Residential and Industrial Water Demand for Boise Valley Municipalities

Garth Taylor
Zena Cook

Agricultural Economics Extension Series No. 05-13
March 2005

University of Idaho
College of Agricultural and Life Sciences

Department of Agricultural Economics
And Rural Sociology
Moscow, Idaho 83844-2334

Residential and Industrial Water Demand for Boise Valley Municipalities

Estimation of M&I demand functions are costly and data intensive. To obtain the degrees of freedom, data needs to be obtained from a cross section of municipalities or a time series for many years from a single city. And given these data limitation will not be particularly accurate. With the time series data are usually discarded because the assumption of a stable demand function over 20 or 30 years is obviously not reasonable.[1] The cross section data are most often estimated a demand per household. In lieu of conducting a costly survey of Boise Valley municipalities, that may not yield the required data to estimate demand functions, we choose to formulate the demand functions from secondary data sources. To formulate a demand function for each municipality in the Boise Valley, elasticities obtain from the plethora of residential water demand studies are calibrated current prices and quantities of residential water for the respective municipality. The rational for this approach will be followed by the rational in selection of elasticities to be implemented. Lastly, we will deal with the case of "Dual Use" systems that are emerging throughout the Boise Valley.

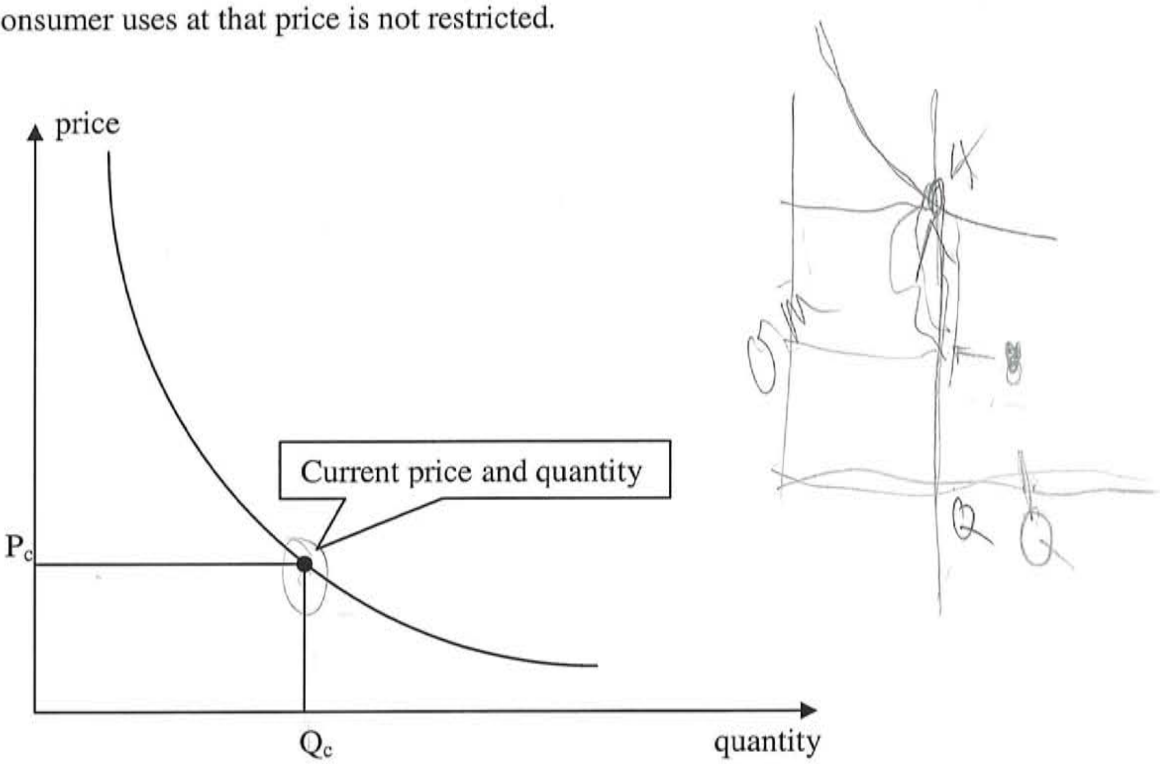
Techniques in forming the M&I demand

Given the data limitations, the required accuracy, the data needs (a demand function for each municipality) and the costs we choose to use secondary data, calibrated with current water use and price to estimated a demand function for each municipality. The technique for doing such is illustrated in Figure 1. An elasticity obtained from secondary sources rather estimated for each BoiseValley municipalities is fitted through the single point that we have

---

[1] Only eight the dozens of studies reviewed by Arbues et al used time series data.

data for, the current level of water use and the price assessed for each municipality. It should be emphasis that the current quantity and price are the sole point on the demand function for each municipality. The concept of an elasticity being a unit less measure of price responsiveness, allows to us to borrow as elasticity from the phelora of secondary water research. The current price and quantity is a point on the demand function because the quantity consumed is not restricted. Even thought the price may be heavily subsidized or just barely cover the local municipal utilities operation and maintenance the quantity of water a consumer uses at that price is not restricted.



Review of qualifications for the elasticity

Extensive research on residential or municipal water demand begin in the early 1960's (Gottlieb, 1963; Howe and Linaweaver, 1967). This research has resulted in widely divergent estimates of elasticity. Elasticity estimates have ranged from highly inelastic (-.003 to -.01 Hansen, 1996) to elastic (-1.57 to -1.63 Hewitt and Hanemann 1995).

According to received demand theory, residential water use varies inversely with price as residential consumers adjust short run seasonal water use and in the long run modify or replace water-using capital stocks. Empirical studies corroborate negative price elasticity, as well as show that prices of closely related goods, consumer incomes, and weather can affect water use. In contrast to the downward sloping water demand determined by autonomous consumers, the supply schedule faced by a consumer is established by a monopolistic utility. Water suppliers, typical of public utilities, administer rate schedules to achieve multiple goals; generate revenue, cover fixed costs, and provide incentives (Hanemann 1998). Rate schedules are designed with combinations of a fixed fee with a flat rate (proportional), increasing or decreasing block rate or non metered (fixed fee only). Administered rate schedules complicate estimation of residential water demand because price becomes endogenous, varying with the amount of water consumed. When rate schedule complications were recognized, research focused on price specification (Billings 1982, 1983; Opaluch 1982; Jones and Morris 1984; Charney and Woodard 1984; Schefter and David 1985; Williams 1985; Chicoine, Deller, and Ramamurthy 1986; Chicoine and Ramamurthy 1986; Williams and Suh 1986; Deller, Chicoine, and Ramamurthy 1986; Agthe and Billings 1987; Griffin and Chang 1990, 1991; Nieswiadomy and Molina 1988, 1989, 1991; and Stevens, Miller, and Willis 1992).

Average versus Marginal Price Specification

The question in the marginal price versus average price controversy is water consumers' knowledge and their decision mechanism. Taylor et al recognized a serious bias in the estimation of price elasticity. Residential water demand is often specified with the marginal price observed from the rate schedule (Howe 1998). Despite theory and empirical evidence, average price has been championed, in both early (Foster and Beattie 1981a) and recent research (Neiswiadomy and Cobb 1993; Michelsen, McGuckin, and Stumpf 1999), as the *behaviorally relevant* price perceived by consumers (italics Howe 1998). Espey et al. (1997) conducted a meta-analysis on 124 observations on the price elasticity of residential water demand. They found that the use of average price in place of marginal price resulted in higher price elasticities. If price elasticity estimates differ systematically when average price is used in place of marginal price then different methodological and policy implications ensue.

Marginal price specification in demand can be empirically equivalent to average price in two cases: (1) when firms are competitive price takers, average price equals marginal price (Edmonds 1977) and; (2) when the data result from a single equation demand function which is double log, price elasticities are invariant to marginal or average price specification (Halvorsen 1975).

As opposed to the equivalency argument in the two cases above, average price has been specified in water demand based on the assumption that consumers *perceive* price to be average price. Foster and Beattie (1981b) submit that the fixed charge is perceived as a marginal cost:

> " ...consumers view their choices in the fixed charge block not as a fixed cost (minimum charge) with associated zero-marginal cost for some range of water used, but as a variable cost associated with the desired level of consumption in the first block. Thus, a positive "marginal cost" is *perceived* in this block. If so perceived, marginal and average cost would be the same for the amount consumed ..." (pages 258-259)

Average price replaces marginal price so that the demand function becomes:

$$W = f\left(P_{Avg}, P_x, M\right) \qquad [3]$$

where, P_{Avg} is computed as a utility's average revenue (total revenue divided by total water sales). The perception argument justifies average price because consumers are alleged to ignore the details of the rate schedule when water represents a small portion of their expenditures (Foster and Beattie 1981b). At issue in the marginal price versus average revenue specification is the consumer's knowledge and decision mechanism. Utility bills inform customers of total expense and in many instances marginal price. Whether, on a widespread basis, consumers convert billing information to an average price to judge cost of water consumption is an empirical question. Except for the special cases described earlier, average revenue is not marginal price but average revenue *could* be a proxy or measure upon which water consumption decisions are mistakenly based.

Specification of average price in demand poses serious estimation difficulties when utilities charge a constant monthly fee sometimes in combination with either flat or block rates. Taylor's (1975) study hinted at the average price specification problem:

> "Also, there is the problem that when average price is defined ex post as the ratio of total expenditures to quantity consumed, as is the usual procedure, a negative dependence between quantity and price is established that reflects nothing more than arithmetic." (p. 78).

Consider the customer bill derived from a rate schedule that includes a fixed charge coupled with a generic variable water rate;

$$TR_{it} = K_i + R(W_{it}), \qquad [4]$$

where, *TR* is total receipts, *K* is revenue derived from a monthly fee fixed by each water utility, and *R(W)* is revenue derived from the variable portion of the rate schedule; indexed over utilities (*i*), and time periods over which revenues are collected (*t*). By definition, the fixed fee charged by the i^{th} utility is fixed over all quantities consumed. Average price based on average revenue is thus;

$$P_{Avg_{it}} = \frac{TR_{it}}{W_{it}} = \frac{K_i}{W_{it}} + \frac{R(W_{it})}{W_{it}} \qquad [5]$$

Equation (5) shows that average revenue is composed of average fixed revenue and average variable revenue components when fixed fees are included in the utility rate schedule. The average revenue definition of the price is substituted into the demand function (equation 3). However, for utilities charging only a fixed fee, the average variable revenue in equation (5) equals zero, and the demand function as shown in (6) becomes an identity with W_{it} on both sides of the equation:

$$W_{it} = f\left(P_{Avg_{it}}, P_x, M\right) = f\left(\frac{K_i}{W_{it}}, P_x, M\right) \qquad [6]$$

When the only charge is a fixed fee, the price quantity relationship is average fixed revenue, which is a rectangular hyperbola with unitary price elasticity. Taylor's "arithmetic" is thus an identity. A perfect fit ($R^2 = 1$) results when this identity is "properly" estimated. For example, assume a linear demand model is estimated for equation (6), $W = b_0 + b_1\left(\frac{K}{W}\right) + b_2 P_x + b_3 M$. If ordinary least squares (OLS) was capable of returning the identity the estimated coefficients would be: $b_0 = 0$, $b_2 = 0$, $b_3 = 0$, and $b_1 = -\frac{W^2}{K}$.

Price elasticity is defined as $E_p = \left(\frac{\partial W}{\partial P}\right)\left(\frac{P}{W}\right)$ *and* $\frac{\partial W}{\partial P} = b_1 = -\frac{W^2}{K}$, when price is average fixed revenue. Thus, price elasticity is $E_p = -\left(\frac{W^2}{K}\right)\left(\frac{P}{W}\right) = -\frac{WP}{K}$, but both *WP* and *K* are total revenue and therefore price elasticity must always be minus one. The embedded identity is easily detected by OLS for a double log demand function. The double log demand equation is shown in (7) where for ease of illustration the nuisance parameters (other prices and income) are omitted:

$$W_{it} = \beta_1 \left[\frac{K_i}{W_{it}} + \frac{R(W_{it})}{W_{it}} \right]^{\beta_2} \qquad [7]$$

For the i^{th} utility, charging only a fixed fee (i.e., average variable revenue = $R(W_{it})$ = 0), the observed time series of price-quantity data again is a rectangular hyperbola. The estimated price elasticity (β_2) will equal minus one and β_1 will equal a constant $\boldsymbol{k}$ representing the fixed fee. If all utilities choose the same value for their fixed fee then the fit of quantity demanded on average price will be perfect and no other explanatory variables should enter the regression. If the value of the fixed fee varies across utilities then there is a set of rectangular hyperbolas whose distance from the origin varies with the magnitude of the fixed charge. (If variations in the fixed charge across the utilities could be explained, data would again fall on a single rectangular hyperbola.) The presence of variation in the fixed fee across utilities or over time may tend to obscure the existence of the embedded identity.

The crux of the argument is that when average fixed revenue (fixed fee) is high, relative to the average variable revenue portion of the rate structure, the change in total revenue over time, will be nearly invariant to water consumption. Thus, the effect of a rate schedule that is dominated by the fixed fee is to dampen any price effects on quantity demanded. When the variance of K_i is small relative to W_{it}, the major source of variation in the average price data originates from variation in water usage, W_{it}. Thus, as average variable revenue tends to zero, estimated demand tends to an unitary elasticity identity and measures of fit will increase and price elasticity will approach minus one.[3]

Short run substitutes for water are virtually nonexistent. Our data are cross sectional and thus portray long run consumer water consumption decisions. Expensive water-saving appliances, irrigation systems, and landscaping are long-run substitutes for water. Utility bills are notoriously vague in detailing water costs and usage. Yet, knowledge of total water costs at different points on the rate schedule and projections of costs over time is essential in making capital investment decisions. Be it from their own experience, talking with neighbors, or contacting the utility, consumers do make long run adjustments to increasing water costs.

Simultaneous equations

A municipal water utility is a local monopoly, with pricing latitude to set a rate schedule and thus administer water price. Typical rate schedules of municipal water distributors include unmetered connections with fixed monthly fees, flat rate (proportional) pricing, increasing block rates, declining block rates, and combinations of fixed monthly fees with block rates. Utility customers paid varying marginal (or average) prices set by an administered rate schedule unique to each utility. The econometric implications of rate schedule(s) must be considered when estimating price elasticity. Thus, identification of the demand function requires specification of an appropriate simultaneous model structure (Taylor 1975, Billings and Agthe 1980).

Price is measured at the margin in the neoclassical demand model in the presence of a rate schedule *and with informed consumers* (Foster and Beattie 1981a, 1981b; Howe 1998). Cost for a consumer of a given amount of domestic water consumption is:

$$TC_W = \int P_{M\arg}\, dW; \qquad [1]$$

where, $P_{Marg|W=w} = R(W)$, the rate schedule, is a function of water quantity (W) and thus marginal price is conditional on water consumed. As shown in Appendix 1, the resulting demand function is:

$$W = f\left(R\left(W\right), P_x, M\right); \qquad [2]$$

where, marginal price $P_{Marg,}$ selected from a given rate schedule R(W), is the appropriate price measure when the consumer maximizes utility subject to an income constraint (M) and P_x is the numeraire price. The quantity of water demanded is thus determined simultaneously with the rate schedule.2 When simultaneity is present, OLS under a declining block tariff will underestimate or overestimate demand elasticity depending on whether the supply schedule is steeper than the demand schedule or otherwise (Griffin and Martin, 1981).

The double–log demand function is a very popular functional form because of the ease of estimation and the demand coefficients can be directly interpreted as the constant-elasticity of demand. The constant elasticity of demand implies an equal price responsiveness to quantity of water use at high and low prices. In contrast, with a linear demand function, elasticity changes at every level of water quantity consumed and consumers are less sensitive to price the lower the price. Al-Quanibet and Johnson 1985 criticize the double-log functional form as being inconsistent with utility theory.

Elasticity for Boise Valley Municipalities

---

[2] In addition to price simultaneity, Neiswiadomy (1992) considers potential endogeneity of conservation and public education variables.

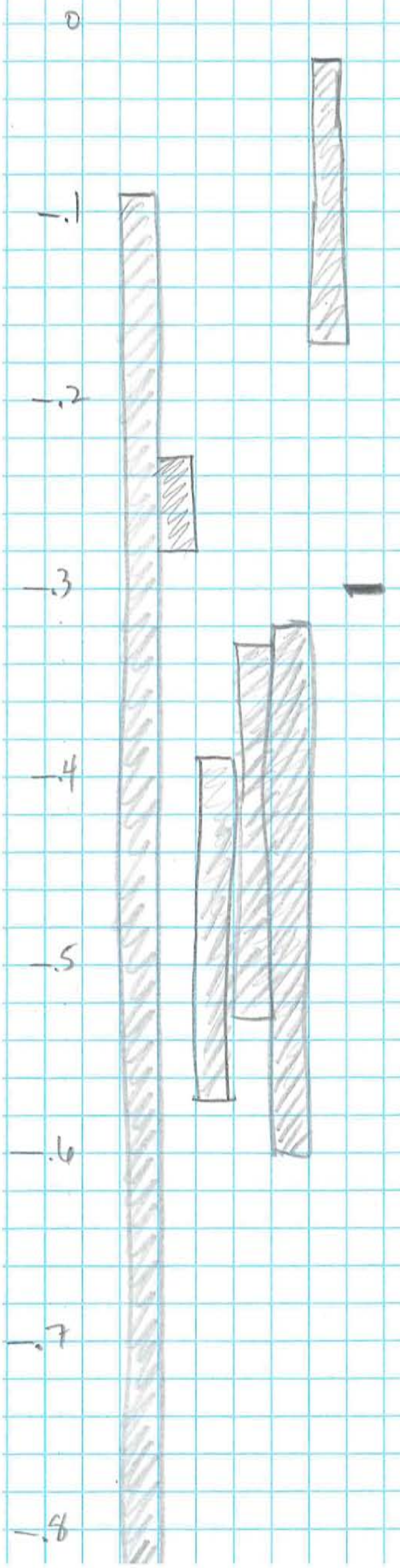


Table 1

In summary we have chosen an elasticity based upon the criteria (1) the demand function will be estimated with a simultaneous equation technique, (2) that marginal price is estimated. Of .the plethora of studies only a few met that criteria and are listed in Table 1.

Table 1. M and I water demand studies that used simultaneous equations and were specified with marginal price

Author	Price Elasticity
Nieswiadomy and Molina (1989)	-0.09 to -0.86
Barkatullah (1996)	-0.23 to -0.28
Agthe and Billings (1997)	-0.39 to -0.57
Renwick and Archibald (1998)	-0.33 to -0.53
Martin and Wilder (1992)	-0.32 to -0.60
Nieswiadomy (1992)	-0.02 to -0.17
Taylor, McKean, and Young (2004)	-0.30

With the exception of Nieswiadomy (1992), these studies show a remarkable converge in their estimates of elasticity. From that set of studies (and without ego) we choose the Taylor study for the elasticity of -0.3 to represent the Boise Valley municipalities demand for residential water demand. The Taylor study was estimated with a double-log functional form so that the elasticity is directly available for our use.

Current price and quantity

Table 1: Current Prices

Municipal Provider	Description of Charge	Summer****: monthly fixed charge	Summer**** monthly incremental rate ($ per 100 cu.ft)	Winter: monthly fixed charge	Winter monthly incremental rate ($ per 100 cu.ft)
United Water Idaho	Incremental charge levied on > 0 use	$ 6.63	$ 1.12	$ 6.63	$ 0.89
Meridian, City of	Fixed Charge only: 0 - 4,000 gal.	$ 6.48	$ 0.92	$ 6.48	$ 0.92
Garden City, City of	Incremental charge levied on > 0 use	$ 7.68	$ 0.60	$ 7.68	$ 0.60
Capitol Water Corp.	Fixed charge only	$ 24.05	$ -	$ 12.65	$ -
Eagle Water Co.	Fixed charge only: 0 - 600 cu/ft.	$ 8.17	$ 0.45	$ 8.17	$ 0.45
Kuna, City of	Incremental charge levied on > 0 use	$ 15.50	$ 0.65	$ 15.50	$ 0.65
Nampa, City of	750 - 3,999 cu. ft.	$ 5.64	$ 0.78	$ 5.64	$ 0.78
	4,000 + cu. ft.	$ 5.64	$ 0.46	$ 5.64	$ 0.46
Nampa, Outside City	750 - 3,999 cu. ft.	$ 11.28	$ 1.86	$ 11.28	$ 1.86
	4,000 + cu. ft.	$ 11.28	$ 0.92	$ 11.28	$ 0.92
Caldwell, City of	Incremental charge levied on > 0 use	$ 3.35	$ 0.55	$ 3.35	$ 0.55
Middleton, City of	Fixed charge only: 0 - 400 cu/ft.	$ 8.00	$ 0.94	$ 8.00	$ 0.94
Middleton, Outside City	Fixed charge only: 0 - 400 cu/ft.	$ 16.00	$ 1.87	$ 16.00	$ 1.87
Parma, City of	Incremental charge levied on > 0 use	$ 14.00	$ 0.97	$ 14.00	$ 0.97
Star	Fixed charge only	N/A	N/A	N/A	N/A
Melba	Fixed charge only	N/A	N/A	N/A	N/A
Eagle Water Company	Fixed charge only	N/A	N/A	N/A	N/A
Other Public Water Systems	Fixed charge only	N/A	N/A	N/A	N/A
Individual wells	Pumping costs *	TBE	TBE	TBE	TBE
Irrigation Water Use **	$30 annual per acre @ 2.4acft per acre	$ 0.01	$ -	$ -	$ -
Irrigation Water Use ***	$200 annual per developed acre	$ 0.09	$ -	$ -	$ -

Notes:

N/A: not available at this time

TBE: to be estimated

* pumping costs at various well depths in the valley are required here

** Non pressurized only. The number of gallons is calculated over the entire population.

** *Pressurized (Based on Nampa Meridian irrigation district average payments)

****Summer months are May thru September inclusive

Table 2: Current and Future Projected Quantities

Municipal Provider	Total Residential Population served (02)	Total Residential Population Projected in 2025	Gallons Provided in Winter in 2000 (per capita per day)	Gallons Provided in Summer in 2000 (per capita per day)	Gallons Provided in Year 2000 (per capita per day)	Gallons Provided in Winter 2025 (per capita per day)	Gallons Provided in Summer 2025 (per capita per day)	Total Amount Provided in Year 2025 (per capita per day)
United Water Idaho	196,945	323,074	104	59	163	121	68	189
Meridian, City of	29,700	63,693	104	59	163	121	68	189
Garden City, City of	9,000	17,728	104	59	163	121	68	189
Capitol Water Corp.	7,400	9,000	104	59	163	121	68	189
Eagle Water Co. (Mun.)	4,328	6,739	104	59	163	121	68	189
Kuna, City of	4,590	9,263	104	59	163	121	68	189
Nampa, City and Outside	44,550	88,868	101	57	157	109	61	171
Caldwell, City of	23,000	50,544	101	57	157	109	61	171
Middleton, City and Outside	2,978	4,194	101	57	157	109	61	171
Parma, City of	1,817	2,091	101	57	157	109	61	171
Star	1,344	2,019	102	58	160	115	65	180
Melba	296	528	102	58	160	115	65	180
Eagle Water Company	1,000	3,411	104	59	163	121	68	189
Other Public Water Systems	30,000	55,000	102	58	160	115	65	180
Individual wells	76,052	94,052	102	58	160	115	65	180
Irrigation Water Use *	433,000	730,204	0	13	13	0	13	13
Irrigation Water Use **	433,000	730,204	0	13	13	0	13	13

* Non pressurized only. The number of gallons is calculated over the entire population with United Water data. They are likely to underestimate water use

** Pressurized. The number of gallons is calculated over the entire population with United Water data. They are likely to underestimate water use

Notes

1. Coefficient values obtained from Cook et al., December 2001
2. For irrigation company controlled water, dual use is calculated across entire population because of the way the coefficients were originally developed.
3. Water use numbers are based on assumption of real price levels remaining the same over time but income levels rising as predicted by JC. They differ among counties mainly because of differences in lot sizes (Canyon is higher) and incomes (Ada is higher).
4. Summer months are May thru September inclusive
5. Average Percentage of summer use obtained from United Water Records

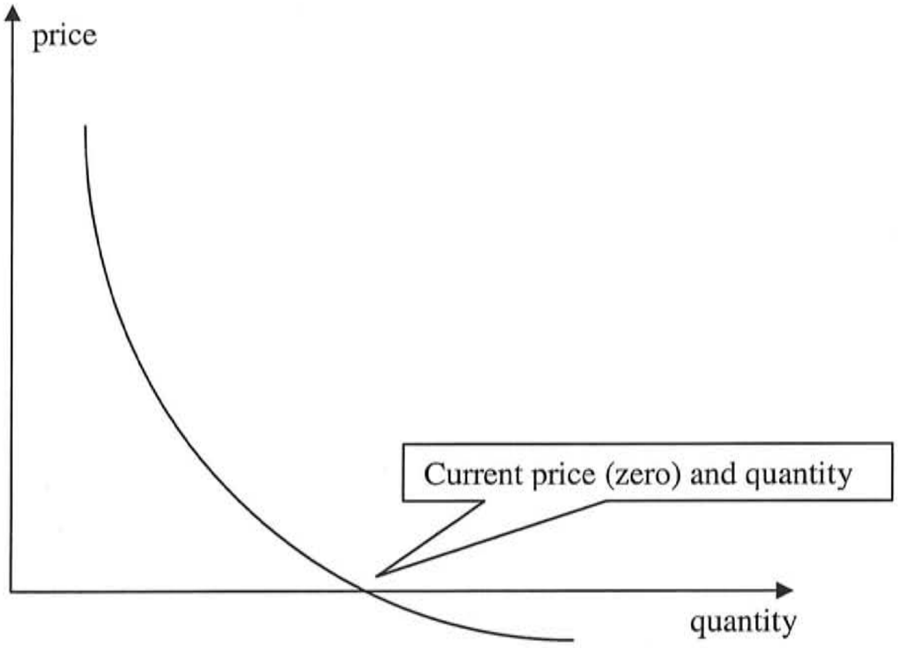
Current price schedules are presented in Table 1. Pricing structures vary considerably throughout the Boise valley. Some municipalities and private providers charge a fixed monthly fee only, e.g. Capital Water Company while others charge both a fixed fee and a proportional one. For those using proportional pricing, most providers adopt flat rates throughout. The exception is Nampa that uses a declining block rate schedule. United Water in Boise charges different rates in winter and summer, higher rates in the summer, lower in the winter. The purpose of raising rates in summer is to reduce demand in the peak use months. For providers using both fixed and proportional pricing, some apply a proportional rate starting from zero use, e.g. Caldwell, while others e.g. Middleton, apply the proportional rate after a specified usage. These price structures imply declining average rates over initial ranges of the schedules and constant zero or constant positive marginal rates over others.

Current and projected future quantities are shown in Table 2. Coefficients were developed using United Water individual customer records (Cook et al.), the largest municipal provider in the valley with a total production of 15 billion gallons in 1999. However, the cross section data for the entire valley was only available by county. Hence, county average differences account for the differences between the estimates for municipalities. Canyon County has lower incomes but higher average lot sizes than Ada County. Lower incomes reduce water use while higher lot sizes increase water use. These two opposite effects on water use tend to reduce the overall differences in the estimates. More important are the differences between summer and winter use obtained from United Water.

Dual Use Demand

In the Boise Valley several municipalities (usually planned communities) have developed "dual use" residential water systems. The first system delivers water at the tap for culinary and sanitation purposes and meet strict drinking water standards. Water delivered through this first system is delivered by municipal water district and is metered and charged at the rates of encompassing municipality. Water in second system (the dual system) is intended for landscaping or small acreages (horse pastures) and is delivered by the cooperative agreement of the planned community. This water is not treated (irrigation water standards) and is purchased from a nearby canal company. Water delivered for the dual use is not metered nor quantity restricted. The water charge is a flat hookup fee for an unlimited quantity of water.

Thus, water delivered by the dual user has a marginal price of zero and the quantity of water consumed is limited by the homeowners desire to divert the water. Since the water intended for landscaping is elastic than drinking water a different elasticity will be used for dual use systems. Further, the marginal price is zero, thus the elasticity will be fitted through the x-axis at the present quantity of water use and through the y-axis at the zero price (see Figure 2).



References

Agthe, D. E., and R. B. Billings. 1987. "Equity, Price Elasticity, and Household Income Under Increasing Block Rates for Water." *Amer. J. of Economics and Sociology* 46(3): 273-86.

Arbues, F. M., A. Garcia-Valinas, and R. Martinez-Espineira. 2003. "Estimation of Residential Water Demand: A State-of-the-Art Review." *The Journal of Socio-Economics* 32 (2003): 81-102.

Billings, R. B., and D. E. Agthe. 1980. "Price Elasticities for Water: A Case of Increasing Block Rates: Reply." *Land Economics* 57(2): 276-78.

Billings, R. B. 1982. "Specification of Block Rate Price Variables in Demand Models." *Land Economics* 58 (3): 386-94.

———. 1983. "Specification of Block Rate Price Variables in Demand Models: Reply." *Land Economics* 59 (3): 370-71.

Burt, O. R. 1971. "Positivistic Measures of U.S. Agricultural Supply: Some New Approaches." *Amer. J. Ag. Econ.* 53 (4): 674-75.

Charney, A. H., and G. C. Woodard. 1984. "A Test of Consumer Demand Response to Water Prices: Comment." *Land Economics* 60 (4): 414-16.

Chicoine, D. L., S. C. Deller, and G. Ramamurthy. 1986. "Water Demand Estimation Under Block Rate Pricing: A Simultaneous Equation Approach." *Water Resources Research* 22 (6): 859-63.

Chicoine, D. L., and G. Ramamurthy. 1986. "Evidence on the Specification of Price in the Study of Domestic Water Demand." *Land Economics* 62 (1): 26-32.

Cook, Z. L., S. Urban, M. Maupin, J Church, 2001, "Domestic, Commercial, Municipal and Industrial Water Demand Assessment and Forecast in Ada and Canyon Counties, Idaho", IDWR publication.

Deller, S. C., D. L. Chicoine, and G. Ramamurthy. 1986. "Instrumental Variables Approach to Rural Water Service Demand." *Southern Economic Journal* 53(2): 333-46.

Dhrymes, P. J. 1978. *Introductory Econometrics*. New York: Springer-Verlag.

Edmonds, J. A. 1977. *The Marginal-Average Price Elasticity Problem*. Draft Report. Oak Ridge National Laboratory.

Espey, M., J. Espey, and W. D. Shaw. 1997. "Price Elasticity of Residential Demand for Water: A Meta-Analysis." *Water Resources Research* 33 (6): 1369-74.

Foster, H. W., and B. R. Beattie. 1981a. "Urban Residential Demand for Water in the United States: Reply." *Land Economics* 57 (2): 257-65.

———. 1981b. "On the Specification of Price in Studies of consumer Demand under Block Price Scheduling." *Land Economics* 57 (4): 624-29.

Goldberger, A. 1964. *Econometric Theory*. New York: Wiley.

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

Griffin, R. C., and C. Chang. 1990. "Pretest Analyses of Water Demand in Thirty Communities." *Water Resources Research* 26 (10): 2251-55.

Griffin, A. H.., and W. Martin. 1981. "Price elasticities for water: a case of increasing block rates: A comment." *Land Economics* 26 (10): 2251-55.

———. 1991. "Seasonality in Community Water Demand." *Western Journal of Agricultural Economics* 16 (2): 207-17.

Halvorsen, R. 1975. "Residential Demand for Electricity." *Review of Economics and Statistics* 57 (1): 12-18.

Hanemann, W. M. 1998. "Price and Rate Structures." In *Urban Water Demand Management and Planning* eds. D.D. Baumann, J.J. Boland and W.M. Hanemann. McGraw-Hill Company. 137-79.

Howe, C. W. and F. P. Linaweaver, 1967 The impact of price on residential water demand. Water Resources Research. 3(1) 13-32.

Howe, C.W. 1982. "Impact of Price on Residential Water Demand: Some New Insights." *Water Resources Research* 18 (4): 713-16.

———. 1998. "Forms and Functions of Water Pricing: An Overview." In *Urban Water Demand Management and Planning* eds D.D. Baumann, J. J. Boland and W.M. Hanemann. McGraw-Hill Company. p181-89.

Jones, C. V., and J. R. Morris. 1984. "Instrumental Price Estimates and Residential Water Demand." *Water Resources Research* 20 (2): 197-202.

LaFrance, J. T. 1998. "The Silence of the Lambdas: Comment." *Amer. J. Ag. Econ.* 80 (1): 221-30.

Michelsen, A. M., T. McGuckin, and D. Stumpf. 1999. "Effectiveness of Conservation Programs in Municipal Water Demand." *J. of Amer. Water Resources Assoc.* 35 (3): 593-03.

Nieswiadomy, M. L. 1992. "Estimating Urban Residential Water Demand: Effects of Price Structure, Conservation, and Education." *Water Resources Research* 28(3): 609-15.

Nieswiadomy, M. L., and S. L. Cobb. 1993. "Impact of Pricing Structure Selectivity on Urban Water Demand." *Contemporary Policy Issues* 11 (3): 101-13.

Nieswiadomy, M. L., and D. J. Molina. 1988. "Urban Water Demand Estimates Under Increasing Block Rates." *Growth and Change* 19 (1): 1-12.

———. 1989. "Comparing Residential Water Demand Estimates under Decreasing and Increasing Block Rates Using Household Data." *Land Economics* 65 (3): 280-89.

———. 1991. "A Note on Price Perception in Water Demand Models." *Land Economics* 67 (3): 352-59.

Nordin, J. A. 1976. "A Proposed Modification of Taylor's Demand Analysis: Comment." *Bell J. of Econ.* 7 (2): 719-21.

Opaluch, J. J. 1982. "Urban Residential Demand for Water in the United States: Further Discussion." *Land Economics* 58 (2): 225-27.

——. 1984. "A Test of Consumer Demand Response to Water Prices: Reply." *Land Economics* 60 (4): 417-21.

Schefter, J. E., and E. L. David. 1985. "Estimating Residential Water Demand Under Multi-Part Tariffs Using Aggregate Data." *Land Economics* 61 (3): 272-80.

Shin, J. 1985. "Perception of Price When Price Information is Costly: Evidence from Residential Electricity Demand." *Review of Economics and Statistics* 67(4) 591-98.

Stevens, T. H., J. Miller, and C. Willis. 1992. "Effect of Price Structure on Residential Water Demand." *Water Resources Bulletin* 28 (4): 681-85.

Taylor, L. D. 1975. "The Demand for Electricity: A Survey." *Bell Journal of Economics and Management* 6 (1): 74-110.

Taylor, R. G., John R. McKean, and R. A Young. Alternate Price Specifications for Estimating Residential Water Demand with Fixed Fees. Land Economics 30(3) p463-475.

Van Helden, G. J., P. S. Leeflang, and E. Sterken. 1987. "Estimation of Demand for Electricity." *Applied Economics* 19 (1): 69-82.

Walters, L. L., and R. A. Young. 1994. *Economic Factors Affecting Residential Water Demand in Colorado*. Completion Rpt. 175, Colorado Water Resources Research Institute, Colorado State University, Ft. Collins, CO.

Williams, M. 1985. "Estimating Urban Residential Demand for Water under Alternative Price Measures." *Journal of Urban Economics* 18 (2): 213-25.

Williams, M., and B. Suh. 1986. "The Demand for Urban Water by Customer Class." *Applied Economics* 18 (12): 1275-89.

APPENDIX 1

Consumer Demand Optimization in the Presence of a Rate Schedule

The marginal price for domestic water, conditional on amount consumed, is:

$$P_{Marg\,|W=w} = R(W)$$

where, *R(W)*, the rate schedule, is a function of water quantity. Thus, cost of a given amount of domestic water consumption is:

$$TC_W = \int P_{Marg}\, dW.$$

Incorporating this definition of cost in the consumer's income constraint, a water consumer's optimal choice becomes:

$$Z = U(W, X) - \lambda\left(M - \int R(W)\, dW - P_x X\right).$$

with first order conditions to maximize utility (U) yielding the equal marginal rule;

$$\frac{\partial U / \partial W}{R(W)} = \frac{\partial U / \partial X}{P_x};$$

where, M is income, X are other goods with price P_x, and W is water quantity. This formulation contrasts to Hanemann's (1998), where a linear budget constraint was assumed.