Seasonality in Community Water Demand

Ronald C. Griffin and Chan Chang

Secondary data and survey information are used to develop a large data set for analyzing water demand in 221 communities. The resulting monthly data are employed to examine seasonal variability in consumer price sensitivity. Several functional forms are contrasted for their abilities to identify monthly price elasticities. Results demonstrate the statistical contribution of a new climate variable for fitting monthly data, generally indicate that summer price elasticities exceed winter price elasticities by 30%, and appear to reject the use of the translog functional form as well as traditional linear and Cobb-Douglas forms for statistical analyses of pooled monthly data. The generalized Cobb-Douglas and augmented Fourier forms are more viable alternatives for pooled monthly data.

Key words: water conservation, water demand, water policy.

Interest in residential water demand stems fundamentally from the potential of price as a rationing mechanism and the use of surplus measures to calculate value. Literature in this area is now voluminous and has increasingly turned to more complex econometric endeavors seeking to fine tune findings by eliminating intrinsic biases and misspecifications (Billings; Billings and Agthe; Charney and Woodard; Chicoine, Deller, and Ramamurthy; Foster and Beattie 1979, 1981; Griffin, Martin, and Wade; Jones and Morris; Opaluch 1982, 1984). The chosen tack of the research reported here places more emphasis on end uses of the analysis and the compilation of a large data set with the ability to address seasonality in water demand.

The seasonality of water demand is important in two respects. First, available evidence that summer residential water demands are more price responsive than winter demands implies that price can be a more effective allocative tool during the summer. It is argued that time-of-year water pricing can be an effective water conservation policy (Feldman; Hanke and Davis), but such an approach cannot be analyzed without knowing seasonal price elasticities. Second, these same arguments suggest that the value of water supply enhancements has dynamic dimensions. More simply, supply enhancements contributing to summer supply are more highly valued than similar enhancements to winter supply. Because the value of a supply increment or decrement is estimable as a change in consumer surplus, knowledge of seasonal demand, rather than annual demand, permits a much more accurate assessment of water value.

Pretest analyses were undertaken to focus the research conducted here (Griffin and Chang). These pretest analyses utilized a more general set of explanatory variables and models than those explored in this article but only employed linear forms. A small portion of the sample generated for this final analysis was carefully selected for use in the pretest analyses. Among other things, pretest work determined that (*a*) average price is a statistically preferred price specification for demand when contrasted to marginal price, (*b*) demand price elasticity appears to vary seasonally, and (*c*) the demand price specification should include sewer fees.[1] These results were accepted as guidance for further work using the complete data set.

The authors are an associate professor and a research associate, respectively, in the Department of Agricultural Economics, Texas A&M University.

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[1] Monthly sewer bills are commonly dependent upon metered water use.

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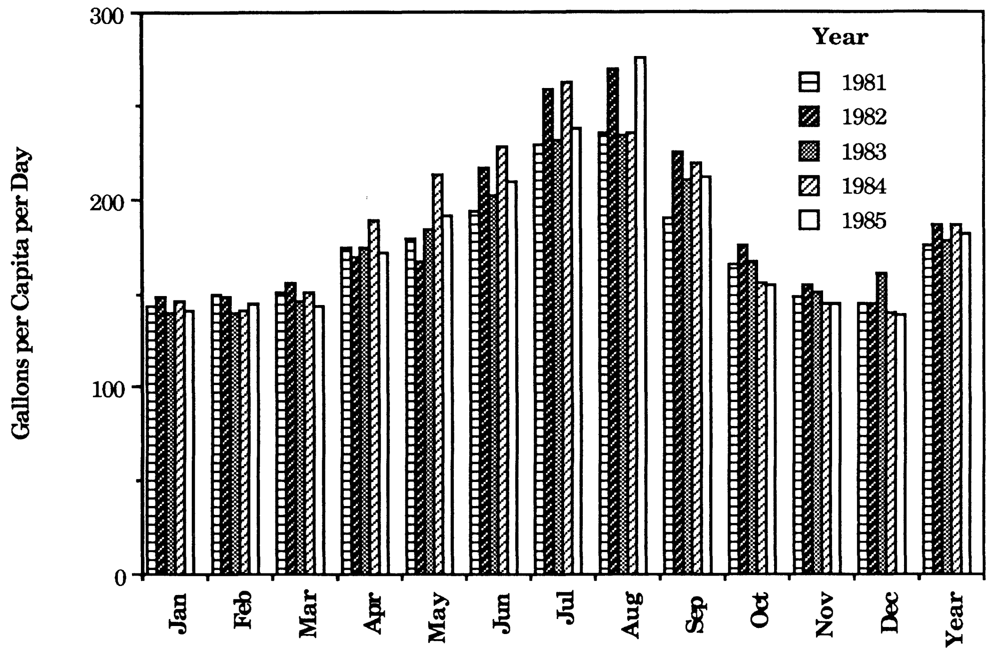

Figure 1. Monthly and annual water use by year

General Model and Data

Monthly water use is hypothesized to be functionally related to five variables,

$$Q = f(AP, I, SP, C, AAP),$$

where Q is per capita residential and commercial water consumption (gallons per day), AP is the average real price of water ($ per 1,000 gallons) over the month to the average (2.84 persons) household when consumption is Q, I is a community's average 1980 income ($1,000 per capita), SP is percentage of the community's 1980 population of Hispanic origin, C is the number of days without a significant rainfall ($\geq .25$ inches) in the community multiplied by the month's average temperature (°F), and AAP is average annual precipitation (inches) from 1951–80. Comparing this specification to others in the literature reveals that only SP and C are atypical. The Hispanic ethnicity variable was suggested by a sociological study that found a negative relationship between this variable and per capita water use, presumably caused by the larger household size of Hispanic families (Murdock et al.). AAP was not employed in pretest work, but it is included here in an attempt to demystify pretest results regarding SP. Pretest parameter estimates for SP were of a counterintuitive sign (positive) until we realized SP increases as one goes south and west in Texas. Thus, it may have been acting more as an index of average climate conditions. The addition of AAP, therefore, seemed appropriate as a correction.

The monthly climate variable, C, is an original construct intended to be sensitive to outdoor water demands. Simplistic climate variables such as monthly rainfall or average temperature are more easily obtained, but C embodies more information. C maintains that (*a*) water demand behavior responds more to rainfalls than rainfall amounts and (*b*) temperature and the absence of rainfall events interact in a multiplicative fashion influencing demand. C is also successful in observing the differing lengths of months.

Data for these six variables were accumulated for five years, 1981–85, and 221 Texas communities. Q, AP, and C are monthly variables which vary cross sectionally and temporally. Data for I, SP, and AAP have no time-series component and vary only cross sectionally.

Consumption data acquired from the Texas

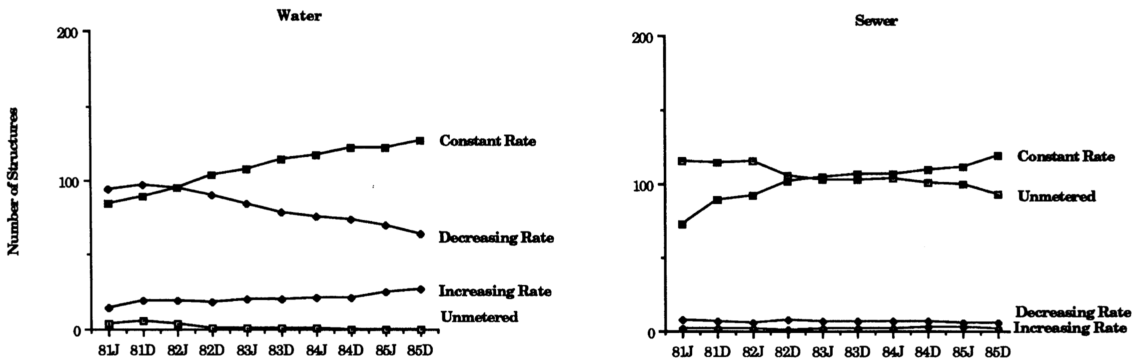

Figure 2. Trends in rate structure

Water Development Board were employed to calculate Q. This variable is highly variant across the data set, ranging from 21 to 731 gallons per capita per day.[2] Because communities actually report water production rather than water consumption, monthly data have more measurement error than do annual data.[3] Averaging population-weighted data across the entire sample produces the patterns of water use illustrated in figure 1. The seasonality of water use is quite evident from this graphic, but other interesting details are also apparent. Demand in winter months is rather invariant from year to year except in the case of December 1983. A severe freeze during this month caused widespread broken pipes. Annual demands are also relatively constant. Water use during summer months can be highly variable from year to year.

A survey designed to obtain water and sewer rate structures for the study period was mailed to 1,140 Texas communities; usable responses were received from 479. The availability of weather, census, and water consumption data, as well as other considerations reduced the sample to 221 communities. Water and sewer rates were computer coded for these communities and, together with consumption data, were used to calculate AP. The monthly Consumer Price Index was used to place all prices on a real basis (January 1981 = 100). All communities in the sample charge both water and sewer rates, and AP includes both water and sewer fees.

For illustration, each community's rates in June and in December were examined to assess rate structure. Because it is possible for a multiblock[4] structure to take on a decreasing block character across one range of consumption levels and an increasing block character across another, this examination identifies marginal water price at 30,000 gallons and compares this marginal price to the marginal price for the preceding block (if one exists). The number of communities using each structure type was counted for both water and sewer rates, and the results appear in the two panels of figure 2. Figure 2 shows that decreasing block

[2] Water use data were collected initially for 255 communities, but the range of water use data was unacceptably extreme (three to 1,631 gallons per capita per day). Nineteen communities were deleted from the sample because of exceedingly low reported water use (less than 2,300 gallons per capita per month) in more than 10% of months reported. Seventeen communities were deleted because of exceedingly high reported water use (more than 13,600 gallons per capita per month) in more than 10% of the months reported. Two communities were members of both low and high groups, so 34 communities were deleted from the original sample.

[3] Production and consumption are unequal because of intermediate ground and elevated storage. This is more problematic for monthly data in that heightened production during one month may be in anticipation of next month's expected higher consumption.

[4] Block rates are common in water and sewer pricing and are defined generally by

Monthly Bill =

$$\begin{cases} BR & \text{if } \quad W \leq B_0 \\ BR + P_1\cdot(W - B_0) & \text{if } B_0 < W \leq B_1 \\ BR + P_1\cdot(B_1 - B_0) + P_2\cdot(W - B_1) & \text{if } B_1 < W \leq B_2 \\ \vdots & \vdots \end{cases}$$

where BR is the base rate (a fixed monthly fee independent of water consumption), P_i is the marginal price within block i, W is metered water consumption, B_0 is the amount of "free" consumption, and B_i is the water quantity defining the end of block i (and the beginning of block $i + 1$). For decreasing block rates, $P_1 > P_2 > P_3 > \ldots$, and $P_1 < P_2 < P_3 < \ldots$ for increasing block rates. Constant rates imply equality of all block prices.

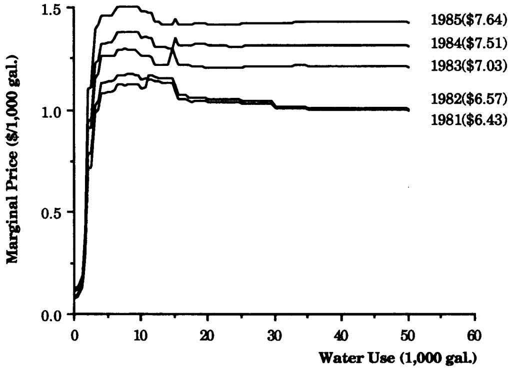

Figure 3. Average marginal water and sewer price by year (January 1981 dollars)

water rate structures are being abandoned in favor of constant rates, and, to a much lesser extent, increasing block rates. Unmetered sewer rates apparently are being converted to constant rates.

To illustrate combined water and sewer rate schedules, June and December marginal prices faced by the average Texas household were computed for each community at 500-gallon intervals beginning at 250 gallons. Averaging prices in these two months and across all 221 communities produced the schedules of marginal water plus sewer prices shown in figure 3. Average combined base rates for each year are given parenthetically in figure 3. Inspection of this graphic reveals significant growth in real water rates. This may be a very important trend insofar as the price responsiveness of consumers combined with price growth could reduce/eliminate the need for enhancing urban water supply.

I and *SP* were computed directly from U.S. census data. *AAP* is contained in a National Oceanic and Atmospheric Administration report (U.S. Department of Commerce). Daily National Weather Services data on magnetic tape for all Texas weather stations were used to calculate *C* after each community was paired with a specific weather station.

Because of missing consumption, rates, or weather information, there is not data for five years for every community. The average record is 4.5 years per community, and there are 12,050 observations in the completed data set. Most of the above variables as well as others and about 8% of the data set were used in the pretest analyses mentioned previously.

Form Considerations

We proceed with the presumption that decision makers engaged in demand projection, rate evaluation, or policy analysis know, at least approximately, a point (Q_t, AP_t) on each month's per capita water demand curve in their study area. It is also assumed that planners know population and possess a population projection method or model. Therefore, planning pursuits would be most readily assisted by the additional knowledge of the slope or elasticity of demand at the known point. Together with the known point, this information permits the local approximation of monthly water demand and thereby enables the desired analysis. Aggregate demand can be forecasted, responses to rate changes can be estimated, and surplus measures corresponding to supply enhancements or demand management policies can be calculated (Griffin).

For these reasons, we emphasize the determination of monthly water demand elasticities rather than the estimation of the entire monthly water demand function. Thus, it may be important to use functional forms which are flexible in the sense that few a priori restrictions are placed upon parameter estimates involving the price variable. Previous water demand studies used linear and Cobb-Douglas forms almost exclusively. The inflexibility of the linear form is well acknowledged in other literature areas (Griffin, Montgomery, and Rister). The Cobb-Douglas form can be suitable for analyses investigating annual demand, but the form maintains (forces) constant price elasticity and may be limiting for studies of monthly water demand.

For purposes of comparison with earlier studies, elasticities from linear and Cobb-Douglas models are reported here. The analysis emphasizes, however, elasticity estimates resulting from generalized Cobb-Douglas, translog, and augmented Fourier forms. Both generalized Cobb-Douglas and translog forms incorporate the Cobb-Douglas form as a special case (Griffin, Montgomery, and Rister). The translog form is locally flexible and the augmented Fourier form is globally flexible (Griffin, Montgomery, and Rister).

Model Results

OLS estimates for four models are reported in tables 1 and 2. Our use of aggregate data in-

Table 1. Parameter Estimates for Linear and Cobb-Douglas Models

	Linear			Cobb-Douglas	
$Q =$	10.33 (1.64)		$\ln(Q) =$	0.706 (8.12)	
	+27.30 (9.21)	AP		−0.350 (−50.53)	$\ln(AP)$
	−0.0310 (−19.15)	$AP \times C$			
	+4.20 (13.33)	I		+0.128 (11.10)	$\ln(I)$
	−1.21 (−13.22)	SP		−0.00669 (−13.33)	SP
	+0.128 (43.18)	C		+0.649 (60.07)	$\ln(C)$
	−1.36 (−26.32)	AAP		−0.154 (−18.55)	$\ln(AAP)$
F	1,338.7			1,618.2	
R^2	.40			.40	
n	12,050			12,050	

Note: t-statistics are in parentheses.
Key: Q = Water Consumption; AP = Average Price; I = Income; SP = Percent Hispanic; C = Climate; AAP = Average Annual Precipitation.

corporating a variety of rate types (recall figure 2) legitimizes OLS, because a simultaneity problem is not expected (Shin). To better capture the periodic nature of price elasticity, a price-climate cross-product, $AP \times C$, has been included in the "linear" model. Also, the Cobb-Douglas and translog models are not pure because the fact that SP can equal zero makes it impossible to include $\ln(SP)$ as a separate term; therefore, SP was used in these models in lieu of $\ln(SP)$.

Exogenous variables must be normalized into $[0, 2\pi]$ prior to estimating the augmented Fourier form. To accomplish this, the exogenous variables were divided by the constants given parenthetically: AP (2), I (5), SP (12), C (900), and AAP (20). All calculations using this model must take account of this normalization. The selected degree of the Fourier portion of this model is two, so the model possesses 21 polynomial terms (counting the intercept) and 60 trigonometric terms. The large size of this model is intended to take advantage of the large data set and to exploit the global flexibility of this functional form. Additional conceptual details for the augmented Fourier functional form can be obtained from Griffin, Montgomery, and Rister. Parameter estimates for this model are provided in table 3. Neither t-statistics nor standard errors are given because of space limitations. The enhanced fit of this model ($R^2 = .57$) is expected.

All five models offer similar measures of overall fit.[5] R^2 is uniformly low but is not poor in light of the realities of dealing with monthly data peculiar to this study and the level of aggregation (community) common to most studies. Reported t-statistics demonstrate that most parameter estimates are statistically significant and tightly known. Climate (C) and price (AP) variables are the two most significant variables in the models. Global price and income elasticities are immediately apparent from the Cobb-Douglas results: $\epsilon = -.350$, $\eta = .128$. A 99% confidence interval for ϵ from this model ranges from $-.348$ to $-.352$.

Two plots of the generalized Cobb-Douglas (GCD), translog (TL), and augmented Fourier (AF) demand models are presented in figure 4. All of these demand curves correspond to mean levels of income, ethnicity, and average annual precipitation ($\bar{I} = 6.397$, $\overline{SP} = 6.071$, $\overline{AAP} = 32.46$). January and July versions of each functional form specification are illustrated using mean values of the climate variable ($\bar{C}_{JAN} = 1{,}287.13$, $\bar{C}_{JUL} = 2{,}358.64$). It is demonstrated by figure 4 that the AF form performs poorly at winter prices exceeding \$2.50 and at summer prices exceeding \$4.50.

[5] The linear and augmented Fourier models are not directly comparable to the other three models on the basis of R^2 because they have a different dependent variable.

Table 2. Parameter Estimates for Generalized Cobb-Douglas and Translog Models

	Generalized Cobb-Douglas			Translog	
ln(*Q*) =	−5.09		ln(*Q*) =	48.25	
	(−17.35)			(20.77)	
	−0.584	ln(*AP*)		+0.405	ln(*AP*)
	(−23.07)			(1.78)	
				+0.0217	$(\ln(AP))^2$
				(2.02)	
	+0.480	ln(*AP* + *I*)		−0.0370	ln(*AP*)ln(*I*)
	(3.33)			(−1.23)	
	+0.117	ln(*AP* + *SP*)		−0.0134	(ln(*AP*))*SP*
	(7.60)			(−9.98)	
	+123.95	ln(*AP* + *C*)		−0.0166	ln(*AP*)ln(*C*)
	(6.55)			(−0.61)	
	−0.557	ln(*AP* + *AAP*)		−0.148	ln(*AP*)ln(*AAP*)
	(−1.54)			(−6.81)	
	−0.104	ln(*I*)		−3.59	ln(*I*)
	(−0.92)			(−8.97)	
				+0.398	$(\ln(I))^2$
				(15.19)	
	−0.354	ln(*I* + *SP*)		+0.0158	(ln(*I*))*SP*
	(−8.13)			(6.54)	
	+71.30	ln(*I* + *C*)		+0.472	ln(*I*)ln(*C*)
	(8.96)			(9.72)	
	−0.957	ln(*I* + *AAP*)		−0.374	ln(*I*)ln(*AAP*)
	(−5.10)			(−10.13)	
	+0.0105	*SP*		0.0643	*SP*
	(3.54)			(3.75)	
				−0.000214	SP^2
				(−3.37)	
	+17.97	ln(*SP* + *C*)		−0.00373	*SP*ln(*C*)
	(6.16)			(−1.84)	
	−0.540	ln(*SP* + *AAP*)		−0.0177	*SP*ln(*AAP*)
	(−8.92)			(−10.36)	
	−243.80	ln(*C*)		−14.86	ln(*C*)
	(−12.41)			(−26.19)	
				+1.16	$(\ln(C))^2$
				(30.74)	
	+32.31	ln(*C* + *AAP*)		−0.739	ln(*C*)ln(*AAP*)
	(18.97)			(−22.26)	
	+1.06	ln(*AAP*)		+7.45	ln(*AAP*)
	(3.01)			(26.56)	
				−0.180	$(\ln(AAP))^2$
				(−9.39)	
F	633.78			575.47	
R^2	.44			.49	
n	12,050			12,050	

Note: *t*-statistics are in parentheses.
Key: *Q* = Water Consumption; *AP* = Average Price; *I* = Income; *SP* = Percent Hispanic; *C* = Climate; *AAP* = Average Annual Precipitation.

Monthly Demand Elasticity

Elasticity formulae for the linear (L), GCD, and TL models are given by

$$\epsilon_L = \frac{AP}{Q}\cdot(\delta_1 + \delta_2\cdot C),$$

$$\epsilon_{GCD} = \delta_1 + AP\cdot\left[\frac{\delta_2}{AP + I} + \frac{\delta_3}{AP + SP} + \frac{\delta_4}{AP + C} + \frac{\delta_5}{AP + AAP}\right],$$

and

$$\epsilon_{TL} = \delta_1 + \ln(AP^{2\delta_2} I^{\delta_3} C^{\delta_5} AAP^{\delta_6}) + \delta_4\cdot SP,$$

Table 3. Parameter Estimates for the Augmented Fourier Model

Q =	2,500		+8.25	cos(AP + SP)	−67.2	sin(I − C)
	+8,024	AP	−42.8	sin(AP + SP)	−202	cos(I − AAP)
	−2,693	AP^2	−62.4	cos(AP + C)	+120	sin(I − AAP)
	−506	AP·I	+36.1	sin(AP + C)	+5,507	cos(SP)
	−90.3	AP·SP	−297	cos(AP + AAP)	+17,089	sin(SP)
	−41.2	AP·C	+38.2	sin(AP + AAP)	+1,183	cos(2SP)
	+68.0	AP·AAP	−5.48	cos(AP − I)	−918	sin(2SP)
	−22,860	I	−49.4	sin(AP − I)	−1.82	cos(SP + C)
	+6,555	I^2	+52.6	cos(AP − SP)	+42.5	sin(SP + C)
	+96.7	I·SP	−28.2	sin(AP − SP)	+112	cos(SP + AAP)
	−5.66	I·C	+113	cos(AP − C)	−168	sin(SP + AAP)
	+217	I·AAP	−16.9	sin(AP − C)	+26.7	cos(SP − C)
	−14,759	SP	+101	cos(AP − AAP)	−14.2	sin(SP − C)
	+5,932	SP^2	−171	sin(AP − AAP)	+119	cos(SP − AAP)
	−9.51	SP·C	−2,995	cos(I)	−62.7	sin(SP − AAP)
	−314	SP·AAP	+18,951	sin(I)	−5,470	cos(C)
	−23,704	C	+1,257	cos(2I)	+16,922	sin(C)
	+6,346	C^2	+419	sin(2I)	+1,100	cos(2C)
	−25.2	C·AAP	+42.9	cos(I + SP)	+765	sin(2C)
	−40.0	AAP	−82.5	sin(I + SP)	+80.6	cos(C + AAP)
	+129	AAP^2	+19.9	cos(I + C)	+20.8	sin(C + AAP)
	−1,515	cos(AP)	+22.2	sin(I + C)	−105	cos(C − AAP)
	−7,560	sin(AP)	−83.2	cos(I + AAP)	−28.8	sin(C − AAP)
	−570	cos(2AP)	+35.3	sin(I + AAP)	+756	cos(AAP)
	+201	sin(2AP)	−210	cos(I − SP)	+829	sin(AAP)
	+426	cos(AP + I)	−63.2	sin(I − SP)	+164	cos(2AAP)
	−404	sin(AP + I)	+16.5	cos(I − C)	−93.8	sin(2AAP)
F	195.41					
R^2	.57					
n	12,050					

Note: 56 of the 81 parameter estimates are significant at the 5% level.
Key: *Q* = Water Consumption; *AP* = Average Price; *I* = Income; *SP* = Percent Hispanic; *C* = Climate; *AAP* = Average Annual Precipitation.

where δ_i is the model's *i*th term (δ_0 is the intercept) listed in tables 1 or 2. An elasticity formula for the AF model is omitted because of its large size.

The first four columns of table 4 contain monthly demand elasticities resulting from the linear, GCD, TL, and AF models. These elasticities have been computed using the parameter estimates of tables 1–3; overall means for *I, SP,* and *AAP*; monthly means for *AP* and *C*; and predicted values for *Q*. These same findings are illustrated in figure 5 (annual elasticities are offered parenthetically in this figure). The last five columns of table 4 contain elasticities computed from unreported regressions involving separate models for each month.

Focusing on the "Aggregate Data Models" results of table 4, linear model elasticities are clearly deficient in that they are much lower than elasticity results of the remaining models. It is noteworthy that the GCD, TL, and AF models produce highly consistent elasticities at annual means and that these elasticities are only slightly lower than the −.35 value from the Cobb-Douglas (CD) model. The TL model produces a slight seasonal variation in consumers' price responsiveness. Not only are the TL results counterintuitive in this respect, but they contradict GCD and AF elasticities which illustrate substantial seasonal variation. It appears that when monthly data are pooled across months, linear and translog functional forms may be incapable of capturing seasonal price sensitivity. The CD form maintains constant price elasticity, so it is obviously incapable in this respect. The GCD results indicate higher winter elasticities and lower summer elasticities than those from the AF model.

These results suggest that seasonality exists, but its extent is unclear due to functional form sensitivity. Another perspective can be obtained by (*a*) partitioning the data into 12 sets corresponding to separate months, (*b*) estimating demand models for each month, and (*c*) computing elasticities. Our large data set makes such a procedure feasible. It is noteworthy that this method implicitly presumes

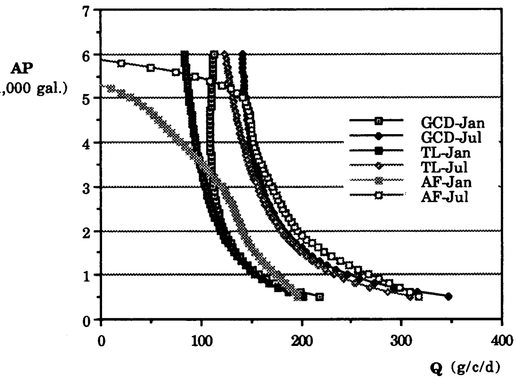

Figure 4. January and July plots of translog (TL), generalized Cobb-Douglas (GCD), and augmented Fourier (AF) models

that, for example, consumer behavior during June does not elucidate May behavior. Regression results obtained with this method are characterized by low R^2 for winter months and high R^2 for summer months, but parameter estimates are not reported here. Elasticity findings are reported in the final five columns of table 4 and graphed in figure 6. With the exception of the linear model, seasonality becomes more pronounced for all functional forms when estimation is done using data from individual months. This is most apparent for the translog form. Summer elasticities are generally higher and winter elasticities are typically lower using monthly data models. Graphs of these results for all five forms are shown by figure 6 to be related in a rather parallel manner. Taken with the evidence produced from the pooled data, the monthly data results indicate that Cobb-Douglas and translog forms should not be employed with pooled data. The linear form produces results which are inconsistent with results from other forms for both data types.

Elasticity Confidence Intervals

To further explore the issue of seasonal elasticity, confidence intervals for the GCD and TL elasticities were estimated for the aggregate data findings. In general, elasticity estimates are nonlinearly dependent upon parameter estimates. Because the parameter estimates are imperfectly known, so are the elasticities which are computed with them. Generally,

$$\hat{\epsilon} = h(\hat{\delta}; AP, I, SP, C, AAP),$$

where $\hat{\epsilon}$ are elasticity estimates (such as those in table 4), h is a nonlinear function, and $\hat{\delta}$ is the vector of stochastic parameter estimates (tables 1–3). Letting δ denote the vector of true and unknown estimators, the Taylor-series expansion of h about δ is

$$\hat{\epsilon} = h(\delta; \ldots) + h'(\delta; \ldots)(\hat{\delta} - \delta) + \text{higher-order terms},$$

where $h'(\,)$ is the vector of partial derivatives of h with respect to δ and $h(\delta; \ldots)$ is the true and unknown elasticity, ϵ. The higher-order

Table 4. Price Elasticities Evaluated at Monthly Means

	Aggregate Data Models				Monthly Data Models				
Month	L	GCD	TL	AF	L	CD	GCD	TL	AF
January	−.175	−.311	−.354	−.281	−.245	−.294	−.357	−.322	−.320
February	−.172	−.301	−.352	−.272	−.274	−.324	−.388	−.358	−.384
March	−.271	−.348	−.358	−.329	−.265	−.306	−.363	−.328	−.395
April	−.301	−.369	−.361	−.366	−.288	−.335	−.398	−.365	−.373
May	−.309	−.382	−.364	−.389	−.269	−.331	−.390	−.372	−.345
June	−.316	−.391	−.365	−.408	−.291	−.372	−.433	−.395	−.388
July	−.329	−.410	−.370	−.467	−.292	−.386	−.437	−.418	−.456
August	−.329	−.412	−.370	−.476	−.282	−.373	−.384	−.381	−.454
September	−.314	−.394	−.366	−.414	−.260	−.327	−.355	−.343	−.371
October	−.302	−.360	−.360	−.350	−.243	−.299	−.341	−.308	−.208
November	−.270	−.332	−.355	−.303	−.234	−.276	−.323	−.300	−.114
December	−.209	−.310	−.353	−.276	−.257	−.313	−.328	−.323	−.226
ANNUAL	−.293	−.366	−.361	−.361	—	—	—	—	—

Key: L = Linear; CD = Cobb-Douglas; GCD = Generalized Cobb-Douglas; TL = Translog; AF = Augmented Fourier.

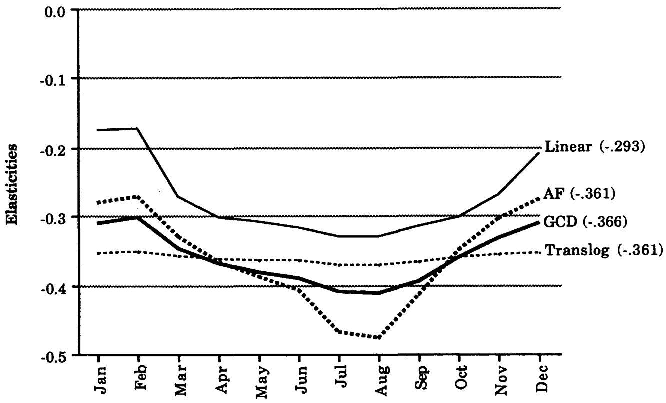

Figure 5. Price elasticities from aggregate models

terms, which tend towards zero, can be dropped to obtain a linear approximation. When h is linear in $\boldsymbol{\delta}$ (as in the linear, generalized Cobb-Douglas, and translog cases), the higher-order terms are zero. Omitting the higher-order terms and rearranging the previous equation,

$$\hat{\epsilon} - \epsilon \cong h'(\boldsymbol{\delta}; \ldots)(\hat{\boldsymbol{\delta}} - \boldsymbol{\delta}).$$

Therefore, an estimated variance for elasticity is given by

$$s_{\hat{\epsilon}}^2 \cong (h'(\hat{\boldsymbol{\delta}}; \ldots))(\mathrm{Var}\,(\hat{\boldsymbol{\delta}}))(h'(\hat{\boldsymbol{\delta}}; \ldots))^t$$

where Var($\hat{\boldsymbol{\delta}}$) is the square matrix of estimator covariances and t denotes the transpose operation. Performing the calculations to obtain monthly $s_{\hat{\epsilon}}^2$ for linear, GCD, and TL elasticity estimates produces values ranging from about .00005 to .0002 across the three models. Assuming $s_{\hat{\epsilon}}^2 = .0002$ and employing the t-distribution, 99% confidence intervals lie ±.00033 about the estimates given in table 4. Similar calculations were not attempted for the AF model because of the large size of Var($\hat{\boldsymbol{\delta}}$).

Because elasticity confidence intervals resulting from one model do not generally contain elasticity estimates from another model, we conclude that results are statistically sensitive to inherent functional form rigidities. It appears that linear, Cobb-Douglas, and translog forms are not appropriate models for investigations of monthly or seasonal water demands, at least when a pooled data set is employed. If data availability is sufficient to permit the estimation of separate monthly models, then the Cobb-Douglas and translog forms can be successful in emulating more flexible GCD and AF models. As a consequence of its global flexibility, the augmented Fourier form is often promoted by theoreticians. If this

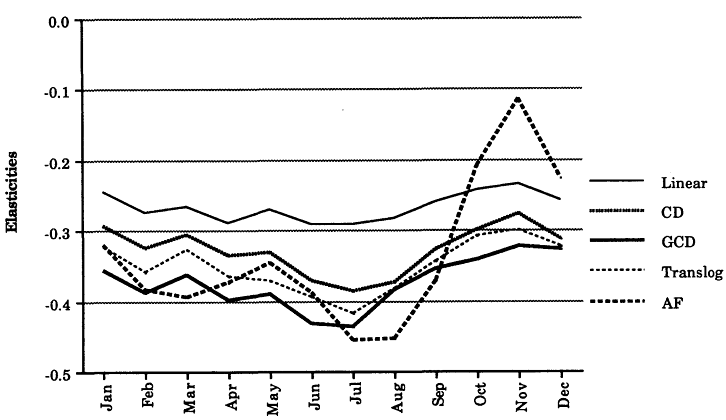

Figure 6. Price elasticities from monthly models

Table 5. January and July Price Elasticities

	January			July		
AP	TL	GCD	AF	TL	GCD	AF
$1.00	−.378	−.423	−.278	−.388	−.467	−.379
$2.00	−.349	−.281	−.255	−.359	−.368	−.393
$3.00	−.332	−.151	−.793*	−.343	−.282	−.377
$4.00	−.320	−.030	−2.175*	−.331	−.204	−.278
$5.00	−.311	+.085	−13.375*	−.321	−.133	−1.377*

* Figure 4 plots of the AF model suggest that these elasticities are unreliable and should be ignored.
Key: TL = Translog; GCD = Generalized Cobb-Douglas; AF = Augmented Fourier; *AP* = Average Price.

model can serve as a benchmark, the generalized Cobb-Douglas form produces good results in all months except July and August. Figure 4 demonstrated, however, that the AF model does not perform satisfactorily at the edges of the data range. Therefore, while some models examined here are clearly deficient in particular usages, no particular model emerges as the preferred choice.

Demand Elasticity over the Price Range

Plotting demand curves for the aggregate data models (as in figure 4) enables a ready comparison of forms but is also interesting from the perspective of illustrating price sensitivity across the range of observed prices. For example, the plotted GCD model suggests no price sensitivity in January demand at high prices ($AP \geq \$3.50$). Such a finding, if verified by other researchers, has important implications for rate evaluation and policy analysis.

To better examine the variability of price elasticities across the range of observed prices, elasticities were calculated and are reported in table 5. All three of these aggregate data models support the idea that price sensitivity declines as price rises. The TL model suggests moderate declines in price responsiveness as price rises, but dramatic changes in price elasticity are indicated by the GCD model. Recalling the rather flat TL elasticities of figure 5 which illustrated fairly invariant elasticities across months (and *C*), we suspect that inherent rigidities of the TL form prohibit much sensitivity to either *C* or *AP*. The AF form is difficult to interpret (in light of figure 4) but seems to suggest a rather constant price elasticity across a range of low prices before declining (in absolute value) at higher prices.

Conclusions

Based upon these results, linear models of community water demand are useful only as local approximations of more realistic models—statistical estimation should not be employed with a linear model unless the application of these results will only involve scenarios lying within or very close to the data region. The same can be said for the Cobb-Douglas form because community water demand has not been shown to be a constant elasticity relationship. In fact, major errors in application are possible by assuming a fixed demand elasticity. We suspect that the translog form offers a small improvement over the Cobb-Douglas alternative. Translog results indicate a fairly rigid range of elasticity estimates across both prices and seasons. Moreover, translog results from pooled data produce quite different elasticities as compared to translog results for 12 separate, monthly models. The same result is obtained in comparing Cobb-Douglas models. The generalized Cobb-Douglas and augmented Fourier models produce elasticity estimates which conform with expectations, but a statistical basis strongly favoring either model is not available.

The performance of the augmented Fourier form is disappointing, especially in light of the effort required to estimate and apply it. It is not surprising that extremely flexible forms rapidly lose predictive capacity at the edge of data ranges because of the relative absence of any imposed structure. The pursuit of flexibility places great faith in the ability of data to accurately specify the desired relationship. When the data fail (or are absent), so must the model.

Returning to the major objective of this research, we find that price elasticities do experience seasonality. Considering GCD and AF results from the pooled data and CD, GCD, TL, and AF results from the monthly data, it appears that summer price sensitivities can easily be 30% greater than winter price responsiveness. This finding has important implications for conservation policy, rate analyses, and the value of supply increments/decrements, among other things. Evidence is strong that peak load pricing will evoke a more substantial consumer response than that identified by models of annual community water demand. These findings have been employed by Griffin to exhibit the substantial sensitivity of water value to seasonal demand elasticities.

Evidence indicates that price sensitivity wanes as price increases. Therefore, price-induced conservation becomes a weaker policy option at higher prices. It may be true, however, that high prices will cause long-term structural changes in the way people use water. This possibility remains an untold story in the sense that Texas data do not incorporate much experience with high water prices.

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