

# Price and Non-Price Influences on Water Conservation: An Econometric Model of Aggregate Demand under Nonlinear Budget Constraint

Prepared for presentation at the 1998 Agricultural Economics Association  
Annual Meeting in Salt Lake City

Leonardo Corral  
Food and Agricultural Organization, United Nations,  
Santiago Chile

Anthony C. Fisher  
Department of Agricultural and Resource Economics,  
University of California, Berkeley

Nile W. Hatch  
Department of Business Administration,  
University of Illinois at Urbana-Champaign

June 1998

## Abstract

In this paper, a basic theoretical model of residential water consumption that adequately represents consumer behavior when facing a nonlinear budget constraint is developed. The theoretical model for an individual consumer is adapted to yield an aggregate model that essentially preserves the structure of the demand function for the individual. The model is used to study the influence of prices and nonprice conservation programs on consumption and conservation behavior in three water districts in the San Francisco Bay Area. The empirical results show that pricing can be an effective tool in reducing water consumption but, when the influence of conservation programs is controlled for, the pricing effect is mitigated. Use restrictions and landscaping audits appear to be particularly effective in inducing conservation from consumers.

**JEL Classification:** C43, Q21, Q25

---

*Copyright 1998 by Leonardo Corral, Anthony C. Fisher, and Nile W. Hatch. All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided that this copyright notice appears on all such copies.*

# Price and Non-Price Influences on Water Conservation: An Econometric Model of Aggregate Demand under Nonlinear Budget Constraint

## 1. Introduction

The increased frequency of droughts, diminishing supplies of high quality water, and reduced reliability of current supplies in nearly all parts of the U.S. have deepened the need to understand both residential water consumption and conservation behavior. It has become increasingly difficult to add to current water supplies both in terms of costs, including environmental costs, and supply reliability, hence water district managers have turned their attention to improved management of existing supplies. We study the impact of their efforts to manipulate price structures and implement non-price measures to induce conservation.

We analyze residential water consumption and conservation behavior of three water districts in the San Francisco Bay Area before and during a drought.<sup>1</sup> Beginning with the rainy season of 1987-1988, the Bay Area suffered from a drought that ultimately lasted seven years. As the drought continued, all water districts responded with policy measures to reduce demand and induce conservation. The water districts in our study serve the communities of Great Oaks, San Leandro, and San Mateo. During the drought, average annual water consumption per household in the community of Great Oaks fell from 33.55 ccf to 27.02 hundred cubic feet (ccf) during the drought. Similarly, the drought led to a decrease in average consumption from 10.82 ccf to 8.36 ccf in San Leandro and from 12.81 ccf to 11.39 ccf in San Mateo. To understand the role of conservation measures in these reductions, we formulate an empirical specification that allows us to analyze the influence of pricing and non-price conservation programs on water demand using aggregate panel data.

One of the principle tools a water district has to influence consumption behavior is price structure. In recent years, increasing block rate structures have been instituted in numerous water districts in

---

<sup>1</sup>Our data collection efforts originally focussed on nine Bay Area water districts. Unfortunately, due to data limitations we are only able to analyze three districts. The communities chosen for this study correspond to those included in the study by Bruvold (1979) of conservation during a previous drought in the San Francisco Bay Area.

order to induce conservation by charging a lower price for small amounts of consumption and a higher price for units above a certain threshold. Given the prevalence of block rate pricing, we model the consumption decision with a nonlinear budget constraint and aggregate the model to overcome the need for expensive micro-level survey data. Our empirical results show that price policies are significant in combating the drought and that the influence that price has on consumption is greater in periods of drought. It is not clear whether this result is due to consumers reacting to the change in price policy as a signal of the severity of the drought, or whether this result truly represents a price effect.

Of course, non-market tools are also available to water utility districts in their efforts to induce conservation. For this study, variables have been constructed to control for the influence of a variety of conservation programs on water consumption. Most of these programs were instituted in response to the drought. The conservation variables can be categorized as use restrictions, education, billing information, landscaping, and plumbing (retro-fit) programs. We find that use restrictions and landscaping programs proved effective in lowering water demand during the drought.

Our results indicate that water pricing as well as conservation policies are more effective in inducing conservation under certain conditions. In particular, pricing policies influence water consumption during non-rainy months (summer and parts of spring and fall), whereas pricing policies are less significant in winter. Households can exercise greater discretion during summer months where outdoor activities such as filling swimming pools, washing cars and sidewalks and watering lawns are common. The experience shared by water utility managers of the Bay Area during the drought shows that using a proper mix of market and non-market policies to combat droughts can successfully induce conservation behavior from their customers.

## **2. Literature Review**

The literature on residential water demand is extensive. At the core of the literature lie the complexities of theoretical and econometric modeling arising from the block rate structure of prices

used in most municipal water districts. Taylor (1975) and Nordin (1976) were the first to propose a model that accounted for the increasing or decreasing block rate structure of prices. These papers proposed what has become known in the literature as the *difference* variable, where *difference* is defined as the amount the consumer actually gets billed minus what the consumer would have been billed if all consumption was charged at the same price as the price for the last unit of consumption. A theoretical argument was made that this variable should be of equal magnitude, but opposite in effect, to income in the case of increasing block rates, where it acts as a tax, and vice versa with decreasing block rates, where it acts as a subsidy. This gave rise to a number of papers which tried to test this relation empirically.<sup>2</sup> Econometric estimation of these models has used instrumental variables and two- or three-stage least squares techniques to try to correct for the bias that arises in simple OLS estimation due to the co-determination of quantity, price and *difference*.<sup>3</sup>

A few papers in the water demand literature have studied the effectiveness of prices and conservation programs as tools for influencing water demand in the face of a drought. One example is Moncur (1987), which uses panel data on single family residential customers of the Honolulu Board of Water Supply to estimate demand for water as a function of price, income, household size, rainfall and a dummy variable denoting a water restrictions program. Moncur (1987) concludes that marginal price can be used as an instrument to achieve reduction in water use, even during a drought episode, and that the conservation program would mitigate the necessary increase in price, but only slightly. Similarly, the recent study of Fisher, Fullerton, Hatch and Reinelt (1995) compares the cost-effectiveness of price-induced water conservation with other drought management tools such as building a dam and conjunctive use of ground and surface water. They find that a combination of conjunctive use and conservation pricing are the least cost technique of managing a 25% reduction in supply. On the other hand, Gilbert, Bishop and Weber (1990) argue that, during a drought,

---

<sup>2</sup>Many studies using the Taylor and Nordin price specification have performed this test. These include Billings and Agthe (1980), Foster Jr. and Beattie (1981), and Howe (1982). The only study to actually obtain estimates of the income and difference variables that were equal but opposite in sign was Schefter and David (1985), which used simulated data.

<sup>3</sup>See, for example, Chicoine, Deller and Ramamurthy (1986), Deller, Chicoine and Ramamurthy (1986), Jones and Morris (1984), Nieswiadomy and Molina (1989).

price elasticity studies are of limited use in predicting the impact of price changes on consumption because other, drought related, forces have a stronger influence on consumption decisions.

Until recently, no attempt had been made to explicitly model the discrete choice embedded in the decision process of the consumer facing a multi-tiered price schedule for water. By directly modeling the discrete and continuous choice, using the two error model originally proposed in the labor supply literature by Burtless and Hausman (1978), Hewitt and Hanemann (1995) solve the co-determination problem in the context of water demand. In this study, we directly account for the block rate structure of prices in its theoretical model and econometric specification. In addition, we contribute to the current literature by including non-price conservation efforts in the econometric specification to gain some insights into price and non-price influences on urban water conservation.

### **3. An Aggregate Model of Residential Water Consumption**

Contrary to traditional consumer demand analysis, the demand function for a good facing block rate pricing is typically nonlinear, nondifferentiable and often includes discrete jumps. Consequently, conventional demand curves cannot adequately represent consumer behavior when facing a nonlinear budget constraint. While the derivation of the correct demand function is relatively straightforward, the resulting demand function often changes the comparative statics results of consumer demand and is relatively cumbersome for empirical estimation.<sup>4</sup>

The derivation of the water demand function for an individual begins with the specification of

---

<sup>4</sup>In order to comply with space constraints, the full derivation of the water demand function with nonlinear budget constraints is omitted from this version of the paper. The survey by Moffitt (1986) provides a general derivation of the demand function. Also see Hewitt and Hanemann (1995) for a careful derivation of the demand function in the context of water demand with a three tiered block rate pricing structure. A longer version of this paper is available from the authors that includes the full derivation of the model with  $m$  segments in the block rate pricing structure.

the nonlinear budget constraint which, in the case of  $m$  piecewise linear segments, is given by

$$\begin{aligned}
 I + d_1 &= P_1x + \mathbf{y} && \text{if } x \leq \bar{x}_1 \\
 I + d_2 &= P_2x + \mathbf{y} && \text{if } \bar{x}_1 < x \leq \bar{x}_2 \\
 &\vdots && \vdots \\
 I + d_m &= P_mx + \mathbf{y} && \text{if } \bar{x}_{m-1} < x \leq \bar{x}_m
 \end{aligned} \tag{1}$$

where  $I$  is income,  $d_i$  represents the *difference* variable for the  $i^{th}$  segment,  $x$  is water consumption,  $\bar{x}_i$  is level of consumption at which the price changes, and  $\mathbf{y}$  is a vector of all other goods.  $P_i$  represents the price of  $x$  on the  $i^{th}$  segment of the budget constraint and  $\mathbf{y}$  is the *numeraire*. Typically, any fixed charges are included in the difference variable as well. If we let  $d_i$  denote the difference variable in the  $i^{th}$  block, then

$$d_i = -fc - \sum_{j=1}^{i-1} (P_j - P_{j+1})\bar{x}_j. \tag{2}$$

Note that  $d_1 = -fc$ .<sup>5</sup>

The consumer's problem is to maximize a strictly quasi-concave utility function  $U(x, \mathbf{y})$  subject to the budget constraint in equation (1). Since the budget constraint is clearly nondifferentiable, optimization requires two stages. Conceptually, the optimization stages correspond to the continuous and discrete choices faced by the consumer. In the first stage of maximization, we choose the optimal level of consumption for each segment of the kinked budget constraint. This stage results in the conditional demand function. In the next stage, the consumer chooses the segment with the conditional demand that maximizes overall utility.

Finally, combining the solutions to the continuous and discrete choice optimization problems

---

<sup>5</sup>The difference variable proposed by Taylor (1975) and Nordin (1976) is actually the negative of that defined in equation (2).

gives the unconditional demand function. We can express this function as

$$x = b_1 x_1^*(P_1, I + d_1) + b_2 x_2^*(P_2, I + d_2) + \dots + b_m x_m^*(P_m, I + d_m) + c_1 \bar{x}_1 + c_2 \bar{x}_2 + \dots + c_{m-1} \bar{x}_{m-1} \quad (3)$$

where  $x_i^*$  gives the optimal level of consumption conditional on being located on the  $i^{th}$  segment for  $i = 1, 2, \dots, m$ ,

$$\begin{aligned} b_1 &= 1 & \text{if } x_1^*(P_1, I + d_1) \leq \bar{x}_1; & & b_1 &= 0 & \text{otherwise;} \\ b_i &= 1 & \text{if } \hat{b}_{i1} > 0 \text{ and } \hat{b}_{i2} > 0; & & b_i &= 0 & \text{otherwise;} & \text{for } i = 2, 3, \dots, m-1 \\ b_m &= 1 & \text{if } \bar{x}_{m-1} < x_m^*(P_m, I + d_m); & & b_m &= 0 & \text{otherwise;} \\ c_i &= 1 & \text{if } \hat{c}_{i1} > 0 \text{ and } \hat{c}_{i2} > 0; & & c_i &= 0 & \text{otherwise;} & \text{for } i = 1, 2, \dots, m \end{aligned}$$

and

$$\begin{aligned} \hat{b}_{i1} &= \bar{x}_i - x_i^*(P_i, I + d_i); \\ \hat{b}_{i2} &= x_i^*(P_i, I + d_i) - \bar{x}_{i-1}; \\ \hat{c}_{i1} &= x_i^*(P_i, I + d_i) - \bar{x}_i; \\ \hat{c}_{i2} &= \bar{x}_i - x_{i+1}^*(P_{i+1}, I + d_{i+1}). \end{aligned}$$

We now specify an econometric model to estimate the water demand function. Previous empirical studies that employ a models that account for the nonlinear budget constraint and resulting endogeneity of prices, have used micro-level data for their analysis. This requires expensive survey techniques to gather the relevant data. Instead, we utilize much cheaper and more readily available aggregate data, in this case from three water districts in the Bay Area. This approach requires that the demand functions in equation (3) be aggregated to accommodate the available data.

Initially, we sum the demand functions over all the consumers in the district. For the demand

functions based on increasing block rates (convex budget set), we get

$$\begin{aligned}
X &= \sum_{i=1}^m [b_1 x_{i1}^*(P_1, I + d_1) + b_2 x_{i2}^*(P_2, I + d_2) + \dots + b_m x_{im}^*(P_m, I + d_m)] \\
&= X_1(P_1, I + d_1) + X_2(P_2, I + d_2) + \dots + X_m(P_m, I + d_m) \\
&= n_1 \cdot q_1(P_1, I + d_1) + n_2 \cdot q_2(P_2, I + d_2) + \dots + n_m \cdot q_m(P_m, I + d_m).
\end{aligned}$$

where  $x_{ij}^*(\cdot)$  refers to the conditional demand of the  $i^{th}$  consumer in the  $j^{th}$  block,  $X_j = \sum_{i=1}^n b_j x_{ij}^*(\cdot)$ , and  $n_j$  and  $q_j$  are the number of consumers and the average consumption on the  $j^{th}$  segment. The discrete choice component of the consumer choice problem determines the number of households on the  $j^{th}$  segment  $n_j$ , while the continuous choice problem defines the average household consumption  $q_j(\cdot)$  conditional on being located in the  $j^{th}$  block. Thus, the structure of the unconditional demand function for micro-data (equation (3)) is essentially preserved in the aggregate demand function.<sup>6</sup>

To control for population differences between water districts, we normalize by the total number of consumers in each district. The aggregate demand function becomes

$$\begin{aligned}
q &= \frac{X}{n} = \frac{n_1}{n} q_1(P_1, I + d_1) + \frac{n_2}{n} q_2(P_2, I + d_2) + \dots + \frac{n_m}{n} q_m(P_m, I + d_m) \quad (4) \\
&= s_1 \cdot q_1(P_1, I + d_1) + s_2 \cdot q_2(P_2, I + d_2) + \dots + s_m \cdot q_m(P_m, I + d_m)
\end{aligned}$$

where  $q$  is average consumption per household and  $s_j$  is the fraction of consumers located in the  $j^{th}$  price block. Although we cannot identify consumers located at the kinks, our data are rich enough to identify the share of consumers and average consumption in each block.

In past studies, the water demand literature has recognized the importance of climate, socioeconomic variables and the water-consuming capital stock (landscaping, swimming pools, bathrooms,

---

<sup>6</sup>The notable exception is that we are unable to consider the question of consumers locating at the kinks because our aggregate data do not allow us to identify such consumers. We believe that the clustering problem is not serious in our data set given that visual inspection of frequency distributions of customers across levels of consumption that show strikingly little clustering at the kink points.

plumbing fixtures, etc.) in determining water consumption. We incorporate these commonly used variables in our econometric model, but also include less frequently used variables such as specific conservation measures employed by the different water districts to induce conservation. Including these additional variables and a stochastic specification gives us our econometric model of water demand:

$$q_t = s_{1t} \cdot q_{1t}(P_{1t}, I + d_{1t}, Z_t | \beta) + s_{2t} \cdot q_{2t}(P_{2t}, I + d_{2t}, Z_t | \beta) + \dots + s_{mt} \cdot q_{mt}(P_{mt}, I + d_{mt}, Z_t | \beta) + \varepsilon_t \quad (5)$$

where  $t$  denotes the time subscript,  $Z$  represents the matrix of climate, socioeconomic, capital stock and conservation variables,  $\beta$  is the vector of unknown coefficients, and  $\varepsilon$  is the unobserved error term.

For convenience, we assume linear conditional demand curves. With this assumption, the unconditional demand function in equation (5) simplifies to

$$q_t = \beta_0 + \beta_1 \left( \sum_{i=1}^m s_{it} \cdot p_{it} \right) + \beta_2 \left( \sum_{i=1}^m s_{it} \cdot (I + d_{it}) \right) + \delta Z_t + \varepsilon_t \quad (6)$$

where  $\delta$  is a vector of unknown parameters associated with the matrix  $Z$ . It would be inappropriate to estimate equation (6) using the observed probabilities of being located on a particular segment  $s_i$  because they, like the conditional demands, are functions of preferences and are determined by the consumer's discrete choice problem. Therefore, they are correlated with the error term  $\varepsilon$ . To deal with this issue, we estimate equation (6) in stages that are parallel to the discrete and continuous stages of optimization of the consumer's choice problem. We first estimate the proportion of households located in the different blocks,  $\hat{s}_i$ , using a multinomial logit model.

The general format of the multinomial logit model is

$$\text{Prob[ choice } i \text{ ]} = \frac{e^{\beta_i' X_t}}{\sum_i e^{\beta_i' X_t}}, \quad i=0,1, \dots, M. \quad (7)$$

A possible  $M + 1$  unordered outcomes can occur. This model is typically employed for individual or grouped data in which the  $X$  variables are characteristics of the observed individuals, not the choices. The characteristics are the same across all outcomes. Here, the observed dependent variable is a proportion,  $s_i$ .  $X$  is a matrix of time specific characteristics such as temperature, precipitation, income and household size. Given this specification, we estimate the proportion of households located in each block at time  $t$  in each district. We then utilize the predicted proportions for each of the districts in our sample and estimate the unconditional demand function for all three districts. The pooling technique utilized employs a set of assumptions on the disturbance covariance matrix that gives a cross-sectionally heteroskedastic and timewise autoregressive model as described in Kmenta (1986).<sup>7</sup>

The model specification in equation (6) is similar to that of Schefter and David (1985). The major difference is that the Schefter and David model makes no provision for how the probabilities of being on a particular segment are determined.<sup>8</sup> In other words, their consumer demand model does not explicitly incorporate the discrete choice problem. Notice that if the error term is large, then observed average household consumption must be large, which implies that a larger fraction of consumers must be located in the higher blocks. Thus, the observed probabilities  $s_i$  are positively correlated with the error term.

The data utilized for this analysis consist of variables collected for three residential water districts from January 1982 to October 1992. The variables collected include consumption, price structure, socio-economic, climate and conservation variables.

The quantity variables include the total amount of single family residential monthly consumption of water for the district in ccf (100 cubic feet), the total number of single family residential

---

<sup>7</sup>The preferred technique for estimating equation (6) would be a two error maximum likelihood technique that simultaneously estimates the discrete and continuous choice problems. We use the two stage approach described because the price specifications (number of segments, increasing vs. decreasing block rates) vary within and across the districts we consider. Since the pricing structures vary over time within some districts (San Leandro and San Mateo use both constant and increasing block rates in our sample), we cannot use the maximum likelihood technique previously used in Hewitt and Hanemann's (1995) paper.

<sup>8</sup>Schefter and David (1985) also differ in that the difference variable is not included in income.

households in the district per month, and the number of single family residential households located in each block per month. From the quantity variables we obtain our dependent variable  $q$ , where  $q$  denotes monthly water consumption of the average household for the district.

The price structure variables collected include the fixed monthly charge, the marginal price associated with each block, and the quantity in ccf of water at which each kink occurs. All prices are deflated. The socio-economic variables include  $I$ , which is deflated average monthly income, collected separately for each district, and annual average household size  $HHS$  for each district. The climate variables are temperature ( $Temp$ ) and precipitation ( $Precip$ ), both collected on an average monthly basis and separately for each district. Temperature is measured in degrees Fahrenheit and precipitation is measured in inches.

Conservation variables were constructed to measure the degree to which the residential water districts implemented the different conservation programs available to them. Fifteen dummy variables were created to capture the effect of conservation programs on water demand. These variables define various conservation efforts using Billing Information (information included in periodic customer billing statements), Conservation Education, Use Restrictions, Landscaping Programs, and Low-flow Plumbing programs (efforts to encourage the use of lower water consuming capital stock). Table 1 contains a description of the codes used and their construction.

To measure the influence of price, we create the variable average marginal price,  $\widehat{AMP}$ . We use the predicted proportions  $\hat{s}$  estimated using (7) to create  $\widehat{AMP} = \sum_{i=1}^m \hat{s}_{it} \cdot p_{it}$ . This price variable represents the mean marginal price faced in the district.<sup>9</sup> The variable  $\hat{d}$  is also created using  $\hat{s}$ , and it represent the mean *difference* faced by all households.

#### 4. Estimation and Results

The main results of the estimation are summarized in Table 2. Four specifications of the model

---

<sup>9</sup>Schefter and David (1985) were the first to note that the correct marginal price to use in an aggregate setting is the mean marginal price and not the marginal price faced by the average consumer.

Table 1: Construction of Conservation Dummies

Conservation Program	0	1	2	3
Billing Information	Total only	Use for period last year	1 + allotment message	1 + 2 + bill insert
Conservation Education	None	Flyers only	1 + speakers bureau	1 + 2 + in-school education
Use Restrictions	None	% reduction or allotment	1 + use restrictions	1 + 2 + enforcement
Landscaping Program	None	Education (flyers, etc.)	1 + restrictions or limits	1 + 2 + landscape audits
Low-flow Plumbing	None	Retro-fit kits available	1 + rebates	1 + 2 + new construction code

were estimated using the 2-stage procedure discussed in Section 3, employing a set of assumptions on the disturbance covariance matrix that gives a cross-sectionally heteroskedastic and time-wise autoregressive model as described in Kmenta (1986). The values in parentheses are t-ratios.

The first specification, labeled Model 1, is the standard model of water demand used by most water demand studies. Here we find that all estimated coefficients have p-values of less than 0.05, except for  $\widehat{AMP}$ , which has an associated p-value of 0.12. The coefficient on price is used to obtain the elasticity measure presented in Table 3 of  $-0.1710$ , which indicates a relatively inelastic price response.

Model 2 expands the standard model by introducing the conservation to measure impact of the districts' conservation efforts. We find that only the implementation of use restrictions (variable UR2) and landscaping audits (Land3) are significant in reducing consumption.<sup>10</sup> These results seem

---

<sup>10</sup>Originally all conservation dummy variables were introduced, but only UR2 and Land3 proved significant. High collinearity between conservation programs likely affected the individual estimated influence attributed to the different programs. UR3 and Land3 were used exclusively by San Leandro. These programs were implemented simultaneously at the beginning of the drought, and lasted for the duration of the available data. Thus, we cannot separate their individual effects on water consumption. UR2 was implemented in the Great Oaks district, also as a response to the drought.

Table 2: Regression Results for Residential Water Consumption

Model	1	2	3	4
Constant	-57.765 (-7.7829)	-66.697 (-11.183)	-68.101 (-11.447)	-68.101 (-11.447)
$\widehat{AMP}$	-4.4031 (-1.5227)	-2.8720 (-1.0918)	-0.14947 (-0.0541)	
$I + \hat{d}$	0.00189 (1.9085)	0.0009 (0.94567)	0.001148 (1.2832)	0.001148 (1.2832)
HHS	22.476 (6.4277)	27.369 (9.4840)	26.919 (9.5605)	26.919 (9.5605)
Temp	0.20902 (7.8114)	0.21960 (8.5199)	0.22418 (8.7996)	0.22418 (8.7996)
Precip	-0.13422 (-2.6424)	-0.17390 (-3.4399)	-0.18497 (-3.6492)	-0.18497 (-3.6492)
UR2		-7.3257 (-3.0560)	-6.4111 (-2.6415)	-6.4111 (-2.6415)
Land3		-2.8163 (-5.2275)	-1.8099 (-2.9561)	-1.8099 (-2.9561)
$D \cdot \widehat{AMP}$			-2.4133 (-2.7915)	-2.5627 (-1.0192)
$C \cdot \widehat{AMP}$				-0.14947 (-0.0541)
$n$ (per district)	130	130	130	130
Buse $R^2$	0.3257	0.5044	0.5198	0.5198

Table 3: Price Elasticities (at means)

Model	1	2	4	
			Drought	Normal
Non-rainy Months	-0.21801 (-1.4007)	-0.22853 (-1.7573)	-0.30262 (-1.9212)	-0.13782 (-1.2638)
All Months	-0.17100 (-1.5227)	-0.11154 (-1.0918)	-0.12050 (-1.0192)	-0.00051 (-0.05412)

to indicate that only the most aggressive conservation programs significantly influence consumption. Once we control for the influence of the conservation programs (use restrictions and landscape audits ) on household consumption decisions in Model 2, the effect of average marginal price on consumption is mitigated, and becomes statistically insignificant at conventional levels, though the sign is still “correct.”

We use model 3 to test whether households respond differently to water prices during the drought. In other words, was there a structural shift in consumer behavior due to the drought? We create a dummy variable,  $D$ , which takes on the value of 1 during the drought, and 0 otherwise, and look at the interaction of  $\widehat{AMP}$  and  $D$ . For purposes of estimation, we define the beginning of the drought as April 1988.<sup>11</sup> Since we control for differences in water needs through the precipitation variable, any change in consumption behavior during the drought must be in response to the existence of the drought, and not because of a lack of precipitation. We find that there was indeed a structural shift in demand during the drought as the estimated coefficient for the  $D \cdot \widehat{AMP}$  variable is  $-2.4133$  with a p-value of 0.0055. This confirms our belief that households responded differently to price signals during the drought than during normal periods of rainfall.

While the estimates of model 3 tell us whether or not households behaved differently with respect to water prices during the drought, the estimates of model 4 gives us different slope coefficient measures for price during the drought and during normal periods of rainfall. We make use of  $C = 1 - D$  to accomplish this.  $D \cdot \widehat{AMP}$  reflects the influence that price had on consumption decisions during the drought, whereas  $C \cdot \widehat{AMP}$  reflects the estimated influence that price has on consumption during normal periods of precipitation. Based on the estimated coefficients of  $D \cdot \widehat{AMP}$  and  $C \cdot \widehat{AMP}$  in Model 4, we construct price elasticities during the drought and during periods of normal precipitation. These are presented in Table 3. When we consider all months, and include the nonprice conservation variables, the effect price has on consumption during normal

---

<sup>11</sup>The regular rainy season in the Bay Area ends by the end of March. Therefore, expectations of additional rain are insignificant by April.

periods is negligible—the elasticity measure is  $-0.00051$ . During the drought, the price effect is much stronger at  $-0.12050$ . The estimated influence of all other included variables stayed similar across all specifications of the model in Table 2.

We estimated the specifications using the full data set and a restricted data set that included only the non-rainy months in the Bay Area, from April to October of 1982 to 1992. Using both data sets, all coefficients are of the expected sign, but, due to more discretionary water needs associated with the non-rainy months, such as watering lawns, filling swimming pools, washing cars and sidewalks, etc., are associated with larger impacts of changes in explanatory variables, including price. For the sake of brevity, the estimates using only the non-rainy months are not reported here, but these estimates are available on request.

## **6. Conclusions**

In this paper we have analyzed consumption and conservation behavior for the San Francisco Bay Area utilizing aggregate panel data comprised of three water utility districts. Our results indicate that water pricing as well as conservation policies are more effective in inducing conservation under certain conditions. In particular, pricing policies influence water consumption during non-rainy months (summer and parts of spring and fall), whereas pricing policies are less significant in winter. Households can exercise greater discretion during summer months where outdoor activities such as filling swimming pools, washing cars and sidewalks and watering lawns are common. Also, water consumption in the Bay Area is low compared to Southern California. In fact, Southern California's water consumption per household in 1991, the most severe year of the drought, was approximately equivalent to the Bay Area's consumption in 1986, the last year of normal precipitation before the drought began (Dixon, Moore and Pint (1996)). This empirical observation implies that consumption in the Bay Area is closer to subsistence levels, so the response to price changes should be expected to be low.

Our results also show price policies to be significant in combating the drought. The influence

that price has on consumption was shown to be greater in periods of drought. It is not clear whether this result is due to consumers' reaction from perceiving change in price policy as a signal of the severity of the drought, or whether this result truly represents a price effect.

Conservation programs such as use restrictions and landscaping programs proved effective in lowering water demand during the drought. The experience shared by water utility managers of the Bay Area during the drought shows that using a proper mix of market and non-market policies to combat droughts can successfully induce conservation behavior from their customers.

## References

- Billings, R. Bruce and Donald E. Agthe**, “Price Elasticities for Water: A Case of Increasing Block Rates,” *Land Economics*, February 1980, 56 (1), 73–84.
- Bruvold, William H.**, “Residential Response to Urban Drought in Central California,” *Water Resources Research*, December 1979, 15 (6), 1297–1304.
- Burtless, Gary and Jerry Hausman**, “The Effect of Taxation on Labor Supply,” *Journal of Political Economy*, 1978, 86, 1103–1130.
- Chicoine, David L., Steven C. Deller, and Ganapathi Ramamurthy**, “Water Demand Estimation Under Block Rate Pricing: A Simultaneous Equations Approach,” *Water Resources Research*, June 1986, 22 (6), 859–863.
- Deller, Steven C., David L. Chicoine, and Ganapathi Ramamurthy**, “Instrumental Variables Approach to Rural Water Service Demand,” *Southern Economic Journal*, October 1986, 53, 333–346.
- Dixon, Lloyd S., Nancy Y. Moore, and Ellen M. Pint**, “Drought Management Policies and Economic Effects in Urban Areas of California, 1987-1992,” Technical Report, RAND 1996.
- Fisher, Anthony, David Fullerton, Nile W. Hatch, and Peter Reinelt**, “Alternatives for Managing Drought: A Comparative Cost Analysis,” *Journal of Environmental Economics and Management*, November 1995, 29, 304–320.
- Foster Jr., Henry S. and Bruce R. Beattie**, “On the Specification of Price in Studies of Consumer demand under Block Price Scheduling,” *Land Economics*, November 1981, 57, 624–629.
- Gilbert, Jerome B., Walter J. Bishop, and Jack A. Weber**, “Reducing Water Demand During Drought Years,” *Journal of the American Water Works Association*, May 1990, pp. 34–39.
- Hewitt, Julie A. and Michael Hanemann**, “A Discrete/Continuous Choice Approach to Residential Water Demand under Block Rate Pricing,” *Land Economics*, May 1995, 71 (2), 173–192.
- Howe, Charles W.**, “The Impact of Price on Residential Water Demand: Some New Insights,” *Water Resources Research*, August 1982, 18 (4), 713–716.
- Jones, C. Vaughan and John R. Morris**, “Instrumental Price Estimates and Residential Water Demand,” *Water Resources Research*, February 1984, 20, 197–202.
- Kmenta, Jan**, *Elements of Econometrics*, second ed., Macmillan, 1986.
- Moffitt, Robert**, “The Econometrics of Piecewise-Linear Budget Constraints: A Survey and Exposition of the Maximum Likelihood Method,” *Journal of Business & Economic Statistics*, July 1986, 4 (3), 317–328.
- Moncur, James E. T.**, “Urban Water Pricing and Drought Management,” *Water Resources Research*, March 1987, 23 (3), 393–398.

**Nieswiadomy, Michael L. and David J. Molina**, “Comparing Residential Water Demand Estimates under Decreasing and Increasing Block Rates Using Household Data,” *Land Economics*, August 1989, 65, 280–289.

**Nordin, John A.**, “A Proposed Modification of Taylor’s Demand Analysis: Comment,” *The Bell Journal of Economics*, 1976, 7 (2), 719–721.

**Schefter, John E. and E. L. David**, “Estimating Residential Water Demand Under Multi-Part Tariffs Using Aggregate Data,” *Land Economics*, Aug 1985, 61, 272–280.

**Taylor, Lester D.**, “The Demand for Electricity: A Survey,” *The Bell Journal of Economics*, 1975, 6 (1), 74–110.