

# Pretest Analyses of Water Demand in Thirty Communities

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Using 3 years of monthly data for 30 carefully selected Texas communities, several characteristics of community water demand are investigated. The average price versus marginal price specification issue is examined in the same manner as preceding literature and again demonstrates the superiority of the average price approach. More original contributions identify (1) the need to include sewer rates in water demand models, (2) the importance of studying seasonal demand rather than annual demand, (3) seasonal variations in the price elasticity of demand, and (4) an interesting index for relating monthly community water demand to monthly climatic conditions.

Beginning with classic studies published by *Howe and Linaweaver* [1967] and *Young* [1973] in *Water Resources Research* and by *Wong* [1972] in *Land Economics*, these two journals have been home to a growing number of articles concerning urban water demand estimations. The focus of these studies has always been to obtain accurate estimates of price elasticities and has been motivated by growing water scarcity which gives policy relevance to the topic of price sensitivity to administratively determined rate structures. Economists are predisposed to believe that price is important, although utility managers are sometimes quick to disregard price as a potential control variable. During the 1980s this expanding body of literature borrowed heavily from a parallel, but leading, literature in the energy (electricity) area [*Taylor*, 1975; *Nordin*, 1976]. Energy-related studies were at advantage, having benefited from research incentives created by the acute scarcities of the 1970s and, probably, the availability of better data.

More recent water demand studies have not been confined to repetitions of earlier work with new data. Following *Chicoine et al.*'s [1986] observation, issues of specification (functional form and variable selection) and econometrics prevail in importance. We can say that what began as a debate concerning average price (AP) versus marginal price (MP) specifications of the water price variable [*Gibbs*, 1978] has become a situation where both alternatives have gained some theoretical or empirical credibility. Recent work includes multiple price variables in the same model in order to capture substitution and income effects of rate changes [*Billings and Agthe*, 1980; *Griffin et al.*, 1981]. Neither AP nor MP formulations are capable of this in isolation. Recent econometric contributions have addressed the peculiar simultaneity problem caused by increasing or decreasing block rate structures in the face of measurement error [*Griffin and Martin*, 1981; *Terza and Welch*, 1982; *Jones and Morris*, 1984; *Agthe et al.*, 1986].

There are several objectives for the work reported here. Most generally, we are attempting to focus and direct future work by employing various pretest analyses to recommend or eliminate certain specifications. One such case concerns AP versus MP specifications for pooled monthly data. Second, all previous studies known to us have omitted sewer charges. Our incorporation of sewer rates offers a unique

opportunity for examining the validity of excluding sewer charges. Third, the majority of previous studies focus on annual water demand. It now appears that growing water scarcity will place more attention upon managing and providing peak loads. Therefore our development of monthly data enables the investigation of seasonal price sensitivity which may convey useful information concerning the potential influence of time of year (TOY) rates upon demand. Of parallel interest is the identification of an adequate monthly climate variable. No single climate variable, such as temperature, precipitation, or evapotranspiration, seems capable of serving in this role.

## THE MODEL

Given data availability and the insight contributed by published studies, the following model is postulated:

$$Q = \alpha_0 + \alpha_1 AP + \alpha_2 PO + \alpha_3 CH + \alpha_4 I + \alpha_5 SP + \alpha_6 C + \mu \quad (1)$$

where

- $Q$  per capita residential and commercial water consumption (gallons per capita per day);
- $AP$  average price of water paid by an average 2.84 person household;
- $MP$  marginal price of water paid by an average 2.84 person household;
- $PO = MP - AP$ ;
- $CH$  rate change dummy variable which equals 1 if a rate change occurred during the current month or the previous two months;
- $I$  the annual personal income per capita (thousands of dollars);
- $SP$  percent of the population with Spanish origin;
- $C$  a climate variable (to be defined).

As the definitions of these variables suggest, estimation of this model will employ community data rather than microdata. Hypothesis tests involving  $\alpha_1$  and  $\alpha_2$  are commonly used to obtain empirical evidence regarding whether consumers respond to marginal or average prices. Theoretical models of utility maximization under perfect information show that *Nordin's* difference variable (not included in our model) captures the income effect induced by changes in inframarginal rates [*Opaluch*, 1982, 1984]. Utility-maximiza-

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TABLE 1. Characteristics of the 30 Analyzed Communities (10 per Group)

Group	Percentage Groundwater	Population (1980)		
		Minimum	Mean	Maximum
Groundwater	92–100%	1,845	97,190	785,809
Mixed	17–82%	3,175	71,294	425,259
Surface water	0–13%	3,052	66,058	345,544

tion models can be deployed to promote one specification over others, but all such theoretical models have unfortunately endowed the consumer with rather perfect information in a situation absent transaction costs. Recent writings appear to accept the notion that choice among alternate price specifications is a matter awaiting empirical, rather than theoretical, resolution [Foster and Beattie, 1981; Opaluch, 1982; Charney and Woodard, 1984]. Theoretically, the parameter estimate for Nordin's difference variable should equal  $\alpha_4$ , but empirical evidence has never supported this hypothesis [Billings, 1982; Jones and Morris, 1984; Chicoine et al., 1986]. Nordin's variable had to be excluded from the demand model postulated here because of high correlation with  $PO$  ( $-0.88$ ). (Correlation between Nordin's difference variable  $D$  and  $PO$  is expected. If  $W$  represents monthly water consumption, then it can be shown that  $D = -W \times PO$ .) Variables  $AP$  and  $PO$  are included to permit testing of the  $AP$  versus  $MP$  specification.

Variables  $CH$ ,  $SP$ , and  $C$  have not been explored in econometric studies, but a sociology study using Texas data did find that  $SP$  had a statistically significant negative relationship with water consumption [Murdock et al., 1986].  $CH$  is included because publicity concerning rate increases is hypothesized to raise public consciousness and decrease water demand. The calculated monthly variable ( $C$ ) is the number of days without a significant rainfall ( $\geq 0.25$  inches) times the month's average temperature ( $^{\circ}F$ ). While such a measure has not been used previously, it seems to offer highly desirable conceptual properties.  $C$  is sensitive to (1) summer lawn watering behavior which usually postpones irrigation when a significant rainfall occurs, (2) winter behavior in which irrigation is minimal, and (3) the varying number of days in different months. We also considered defining significant rainfall to be  $\geq 0.5$  inches but abandoned this alternative when correlation between the two was determined to be 0.98.  $C$  should perform much better than simplistic alternatives (e.g., monthly precipitation), thereby justifying the extensive calculations required to obtain  $C$  from daily data.

#### THE DATA

The use of monthly water consumption data allows us to examine the seasonality of demand and is useful for policy evaluations of peak load pricing [Hanke and Davis, 1973]. Monthly water quantity information ( $Q$ ) was obtained from annual reports made to the Texas Water Development Board by several hundred communities. A mail survey was constructed to obtain water and sewer rate structures for the primary study period, January 1981–December 1986. Rate structure was used to compute each community's  $MP$ ,  $AP$ ,  $PO$ , and  $CH$  during every month. Unlike similar variables in

most studies, these values include both water and sewer rates. Data from a nearby weather station was selected for each community and used to calculate the monthly climate variable. Personal income ( $I$ ) and ethnicity ( $SP$ ) information was obtained from U.S. census information. All data vary monthly except  $I$  and  $SP$  which vary only cross sectionally.

To limit computing expense, test data management programs, and more validly perform pretest statistical work, a subset of the surveyed communities and a more limited time period were chosen for detailed analysis. The restricted study period extends from January 1983–December 1985, inclusively. Thirty communities were selected using the following criteria. No two cities are located in the same county. In terms of the communities' water sources, ten groundwater-dominated, ten surface water-dominated, and ten mixed systems were selected. Each group of ten communities includes a similar range of populations and is as geographically dispersed about the state as the master data set permitted. Preference was given to those communities providing seemingly high quality data in response to the survey.

Table 1 provides a few details concerning the three community groupings selected as a result of these procedures. The completed data set should contain 36 months of data for each of 30 communities, but six observations were discarded because two communities reported being unable to satisfy demand during certain months. Missing water consumption data (36) and missing climate data (17) further reduce the final data set to 1031 observations. Information concerning the range, mean, and standard deviation of individual variables is provided in Table 2. Monthly means for  $Q$ ,  $C$ ,  $AP$ , and  $MP$  are given in Table 3.

To illustrate rates, June and December marginal prices faced by the average household were computed at 500 gallon intervals ( $1.8925 \text{ m}^3$ ) beginning at 250 gallons. Averaging prices in these two months produced the schedules of marginal water and marginal sewer prices exhibited in Figures 1 and 2. Inspection of these graphics reveals significant growth in both water and sewer rates. The large increase in 1985 rates was probably influenced by the 1984 drought which prompted policy changes and capital investment to enhance water supply. While water rates are predominantly of the increasing block variety for the sample, some communities define a maximum sewer bill (discussed later) which causes the marginal monthly sewer price schedules of Figure 2 to begin declining after a certain point. Average monthly bills can be obtained by integrating under the appropriate schedules of Figures 1 and 2 and adding the result to the appropriate base rate (given parenthetically for each year in the figures).

TABLE 2. Data Characteristics ( $N = 1031$ )

Variable	Units	Range	Mean	$\sigma$
$Q$	gal/capita/day	48.4 → 412.6	165.7	55.5
$AP$	\$/1000 gal	0.91 → 4.32	2.12	0.69
$MP$	\$/1000 gal	0.55 → 4.16	1.55	0.63
$PO$	\$/1000 gal	-2.81 → 0.23	-0.56	0.43
$CH$	0, 1	0 → 1	0.16	0.37
$I$	\$/1000	3.66 → 8.23	6.04	1.14
$SP$	percent	0.65 → 19.37	8.23	5.52
$C$	days times °F	732 → 2757	1811	426

## RESULTS

*The Demand Model*

Table 4 presents ordinary least squares (OLS) estimates for equation (1). Model fit is not disappointing in light of the number of communities included in the sample. While the model has poorer fit than many similar models, it is noteworthy that other models have generally employed annual time series data, sometimes for a single water system. *Chicoine et al.* [1986] has also observed that data from different water systems confounds demand modeling. To inspect the effect of pooling 30 communities and thereby investigate this observation, the  $F$  statistic described by *Maddala* [1977, p. 323] was computed after adjusting the statistic to account for more than two cross sections. The correct test statistic is given by

$$F = (S_2 - S_1)(T - KN) / ((KN - K)S_1)$$

where  $S_1$  is the sum of residual sum of squares for  $K$  individual regressions,  $S_2$  is the residual sum of squares for a single regression using all pooled data,  $T$  is the number of pooled observations (1031),  $K$  is the number of cross sections (30), and  $N$  is the number of parameters to be estimated (5). Separate regressions for each community must be performed to obtain information for the test statistic computation.  $I$  and  $SP$  variables were necessarily dropped from all models employed in these calculations because these data are time invariant. According to this statistic ( $F = 31.4$ ), there is strong evidence to not pool this data. This is not surprising, since the individual regressions produce an average  $R^2$  of 0.83 while the pooled regression produced an  $R^2$  of 0.43. Although the pooling test reveals that pooling is inappropriate for the data, the pooled approach produces a more general, statewide model, and very importantly, the pooled data is richer in that prices are more variable. If the

TABLE 3. Monthly Means for Selected Variables ( $N = 1031$ )

	$Q$	$C$	$AP$	$MP$
Jan.	132.8	1240	2.13	1.53
Feb.	130.8	1288	2.20	1.59
March	132.5	1638	2.14	1.55
April	160.9	1867	2.05	1.49
May	178.8	2036	2.01	1.51
June	191.7	2115	2.00	1.51
July	226.0	2363	1.94	1.49
Aug.	224.5	2391	1.94	1.49
Sept.	195.3	2054	2.05	1.56
Oct.	145.3	1788	2.24	1.61
Nov.	131.6	1571	2.37	1.69
Dec.	135.8	1347	2.35	1.66

practitioner wishes to obtain a practical model of water demand for an individual community, the conceptual model can be fitted first to the pooled data. Then, the model can be refitted using only the community's data while constraining parameter estimates for (especially) the economic variables.

A hypothesis test for  $\alpha_1 = \alpha_2$  is rejected ( $F = 65.1$ ) which adds to the literature's weighty evidence that consumers do respond to average price. This finding led us to also estimate a model with  $MP$  replacing the  $AP$  term of equation (1) but equivalent in all other respects. A hypothesis test for  $\alpha_1 + \alpha_2 = 0$  in this latter model cannot be rejected ( $F = 0.124$ ). We conclude that there is strong empirical evidence to prefer the  $AP$  specification over the  $MP$  alternative.

The parameter estimate for the rate change dummy ( $CH$ ) is surprisingly positive but statistically insignificant. The income ( $I$ ) effect is strongly positive, but the Hispanic ethnicity variable ( $SP$ ) has an unexpectedly positive, though quite insignificant, relationship with demand. We hypothesize that the  $SP$  variable is correlated with omitted climatic/geographic variables because the percentage of population with Spanish descendency declines as latitude increases. The climatic variable  $C$  performs very well and is of the expected sign. The data show that this variable commonly ranges from a winter low of about 1200 to a summer high around 2600. This 1400 unit swing produces a 102 gallon ( $0.386 \text{ m}^3$ ) per capita per day change in consumption, according to OLS estimates.

*Can Sewer Rates Be Excluded?*

The  $AP$  and  $MP$  variables include both water and sewer prices ( $AP = APW + APS$ ;  $MP = MPW + MPS$ ). Sewer

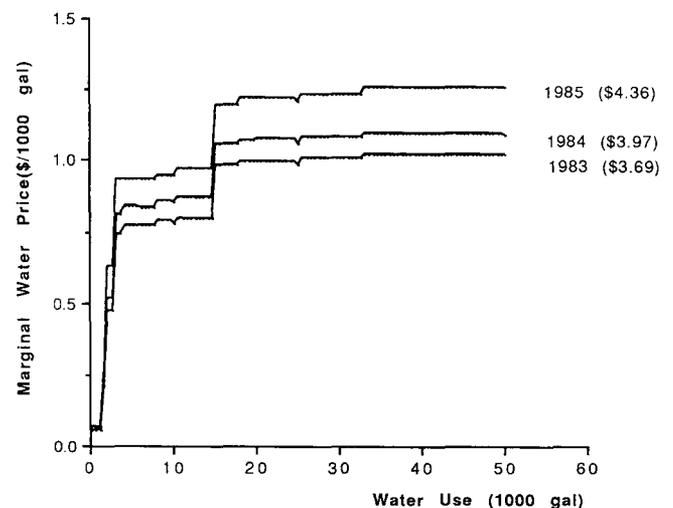


Fig. 1. Marginal water prices by year.

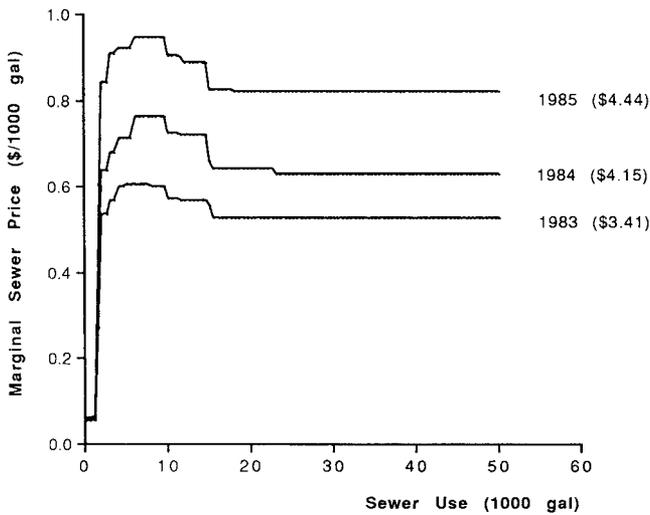


Fig. 2. Marginal sewer prices by year.

rates have been increasing faster than water rates for the data sample. Higher treatment standards and renewed public concern for water quality are likely to maintain pressures which cause sewer rates to increase rapidly. Because previous studies have ignored the potential influence of sewer rates, which are commonly dependent upon water consumption, a natural inquiry concerns the legitimacy of such an exclusion. Sewer rate structures are more variable than water rate structures and are therefore more difficult to deal with. Some communities employ flat rates and others employ flat rates plus an added charge for each fixture (bathrooms, garbage disposals, washing machines, etc.) or for each fixture exceeding a certain number ( $APS > 0$  and  $MPS = 0$  for these structures). Some communities employ sewer rate structures which exhibit blocks (increasing, constant, or decreasing) very much like water rates ( $APS > 0$ ,  $MPS > 0$ ).

Some communities employ typical waterlike rates for winter sewer charges but then fix the consumer's nonwinter sewer charges at an average winter monthly sewer bill. An interesting feature of the latter arrangement observed by Brunton [1981] is that in the common three-month averaging system the actual winter  $MPS$  is 4 times the stated rate ( $APS > 0$  all year,  $MPS > 0$  during winter,  $MPS = 0$  during nonwinter). Other communities have waterlike sewer rates yearround except that the sewer bill reaches an upper bound at or above a chosen amount of metered water consumption ( $MPS > 0$  below this chosen amount and  $MPS = 0$  above it).

TABLE 4. Ordinary Least Squares Estimates for the Demand Model

	$\alpha_j$	$t$
Intercept	26.84	2.21
$AP$	-26.78	-11.91
$PO$	-1.23	-0.35
$CH$	5.36	1.55
$I$	9.95	7.88
$SP$	0.185	0.70
$C$	0.0731	23.67
$F$	148.4	
$R^2$	0.47	
$n$	1031	

TABLE 5. Auxiliary Regressions (Ordinary Least Squares) for Obtaining Seasonal Elasticities

	A	B
Intercept	-98.00 (-4.54)	-95.98 (-4.52)
$AP$	25.58 (2.75)	31.40 (3.69)
$AP \times C$	-0.0288 (-5.74)	-0.0317 (-6.94)
$PO$	-22.67 (-1.58)	
$PO \times C$	0.0118 (1.49)	
$I$	10.64 (8.59)	10.50 (8.84)
$SP$	0.137 (0.53)	0.198 (0.77)
$C$	0.139 (13.96)	0.138 (13.94)
$F$	140.0	195.4
$R^2$	0.49	0.49
$n$	1031	1031

The  $t$  statistics are in parentheses.

Due to the several types of sewer rate structures, accurate incorporation of sewer rates can be arduous. The sewer rates calculated for the earlier analysis were correctly obtained, but we did not include 12x, 6x, 4x, or 3x factors for winter rates in which the sewer rate structure was based on average winter water consumption. We feel that the consumer is unaware of this property so we have ignored it.

To test the legitimacy of excluding sewer rates we reestimate equation (1) with  $-APS$  replacing the  $PO$  variable. Pertinent parameter estimates (and  $t$  statistics) are  $\alpha_1 = -20.85$  (-6.88) and  $\alpha_2 = 14.96$  (2.34). (We are aware that fundamental OLS assumptions for the earlier demand model and this revised model are incongruent. The result is that  $t$  statistics for one of these models are unavailable. We are willing to proceed with the injustice because the invalid  $t$  statistics convey useful knowledge which we are unwilling to discard.) The general measures of fit for this model are  $R^2 = 0.47$  and  $F = 150.2$ . If  $APS$  can be neglected, then  $\alpha_1 = \alpha_2$ . The  $F$  statistic for this hypothesis is 67.9 so it is rejected with over 99.9% confidence. This clearly suggests that analyses which fail to incorporate sewer prices are deficient in the sense that an important explanatory variable is excluded. Moreover,  $APW$  and  $APS$  are positively correlated, so the exclusion  $APS$  biases the regressor of  $APW$  negatively ( $APW$  elasticity is overstated). The statistical importance of sewer prices is interesting in that the majority of consumers are probably unaware that their water consumption influences

TABLE 6. Seasonal Elasticity Estimates

	A	B
$AP$		
$\epsilon_{winter}$	-0.19	-0.16
$\epsilon_{summer}$	-0.37	-0.38
$PO$		
$\epsilon_{winter}$	+0.035	
$\epsilon_{summer}$	-0.010	
$I$		
$\eta_{winter}$	+0.48	+0.48
$\eta_{summer}$	+0.30	+0.30

their sewer bill. This is additional evidence, along with the superior performance of the AP specification, that what consumers really respond to is their utility bills. Whereas consumers do not necessarily understand the mechanisms by which their utility bills are computed from their water consumption quantities, they do understand that higher consumption implies higher bills (including sewer).

### Seasonal Elasticity Measures

To obtain seasonal price elasticity estimates, equation (1) is reestimated (with *CH* dropped) after adding price-climate cross products. To better gauge sensitivities to price specification, two models are investigated. Estimates and pertinent statistics are presented in Table 5. The overall predictive abilities of these models is similar to the original demand model.

Using appropriate parameter estimates for models A and B and average winter (December–February) and summer (June–August) values for *AP*, *PO*, *I*, and *C* in all 30 communities, winter and summer price and income elasticities are computed (Table 6). Price elasticities for the *PO* variable are obviously very low. *AP* and *I* elasticity estimates compare favorably to elasticities tabulated from other studies [Wong, 1972; Danielson, 1979]. If model B elasticities are used for clarity, a 10% increase in mean winter average price (from \$2.22 to \$2.44 per thousand gallons) produces a 1.6% decrease in daily water consumption (from 133.1 to 131.0 gallons per capita per day) (1000 gallons is equal to 3.785 m<sup>3</sup>). Similarly, a 10% increase in summer average price (from \$1.96 to \$2.16) decreases water consumption by 3.8% (from 214.0 to 205.9 g/c/d). These numbers translate into 15 million gallons of reduced water use during a 90-day winter period for our average 80,000 person community and 59 million gallons during a 90-day summer period. Utility revenues are accordingly increased by 8.2% for the winter price hike and 6.0% for the summer increase.

As reported for west Texas [Jonish and Butler, 1983], no community in our sample employs peak load pricing during summer months. The results of this analysis suggest, however, that higher summer water (plus sewer) rates can be an effective conservation tool. Because (1) summer demand is more elastic than winter demand and (2) base summer demand is higher, our results indicate that the same percentage increase in average price will conserve nearly 4 times as much water during the summer than in the winter.

### CONCLUSIONS

These analyses have investigated some previously neglected aspects of residential water demand. Like previous research, OLS demand results indicate consumers respond to average price rather than marginal price. Calculated demand elasticity is similar to those reported from other research. An appropriately specified hypothesis test indicates that econometric estimates of community water demand should include water-dependent sewer rates. The omission of sewer rates can bias estimated demand sensitivity to water price.

The acquisition of monthly data for this study permits the evaluation of monthly or seasonal price sensitivity. A new climate variable is introduced for explaining seasonal varia-

tions in water use, and this variable is found to be highly significant. Moreover, results clearly indicate summer price elasticities which, depending on the specification employed, are about 50% higher than winter elasticities. Coupled with the fact that capital expenditures to create peak load capacities represent a large proportion of utility costs, this information offers an important argument favoring TOY rates.

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