 4,999-less. For the time-series analysis, prices and income were deflated to 1961 constant dollars. For the cross-sectional analysis the temperature variable was omitted as it was found to be relatively uniform across the study region, thereby insignificantly influencing per capita water demand. Both temporal and spatial impacts on water consumption were investigated. Ordinary least squares multiple regression analysis was used to model average per capita water demand as a function of price per unit, average household income and average summer temperature. Substitutability between surface and ground water was considered zero and cross-effects were omitted. However, the 103 supply systems tended to be more dependent on ground water than surface water enabling a comparative analysis to be done between the two sources. A logarithmic model was used. The differences in elasticities indicated that for Chicago itself the responsiveness was small (inelastic) mainly due to the extremely low water rate, this rate however was higher for the outer lying suburbs as a result of higher distribution costs and greater distances from the supply source. The time series analysis appeared to suppress the magnitude of the income elasticity. The results further indicated that groundwater tended to be more price elastic than surface water sources and no distinction was made between short and long-run price elasticities as this study focussed more on the spatial effects of price and demand.

In response to the study done by Wong (1972); Young (1973), recognised the dirth of empirical work done using time series data. As a result, he studied the effects of population, price and income on the demand for municipal water supplies in Tucson, Arizona for the period 1946 to 1971, using time series analysis. Marginal value changes in water deliveries were not used due to a lack of sufficient data and average charge per 1000 gallons was used as the measure of price. This charge was then deflated using the consumer price index for 1968. Active service was used as a measure of population and a proxy for per capita income was 'defined in terms of retails sales per capita per unit time. Rainfall, temperature and evaporation measures were obtained from the local weather bureau. Ordinary least squares was used to estimate the model and the temperature, evaporation and income variables were omitted due to insignificant statistical results and hypothesis inconsistency. As a result, only average charge and rainfall, were included as explanatory variables. As seen in the study by Wong [1972] no distinction was made between short and long-run price elasticities.

Moving from the United States, Katzman (1977), estimated the income and price elasticities of demand for domestic water for Penang Island, Malaysia. Cross-sectional data from 1400 households was used to derive elasticities for low income (per capita income less than US$300) and higher income families. Time series data of a sub-sample of mixed income individuals was also used to estimate short-run price elasticities. Average water consumption was transcribed from the meter books and the households were divided into four categories: very poor (<US$600); poor (US$600 – 2000); middle (US$2000-3200) and rich (US$3200<). Average monthly consumption was regressed against income dummies; number of persons per household, disaggregated by age; urban versus rural residence; and ethnicity to account for cultural practices (these differences were however reduced to those of family size, income and location and were ignored). The income groups, the very poor and poor showed a marginal effect on water consumption due to income, this was not the case for higher income groups. Family size proved to be a major indicator for higher water consumption demands. Income elasticities of demand were estimated for the rural and urban income groups by dividing the percentage increase in consumption by the percentage increase in income. An increase in the water rate was evidenced during the period and was accounted for by grouping the urban and rural areas by neighbourhood and rate class. Due to the use of time series data, it was assumed that the effects of changes in technology and cultural practices were not accounted for, making the estimates short-run estimates. Another interesting feature of this study was that it used a different method to estimate price and income elasticities to those used previously. An 'economic demand projection model' was also derived based on growth in demand and not per capita consumption coefficients. It was found that demand projections incorporating elasticities tended to be more sensitive to policy changes than the traditional approaches.

Foster and Beattie (1979), presented a generalised Fourt[18]-type model allowing for the categorical effects due to regional and size-of-city differences on urban residential water demand for the United States of America. The model was based upon the neo-classical theory of consumer demand. The advantage of the model was that it allowed cities that were not atypical from those used in the model to use the parameter estimates in determining the effects of various policies, when demand was 'invariant' to city size. The model was applied to various functional forms with price in the exponential and all other explanatory variables in the power form. Dummy variables were then added in three steps: first for the constant factor; second for the constant factor and the price coefficient; and third for the former two and the income coefficients. Ordinary least squares was used to estimate the regression coefficients for 218 cities. The signs for the various coefficients were: negative for price; positive for income and number of residents; and negative for

[18] See Fourt, 1958.

rainfall. This study was able to account for changes in constant factor and price coefficients across regions by including the dummy variables for region.

5.3.3 Demand models redefined accounting for price structure variations

In order to explain the nature of advances in economic consumer behaviour theory with regard to price structures (increasing or decreasing block rates), Billings and Agthe (1980), used a model based on two price-related variables (marginal price and a difference variable) and an income variable to estimate the demand for water under block rate pricing or where service charges appeared in the rate schedule. Data for Tucson, Arizona, for the period 1974 to 1977 was used. The implicit signs expected for the difference coefficient of income was positive (water is a normal good) and for the price difference variable and marginal price variable, negative. However, where there were no block-rates the difference variable was expected to have a value of zero. Due to large inflationary changes during the study period both real values and nominal values of the variables were used, real values were adjusted by the consumer price index. Three functional forms were estimated namely, a linear model, a multiplicative model and a log transformation model from which direct elasticities were estimated. The results indicated that the estimations were free from serial correlation and that the estimates for price elasticities were stronger than previously found when only one price variable was included in the model.

In response to the limitations of former studies that aimed to analyse water demand using static models, Agthe and Billings (1980), recognised that current water use was strongly influenced by historical water use patterns. They used a dynamic model to estimate water demand and accounted for this relationship. Monthly residential demand for water in Tucson, Arizona, was estimated for the 1974 to 1977. The static, Fisher-Kaysen, Koyck, Bergstrom flow adjustment and stock adjustment econometric models were tested and the price elasticity of demand was estimated. Both marginal price and a second price related variable (*difference*) were used to account for block rates and fixed charges in the rate schedules (Taylor, 1975; Nordin, 1976; and Billings and Agthe, 1980). The Fisher-Kaysen model produced poor statistical results and was omitted, the linear flow adjustment model overestimated the short-run marginal price elasticity of demand for water, while the stock and logarithmic flow adjustment models indicated insignificant t values on some important variables. The linear and log versions of the Static and Koyck models however, showed strong statistical results for long-run price elasticities of water demand Furthermore the equal-in-magnitude-opposite-in-sign (EMOS) hypothesis referring to the income and *difference* coefficients was found to be untrue for magnitude but true for sign. Further research using different data sets and time-periods was proposed to resolve the inconsistencies indicated.

Using pooled time series and cross-sectional data, Carver and Boland (1980), estimated the short and long-run effects of price on municipal water use, thereby distinguishing between short and long-run responses. Pooled time series and cross-sectional data for the Washington D. C. metropolitan area were fitted to a flow adjustment model of the Nerlove (1958) type. Furthermore, a distinction was made between seasonal and non-seasonal water use, using dummy variables. The results showed that response changes to price for aggregate annual water use in the short-run were small falling below the absolute value of 0.1, while long-run responses tended to fall into the range of –0.2 to –0.7 (similar to the ranges found in other studies). Seasonal price elasticities, however, appeared to be much smaller than those previously estimated.

Using advances in consumer theory, Howe (1982) derived more appropriate household water demand functions that accounted for the effects of rate structures. Marginal price elasticities were re-estimated from the John Hopkins Residential Water Use Project data of 1963-1965 for the USA. The study stated that marginal price alone did not adequately reflect the effect on the consumer of various rate structures. Recognition of the inclusion of the 'difference variable' in demand functions as a superior approach to that of using average or marginal price was made. The value of D was also expected to be positive for decreasing block rate structures and positive for increasing block rate structures (Billings and Agathe, 1980). The revised models included the 'D' variable and changed the household demand variable to total household demand and not in-house and sprinkling use (this division was regarded as inappropriate due to the observation that household positioning on the rate schedule depended on total demand per billing period).

In response to the developments in consumer theory Schefter and David (1985), estimated residential water demand under multi-part tariffs using aggregate data. Their results indicated that mean marginal price and mean difference are the appropriate measures to use when working with aggregate data. It was proposed that more information on residential water demand be required in order to do estimations under multi-part tariffs. Further research on the form of water distribution across households and its variation as a function of rate structure was proposed.

In light of the continuing debate surrounding the use of marginal cost pricing and some difference variable (Nordin, 1976) versus the use of average cost pricing (Foster and Beattie, 1981), Opaluch (1982) proposed an hypothesis concerning the measure of price to which consumers responded. The results indicated that a proper model of consumer behaviour is a case specific empirical question.

Following the procedures outlined by Opaluch (1982), Chicoine and Ramamurthy (1986), used household level data from a sample of Illinois rural water district customers to test which price consumers responded too when potable water was sold under declining block-rate structures. The model employed was based on the utility maximising framework used by Opaluch (1982), an average price model with the price measure decomposed into a marginal price and a difference variable, applied to time-series and cross-sectional data. The results indicated that neither the marginal price nor the average price models were appropriate models of consumer behaviour as they inadequately explained consumer demand for rural domestic water. However, the decomposed measure of average price model proved to be the correct form for the Illinois rural water districts. Further research efforts on the versatility of this more general model along with the simultaneity issue (responsiveness to two pricing structures) were proposed.

5.3.4 Demand models using discrete and continuous choice specifications

Another specification of the demand model under block rate pricing was presented by Hewitt and Hanemann (1995), using a discrete and continuous choice model (D/C) approach to residential water demand. Based on the same data set used in the Nieswiadomy and Molina (1989) study of household level panel data for summer months from 1981 to 1985. Four estimations were run. The first three were regression estimations of the types: logarithmic form of the ordinary least squares (OLS); instrumental variables (IV); two-stage least squares (2SLS); and the fourth was the D/C choice model. The D/C model allowed the error term to be separated into a heterogeneous preferences error and a perception error. The former pertained to the econometrician and the latter pertained to the consuming household subsequent to decision-making. Therefore the demand for household water was estimated as a function of the price of water (p); household income and *difference* (y + d); sociodemographic variables (Z) and error terms (ε, η); where (δ, α, μ) were the unknown parameters of the utility function. The D/C model was based upon marginal prices and implied that households were aware of the price schedules they faced, making the debate over the use of average or marginal price irrelevant. The model was however, more costly than traditional models to run, in light of its strict specification assumptions.

5.3.5 Derived demand from a household production function

Unlike the previous studies on residential water demand, Hansen (1996) derived a demand function from a model of household production of final consumption goods including water, energy and other aggregate inputs. The estimation was run on pooled time-series data for the Copenhagen metropolitan area. Two production functions, one based on aggregate water dependent final consumption and the other on water independent final consumption were described. Through cost minimisation, a water demand function was derived from which marginal final good production costs were found. Differentiation of this function then yielded the components of price, income and weather effects that were estimated using four functional forms of the standard water model. They were the standard linear and log-linear, and the linear and log-linear sprinkler models (accounting for sprinkling water demand). Ordinary least squares estimations were run and the results indicated that residential water demand was generally income and water price inelastic and that meteorological variables also significantly influenced water demand.

The above-mentioned studies indicate that price elasticities for residential water demand vary considerably. Espey, Espey and Shaw (1997), used a meta-analysis to determine which factors systematically affected price elasticity estimates for residential water demand. The meta-analysis used empirical estimates from previous studies (price elasticities) and attempted to explain their variation by using 'inter-study differences as explanatory variables' such as: functional form, cross-sectional versus time-series data, price specification, rate structure, location and season. Twenty-four articles on price elasticity estimations for the United States were reviewed, yielding 124 estimates of price elasticities and 27 explanatory variables excluding the constant term. The results indicated that the evapotranspiration rate, rainfall, pricing structure and season had the most influential effects on the demand for residential water. Significant differences were also noted between short-run and long-run price responsiveness and between residential and commercial demand. Population density, household size and temperature did not however appear to significantly affect the price elasticities of water demand for the USA studies. It was noted that policy-makers would be advised to consider these aspects when selecting a particular study and its corresponding elasticity for decision-making.

5.3.6 Pricing policies and their impacts on elasticity results

In conjunction with consideration of the impacts of explanatory variables on the elasticity results yielded in many of the above-mentioned studies, the underlying pricing policies that direct the water management strategies in the respective countries and regions also need to be accounted for and assessed as they have direct implications for the specifications of the price variables in each study. The following table, table 5-2, outlines a number of related studies, their pricing policies and the resulting price elasticities of demand. Another aspect of interest is the wealth of respondents in relation to their responsiveness to price changes but due to information shortcomings, a review on wealth was not carried forward here.

The majority of studies fell into the three typically observed pricing structure categories, flat-rates, fixed rates and decreasing or increasing block rate pricing. Flat rates and fixed rates structures can be dealt with relatively simply in the modelling and one generally expects that consumers have a good understanding of the implications of water use for their bills at the end of each month, where metering takes place. Block rate pricing structures on the other hand are more complex to deal with in the modelling of water demand and consumers are often unaware of the impacts of these pricing structures on their final water bills, making them less responsive in the short-run to the price changes from one block to the next. These types of pricing structures also have the curious effect of leading to a positively signed price elasticity of demand when consumers a re faced with increasing block rate tariffs. This is simply explained by the increase in demand for water being met by an increase in the price of water as the consumer moves into the next pricing block. This effect is discussed in detail in chapter 7 with specific application to the Tshwane study. Interestingly, the price elasticity of demand results from the studies reviewed below seem to vary insignificantly with the different pricing policies and this may be due to the observation that on average they tend to face similar pricing structures.

Table 5-2: Pricing policies for different price elasticity of demand studies

Study	Region	Year	Pricing policies	Price Elasticities
Gibbs, K.C.	USA – Miami, Florida	1978	Mixed combinations of flat-rates for the first block of water consumed, fixed rates, and decreasing block rates	AP: - 0.62 MP: - 0.51
Nieswiadomy, M.L.	USA – Four regions	1992	Block price structures	AP: –0.22 to –0.6 MP:-0.11 to –0.17 PP: -0.29 to –0.45
Howe et al.	USA, 35 study areas – cross-sectional	1967	Metered and flat-rate based pricing	D: –0.23 S: -0.7 to – 0.16
Turnovsky	US,19 Massachusetts towns – cross-sectional data.	1969	Multiple rate structures	D: -0.3 I: -0.5

Table 5-2: Pricing policies for different price elasticity of demand studies continued

Study	Region	Year	Pricing policies	Price Elasticities
Wong	Chicago: time series (1951-1961) Four community size groups: cross-sectional	1972	Differential pricing structures and higher distributional costs with distance from source	D: -0.02 to –0.28 D: -0.26 to –0.82
Young	Tucson, Arizona Time series	1973	A basic delivery fee for a specified level of water delivery, successive increments priced at decreasing unit cost	D: -0.63 to –0.41
Katzman	Penang Island – Malaysia Time series	1977	-	D: -0.1 to –0.2
Lynne et al	Miami, Florida Derived demand model	1978	-	C: - 0.174
Foster & Beattie	USA Generalised model	1979	-	D: -0.35 to –0.76
Billings & Agthe	Tuscon, Arizona	1980	Fixed charges and block rates	LR: -0.27 to –0.49 Di: -0.12 to –0.14
Agthe & Billings	Tuscon, Arizona	1980	Fixed charges and block rates	SR: -0.12 to –2.22 LR: -0.27 to –0.49 Di: -0.12 to –0.15
Carver & Boland	Washington D.C metropolitan, Pooled time series and cross-sectional	1980	-	SR: < [0.1] LR: -0.2 to –0.7
Howe	Hopkins residential water use data	1982	-	D: -0.52 to –0.86
Hanke & De Mare	Malmo, Sweden, Pooled time series cross section	1982	Metered pricing	D: -0.15
Opaluch	USA, Utility maximising framework	1982	Block pricing structure	
Schefter & David	Wisconsin, USA	1985	Multi-part tariffs	-
Hewitt & Hanemann	Texas, USA Household level panel data ('81 to '85)	1995	Block rate pricing	D: -0.57 to –0.63
Hansen	Copenhagen Pooled time-series data	1996	Simple one or two part tariffs with marginal costs for households independent of volume consumed	D: -0.003 to –0.1
Chicoine & Ramamurthy	Illinois rural water districts, average price model	1986	Declining block rate structure	MP: -0.61 2nd P variable: -1.02
Thomas & Syme	Perth, Australia Contingent valuation	1988	Privately extracted groundwater and public mains supply on a two-part block tariff system	D: -0.2
Dockel & Groenewald	Witwatersrand, RSA Cross-sectional data, macro-econometric model	1973	Flat rate and increasing block rate pricing	D: -0.63 to –0.84
Espey et al.	Multiple study results across regions, a meta-analysis	1997	Multiple rate structures	-
Veck & Bill	Thokoza, RSA Contingent Valuation, Econometric approach	2000	Based on CVM approach and the related tariffs for levels of service as stated in the study, and increasing block rates	D: -0.12 to –0.14 S: -0.19 to –0.47 Average: -0.14 to -0.18

Source: Own compilation

5.4 Outcomes of the domestic water demand studies

From the above reviews, it is evident that several different models have been used in the literature. Not only do these models differ significantly, but their independent variables also vary extensively. One such variable that is frequently reviewed is the choice of a price variable. Some use marginal price as the price variable, others use average price as the price variable, some use Shin's [1985] price perception model and still others account for the effects of fixed fees and inframarginal prices by using the 'difference variable' or rate structure premium. Endogeneity of the price variables is thoroughly covered in most of the literature and tests such as the Hauseman (1978) chi-square test were used to ensure econometric viability.

Income and substitution effects are discussed. However, the income effect of price changes for water resources is considered minimal and therefore relatively insignificant. Water is also characterised as a good with limited substitutes and the substitution effect in most studies is ignored, except for (Hansen, 1996) who included energy as an independent variable in the water demand model, deriving a cross-price elasticity of –0.2. Another aspect that clearly influences estimation results is the time frame of adjustment. Changes in quantity demanded are expected to be greater the longer the period of adjustment. Evidently, consumer behaviour indicates that users tend to over-adjust to price changes in the short-term and then revert to long-run equilibrium positions, resulting in short-run price elasticities being larger than long-run price elasticities. (Keller, 1975; Carver, 1980) found that water does not have a permanent elasticity of demand, but a temporary effect on limiting demand. Water use is observed to return to the rate of usage seen prior to price increases, in only short time frames. The reason for this behaviour is assumed to be due to lags in users' responses to price adjustments, in conjunction with their inability to differentiate between nominal and real prices.

The price variable is not the only independent variable that influences the demand estimations. Many other variables are identified as having significant effects on demand. Where a period of inflation coincides with water price changes, a frame of mind may be cultivated where consumers become less concerned with water costs and their implications for demand, (Young, 1973). Rising incomes also ensure that water costs form a smaller portion of total household expenditures, resulting in water consumption becoming less responsive to price, (Young, 1973). User profiles defined by multiple-family dwellings and swimming pools tend to be characterised by an increasing proportion of total water consumption. Furthermore, households that are fitted with larger numbers of water using durable's such: as washing machines, dishwashers, bathtubs and showers tend to be larger consumers of water than those with fewer water using appliances. Price increases do not appear to impact on water demand for these goods. They do however play a more significant role in adjusting user habits such as: showering times, lawn watering and car washing.

The majority of studies discussed above tend to be limited by static estimations and do not account for the simple observation that consumers' decisions depend to some extent on the price of a good in the previous year. It may therefore be wise to include price lags in the demand models, moving from static estimations to dynamic estimations as reported in (Agthe and Billings, 1980). The debate on functional form has been limited to regression methods of estimation, some however have included instrumental variables and two stage-least squares, (Hewitt and Haneman, 1995). Model specifications and estimation techniques were initially based on demand equations using either an average price or marginal price variable (Howe and Linaweaver, 1967). Taylor (1975) and Nordin (1976), recognised the discrepancy in decision-making by the consumer between the actual price paid and the expected price to be paid. To counteract this, a difference variable (discussed earlier) was introduced to the model. Similarly, Shin (1985) and Nieswiadomy (1992) introduced a perceived price specification. A more general model was then estimated that accounted for both marginal price and average price (Opaluch, 1982; Chicoine and Ramamurthy, 1986). These models are however all limited by their inability to model the choice of block in which to locate consumption (Hewitt and Hanemann, 1995). Model specifications also have significant effects on the estimates of elasticities, indicated by (Howe, 1982).

The choice of explanatory variables and functional forms further determine the nature of the elasticities. Wong (1972) and Gottlieb (1963) used power forms for their models, thereby obtaining constant elasticities throughout the ranges of their variables. The shortcoming of this approach lies in its implicit rejection of the possibility that water may become "satiated" in various uses. This limitation may be overcome by including price in the exponential form of a model, allowing the elasticities to "vary directly with price". This approach also allows for a quantity intercept to be obtained when price is zero (satiated), (Foster and Beattie, 1979). Where the independent variables maintain stable differentials across their units, then the price elasticity estimates will be more likely to represent the long-run. Furthermore, Higher elasticities are expected for outdoor water demands than for indoor water demands, (Howe and Linaweaver, 1967).

Data selection further complicates the derivation process. Both time-series data and cross-sectional data have their limitations. These data sets may produce further varied results depending on whether they are aggregated or disaggregated. The majority of the studies reviewed here are based on cross-sectional data as it appears to be more comprehensive and easily obtained in many areas. Time series data does have the advantage of enabling one to distinguish between the short-run and the long-run.

Econometric studies of water demand may also be based on primary or secondary data, (Carer, 1980).

Evidently, a wide range of studies has estimated the demand functions for numerous countries within the developed and developing world (Howe and Linaweaver, 1967; Dockel, 1973; Gibbs, 1978; Foster and Beattie, 1979; Howe, 1982; Billings and Agthe, 1980; Hansen, 1996). There are however very few studies on demand estimation and elasticity derivation done for developing countries. In South Africa only one study using empirical analysis for domestic water demand has been completed for the former Witwatersrand region (Dockel, 1973), the Water Research Commission has also completed a study based on the pragmatic approach for household water demand in two areas, namely Alberton and Thokoza. This study uses contingent valuation to determine the price elasticities of demand for water, an econometric approach was also taken but the results did not prove to be statistically significant (Veck and Bill, 2000).

In light of the above discrepancies and various determinants of demand, policy makers are advised to act with caution when selecting a price elasticity of demand for decision-making purposes.

The objective of most empirical studies on water demand management is to determine the "price elasticity of the demand for water rather than other welfare measures" (Hewitt and Hanemann, 1995). Similarly, evidenced by the existing literature, research efforts on the implications of demand management through pricing mechanisms in South Africa is sorely needed. The objective of this research effort will be to estimate the demand function for water in the Tshwane Metropolitan area of South Africa, using cross-sectional and time-series data from which price elasticities of demand will be estimated.

5.5 Econometric specification of demand for water in Tshwane

Supply-side estimation would depend on the use of the theory of profit maximisation or cost minimisation from which input demand and output supply functions could be derived. This would require data to be collected on budgets and total expenditure for water, as well as data on the costs associated with water supply such as, administrative costs, capital costs, transfer costs and subsidy costs. This kind of data was not however available at such a disaggregated level and so the theoretical approach based on supply was not followed for this study.

The theoretical approach based on consumer theory assumes that all consumers are utility maximisers from which Marshallian demand functions can be estimated. This approach is reliant on household level data. Demand systems may also be estimated using the AIDS or LES approaches but these require the specific disaggregation of data outlining household budgets, shares spent on food, electricity, water, and other goods on a monthly basis. This approach would require the compilation and distribution of household specific questionnaires such an approach was not taken for this study.

Due to the availability of secondary data on the prices and quantities of water demanded by consumers, including the number of consumers, regional income, and various weather variables, it was decided that the pragmatic approach should be used to estimate Marshallian demand functions for water disaggregated by area within the municipality. A systems approach was then applied for the whole of the Pretoria Municipality area and an aggregate demand function was obtained. Ordinary least squares was used to run the estimations, while various functional forms were changed to assist with the estimation of elasticities. From the estimated demand curves, price elasticities of demand were derived and analysed. The respective data, equations and elasticity results are shown in the next chapter, chapter six.

5.5.1 Choice of functional form

The linear, logarithmic and translog functional forms were applied to the demand models. The statistical results from each varied only slightly. In light of the hypotheses and the need to determine price elasticities of demand, the logarithmic functional form was adopted. This allowed for the direct observation of elasticities and their respective levels of statistical significance.

5.5.2 Data collection and model development

5.5.2.1Hypothesised relevant variables

Many variables have been identified throughout the literature on domestic water demand. These include price variables ranging from average price to marginal price, specifically formulated prices and aggregated prices; weather variables such as precipitation and temperature with the usual focus falling on maximums; seasonal variables such as wet and dry seasons or summer, autumn, winter and spring, these variables are often included as dummy variables within the models. Other variables included become dependent on the nature of the study such as: population estimates, household demographic charatersics, household infrastructural characteristics, type of water supply, nature of demand, time of day, and household income.

The variables selected for this study included monthly data on precipitation, maximum temperature, average price and marginal price, seasonal variables and the quantity of water consumed. Annual data that was adjusted to monthly data was also collected for the number of users, household income, and population.

5.5.2.2 Selection of variables for the empirical analysis

The data set used for this study was obtained from the Tshwane Municipality for 1995 to 2000. It contains information on aggregate monthly household expenditure on water for different regions within the municipality. Expenditure in South African rands and quantities consumed in kilolitres were obtained directly, from which average prices were derived. The marginal prices were determined as the difference between average prices for different consumption classes, ranging from 0 to 0.2kl; 0.2 to 0.7kl; 0.7 to 1.0kl; and more than 1,0kl's of the daily water consumption. The number of users in each category was also included.

The monthly weather data on temperatures and rainfall was obtained from the South African weather bureau for the five years of the study period. It was then grouped according to the countries rainfall and temperature patterns into four seasons, summer, autumn, winter and spring. These variables were included in the model as seasonal dummies.

Data on income disaggregated by the respective municipal regions was limited and it was finally decided to use population and household income data for Mamelodi and Attridgeville from the DBSA. This data was for the year 1995 and was adjusted using an inflation index to obtain data for the five-year period. A shortcoming of this approach is that the data is highly normalised and does not account for subtle adjustments in income over the period. Income for the whole of the Tshwane municipality was obtained from the SSA 1996 Census and was adjusted using the inflation index to obtain a five-year data set.

The different user categories for the Tshwane municipality are described in (table 5-3). The reason for the distinction between Mamelodi, Attridgeville and the rest of Tshwane was to enable some level of the effect of income on demand to be captured.

Table 5-3: User scales for Tshwane

User category	Description
Scale A	Agricultural Small-holdings
Scale B	Residential housing
Scale C	Duplexes / Simplexes
Scale D	Domestic businesses
Scale E	Old age homes
Scale F	Large industrial user
Scale G	Attridgeville
Scale H	Mamelodi

These user scales are further disaggregated into user classes, based on the amount of water extracted over the stipulated daily allowances. These classes are shown in (table 5-4). Due to the nature of the data, classes 1a and 1b were excluded from the study as was class 4. The difference between prices from class 1 to class 2 and from class 2 to class 3 was used to determine marginal prices for water use, hence the inclusion of variables marginal price 1 (P_{mp1}) and marginal price 2 (P_{mp2}) in the models. For the purposes of clarity, demand schedules were also derived for each user class, individually and aggregated, these are reported as Scale A/ B/ C/ D/ E/ F/ G/ H, level low/ medium/ high/ total.

Table 5-4: User classes for Tshwane

Description by Tshwane	Class for this study	Level of use
Less than 0,2 kl of the daily consumption	1	Low
Between 0,2 and 0,7 kl of the daily allowance	2	Medium
Between 0,7 and 1,0 kl of the daily allowance	3	High
More than 0,1 kl of the daily allowance	4	-
Up to 30% of total daily allowance	1a	-
More than 30% of total daily allowance	2a	-

Assuming water consumers derive utility from consuming characteristics of a composite commodity, the vector of rainfall characteristics, vector of temperature characteristics, vector of price characteristics, vector of user characteristics and the vectors of seasonal characteristics are included in the specified demand model. The set of dependent and independent variables included in the demand models are given in (table 5-5).

Table 5-5: Base model variables

Variable name	Description	Unit of measurement	Expected sign
Dependent variables			
Q_w	Quantity of water demanded	Kilolitres	+
Independent variables			
P_{ap}	Average price of water	Rand / unit	(+) - **
P_{mp}	Marginal price of water	Rand / unit	-
$P_{ap(-6)}$	Average price lagged by the number of months in parenthesis	Rand / unit	-
$P_{mp(-6)}$	Marginal price lagged by the number of months in parenthesis	Rand / unit	-
Rain	Rainfall	Millimetres per month	-
Maxtemp	Maximum temperature	Degrees celcius per month	+
Users	No of users	Aggregated unit	+
Pop	Population	Aggregated unit	+
HHI	Household income	Rands	+
D1	Dummy for summer		+/-
D2	Dummy for autumn		+/-
D3	Dummy for spring		+/-
C	Constant (often takes on the dummy value for winter)		+/-

**The expected sign for the average price is negative, although when a consumer faces block rate pricing structures the sign is often positive. Current literature is investigating ways in which to deal with these complexities.

5.5.2.3 Transformation of variables

When estimating the log form of the water demand model the independent variables are expressed in their natural logarithmic forms. When some of the observations report zero or negative units problems arise in obtaining an output. In order to address this shortcoming, the respective units were scaled by a constant (either one or ten) making all independent observations larger than zero. By doing this, the sample size of sixty observations was maintained.

The rainfall variable was lagged by one month for all the models as this adjustment allowed for the Tshwane billing data to correspond directly with the rainfall data, so that results represented the consumer response for the same period.

The price variables were lagged for a period of between three and thirty months depending on the statistical significance or the results, allowing for comparison between short-run and long-run responses to price changes.

5.6.3 Specification of the empirical model

Equation 5-3, shows the specification of the empirical normalised demand function. The derived price elasticity of demand and income elasticity are the coefficients of the respective variables in the model.

Equation 5-3:

$$LnQ_{water} = \beta_o + \beta_1 \ln \textit{average price} + \beta_2 \ln \textit{marginal price} + \beta_3 \ln \textit{average price (lagged)} + \beta_4 \ln \textit{marginal price (lagged)} + \beta_5 \ln \textit{average rainfall} + \beta_6 \ln \textit{maximum temperature} + \beta_7 \ln \textit{household income} + \beta_8 \ln \textit{population} + \beta_9 \textit{ dummy1} + \beta_{10} \textit{ dummy2} + \beta_{11} \textit{ dummy3} + \beta_{12} \ln \textit{no of users}$$

Different combinations of the independent variables were estimated for each user category at different scales using OLS, until a best fit was obtained.

Chapter five set out to identify the appropriate methodology for building demand functions for residential water users. After an extensive literature review process the pragmatic approach was selected and the relevant hypothesised variables were identified. The latter half of the chapter introduced the expected economic results behind the estimations, and the single equation specifications and results are reported in the next chapter.