Extending the Model of Residential Water Conservation Nature and Scope

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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.

Key Words: Urban Water conservation and demand, water pricing, policy anlysis

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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 raised awareness of the need to understand both residential water consumption and conservation behavior. It has become increasingly more difficult to add to current water supplies both in terms of costs and supply reliability, hence water district managers have turned their attention to improved management of this precious resource.

Fulfilling residential water needs has become an important policy issue in California and many other parts of the country. Many water districts have turned to pricing and other programs to induce conservation from their customers.

One of the principal tools a water district has , to influence consumption behavior, is price structure. Until the 1970's many urban water utilities employed decreasing block rates, the rationale being that this pricing scheme encouraged the exploitation of economies of scale. Later, utilities began switching to flat rates, and lately increasing block rate structures have been instituted in numerous districts. By charging a lower price for small amounts of consumption, and a higher price for units above a certain threshold, increasing block pricing may induce conservation.

The use of increasing block pricing by some water utility districts raises issues of appropriate modeling of demand. Detailed attention is given to this issue in this work, since it has been the cause of much debate in the academic economics literature on water demand. Typically, empirical studies that have properly modeled demand, given non linearity in budget sets, have used micro-level data for their analysis. This requires expensive survey techniques to gather the relevant data. In this work aggregate data collected from three water districts in the San Francisco Bay Area is utilized for the empirical analysis.

Of course, non-market tools are also available to the water utility districts in their efforts to induce conservation behavior. In this study variables created to depict the influence of a variety of conservation programs on consumption and conservation behavior have been prepared. The conservation variables have been categorized as use restrictions, education, billing information, landscaping, and plumbing (retro-fit) programs. This study will make use of the most extensive data set on conservation measures ever collected.

The report is organized as follows. First, a brief literature review is presented . The next section describes residential water consumption and conservation in three district in the San Francisco Bay Area. Section 4 presents the theoretical model of residential water consumption. In section 5, aggregation and the empirical specification are dealt with. Section 6 addresses the data, estimation and results. The conclusions and policy implications are presented in section 7.

2 Literature Review

The literature on residential water demand is extensive. At the core of the literature lies the complexities in theoretical and econometric modeling arising from the block rate structure of prices prevalent 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. They proposed what has become known in the literature as the *difference* variable, where *difference* is defined as the amount the consumer actually gets billed for minus what the consumer would have been billed if all consumption was charged at the same marginal price as the price where the last unit of consumption occurs. A theoretical argument w as made that this variable should be of equal marginal 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 empirically tried to test this relation.[1] Econometric estimation of these models have used instrumental variables and two- or three-stage least squares techniques to try to correct for the biasedness that arises in simple OLS estimation due to the co-determination of quantity, price and *difference*.[2]

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), who 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 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. 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, price elasticity studies are of limited use in reducing 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

[1]Many studies using the Taylor and Nordin price specification have performed this test. These include Billings and Agthe (1980), Foster 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.

[2]See, for example, Chicoine, Deller and Ramamurthy (1986), Deller, Chicoine and Ramamurthy (1986), Jones and Morris (1984), Nieswiadomy and Molina (1989).

Hanemann (1995) solve the co-determination problem in the context of water demand. The present study directly accounts for the block rate structure of prices in its theoretical model and econometric specification. In addition, we add 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 Residential Water Consumption and Conservation in the San Francisco Bay Area

The San Francisco Bay Area is both demographically and geographically diverse. From the foggy coastal regions to the arid inland valleys, temperatures, precipitation, incomes, and house and lot sizes vary widely. As a result, water consumption varies as well. The rainy season of the Bay Area runs from approximately November through February or March. In the inland areas, summers are dry and hot. On the coast, however, the months of June, July, and August bring heavy fog and cool temperatures. Communities that lie around the San Francisco Bay typically experience temperatures between these two extremes.

Beginning with the usually rainy season of 1987–1988, the Bay Area suffered from a drought that ultimately lasted seven years. For the first year or two, some water districts did little to encourage residential water conservation. Instead, they relied on stored water reserves (typically reservoirs) and the waited for precipitation patterns to return to normal. As the drought continued, all water districts responded with measures to reduce demand so that water supplies would not be totally exhausted. The measures employed varied widely in scope and intensity. Many districts raised prices and/or imposed increasing block rate prices. It was also common to engage in a variety of conservation programs which we categorize as use restrictions, and education, billing information, landscaping, and plumbing (retro-fit) programs. The result was a substantial reduction in residential consumption in many districts.

In this study we consider the residential water consumption patterns of three Bay Area water districts.[3] The water districts serve the communities of Great Oaks, San Leandro, and San Mateo. Summary statistics of consumption and other relevant variables before and during the drought are listed in Table 1 for each of the communities.

The first water utility we discuss is the Great Oaks Water Company which serves the community of Great Oaks near San Jose in the south of the Bay Area. The district is very small, serving an area of approximately six square miles. It is also unusual in that all of the water consumed is from underground aquifers obtained from 12 active wells. Officials from the Great Oaks Water Company are confident that their supply of water is safe and, thus, were relatively insulated from the effects of the drought. It is not surprising that consumption in this community is the highest in our sample. This district is the only one in our sample that uses decreasing block rate prices (marginal price falls as consumption rises).

In the undated "management plan," the Great Oaks Water Company states that it does not have an active conservation agenda. Subsequently, the district's conservation programs are relatively minimal. Some education programs, including presentations to homeowners and school children, and a period of distribution of low-flow shower heads and toilets comprise much of the districts conservation efforts. The most aggressive conservation program was a use restriction program initiated in 1989. Initially, they set a 25% mandatory reduction in consumption. Later the goal was revised to a 20% cutback and then, in 1991, was relaxed to a request for a voluntary reduction of 25% from 1987 usage levels. Figure shows the consumption history of the Great Oaks community from 1985 through 1992.

The next community included in our study is the city of San Leadro. Located south

[3]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.

Table 1: Summary Statistics for the Water Districts

Great Oaks	Before the Drought		During the Drought	
variable	mean	std. dev.	mean	std. dev.
household consumption (ccf)	33.55	9.85	27.02	6.57
household income	$63,426	2812.8	$77,552	5234.3
number of households	8542.5	695.56	8799.4	897.98
household size	3.06	0.015	3.08	0.032
temperature	60.49	7.66	61.37	8.11
precipitation (inches)	1.05	1.33	0.93	1.44
San Leandro	**Before the Drought**		**During the Drought**	
variable	mean	std. dev.	mean	std. dev.
household consumption (ccf)	10.82	2.92	8.36	1.40
household income	$36,766	5669.8	$50,308	2705.8
number of households	22,168	745.3	21,666	1170.5
household size	2.35	0.010	2.35	0.019
temperature	59.62	5.79	59.99	5.71
precipitation (inches)	2.15	2.72	1.25	1.79
San Mateo	**Before the Drought**		**During the Drought**	
variable	mean	std. dev.	mean	std. dev.
household consumption (ccf)	12.81	3.77	11.39	2.58
household income	$47,247	8162.9	$66,882	4086.9
number of households	22,646	643.34	22,344	112.46
household size	2.35	0.025	2.37	0.018
temperature	57.62	5.50	58.71	5.73
precipitation (inches)	1.84	2.40	1.10	1.54

of Oakland, San Leandro receives its water from East Bay Municipal Utilities District (EBMUD). EBMUD is a large utilities provider serving many of the communities on the inland side of the bay. It is also quite aggressive in pursuing water conservation. When the drought began and again when the drought became especially severe, the district raised prices and invoked relatively steeply increasing block rates.

EBMUD also initiated an impressive array of conservation programs to meet their goals of reductions in consumption. Their conservation education efforts included the printing and distribution of a variety of flyers and brochures asking people to conserve, teaching how much water various activities use, and teaching water saving techniques such as drip irrigation and water conserving landscaping. They also made presentations at schools teaching water conservation habits. Their education efforts even extended into advertisements on radio, television, and newspapers. Finally, the district imposed a variety of use restrictions to avoid "wasteful" uses such as water for fountains, washing vehicles, or swimming pools. The efforts were successful as the district reduced consumption substantially. Figure shows the history of average household consumption from 1980 through 1992.

The final region studied here is the San Mateo Water District. The county of San Mateo is located just south of San Francisco on the western peninsula of the Bay Area. The district receives its water through the California Water Service Company, a private, investor owned water utility that serves 20 other water districts. As a result, the City of San Mateo passes all ordinances relating to water. The district appears to make only limited use of block rate pricing to influence consumption. For most of our sample, they used a relatively mild increasing block rate pricing structure. When the drought began, the district abandoned the two-tiered pricing scheme for a constant prices. In fact, when adjusted for inflation, the real price of water stays level or even falls during the drought.

The California Water Service Company has published literature containing water conservation tips, as well as conservation coloring and activity books. In our sample, the San Mateo

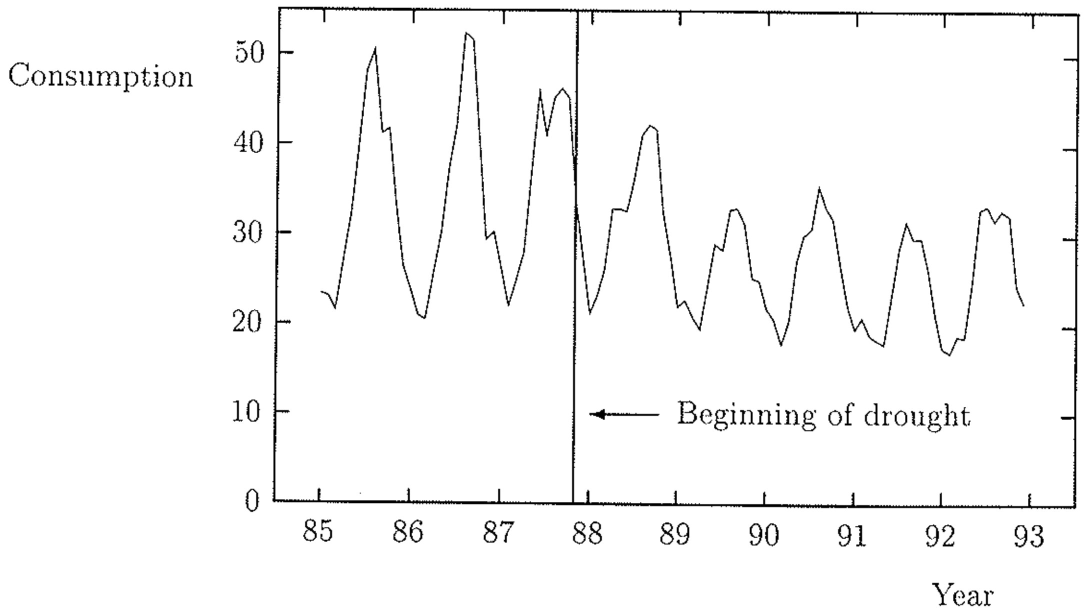

Figure 1: Consumption per Household for the Great Oaks Water District

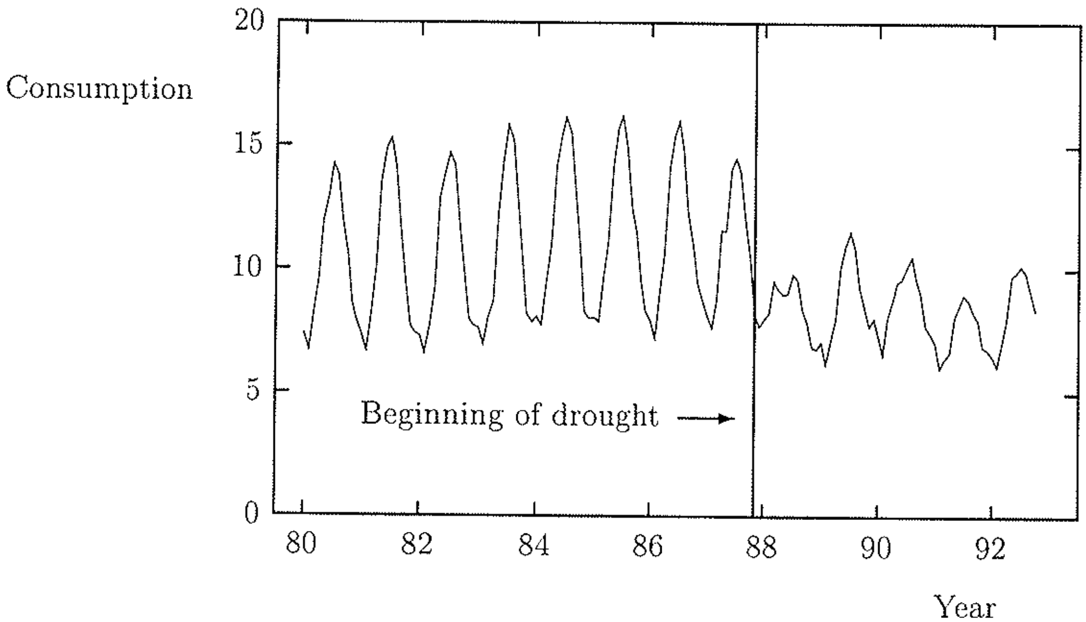

Figure 2: Consumption per Household for the San Leandro Region of EBMUD

district made the greatest use of billing information to educate consumers on their water usage, often urging them to conserve. The water company has also used periodic advertising to promote awareness of water conservation. Well into the drought, the San Mateo customers were submitted to a variety of use restrictions such as prohibiting use above a monthly allocation, excessive landscaping, use for washing hard surfaces (buildings/sidewalks), etc. After a warning, use restrictions were enforced with flow restricting devices. The district's conservation goals from 1990 to 1993 were a 25% reduction in summer usage and 15% reduction in winter consumption. The history of average household consumption from 1980 to 1992 is shown in Figure .

4 A 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. The derivation of the correct demand function is relatively straightforward, however, the resulting demand function often changes the comparative statics results of consumer demand and is relatively cumbersome for empirical estimation.[4]

It is common for water utility districts to charge consumers different marginal rates depending on the quantity consumed. As a result, consumers face a kinked budget constraint. This can be seen in Figure which illustrates the budget constraint for a two tiered block pricing scheme where I is income, x is water consumption, $\bar{x}_1$ 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

[4] 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.

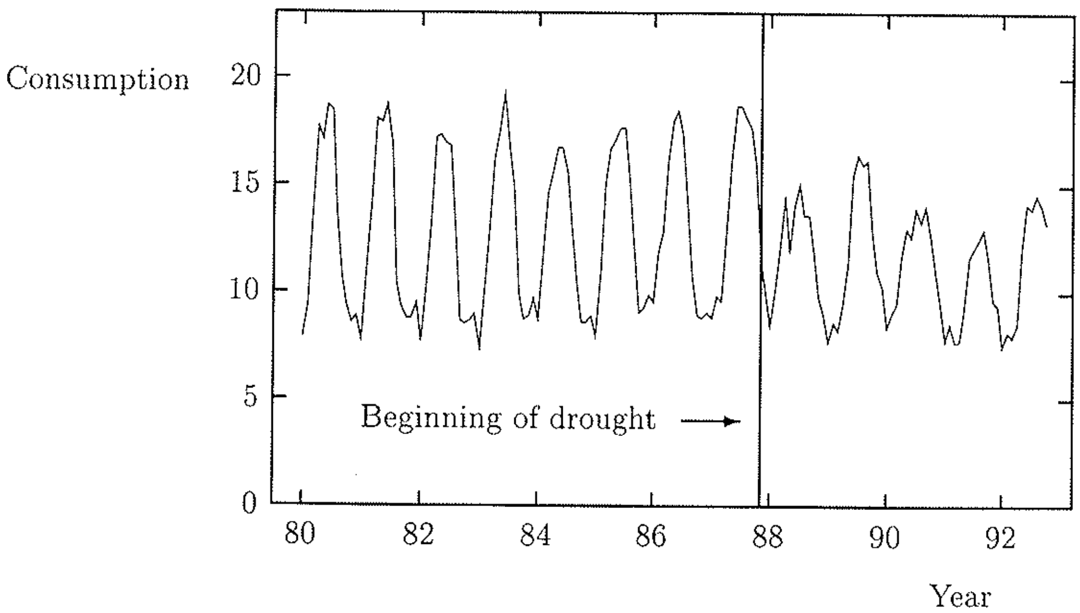

Figure 3: Consumption per Household for the San Mateo Water District

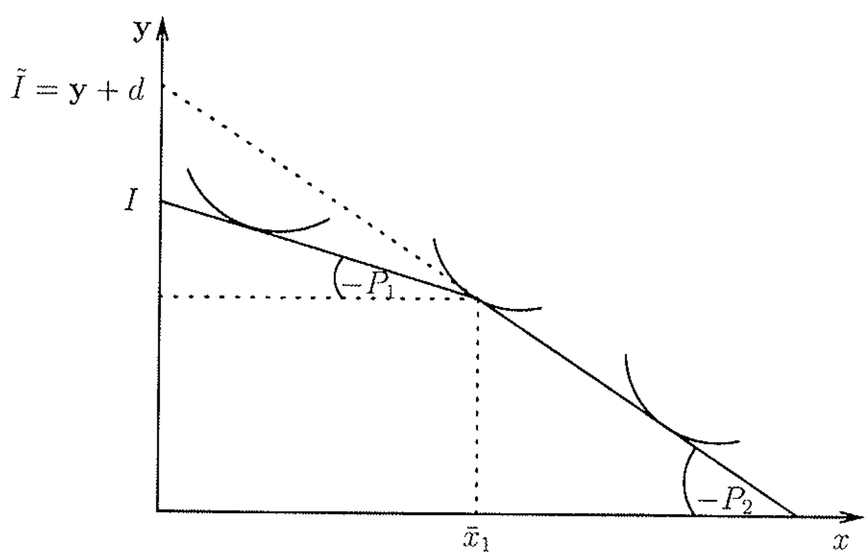

Figure 4: Budget Constraint for a Two Tiered Pricing Scheme

on the i^{th} segment of the budget constraint and **y** is the *numeraire.* When the multi-tiered pricing structure incorporates increasing block rates, the budget set is convex; when rates are decreasing over blocks, the budget set is nonconvex. It is possible to have budget constraints that are both concave and convex. Initially, we consider the case of a convex budget set (concave budget constraint) with m piecewise linear segments. The budget set is given by

$$
\begin{aligned}
I &= P_1 x + \mathbf{y} + fc && \text{if } x \leq \bar{x}_1 \\
I &= P_1 \bar{x}_1 + P_2(x - \bar{x}_1) + \mathbf{y} + fc && \text{if } \bar{x}_1 < x \leq \bar{x}_2 \\
&\vdots && \vdots \\
I &= P_1 \bar{x}_1 + P_2(\bar{x}_2 - \bar{x}_1) + \ldots + P_m(x - \bar{x}_{m-1}) + \mathbf{y} + fc && \text{if } \bar{x}_{m-1} < x \leq \bar{x}_m.
\end{aligned}
$$

For convenience, we can simplify the budget set by incorporating the difference variable first suggested by Taylor (1975) and Nordin (1976). The difference variable is defined as the difference between how much the consumer would have paid if she had been charged the marginal rate for all units and what the consumer actually paid for water. 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

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

Note that $d_1 = -fc$.[5] Using equation (1), we can express the budget constraint more

[5]The difference variable proposed by Taylor and Nordin is actually the negative of that defined in equation (1). In words, they defined it as the difference between how much the consumer actually pays for water and what the consumer would have paid if she had been charged the marginal rate for all units.

succinctly:

$$\begin{aligned} I + d_1 &= P_1 x + \mathbf{y} && \text{if } x \le \bar{x}_1 \\ I + d_2 &= P_2 x + \mathbf{y} && \text{if } \bar{x}_1 < x \le \bar{x}_2 \\ &\vdots && \vdots \\ I + d_m &= P_m x + \mathbf{y} && \text{if } \bar{x}_{m-1} < x \le \bar{x}_m. \end{aligned} \tag{2}$$

The income plus difference variable term in equation (2) is equivalent to the virtual income variable which is more commonly used in studies with piecewise-linear constraints and is found in Figure . We incorporate the difference variable instead of virtual income since the difference variable is so common in water demand literature.[6]

The consumer's problem is to maximize a strictly quasi-concave utility function $U(x, \mathbf{y})$ subject to the budget constraint in equation (2). 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

[6] In the literature on the econometrics of piecewise-linear budget constraints, it is more typical to model the budget constraint, with two segments, as

$$\begin{aligned} I &= P_1 x + \mathbf{y} && \text{if } x \le \bar{x}_1 \\ \tilde{I} &= P_2 x + \mathbf{y} && \text{if } x > \bar{x}_1 \end{aligned}$$

where $\tilde{I} = I + (P_2 - P_1)\bar{x}_1$ is often referred to as "virtual income" (Burtless and Hausman, 1978) and denotes the intercept of the second segment of the budget constraint extended to the axis. Virtual income provides a convenient representation of the situation faced by consumers in the second block. Note that $\tilde{I} = I + d_2$. However, we define the difference variable to be the negative of the variable traditionally used in the water demand literature for the sake of its similarity to virtual income.

budget constraint. This stage results in the conditional demand function

$$
\begin{aligned}
x &= x_1^*(P_1, I + d_1), && \text{if } x < \bar{x}_1, \\
x &= x_2^*(P_2, I + d_2), && \text{if } \bar{x}_1 < x < \bar{x}_2 \\
&\vdots && \vdots \\
x &= x_m^*(P_m, I + d_m), && \text{if } \bar{x}_{m-1} < x < \bar{x}_m \\
x &= \bar{x}_i && \text{if } x = \bar{x}_i \text{ for } i = 1, 2, \ldots, m-1,
\end{aligned} \tag{3}
$$

which gives the optimal level of consumption conditional on being located on a particular segment or kink.

In the next stage, the consumer chooses the segment with the conditional demand that maximizes overall utility. If we denote the conditional indirect utility function as

$$
\begin{aligned}
V_i(P, I) &= \max_{x_i, \mathbf{y}_i} U_i(x, \mathbf{y}) \\
&= U[x_i^*(P_i, I + d_i), I + d_i - P_i \cdot x_i^*(P_i, I + d_i)],
\end{aligned}
$$

then the second stage problem is

$$
\max\{V_1(\cdot), V_2(\cdot), \ldots, V_m(\cdot)\}.
$$

Using the conditional indirect utility function and the assumptions of a concave utility function and convex budget set, the utility maximizing choice of segments can be reduced to (see Moffitt (1986)):

$$\begin{array}{ll} \text{Choose segment 1 if} & x_1^*(P_1, I + d_1) \leq \bar{x}_1 \\ \text{Choose segment } i \text{ if} & \bar{x}_{i-1} < x_i^*(P_i, I + d_i) \leq \bar{x}_i \\ & \quad \text{for } i = 2, 3, \ldots, m-1 \\ \text{Choose segment } m \text{ if} & \bar{x}_{m-1} < x_m^*(P_m, I + d_m) \\ \text{Choose the } i^{th} \text{ kink if} & x_{i+1}^*(P_{i+1}, I + d_{i+1}) \leq \bar{x}_i < x_i^*(P_i, I + d_i) \\ & \quad \text{for } i = 1, 2, \ldots, m-1 \end{array} \tag{4}$$

Finally, combining the solutions to the continuous (equation (3)) and discrete choice (equation (4)) optimization problems gives the unconditional demand function. We can express this function as

$$\begin{aligned} x = {} & b_1 x_1^*(P_1, I + d_1) + b_2 x_2^*(P_2, I + d_2) + \ldots + b_m x_m^*(P_m, I + d_m) + \\ & c_1 \bar{x}_1 + c_2 \bar{x}_2 + \ldots + c_{m-1} \bar{x}_{m-1} \end{aligned} \tag{5}$$

where

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

and

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

It is straightforward to derive the demand function for the nonconvex budget set. In that setting, the budget constraint and conditional demand function are identical to those in equations (2) and (3). The function defining the choice of segments is

$$\text{Choose segment } i \text{ if} \quad V_i(P, I) \geq V_j(P, I) \quad \text{for all } j \neq i \tag{6}$$

Therefore, the demand function is

$$x = b_1 x_1^*(P_1, I + d_1) + b_2 x_2^*(P_2, I + d_2) + \ldots + b_m x_m^*(P_m, I + d_m) \tag{7}$$

where

$$b_i = 1 \quad \text{if } \hat{b}_{ij} > 0 \quad \text{for all } i \neq j; \quad b_i = 0 \quad \text{otherwise}; \quad \text{for } i = 1, 2, \ldots, m;$$
$$\hat{b}_{ij} = V_i(\cdot) - V_j(\cdot).$$

5 Aggregation and an Empirical Model

We now specify an econometric model to estimate the water demand function for San Francisco Bay Area consumers. Typically, empirical studies that employ the model outlined in the previous section use micro-level data for their analysis. This requires expensive survey techniques to gather the relevant data. Instead, we utilize aggregate data collected from three water districts in the Bay Area. This requires that the demand functions in equations (5) and (7) 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

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

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 (5)) is essentially preserved in the aggregate demand function. 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 will return to this problem shortly.

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

$$\begin{aligned} q = \frac{X}{n} &= \frac{n_1}{n} q_1(P_1, I + d_1) + \frac{n_2}{n} q_2(P_2, I + d_2) + \ldots + \frac{n_m}{n} q_m(P_m, I + d_m) \qquad (8) \\ &= s_1 \cdot q_1(P_1, I + d_1) + s_2 \cdot q_2(P_2, I + d_2) + \ldots + s_m \cdot q_m(P_m, I + d_m) \end{aligned}$$

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.

One of the principle contributions of the piecewise-linear budget constraint model is its stochastic specification. In contrast to traditional models of consumer demand, studies of demand subject to a piecewise-linear budget constraint usually separate the error into heterogeneity and "measurement" error components. The heterogeneity error explicitly accounts for the variation in consumer preferences, while the measurement error incorporates all other types. The heterogeneity error produces clustering of consumers around kinks because there is a range of preferences which lead to utility maximization through consumption at the kinks (Moffitt, 1986).[7] Therefore, the importance of analyzing consumer behavior at the kinks is in relation to the degree of clustering around the kinks.

We believe that our inability to identify consumers at the kinks is a relatively small problem given the lack of clustering evident in our consumption data. In figures , , and we present the distribution of consumers across levels of consumption from representative summer months for the San Mateo, Great Oaks, and San Leandro municipal water districts.[8] There is strikingly little clustering (or dispersion in the case of the Great Oaks Water District) in these data sets. It is impossible to know from the data available why there is so little clustering. It seems unlikely that there is no heterogeneity error (i.e., that all consumers have the same preferences). Instead, this condition could result if the optimization error, which tends to smooth the data across the kinds, overwhelms the influence of heterogeneity error. This is plausible given that a consumer seldom knows the amount of water consumed when she turns on the faucet, thus, limiting her ability to obtain the utility maximizing level

[7]In the case of decreasing block rates, heterogeneity error would cause dispersion of consumers away from the kink since it is never an optimal location for consumption.

[8]Note that there appears to be a small clustering of consumers around the kink at 30 ccf in figure . This does not seem to be the result of heterogeneity error because the clustering at 30 ccf persists even when the kink point moves far from 30 ccf in other periods.

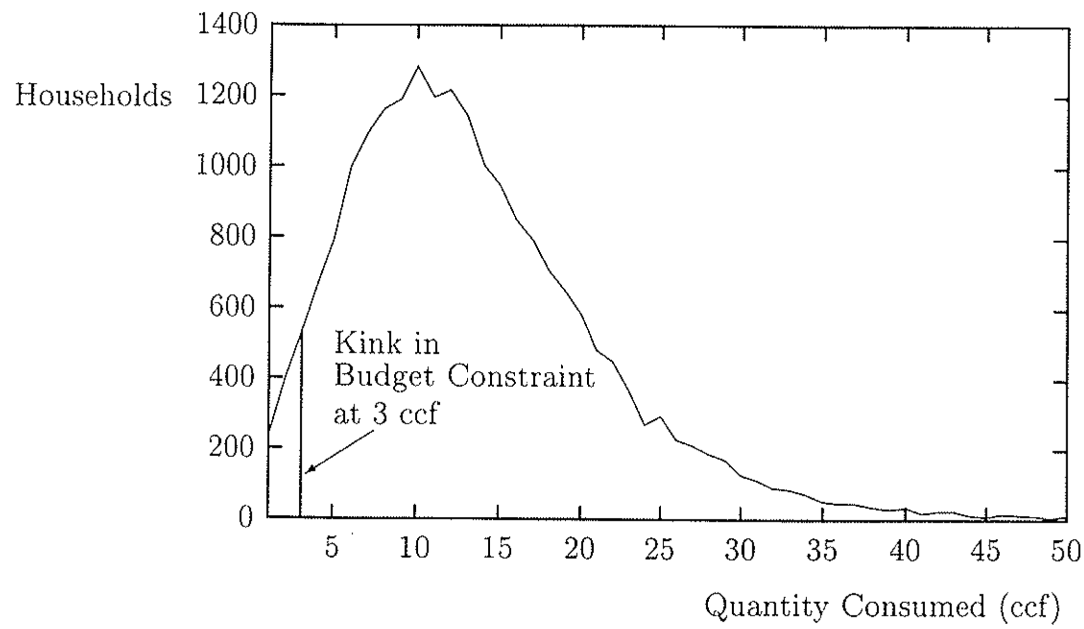

Figure 5: Frequency Distribution of San Mateo Water Consumers

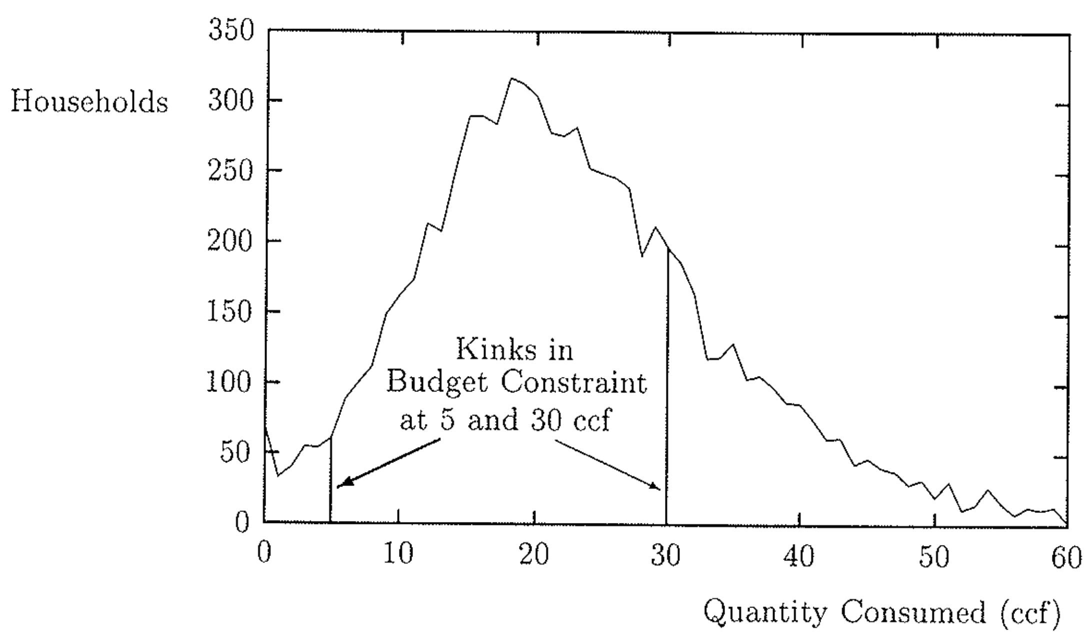

Figure 6: Frequency Distribution of Great Oaks Water Consumers

of consumption.

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, plumbing fixtures, etc.) in determining water consumption. We incorporate this 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:

$$\begin{aligned} q_t =& s_{1t} \cdot q_{1t}(P_{1t}, I + d_{1t}, Z_t \mid \beta) + s_{2t} \cdot q_{2t}(P_{2t}, I + d_{2t}, Z_t \mid \beta) + \\ & \ldots + s_{mt} \cdot q_{mt}(P_{mt}, I + d_{mt}, Z_t \mid \beta) + \varepsilon_t \end{aligned} \tag{9}$$

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

For convenience, we assume linear conditional demand curves. With this assumption, the unconditional demand function in equation (9) simplifies to

$$q_t = \beta_0 + \beta_1 \left(\sum_{i=1}^{m} s_{it} \cdot p_{it} \right) + \beta_2 \left(\sum_{i=1}^{m} s_{it} \cdot (I + d_{it}) \right) + \delta Z_t + \varepsilon_t \tag{10}$$

where δ is a vector of unknown parameters associated with the matrix Z. It would be inappropriate to estimate equation (10) 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 ε. To deal with this issue, we estimate equation (10) in stages that are parallel to the discrete and continuous stages of optimization of the consumer's choice problem. In particular, we first estimate the coefficients of the multinomial logit model for the probabilities s_i. We then substitute predicted values for the probabilities for each of the districts in our sample and estimate the unconditional demand function for all three districts using a full cross-sectionally correlated and time-wise autoregressive model.[9]

The model specification in equation (10) is similar to that of Schefter and David (1985). The only major difference is that the Schefter and David model makes no provision for how the probabilities of being on a particular segment are determined.[10] 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 the higher blocks. Thus, the observed probabilities s_i are positively correlated with the error term. If instrumental variables are used to correct for the endogeneity, the estimator used is mechanically identical to our approach for estimating the aggregate unconditional demand function.

6 Data, Estimation, and Results

The data utilized for this preliminary analysis consists of variables collected for three residential water districts, Great Oaks, San Mateo and San Leandro. The data spans 7 years, from January 1985 to October 1992. The three districts are located in the San Francisco Bay Area region. The variables include quantity, price structure, socio-economic, climate and conservation variables.

The quantity variables include the total amount of single family residential monthly

[9]The preferred technique for estimating equation (10) would be a two error maximum likelihood technique that simultaneously estimates the discrete and continuous choice problems. We use the instrumental variables approach described mainly because the price specifications (number of segments, increasing vs. decreasing block rates) vary 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 during our sample), we cannot even use the maximum likelihood technique previously used in Hewitt and Hanemann's (1995) paper. We need to consider this problem, and use some of the insights from the labor supply literature to estimate the coefficients of each district separately.

[10]Schefter and David also differ in that they do not include the difference variable in income.

Table 2: Construction of Conservation Codes

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

consumption of water for the district in ccf (100 cubic feet), the total number of single family residential households in the district per month, 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 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 in inches. The conservation variables where created to measure the degree to which the residential water districts implemented the different conservation programs available to them. Table 2 contains a description of the codes used.

Fifteen dummy variables were created to capture the effect of conservation programs on water demand. Billing information (Bill) refers to information accompanying the billing statement. There are three dummy variables under this heading. When the statement includes the amount of water used in the same period last year, a value of 1 is assigned to the variable (Bill1), otherwise 0 is assigned. When the billing statement includes the amount of water used last year for the same period in addition to an allotment message a value of 1 is assigned to Bill2, otherwise 0 is. When a billing insert is included in addition to an allotment message and last year's period consumption the Bill variable (Bill3) is assigned a value of 1, otherwise 0 is assigned.

Similarly, there are three dummy variables under the heading Conservation education (Ed). Ed1 is given a value of 1 when flyers containing conservation information are distributed by the water district, a value of 0 otherwise. A value of 1 is assigned to Ed2 when in addition to flyers the district has a speaker bureau, 0 otherwise. Ed3 represent flyers, speaker bureau and an in school program, a value of 1 is given if all three are present, otherwise 0.

There are three dummy variables corresponding to levels of use restrictions (UR). UR1 gets a 1 when a request is made to consumers in the district to reduce their consumption by a given percentage amount, otherwise 0 is assigned. When use restrictions are mandatory a 1 is assigned to UR2, otherwise 0. When the use restriction is enforced a 1 is coded, if not, 0 is assigned to UR3.

The landscaping program variables (Land) and Low Flow Plumbing variables (Plumb) are similarly coded. Land1 is given a value of 1 when landscaping education is provided, 0 otherwise. Land2 is equal to 1 when in addition to education there are restrictions or limits to landscaping activities, 0 otherwise. Land3 is 1 if landscape audits are performed, otherwise 0. Plumb1 equals 1 if retro-fit kits are available, otherwise 0. Plumb2 is 1 when rebates are offered, 0 otherwise, and Plumb3 is 1 when new construction codes are in effect, 0 otherwise.

To create our price variable $\widehat{AMP}$ we first need to estimate the predicted shares $\hat{s}$. We use maximum likelihood to estimate a multinomial logit model that provides us with predicted probabilities of locating on the different blocks of a given price structure. the choice of location is assumed to be related to aspects specific to the group such as income I, temperature (Temp), precipitation (Precip), Household size (HHS), use restrictions (UR), and billing information (Bill), in addition to aspects specific to the choices, such as prices. With these $\hat{s}$ in hand we proceed to create a price variable which represents the mean price faced by all households.[11] The variable $\hat{d}$ is also created using $\hat{s}$, and it represent the mean difference faced by all households.

Table 3 presents preliminary results. The different specifications of the model where estimated using a full cross-sectionally correlated and time-wise autoregressive model as described in Kmenta (1986). The first column of Table 3 presents estimates for what can be called the standard model of water demand. Practically all studies have considered these variables, in some form or another, and their influence on water demand. All parameter estimates are of the expected sign and significant. Elasticity measures can be obtained by multiplying the estimated parameter by the ratio of the relevant variables. The price elasticity calculated at the means is -0.297 which implies an inelastic price response.[12] The magnitude of the elasticity is consistent with what has been found in the literature, where except for four studies, all have found inelastic response.[13] The $I + \hat{d}$ coefficient is used to calculate an income elasticity of 0.841, which is significantly larger than that found by

[11] Schefter and David (1985)where the first to note that the correct marginal price to use in an aggregate setting is tha mean marginal price and not the marginal price faced by the average consumer.

[12] In actuality this estimate represents a conditional elasticity, since if price, block structure or income change, the predicted probabilities associated with location in the different blocks could also be affected and hence $\widehat{AMP}$.

[13] The papers that find elastic responses include Hewitt and Hanemann (1995), Howe and Linaweaver (1967), Deller et al. (1986) and Danielson (1979). Of these studies, Hewitt and Hanemann, Danielson and Howe and Linaweaver find elastic response to prices when using summer months to represent outdoor consumption.

Hewitt and Hanemann (1995).

The next column presents the conservation model, in which the created variables to measure the district's conservation efforts are included. Originally all dummy variables were utilized, but only use restrictions and landscaping programs proved to be significant. Once the influence of these conservation variables on water demand is controlled for the coefficient on price ceases to be significant, but still has the theoretically expected sign. The effect of income on water consumption also becomes insignificant. The climatological variables and household size continue to influence water consumption significantly. Not surprisingly, a negative and significant coefficient is found on use restrictions, implying their importance to water district managers in trying to reduce water use. It should also be noted that once use restrictions are placed into effect, enforcement of these restrictions does not add significantly to conservation efforts as can be seen by the insignificant coefficient UR3. Landscaping audits, on the other hand, prove to be effective in conservation efforts.

The last column presents what we call the drought interaction model, where a variable created to pick up the interaction effect of price during the drought is added to the conservation model. In this specification, the influence of price on water consumption in periods other than when a drought is present becomes negligible. The created interaction variable, $D \cdot \widehat{AMP}$ has a negative, but insignificant coefficient signaling that households don't respond differently to prices when in a drought. This may not be a surprising result, since water districts rarely use price as an instrument to induce lower water consumption. Further analysis, including more districts, and focusing on the summer months, when there is greater scope for discretionary water use, could however result in some revision of this conclusion.

7 Conclusions

The results obtained so far are preliminary and require refinement but do provide some

Table 3: Regression Results

Coefficient	Standard model	Conservation model	Drought interaction
Constant	-50.7920	-63.676	-66.135
	(-7.5884)	(-10.506)	(-10.631)
$\widehat{AMP}$	-7.2923	-3.7709	-1.4717
	(-2.8376)	(-1.4136)	(-0.4949)
$I + \hat{d}$	0.00364	0.00158	0.00121
	(4.9774)	(1.6962)	(1.2774)
HHS	18.5930	25.8590	26.836
	(6.1402)	(9.0028)	(9.2063)
Temp	0.1725	0.2069	0.2082
	(5.1392)	(6.3172)	(6.391)
Precip	-0.1602	-0.1717	-0.1789
	(-2.1258)	(-2.2246)	(-2.3247)
UR1		0.25514	0.21016
		(0.24806)	(0.2058)
UR2		-7.5765	-7.0015
		(-3.3984)	(-3.1109)
UR3		-0.7321	-0.2341
		(-0.9702)	(-0.2936)
Land1		-0.9345	-0.24612
		(-1.4021)	(-0.3186)
Land2		-0.8201	-0.4724
		(-1.2243)	(-0.6839)
Land3		-2.3081	-2.1380
		(-2.4336)	(-2.2759)
$D \cdot \widehat{AMP}$			-1.7428
			(-1.7232)
n (per district)	94	94	94
Buse R^2	0.3801	0.5866	0.5638

new insights into the effectiveness of pricing and non-price conservation programs for inducing water conservation. Our data show that water consumers in the San Francisco Bay Area responded to the prolonged drought by reducing consumption substantially. The empirical results, based on the piecewise-linear budget constraint model, show that pricing can be an effective tool in reducing water consumption. However, when we control for the influence of conservation programs, we find that the pricing effect is mitigated. Even during the drought, the price effect is insignificant once the influence of conservation programs is controlled for.

The conservation programs that seem to be particularly effective are use restrictions and landscaping programs. When use restrictions are imposed, the enforcement of these restrictions seems to be unnecessary. Landscaping audits are also effective in inducing conservation and should be looked at by water district managers as a possible tool.

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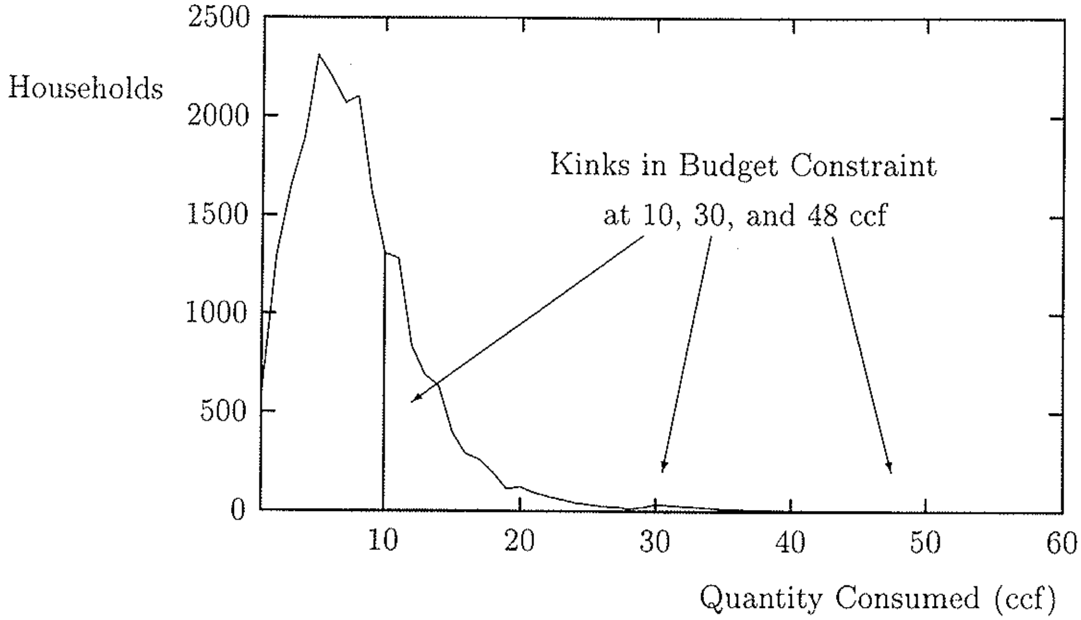

Figure 7: Frequency Distribution of San Leandro Water Consumers