An Economic Investigation of Urban Water Demand in the U.S.

by

David R. Bell
and
Ronald C. Griffin

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Table of Contents

Executive Summary

What is the price of publicly supplied water and how is it changing in American cities? What is the demand for water in important American sectors? These are the questions addressed in the following report. A broad survey of water providers in cities across the U.S. reveals a variety of rate mechanisms and price levels for water and sewer provision. The survey covers the horizon 1995 to 2005 in monthly time steps. Because water is used for both human and productive demands, prices for residential and commercial users are surveyed. Industrial processes are sufficiently distinct from other forms of commerce to merit treatment as a third sector.

Although monthly fees vary widely from sector to sector, the mean price per 1000 gallons is found to be similar for all three sectors across the sample. Water prices are increasing faster than the pace of inflation in most communities. Monthly water consumption data are gathered and summarized for some 200 communities with known price schedules, as are supporting demographic, economic, and climatic data.

Representative components of price are estimated for each monthly observation on each community. Econometric regression relates price and other explanatory variables to total quantity demanded. The model of three sectors emphatically outperforms a model of only residential variables. Sector shares of total consumption are estimated directly from the regression. These sector shares agree with estimates made independently by the Aggregate Water Use Data System of the U.S. Geological Survey. Long- and short-run regression results are integrated using an error correction model. This integration cuts forecasting error in half relative to the long-run-only model.

Each explanatory variable is found to be statistically significant in the long-run model. Demographic, climatic, and some pricing components are significant in the short-run model. The integrated error corrections model allows a time-path of demand adjustment to be estimated. The estimated adjustment path exhibits gradual change over several years. An estimated 85% of total adjustment to new price conditions is reached after 10 years.

As expected weather is the most influential driver of demand change from year to year. Both residential and commercial sectors respond to fixed charges, as well as to increasing block rates. Response to marginal price is more pronounced in the commercial sector. Price effects vary from price component to price component, from sector to sector, from region to region, and across income and season.

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Chapter 1

Overview

1.1 Problem Statement

Because water supplies are intensively utilized in much of the United States, traditional visions of water supply problem-solving will not be sufficient to guide urban areas confronting the challenges ahead. In contemporary settings, opportunities for enlarging urban water supplies typically involve decreases in the water supplies of other sectors, especially when environmental flows become recognized as a legitimate water-using sector in support of human welfare. Water professionals have been concerned about these tradeoffs for many years (Griffin 2006); yet citizens and leaders have been slow to acknowledge the advance of scarcity or the ideas that (i) water planning challenges in the U.S. are better addressed by an array of measures than by sole emphasis on supply development, and (ii) new solutions – particularly demand management programs – must ultimately be enlisted. Novel measures will entail locally new policy options that act to ration water use or guide the reallocation of available supplies. Continued, proactive research is needed to develop a firmer knowledge base for enacting such measures as their desirability increases.

Continued economic growth and the preservation of economic welfare for American cities depend on the cultivation of demand management strategies to augment supply development, which in turn is aided by a refined and comprehensive understanding of water demand. Characterization of the water use of communities without consideration of economic factors fails to capture the element of individual choice that is the theoretical basis of demand management. Water demand, unlike water use, is not a quantity; it is a relationship involving the value of water vis-à-vis the values of other scarce resources in a finite world. The vision of demand management is to characterize and use information about these demand relationships. Without this information, local planners will be less effective in responding to the complex rate-setting operations demanded of them, and policy makers may be deprived of clear projections of water use based on economic and population growth, rate responses, and climatic conditions.

Remarkably, some of the most intense U.S. population expansion and economic development have occurred in areas of high water scarcity. As professional water planners in growth regions grapple with their urban-based tasks, they will be assisted by new information capable of advising a broader array of choices. Demand forecasting is one of these areas. Most water demand projection tools are driven by simple coefficients that oversimplify consumer behavior and mask the potential of new policy options. For example, most domestic water use forecasts employ a single driver, population, thereby limiting planning actions to meeting a population's "water requirements" or conceivably, to limiting population (Griffin 2006, pp. 275-276). If water planning activities are to progress, existing data should be examined for more highly dimensioned insights into demand determination.

An important group of traditional planning duties pertains to capacity expansion, infrastructure planning, and the ensuing rate revisions that must recoup costs and balance budgets for urban utilities. Typical water rates employed across the U.S. are formulated so as to offset the value-adding costs that utilities incur in converting naturally found water (e.g., in rivers or aquifers) into the delivered and pressurized water that is received by clients. Because rates are almost always based on value-adding expenditures, without incorporating an explicit value for the water resource itself, utilities are responding to overstated expressions of quantity demanded (Griffin 2001). As utilities undertake more costly water development measures in water-scarce regions and are thereby forced to raise rates in nonincremental amounts, the deficiencies of traditional pricing policies will become more evident. Moreover, rate increases motivated by water development activities can reduce the quantity of water demanded sufficiently to render particularly expensive developments unnecessary, to the misfortune of customers. Thus it may behoove planners to produce economically specified models of demand prior to engaging costly developments.

Short- and long-term use forecasting, rate-setting and design, project selection, and the menu of management alternatives can all be improved by the insights of a richly specified demand correspondence that statistically relates prices, weather, and demographic indicators to the quantity of water demanded in an urban locale.

1.2 Objectives

The primary objective of this research is to statistically estimate an econometric demand function for publicly supplied water use in the U.S. consisting of domestic, commercial, and industrial demands in cities. Publicly supplied water, or "public supply", refers to all processed deliveries from a central water utility. Demands for each sector are estimated simultaneously based on sectoral characteristics and total water withdrawals. Sensitivity to scarcity signaling is examined, as represented by price elasticity and estimated across multiple econometric formulations, in shorter and longer time intervals, by sector and region, and with respect to both average and marginal price specifications.

Estimation of the demand function requires constructing a model and collecting data. Model construction includes surveying the body of previous literature on water demand and arriving at an original synthesis of methods appropriate to the unique requirements of this research. Collecting data includes assembling and describing withdrawal, pricing, and other data elements, followed by detailed analysis of each element. In the case of pricing, the depth of data assembled for recurring meter charges, volumetric rates, block rates, and average pricing is unprecedented. The value of a purely descriptive look at this element may transcend the value of the statistical demand analysis for some readers. Others will find value in the characterization of the volumetric element (water withdrawals) due to its longitudinal, interstate coverage.

1.3 Scope

This research analyzes demand for publicly supplied water in the urban U.S. for the years 1995 to 2005. Data are collected on the quantities and prices of water supplied in a sample of American cities, as well as measures of population, economic activity, and weather in those cities. Monthly data allow the close inspection of rates of change and seasonal patterns. A greater descriptive emphasis is placed on the price data, since its collection and compilation is original to this research. The functional unit of analysis is the community, an aggregate of 30,000 or more people (as per U.S. Census 2000), along with their concomitant economic activities served by a single water provider or utility system. Because each data element used comes from either a published source or a public record, the analysis is repeatable, the results verifiable, and the method extensible to future research.

The existence of a functional relationship between quantity demanded and price, weather, and economic variables is maintained as a primary assumption. The actual relationships are determined by statistical regression. The consideration of price transforms this research from a study of water use to an analysis of water demand. This research sets itself apart from previous water demand studies by simultaneously addressing residential, commercial, and industrial water demands from the same public sources. Total demand is modeled as the sum of sectoral demands. Another unique feature is its treatment of time. Dynamic adjustment is modeled using a combination of changes and levels of the data within an error corrections model.

Chapter2

Methodology and Procedures

2.1 The Sectoral Approach

Users of publicly supplied water may be classified in a variety of ways, and the number and boundaries of these user classes, or sectors, are not universally defined. A common trichotomy is residential, commercial, and industrial (Williams and Suh 1986). Some researchers have found it convenient to designate other sectors, such as government and schools (Schneider and Whitlatch 1991). This research adopts the trichotomy, albeit including a numerical intercept that allows for an unspecified remainder to measure in-system losses, fire control, and public uses that could constitute a fourth sector. The research assumes that residential use is directly proportional to the population, commercial use is directly proportional to nonfarm earnings, and industrial use is directly proportional to manufacturing earnings. The remainder of total water withdrawn is assumed to be price-unresponsive and invariant to growth, although it may vary with climatic factors.

The body of water demand research indicates, "each user class responds differently to rate changes" (American Water Works Association 2000). The mean of price elasticities derived from a large number of residential water demand studies is –0.41 (Dalhuisen et al. 2003), whereas recent estimates of price elasticity for water in industrial processes include –0.81 (DuPont and Renzetti 2001) and –1.42 (Reynaud 2003). Mean elasticities for commercial subsectors ranged between –0.23 and –0.63 in a recent account (Moeltner and Stoddard 2004). Sectoral differences in adjustment rate and response to fixed charges have not been explored.

Direct comparison of elasticities across studies is not advised, since samples and methodologies are unique to each study. Moreover, it is highly unlikely that any one sector's water demand exhibits constant elasticity across all conditions. Nevertheless, research that provides parallel estimates of water price elasticity for multiple sectors is sparse.

A template for the present research is forged by Williams and Suh (1986). Williams and Suh estimate linear functions for residential, commercial, and industrial water demand based on the number of sector participants and price, as well as income, rainfall, temperature, and population density for residential demand; commercial receipts and temperature for commercial demand; and value added in manufacturing for industrial demand. This specification is quite similar to the short-term model used in this research and quite different from the long-term model developed here, even though Williams and Suh estimate a structural model on assumptions more closely matching those of the present long-term model. Estimating sectoral elasticities with respect to both average price and marginal price, Williams and Suh find mean elasticities of –0.484 and –0.253, respectively, for residential demand, –0.360 and –0.141 for commercial demand, and –0.735 and –0.438 for industrial demand. Thus, sectoral responses do not appear to be identical, and average price response is uniformly greater than marginal price response (although the latter result is arguably forced by their choice of functional form).

Williams and Suh is exemplary for its postestimation diagnostics. Drawbacks are their use of a linear functional form and the vintage of the study, using primarily 1976 data augmented by 1967 data on commercial activity.

Schneider and Whitlach (1991) expand the Williams and Suh model to include government and school sectors and "total metered" demand. Schneider and Whitlach introduce an important temporal component by including 18 annual time-steps. Panel techniques allow for heteroskedasticity across neighborhoods and adjustment over time. Both of these precedents are incorporated in the present research.

Estimating both long- and short-run marginal price elasticities, Schneider and Whitlach find means of –0.262 and –0.119, respectively, for residential demand, –0.918 and –0.236 for commercial demand, and inconclusive results for industrial demand. Again, responses vary by sector. Not surprisingly, complete adjustment does not appear to materialize over a single annual time-step for either residential or commercial demand. Unfortunately, all of the Schneider and Whitlach data are drawn from the vicinity of Columbus, Ohio, compared with a national cross-section of 120 communities in Williams and Suh, so the generality of the Schneider and Whitlach findings remains in question. The multisectoral approach of the two studies has not been followed since, and Williams and Suh remains the single example of multisectoral water demand estimation on a national scale.

Residential Demand

The majority of water demand research has been focused on the residential sector, including the 64 studies reviewed in a recent meta-analysis (Dalhuisen et al. 2003). The general pattern of residential demand models is to posit a relation between consumption and price, weather, income, and household composition. For a detailed review of this study area, see Arbues et al. (2003).

The level of data used in these studies can be classified as household or aggregate. Household-level data, or microdata, is appealing because it enables explanatory power to be ascribed to characteristics such as house and family size and the use of water-conserving fixtures. Such data is also appealing to the theoretical economist who can place the demand correspondence within a formal framework of household utility or preferences. On the other hand, aggregate data can be more directly used to enable public policy applications, and aggregates may be attained from public records rather than requiring personal interviews or questionnaires. The present research deals in aggregates, and the city or community is the fundamental unit of study.

Commercial Demand

Commercial and domestic uses of water are often intertwined, with the unfortunate result that aggregate studies of residential demand may inadvertently capture commercial demand as well. The choice of boundary between these sectors ultimately depends on the questions to be answered. Is a service station or a law office with a 3/4" meter located in a residential neighborhood commercial? One alternative is to accept the utility system's customer classification (Williams and Suh 1986). A recent study of commercial demand takes metered water classified by the utility system as commercial/industrial/institutional and further subdivides it by the 2-digit Standard Industrial Classification of the consuming firm (Moeltner and Stoddard 2004). This assumes explicit firm-level data is available, making it a microdata technique analogous to a household study, rather than an aggregate technique.

The present research takes a different tack. In Williams and Suh, population is explanatory of residential demand and sales receipts are explanatory of commercial demand. Maintaining this hypothesis a priori, this research defines residential demand as responsive to population and defines commercial demand as responsive to nonfarm commercial activity. Similarly, industrial demand is defined as that part of aggregate demand that responds to manufacturing activity. This functional approach identifies water demands by end-use rather than by customer class, circumventing potential conflicts in local definitions of customer class.

Industrial Demand

The standard procedure for estimating industrial demand is to sample the use of water across a number of participating firms and to assume cost-minimizing behavior for each firm in light of water price and the prices of other inputs (Reynaud 2003). Demand may be subdivided into intake, treatment, recirculation, and discharge, to capture the intricacies of industrial water manipulation (Renzetti 1992). Unlike demand models for other sectors, prior industrial models tend to use a translog functional form, including more parameters than a logarithmic form to allow more flexibility in the shape of the estimated function. The flexible form of the structural model in this research follows from the same logic.

Another, older approach to industrial demand estimation employs aggregate data and a simpler functional form (Babin et al. 1982, Grebenstein and Field 1979). The level of aggregation in these studies tends to be too high to support detailed hypothesis testing. A major challenge of aggregating industrial water users is to disentangle demand for publicly supplied water from self-supplied water demand. Manufacturing firms often elect to supply their own water based on firm size or price sensitivity (Renzetti 1993). Utility systems do not know the activity level of their customers, and the Census of Manufactures does not discriminate among water supply sources (U.S. Census Bureau 2004). Reliability of estimates for industrial demand requires at minimum the assumption that a constant proportion of manufacturing activity attributes to firms using publicly supplied water in each community. The extent to which this admittedly strong assumption is not met is an important consideration to make when evaluating the results of the research. Nevertheless, the functional approach to sectoral water demand is a significant step toward identifying the uses of publicly supplied water.

2.2 Change over Time

The present analysis includes two interlocking demand models, one describing the long run and the other describing the shorter run. The long-run model is called structural because it attempts to describe the equilibrium structure of water demand. The structural demand model presumes that allocation decisions are made in perfect knowledge of price and all at once (McKenzie 2002, pp. 52-55). In actuality, consumers continuously make small marginal decisions about water; not all consumers are perfectly aware of price; and conditions change, including weather and prices. The equilibrium behavior predicted by a structural model may take years to materialize, or might never entirely materialize. Because of this, water management considerations that depend on a finite time horizon can benefit from a dynamic model (Bell and Griffin 2008). The short-run model is dynamic in the sense that it attempts to capture incremental adjustments rather than timeless relationships.

Dynamic Water Demand

An early dynamic alternative is the flow adjustment model, introduced by Nerlove and brought to residential water demand in 1980 (Carver and Boland 1980). Also known as the partial adjustment model, this formulation assumes that a steady proportion of any temporary disequilibrium is corrected each period. Mathematically, it improves on the static model by introducing an autoregressive or lagged value of the dependent variable, such as last year's quantity demanded. Model fit is improved and an estimate of annual adjustment is generated, but the formulation itself is simplistic, leading to unrealistic implications.

Improvements to the Nerlove model made by Box and Jenkins have been subsequently incorporated into a time-series water demand study by Fullerton and Elias, who employ an autoregressive integrated moving average (ARIMA) model (Fullerton and Elias 2004). In the ARIMA model, the simple flow adjustment structure is generalized to a methodical selection of lagged values (Box and Jenkins 1990). In the case of Fullerton and Elias, these include an annual lag of price, a semiannual lag of employment rate, and monthly lags of weather variables. A similar model recasts ARIMA in a more modern light by imposing stationarity on the selected lags with first-differences (Billings and Agthe 1998). This model represents a bridge in theory from the old to the recent, although the Billings and Agthe findings may not generalize beyond the single community of their analysis (El Paso, Texas).

In the world of theoretical econometrics, the ARIMA model has given way to vector autoregression and its applied tool, the error correction model (ECM) (Hargreaves 1994). ECM was introduced to electricity demand modeling in 1989 (Engle et al. 1989) and to water demand modeling in 2004 (Martinez-Espineira 2004). ECM integrates the intuition of Nerlove into the formal theory of statistical inference. Instead of lags of variable levels, ECM employs the lagged residual from a structural model in a regression equation of differences. Although rare in water demand estimation, the model has become dominant in estimation of similar service commodities such as electricity (Holtedahl and Loutz 2004, Silk and Joutz 1997) and gasoline (Cheung and Thomson 2004).

Because of its theoretical consistency and its ability to answer interesting questions at annual and equilibrium horizons, ECM is used in the present analysis to model dynamic adjustment. The present analysis, however, dispenses with the ex ante stationarity tests traditional among ECM studies, as well as the claim of a "cointegrating relationship". In macroeconomic contexts, concern arises that first differences of some data series are not stationary and therefore cannot be considered fixed in repeated samples. Unit-root tests such as the Dickey-Fuller test attempt to guarantee the stability of statistical results. This stability is especially important when the claim is made that the regression function is cointegrated, or super-consistent (Juselius 2003). Unit-root tests are performed ex ante because they are conducted on individual data series rather than on regression results.

Such tests are well known to have little power, and they are not necessarily a good substitute for theory or experience. Furthermore, the requirement of a cointegrating relationship is much stronger than restrictions otherwise imposed on applied econometric models (Pesaran 1997). The philosophy motivating the flexible structural equation and the linear dynamic equation is not that the "true" demand relationship has been found, but that an approximation has been made, a first approximation in the linear case and a second approximation in the flexible case. Ex post specification tests are of course conducted, including a Hausman test of exogeneity in price, a Breusch-Pagan test for homoskedastic residuals, and a Cook's D test for influential observations.

Seasonality

Seasonality is a special case of dynamic behavior in the demand for water. Water retailers want to ensure that production matches consumption in every period, most challenging in the summer when demand is highest and recharge lowest in many locales. Seasonal dependence makes the time-path of adjustment more important in water demand than in nonwater contexts. Seasonality refers to differences in model parameters attributable to timing within the calendar year.

Even the earliest water demand studies recognize the value of treating summer months differentially (Howe and Linaweaver 1967). Most treatments of seasonality have held to this summer/nonsummer (peak/off-peak) duality (Lyman 1992, Nieswiadomy and Molina 1988), although each month is considered individually in more thorough treatments (Bell and Griffin 2006, Griffin and Chang 1991).

Weather and climate are not synonymous with seasonality even though weather patterns are the fundamental reason for the interest in seasonality. Separate treatment of seasonality would be unnecessary if weather metrics could adequately model the cyclical pattern of demand over the year. A novel attempt by Renwick and Green to describe seasons as harmonic cycles using temperature and precipitation instruments has not been further pursued (Renwick and Green 2000).

Although monthly seasonality is theoretically subsumable under the ECM framework (Hylleberg 1994), implementation is difficult in practice. Quarterly seasonality is more tractable and has been utilized successfully in water demand (Martinez-Espineira 2004). The procedure may be appealing to the theorist, but its predictive and explanatory powers have not been impressive thus far. The present research most closely follows Griffin and Chang (1991), with the short-run model reestimated for each calendar month to examine seasonal variation.

2.3 Price Specification

Demand estimation is only meaningful if consumers make choices based on their relative valuations of water and other goods. How often are these relative values evaluated? Are consumers perfectly aware of their future choices? How well do suppliers communicate price to consumers? How do we combine everyone's valuations into a single metric? Often these worrisome questions are sidestepped by an appeal to the concept of price. When all consumers at all times experience a single, posted price, the answers do not matter so much because the various conceptions of value converge in a single, static demand correspondence.

When there is no single price, as in publicly supplied water provision, the various possible conceptions do not converge, and the researcher must compromise. We would like a price index that approximates the value of water relative to the other goods and services households and businesses buy and sell. We want it to reflect the richness of the supplier's price signals, yet we want it to be consistent and describable by a small vector of numbers. We want to be able to test hypotheses and alternative specifications. We want to be able to consistently compare the influence of the prominent indices, marginal price and average price, to determine which price better captures customers' experience or whether both are equivalently expressive.

Marginal Price and Average Price

An aspect of price specification that has received considerable attention in the literature on water demand is the treatment of fixed fees. In the standard demand model, consumers making behavioral choices only respond to the marginal price, the price of one more unit (one more drop, or more practically 1000 more gallons or 100 more cubic feet of water) (Carver and Boland 1980). However, significant recurring flat fees are levied by water utilities, irrespective of the volume of water used. Because they do not depend on consumption behavior, these fees do not enter the standard, full-information demand model except to reduce effective income.

Flat fees are part of the bill, though, and not always itemized for consumers, so fees *appear to be* part of the price of water for many consumers (Nieswiadomy 1991). Confusion might even persist up to the level of data collection, if the researcher knows only the amount of the typical bill. This is the case, for example, when charges are compared across utility systems for households using 10,000 monthly gallons or some other predetermined amount(s) (American Water Works Association and Raftelis Financial Consultants 2007). Since average price is simply the amount of the total bill divided by quantity demanded, it is presumably an accessible approximation of the price of water for many consumers. For a more thorough coverage of the price specification controversy, see Arbues et al. (2003). A potential problem with the average price specification, especially in aggregate, is the inherent algebraic relationship between average price and quantity (Griffin et al. 1981).

The full-information model implicitly assumes that each consumer obtains marginal price information, whatever the cost. More likely, consumers weigh the costs of information acquisition against the benefits. As the real costs of water rise, so does the return to information; and more consumers will invest in this information. Increasing prices, therefore, are expected to increase the relevance of marginal price. Transparent disclosure of the price schedule by the billing authority is expected to achieve similar results by reducing the cost of information.

Price specification is an empirical question (Foster and Beattie 1981), but "average price or marginal price" is an incomplete phrasing of the question. If some consumers respond to each, the aggregate will respond to a combination of both. It is also possible that the best specification is neither of the above. Because of this, the flexibility of a vector of price components holds greater potential than any single price index.

Winter Averaging

An especially problematic sewer pricing policy is known as winter averaging. Winter averaging is prevalent in the residential sector and less common in commercial and industrial sectors. Sewer facilities treat recovered water, so their treatment costs are not strongly impacted by landscape irrigation. Assuming that irrigation does not occur in winter and that indoor uses are constant year-round, some utility systems base their sewer billing for the entire year on customer behavior in the winter. Consequently, (i) the effective marginal sewer price in nonwinter months is actually zero, (ii) the effective marginal sewer price in winter is very high (as customers repeatedly pay for winter consumption over the year), and (iii) conserving water in the summer is not encouraged by this policy. The perverse incentive created by winter averaging is counteracted only by the fact that it is poorly understood by consumers. Considering that as few as 10% of residents invest in marginal price information of any kind (Carter and Milon 2005), even fewer are likely to explore the implications of a complicated and opaque policy, however exemplary it might be in assigning costs to beneficiaries.

In the absence of winter averaging, the marginal sewer price is simply the posted price of sewer service per volume unit (1000 gallons or 100 cubic feet of water use). In the face of high information costs, it seems reasonable that most customers would take this posted price to be the price of service year-round. Therefore, this prima facie marginal sewer price (without winter averaging) is adopted as the marginal sewer price metric in the present analysis. Average price is not affected. The wisdom of this specification is tested in the regression using variables to indicate the presence of winter averaging and observations where sewer marginal cost is in fact zero.

Price Endogeneity

Implicit in statements such as "A 1% increase in price will induce a 0.5% decrease in volume demanded," is the assumption that consumers respond to a price they cannot control. Under a block-rate structure, though, consumers simultaneously choose a price and a quantity level. Price depends on quantity. Even under uniform rates, average price depends on quantity inasmuch as the fixed fee plus variable charges are divided by quantity to arrive at average price. These cases are troubling to the analyst because they introduce bias into estimates of price response. Proposed econometric responses to this bias have been numerous (Bell and Griffin 2008, Herriges and King 1994).

One response has been to form an ex ante approximation of representative quantity demanded, to derive price measures from that quantity, then to treat the prices derived as an instrumental variables (IV) estimate of price (Hausman et al. 1979). This approach has advantages and disadvantages. A disadvantage is that the IV price changes from observation to observation as the instruments (the independent variables such as weather and income) change, even though these changes are no longer simultaneous with quantity. In the present research, an auxiliary regression similar to the IV price equation estimates a mean quantity demanded for a representative household and a representative business in each community. Price indices are based on the estimated mean quantity, but the mean stays constant for all observations on a given community.

2.4 Empirical Models

The complete demand model applied here consists of a long-run component and a shorter-run component. Both elements simultaneously estimate demand in each of three sectors plus a weather-dependent constant. The quantity of water demanded by the residential sector, Q_r, is assumed to be a function of residential price components, p_r, income, *m*, and climatic components, *c*:

$$Q_r = f(p_r, m, c)\,. \qquad [1]$$

Similarly, commercial demand, Q_c, is assumed to be a function of commercial price components, p_c, and climatic components:

$$Q_c = g(p_c, c)\,; \qquad [2]$$

and industrial demand, Q_i, is assumed to be functionally related to industrial price components, p_i, and climate:

$$Q_i = h(p_i, c)\,. \qquad [3]$$

Total demand is the sum of sectoral demands, an intercept, *k*, and a random error term, ε:

$$Q = Q_r + Q_c + Q_i + k(c) + \varepsilon\,. \qquad [4]$$

Structural Models

In the long-run model, residential per-capita demand is the demand of the representative resident, commercial demand is estimated per dollar of commercial output, and industrial demand is estimated per dollar of industrial output. Total demand is the aggregate of all demands. The total demand equation for a community with y_r population, y_c nonfarm earnings, and y_i manufacturing earnings, is

$$Q = y_r q_r + y_c q_c + y_i q_i + k(c) + \varepsilon\,. \qquad [5]$$

The functional form for each sectoral per-unit demand (per-capita or per-dollar) is the square root function, a generalization of the Leontief form that allows flexible interactions among independent variables. A set of parameters, α, β_j, and δ_{jk}, are estimated for each per-unit demand with respect to explanatory variables x_j $(x_j \in X)$, such that,

$$q = \alpha + \sum_j^X \beta_j \sqrt{x_j} + \sum_j^X \sum_j^X \delta_{jk} \sqrt{x_j}\sqrt{x_k}\,. \qquad [6]$$

The price elasticity of demand (sectoral or total) in equation [6] is calculated at consumption level *Q* and population or earnings level *y* as

$$\frac{q' x_i y}{Q} = \frac{\left(\beta_i \sqrt{x_i} + 2\delta_{ii} x_i + \sum \delta_{ij} \sqrt{x_i x_j}\right) y}{2Q} \qquad [7]$$

where q' is the first derivative of [6] with respect to price and x_i is the price component under scrutiny.

Auxiliary Price Estimations

If marginal price is known, the relationship between marginal price, *MP*, and average price, *AP*, hinges on the level of fixed charges, *F*. In the case of a single marginal price,

$$AP = \frac{F + MP \bullet Q}{Q} = \frac{F}{Q} + MP . \qquad [8]$$

The expression is more complex in the case of multiple block rates, but average price can still be expressed as a sum of average marginal prices and a function of fixed costs. It is not necessary that the quantity *F* be defined as the periodic fixed charge. In other specifications, *F* could be defined as the total bill minus *(MP • Q)* (Nordin 1976). The formulation of the average marginal price variable, p_1, in this analysis dictates that the fixed part of price is equivalent to the periodic charge.

Which price specification is more explanatory can be tested by nested and nonnested procedures. In a nonnested test, alternate functions *q(AP,m,c)* and *q(MP,m,c)* are compared directly to see which one generates less error. In the nested tests performed in the present analysis, only *q(F,MP,m,c)* is regressed. If the variable *F* does not contribute significantly to the estimation, then marginal price is arguably the preferred specification. Neither test can determine that average price is the best possible specification because consumers may very well respond to a combination of fixed and marginal prices that is not precisely average price. Results of both nested and nonnested tests are given later.

A known marginal price was assumed in the paragraph above, but it has already been established that some price schedules prescribe more than one marginal price. Under block rates, various consumers experience various marginal prices. Data are unfortunately inadequate to appropriately weight each marginal price by its relative influence in the aggregate, because the distribution of consumption levels across consumers is unknown without recourse to microdata. Marginal prices used in the analysis are averaged naively (uniformly) across a range. Even with such a simplistic method, the question remains, what is the appropriate range?

The following procedure is adopted to develop consistent price components. The structural regression indicated by Equation [6] is performed with all price components omitted, yielding a price-neutral prediction of quantity used. This model is used to obtain a mean expected residential and commercial use for each community. Based on the results, residential and commercial marginal price schedules for each observation are averaged from zero consumption to the mean, then from the mean to twice the mean. A low and a high average marginal price are thus constructed for each observation for residential and commercial sectors. Only one marginal price, the volumetrically highest, is used for the industrial component, reflecting the assumptions that (i) industrial users only respond to the long-run marginal costs of inputs, and (ii) industrial users use the highest volumes of water and are therefore the target audience of rate-setters when they set the volumetrically highest block rate.

Three residential price components, three commercial price components, and one industrial price component are re-entered into the regression. The low average marginal price reflects the economic notion of "price", the fixed charge divided by mean projected quantity reflects the nonmarginal part of average price, and the high average marginal price minus the low price represents the degree of increasing or decreasing block pricing. By this method, competing hypotheses on price specification can be tested, and demand effects of specific pricing policies can be quantified, including price-path effects.

Dynamic Models

Whereas the long-run model is a detailed attempt to capture the mechanics of urban water demand, the shorter-run model attempts to capture linear magnitudes of annual adjustments. One important source of adjustment is the constant gravitation toward the structural model. The farther out of equilibrium a community is at a given time, the greater its tendency to move toward equilibrium. This is the purpose of the error correction term. The disequilibrium or "excess demand" is measured by ε in [4]. The shorter-run model includes annual differences of the drivers of the long-run model and a lag of excess demand to describe the annual change in quantity demanded:

$$\Delta_{12}Q = \alpha + \beta\Delta_{12}x + \delta\Delta_{12}y + \varepsilon_{-12} + v\,. \qquad [9]$$

Explanatory variables x and magnitude variables y are not subscripted because they represent vectors of these variables. Annual differences are denoted Δ_{12} because they represent the changes from the same month last year. ε_{-12} is the structural residual from the same month last year. Because the dynamic model is stochastic, it includes a new random error term, v. Equation [9] is regressed across all observations, then once for each month of the year. Short-run elasticities are computed as

$$\frac{\Delta_{12}Q \bullet x}{\Delta_{12}x \bullet Q} = \frac{\beta x}{Q}\,. \qquad [10]$$

Chapter 3

Descriptive Statistics

3.1 Prices and Fees

In contrast to the climatic and economic data used in the analysis, price and quantity data on water demanded are not routinely compiled by a national entity. Quantities of use by utility system are surveyed annually by several states and surveyed every fifth year by the Aggregate Water-Use Data System of the USGS (Hutson et al. 2004). Some cost data are collected by the American Water Works Association or ad hoc by local initiative (American Water Works Association and Raftelis Financial Consultants 2007). Such cost data collection efforts typically reduce complex rate structures in the interest of simplicity. Important price elements are obscured or missing in existing data, so acquiring an original, multidimensional rate dataset is an important prerequisite of the analysis. Rate data acquisition constituted the major activity of the present project. Since current rate data are considerably more accessible than historical data, a continuous effort to maintain a database of current rates would contribute significantly to future research.

Water and sewer rates over the interval January 1995 through December 2005 were obtained for a sample of U.S. cities. Sample cities had a population of at least 30,000 in the year 2000. The 2000 U.S. Census identifies 1223 candidate cities with population over 30,000 in 2000 (U.S. Census 2000 2002). Among these, 101 are served by more than one utility and 106 are served by one of 4 geographically expansive private providers, primarily in the northeastern states and California. Cities with multiple providers are excluded from this analysis because explanatory variables are related to the dependent use variable through the assumption that municipal boundaries approximate service areas. Cities served by geographically expansive private conglomerates are also excluded. Their service does not fit the model of a local monopoly and their service areas are not geographically defined.

For the approximately 1000 remaining sample candidates, rate data were sought in a multistep process. First, the water utility page of the municipal, county, district, or corporate website was consulted. This step often provided current rates but rarely historical rates. Second, rate ordinances and resolutions were located on the secretary or clerk's webpage or within the code of ordinances if such was located online. If rate text was not located, documentation was made of references to rate ordinances and resolutions. A thorough search of the system's website was made at this stage to uncover relevant information.

Third, an attempt was made to contact a records officer of each system for whom data were incomplete, either by telephone or electronically or both. This contact could entail a request for identified rate documents or a more general request for assistance. The fourth step included follow-up and repeat requests to the point that additional information was unlikely or a large fee was requested.

In the case of sample subjects in the state of Wisconsin, a comprehensive rate database maintained by the Wisconsin Public Service Commission allowed rate data to be obtained for that entire state. Gaps in data for some Texas communities were filled with data from an earlier project (Bell and Griffin 2006). Figure 3-1 shows the geographical distribution of rate data gathered. Not shown in Figure 3-1 are a city in Alaska with complete data and two cities in Hawaii with incomplete data.

Some rate data were obtained for 444 subject communities. Discarding out-of-range and ambiguous data, rates that are too complex to be represented, and poor rate data where water use data are also poor, yields a set of 37,159 price-months covering 319 communities in 40 states. Sewer data include 23,060 price-months covering 210 communities in 31 states. Relative to an ideal series of 132 months (11 years) for each community, the average panel includes 116.5 months (9.7 years) of water prices and 109.8 months (9.2 years) of sewer prices. A full series of 132 water and sewer prices exists for 114 communities. Data are generally poorer for sewer rates than for water rates because some cities do not provide centralized wastewater service and because sewer rates are determined more often by resolution and less often by city ordinance. Resolutions are more difficult to retrieve than ordinances because they are not attached to the city code, which is often publicly posted.

Raw data were obtained in many forms, including web documents, electronic document and picture files, spreadsheets, faxes, paper copies, and notes from oral interviews. These were coded using a uniform procedure with quality control and redundant loops. Some individual interpretation was inevitable due to inconsistent language across documents and the multiplicity of pricing policies encountered. Correction of coding errors was continuous, as data manipulations revealed inconsistencies that triggered review and revision. Errors in orders of magnitude were more likely to be discovered by this process than errors in digits. Some incorrect data undoubtedly remain.

Price Components

This research is unique in its endeavor to capture the high dimensionality of water and wastewater pricing. Nevertheless, some elements of pricing resist numerical standardization. Those elements which have been captured are monthly fixed charges for water and sewer service, which may vary by connection capacity (meter size), volumetric marginal prices of water intake and (estimated) effluent, minimum and maximum charges, predetermined seasonal rates, winter-averaged sewer charges, and multiple block rates. Sewer rates are considered because they are almost always determined by water usage. Examples of rate elements that are not represented in this research include meter installation charges, rates dependent on the number of rooms or fixtures at the metered residence or facility, elevation-dependent rates, drought-triggered conservation rates, senior or disadvantaged rates, rates dependent on type of commercial activity, charges for suspended solid concentration and increased biological oxygen demand, and out-of-town rates. A selection bias may have been incurred on this basis due to the more common occurrence of exotic charges in the western states.

Price characteristics of the sample are summarized in Tables 3-1 and 3-2. The statistics in Table 3-1 relate to water service only; sewer service statistics are summarized in Table 3-2. Regardless of the periodicity of billing, the fees appearing in these tables are normalized to monthly dollars. Nominal prices (not adjusted for inflation) for all years and months are averaged into the statistics. High fees do not necessarily imply a high average price for water, since they may include a "free" or minimum consumption volume. The mean monthly fixed fee for residential water service is $6.60. Mean fixed fees for commercial and industrial service are $26.30 and $148.70, respectively.

The mean price for the first 1000 gallons purchased by a residential customer is $1.82. The mean price per 1000 gallons for the highest possible residential consumption is somewhat higher at $1.94, reflecting a slight national trend toward increasing block rates in the residential sector. The average effect of increasing block rates is diluted by the incidence of bill ceilings in residential pricing, for which the last marginal price would be zero. For commercial customers, marginal price declines slightly with volume from $1.86 to $1.77. The pattern is similar for industrial customers as price declines from $1.84 to $1.75. Decreasing block rates and uniform rates are more prevalent for these sectors.

In a given month, a representative system allows each residential consumer 1200 gallons inclusive in the monthly fee. The average minimum allowance increases to 2720 gallons for commercial consumers and to 11,430 gallons for industrial consumers. The ratio of fixed fees to minimum allowance increases from residential to commercial to industrial pricing.

Bills may be assessed monthly, bimonthly, or quarterly. Some northeastern communities without individual metering assess water-related charges quarterly, semiannually, or annually, as a property-based assessment. Across the sample, 12.35% of systems bill quarterly or less often, 3.23% bimonthly, and the rest monthly. 54.67% bill in increments of 1000 gallons, whereas 45.3% bill in increments of 100 cubic feet (100 cubic feet = 748 gallons).

Each geographical region is represented well in this sample except New England. The reason that only 5.8% of sample communities lie in New England relates to the institutional structure of water provision and municipal service in general. Older cities and those with historically abundant water resources exhibit less incidence of metering. Whether with or without meters, northeastern communities are less likely to have updated their charges within the 1995 to 2005 horizon. Consequently, existing rates may not be included in the most current municipal code or on the municipal website. Northeastern communities are more likely to require payment for research, to fail to respond, or to deny requests for information. Nevertheless, some comparison can be made based on the existing data.

Table 3-1 reveals some interesting regional differences in pricing policies. Fixed fees for all customer classes are lower on average in New England, but marginal prices are lowest on average in the West. The minimum use allowance is similar across the regions, except that it does not vary by sector in the New England subsample. None of these regional differences is statistically significant, however, owing to the high variation in all aspects of the data. Quarterly billing is prevalent in New England and common in the Midwest, but virtually unknown in the South and West. Measurement in cubic feet is the norm in all regions except the South, which more often uses gallons. Decreasing block rate structures are more evident in the Midwest, possibly owing to relative industrial intensity in that region.

Table 3-2 parallels Table 3-1, but pertains to sewer charges aggregated over systems, years, and months. The mean monthly fixed fee for a sewer connection in the sample is \$12.52 for residential, \$30.94 for commercial, and \$145.42 for industrial. An important component of wastewater service for some industries is additional processing of more contaminated effluent, a component of price that is beyond this project's scope. Hence, an analysis of quality-taylored or contaminant-specific wastewater rates upon industrial water demand is not conducted. The mean residential first-block price for sewer volume is \$1.76 per 1000 gallons, declining to \$1.33/1000 in the last block. Volumetric commercial and industrial pricing is more uniform, near \$2.00/1000 in both cases. The mean minimum allowances by sector are 840, 2950, and 21,600 gallons, respectively.

Sewer bills are assessed quarterly or less often in 3.63% of observations and bimonthly in 9.08% of observations. The similarity between these numbers and those for water billing indicate that water and sewer billing are normally concurrent. In addition to the bias against New England discussed above, the sewer price sample is geographically biased to the South, partially because of a tendency toward municipal operation of wastewater facilities in southern states and partially because of additional data availability in Texas enabled by an earlier project.

Compared by region, residential sewer fees are considerably higher in the West than elsewhere, although commercial and industrial sewer fees are highest in the South and significantly lower in the Midwest than elsewhere. Marginal prices are typically low and uniform in the West, higher and in decreasing blocks for residential customers in the South, with increasing blocks in New England and decreasing blocks in the Midwest. The mean minimum allowance is higher in the South and lower in the West. Bimonthly billing is common in New England (40.80%) and somewhat common in the Midwest (18.82%), but monthly billing is preeminent nationwide. Winter averaging is not practiced in the New England cities sampled. The only statistically significant regional difference in sewer pricing is the magnitude of industrial fixed fees.

Figures 3-2 through 3-4 graphically summarize the relationship between marginal price and volume used. In Figure 3-2, mean water and sewer marginal prices for residential customers are compared. Each line represents the mean of all marginal prices in the sample for 1000 additional gallons, as it varies by total monthly use. The upward trend of residential water price reflects both block rate and minimum quantity policies. The first 1000 gallons demanded cost an average of about \$1.40, whereas the twentieth 1000 gallons cost over \$2, graphically reinforcing the means identified in Table 3-1. Again, dollar amounts are nominal and averaged across all time periods and communities.

Mean sewer marginal price increases, then decreases and levels out after 15,000 gallons. Although some sewer rates decrease in blocks, the primary factor for this shape is the maximum bill or cost ceiling policy used by some systems, such that a customer can never pay more than a prescribed amount regardless of use. Mean sewer price is lower in the summer than winter because many providers calculate monthly charges based on winter consumption (winter averaging). The graphs of summer mean sewer price factor in zeroes for observations subject to winter averaging. Sewer price seems to be inversely related to water price at higher volumes. Indeed, the correlation between the two is –0.95 in the range 5000 to 30,000 gallons.

Block rate pricing is not as pronounced for commercial and industrial customers, as evinced by Figures 3-3 and 3-4. Leveling in both water and sewer price is evident above 50,000 gallons. Winter averaging is also less prevalent. A distinct winter sewer price for industry is not shown because fewer than 4% of industrial observations exhibit winter averaging.

Price Indices

A price index is a way to numerically summarize the price components. In this section, an average price index and a marginal price index are calculated by uniformly averaging the price components across a set range of volumes. Later, average price and marginal price indices will be developed for each observation based on community characteristics. Descriptive statistics for water and sewer price indices by sector appear in Table 3-3. Marginal prices are averaged uniformly across the range 0 to 30,000 gallons for residential customers, 0 to 160,000 gallons for commercial customers, and 0 to 1,000,000 gallons for industrial customers. The sectoral ranges are proportional to standard maximum flows for 0.75", 2", and 6" meters (American Water Works Association 2004). The monthly fixed fees in Tables 3-1 and 3-2 correspond to these meter sizes as well. The fixed part of the average price metric is evaluated at the midpoint of the appropriate range.

Comparing the marginal and average price statistics in Table 3-3 reveals a high degree of similarity. This quality is reassuring since the metrics attempt to describe the same phenomenon. As the quantity of use increases, the relative influence of the fixed fee decreases, so the difference between marginal price and average price is more pronounced in the residential level and at low levels of water use. This is useful since the hypothesis of incomplete information that leads to the average price specification is most applicable to residential users and users of less water. Businesses are expected (perhaps unrealistically) to be more likely to invest in full information in the pursuit of profit maximization. Average annual changes are all above the line of Consumer Price Index (CPI) inflation, which averaged 2.51% across the horizon.

Price Evolution

Figures 3-5 and 3-6 illustrate the trends in pricing policy over the period of study. Nominal prices and fixed charges by sector are compared with the corresponding Urban CPI (Bureau of Labor Statistics). In the figures, water and sewer charges are combined. As indicated in Figure 3-5, marginal prices for each sector tend to move in unison. Prices for all three sectors have outpaced inflation over the period 1995-2005. Despite a nationwide increase in the frequency of price updating since 2002, the rate of annual increase seems to have remained relatively steady.

Figure 3-6 tells a different story. Monthly fixed fees for residential and commercial customers are perhaps interrelated, but neither series has grown at the rate of inflation. Economic intuition predicts that increasing scarcity will encourage a shift of revenue burden from fixed to volumetric charges. For whatever reason, this behavior is in fact the general trend in residential and commercial pricing.

3.2 Volume Supplied

The dependent variable in this analysis is the quantity of water demanded within a given community during a given month. Quantity demanded is also called "use" or "consumption" volume, and its value depends on the point at which its flow is measured. Aggregated at the level of the community, the most common and consistent measure of quantity is the level of total withdrawal, consisting of ground water, surface water, and purchased water obtained by a utility system over a time interval. This is the datum usually collected by a state regulatory agency if volumetric records are kept, and it is the measure of quantity demanded adopted in this research. Consumption is actually water delivered rather than water withdrawn, so water that is withdrawn and not delivered will show up as random error in the model.

USGS state representatives were contacted for advice on obtaining historical volume records from the various states. Their insights were invaluable, leading to the capture of monthly data for 68% of the cities for which some price data were collected. The assistance of state agencies was also a critical component to the success of the endeavor. These state agencies include California Department of Water Resources, Indiana Department of Natural Resources, Kansas Department of Agriculture, Minnesota Department of Natural Resources, Ohio Department of Natural Resources, Texas Water Development Board, and Wisconsin Public Service Commission. Florida data are courtesy of St. Johns River Water Management District, Southwest Florida Water Management District, and USGS. Data from a community in Alaska was taken from the municipal website.

Volume series were obtained for 216 utility systems, with a full 11 years for 136 systems. A total of 25,844 system-months comprise the volume panel, implying an average of 119.7 observations (10 years) per system. The data are imperfect. Obvious instances of magnitude errors in recording were ameliorated and observations of zero or less than one million gallons were dropped (<1% of all observations). In particular, the timing of bulk transfers (purchased water) is a source of uncertainty.

Figure 3.7 shows the geographical dispersion of volume data. Points are located in Alaska, California, Florida, Indiana, Kansas, Minnesota, Ohio, Texas, and Wisconsin. The lack of New England data reflects the greater interest in water scarcity demonstrated by states outside of New England. Nevertheless, the strong showing in the Midwest allows inferences to be made about communities with similar climatic and economic characteristics that are located farther east.

The mean monthly withdrawal across the sample is 814 million gallons (MG), with a standard deviation of 1.82 billion gallons (BG). This sample represents approximately 13% of the total quantity of publicly supplied water supplied in the United States. Statistics aggregated by state are presented in Table 3.4. In the West (AK and CA), mean withdrawals over 5614 months of data came to 1.15 BG (2.68 BG standard deviation). In the South (FL and TX), 13,573 months averaged 783 MG (1.68 BG standard deviation). The Midwest (IN, KS, MN, OH, and WI) averaged 592 million gallons (994 million gallons standard deviation) over 6657 months of data. Volumes were reported in either gallons (89%), cubic feet (2%), or acre-feet (9%). Outside of California, all volumes were reported in gallons.

Figure 3.8 depicts the seasonal and progressive trends in average volume withdrawn for each state surveyed. In each case, a cyclical seasonality and a gently upsloping time trend are discernable. The mean monthly volume ranges from a winter low of 675 million gallons (December and January) to a summer high of 969 million gallons (July and August), the summer peak being 44% higher than the winter trough. The annual average increased 2.9% per year, from 665 million gallons in 1995 to 860 million gallons in 2005.

3.3 Population and Demographics

Census Data

The intersection of price and volume data consists of 198 communities with an average of 10.0 years of data each. The mean population was 132,919 in 2000 (U.S. Census 2000, 2002). The mean income per capita in 1999 (city-weighted rather than population-weighted) was $22,043 (U.S. Census 2000 2002). Mean population for all 1223 United States cities over 30,000 was 102,870 in the same period. Mean per capita income for all 1223 cities was $22,443. The representative community in our sample is somewhat larger (29%) than its unsampled peers, but with equivalent income per capita. Sample bias for either measure is negligible due to the high degree of variation.

Population for years other than 2000 and income for years other than 1999 are taken from the Regional Economic Information System (REIS) of the Bureau of Economic Analysis (Bureau of Economic Analysis 2008). These figures are not available for some of the smaller communities in the sample and have been calculated from Census 2000 estimates based on the REIS growth rate for the larger metropolitan area or county when a municipal estimate is not available. Population in the sample is estimated to have increased an average of 1.55% annually, from 111,615 in 1995 to 138,779 in 2005. Per capita income is estimated to have increased an average 4.22% annually, from $18,062 to $27,930. Urban CPI (Bureau of Labor Statistics) increased an average of 2.51% annually over the same period.

Economic Data

Measures of economic activity are derived from REIS and the 1997 and 2002 Economic Censuses (U.S. Census Bureau 1999, U.S. Census Bureau 2004). REIS data cover the time horizon annually but may only disaggregate down to the county or metropolitan area. Economic Census data are aggregated at the municipal level but not for every city or every year. The only source of total economic activity data is REIS, whereas manufacturing activity is covered well in the Economic Census. Economic activity is proxied by earnings, which includes wages and salaries, employer contributions to social insurance, and income. Earnings are approximately equal to value added, which is the value of shipped products minus the value of materials.

Parallel to the procedure for calculating personal income and population in off-census years, manufacturing earnings are anchored in the Economic Census and projected using the REIS growth rate. Total nonfarm earnings and manufacturing earnings where municipal data are not available are derived from REIS data, scaled down by the ratio of total household income in the municipality to total household income in the county or metropolitan area.

Ultimately, the geographical boundaries of economic activity are unknown. Utility systems may know the number of connections to businesses, but they do not know the level of business activity. Estimates for manufacturing are further clouded by the unknown level of participation by manufacturers in public supply. The relative intensity of self-supply in a community is unknown, and this is an important source of uncertainty. This research proceeds on the assumptions that commercial demand for publicly supplied water is proportional to total nonfarm earnings and that industrial demand for publicly supplied water is proportional to earnings in the manufacturing sector.

Table 3.5 presents population and economic statistics for the sample by geographic region. The data reported in table 3.5 are 2001 data, a well reported year for the sample. In 2001, cities in the sample averaged 138,794 inhabitants with an average per capita annual income of $24,362.79. Nonfarm earnings averaged $2.483 billion, of which $857 million (34.5%) was earned in the manufacturing sector. The high standard deviations of each variable indicate that variation within states is greater than variation across states. In other words, regional differences are not statistically significant.

When multiple economic indicators are used simultaneously, it is natural to question their relation to one another. Employees come from the population; income comes out of earnings; etc. Table 3-6 shows a correlation matrix of pairwise linear relationships in the demographic data. Two variables are highly correlated, population and commercial earnings. The high value of 0.9813 indicates that larger cities produce proportionally more business earnings. Although this result is not a surprise, it is cause for caution. On the other hand, business activity varies for reasons other than population, and hopefully these exogenous reasons are sufficient to reveal distinct patterns in commercial versus residential water demand. To some degree, the sheer size of the sample is entrusted to support the model. Industrial earnings are moderately related to population and total earnings, but not to a degree likely to confound the statistical results. Per capita income appears to be entirely independent of any other single demographic variable.

3.4 Relative Volume Supplied

This research breaks from tradition by differentiating water used for domestic uses from water used as a factor of production. We argue that water used per capita is not a reliable measure of quantity demanded. In the interest of description, however, this section revisits the volumetric data from section 3.2 equipped with population and earnings data. Table 3-7 presents, by state, two relative measures of volume, gallons per month per capita and gallons per month per commercial dollar earned. The purpose of the table is to compare the relative intensity of water use across the sample, not to offer use coefficients for applied work.

Volume supplied per capita ranges from a mean of 3898 gallons per month in Alaska to 7154 gallons per month in Texas, with an overall mean of 6006 gallons per month. Volume supplied per dollar of nonfarm earnings ranges from 0.177 gallons per month in Alaska to 0.54 gallons per month in Texas, with a mean of 0.43 gallons across the sample. Relative volume supplied was lower in the winter than in the summer. In the months of December and January, an average of 4933 gallons per capita or 0.354 gallons per dollar earned was supplied. In the months of July and August, 7792 gallons per capita or 0.549 gallons per dollar earned were supplied on average.

Table 3-7 also includes a column with monthly mean per capita use from Estimated Use of Water in the United States in 1995 (http://water.usgs.gov/watuse/spread95/usco95.txt). The means in this column correspond to all counties containing cities covered in the present data. The last column of Table 3-7 contains Student's t-statistics, the distance in standard deviations between the 1995 USGS data and the data collected for the present research. Assuming that the collected data of this study are normally distributed, a t-statistic greater than 1.96 indicates a 95% confidence that the USGS mean is not the true mean of the same population. This is only the case for data in Alaska, where only one community is sampled. For all other states and the sample as a whole, the two estimates are comfortably "close" to each other. Thus, the consistency of the data is validated across methods.

3.5 Weather and Climate

Weather and climate data are adopted from daily observations of cooperative weather stations complied by the National Climatic Data Center. Weather data consist of minimum and maximum daily temperatures and frequency of precipitation aggregated monthly over the period of interest (1995-2005), whereas climate data consist of long-term monthly means of the same variables averaged over the years 1971-2000. Two observations on the same location but one year apart, for instance January 1995 and January 1996, will have different weather but the same climate.

Each of the 196 studied locations is matched with one of 680 cooperative stations with complete weather records based on minimum Euclidean distance. With the exception of one point in Alaska, each city is matched with a weather station 42 miles or less from the city center. A total of 119 stations are used for weather and 112 for climate. Due to the proximity of stations substituted for those without climate data, no bias or appreciable error is expected to be incurred by the substitution. Descriptive statistics for the stations used are presented in Table 3-8.

Chapter 4

Econometric Demand Analyses

4.1 Auxiliary Price Regression

Price experienced by residential and commercial customers is represented as a set of 3 variables for each sector that are representative of the price schedule and allow the comparison of marginal price and average price hypotheses. Given a mean consumption volume, the first price variable, p_1, is a uniformly weighted average of marginal prices from zero consumption to estimated mean consumption. The second price, p_2, is the average of marginal prices evaluated from mean consumption to twice the mean consumption. To isolate the effect of increasing block rates, p_2 is operationalized in the analysis as pd (such that $pd = p_2 - p_1$). The third variable, fp, is the ratio of fixed charges to estimated mean consumption. Only one variable represents industrial price, the marginal price corresponding to the highest possible level of consumption.

Residential demand is often modeled as though the community were composed of identical customers, each consuming at a representative level. If (i) the functional form of the empirical model is well specified, (ii) the estimated mean consumption is indeed representative, and (iii) the implied representative consumer responds solely to average price, then $\partial Q / \partial p_1 = \partial Q / \partial fp$ and $\partial Q / \partial pd = 0$. That is, a change in average fixed price would be equivalent to a change in marginal price, and changes in price beyond the representative consumption level would be irrelevant. If, on the other hand, (i) the functional form is well specified, (ii) community consumption is represented by, or at least centered at, the estimated mean, and (iii) the community responds as if to marginal price, then $\partial Q / \partial p_1 = \partial Q / \partial pd$ and $\partial Q / \partial fp = 0$. In words, changes in lower and upper block rates would affect demand identically, but changes in fixed fees would not affect demand at all. These sets of hypotheses are not exhaustive. For example, increasing block rates could have a demand effect of their own, or consumers could respond to some combination of marginal and average price.

But what is the mean consumption volume? Results of a regression identical to the 3-sector structural equation (Equation [6]) with price variables omitted are presented in Table 4-1. Mean quantity demanded per capita and per output dollar are estimated for each community from the table results. The mean quantity per capita is multiplied by the ratio of population to households for each community, taken from U.S. Census 2000 data. The result is taken to be the mean consumption per residential connection. The mean quantity demanded per commercial dollar is multiplied by $194,818, the ratio of earned dollars per establishment in the sample, according to the 1997 Economic Census. The result is taken as the mean consumption per commercial connection. No similar procedure is necessary to calculate industrial price, on the assumption that industry responds only to long-run marginal price, the price of the highest possible quantity demanded. In this and all regressions, the sample excludes data for the year 2005, which is saved to test the forecasting properties of the estimated parameters.

The mean residential monthly consumption estimated by this procedure is 7363 gallons (standard deviation of 5779 gallons). Mean commercial consumption is estimated at 440,066 gallons (standard deviation of 284,903 gallons). Based on these quantity estimates, the mean of residential p_1 is \$2.02 (\$1.70), \$2.76 (\$1.89) for residential p_2, and \$5.73 (\$7.44) for residential *fp*. Means of commercial p_1, p_2, and *fp* are \$2.61 (\$1.82), \$3.15 (\$2.21), and \$0.56 (\$4.09), respectively. The mean of long-run industrial marginal price is \$3.18 (\$2.29). See Table 4-2. These dollar amounts are all nominal. In the regressions to follow, all dollar amounts relevant to residences are deflated by the Urban Consumer Price Index (CPI), dollar amounts relevant to commerce are deflated by nonresidential Producer Price Index (PPI: BLS series BMNR), and dollar amounts relevant to industry are deflated by manufacturing PPI (BLS series OMFG). Results are presented in 2005 dollars.

4.2 Structural Regressions

Ordinary Least Squares

Armed with price indices, the structural equation described in Chapter 2, equation [6] is estimated using the method of least squares. The fit of this regression in 117 parameters over 16,092 observations is approximately 90.34%, according to the adjusted-R^2 statistic. The regression results are highly significant, yet a Hausman test comparing regressions with and without price variables yields a $X^2(15)$ statistic of 977, meaning less than 0.01% likelihood that the price variables are exogenously specified. Similarly, the Breusch-Pagan test for heteroskedasticity (that the errors are of consistent magnitude across the sample) produces a $X^2(1)$ statistic of 22,024, meaning less than 0.01% likelihood that the error variance is constant. These statistics are not only significant, they are extreme compared with the 99% critical values of 30.6 for $X^2(15)$ and 6.6 for $X^2(1)$.

A potential reason for these indications of misspecification is the strong influence of a few outlying values. These observations would not be desirable in the regression, even if the above tests had proved positive. Influential observations are identified by their Cook's Distance. The regression is repeated following the elimination of 646 observations (2.5% of data) with the highest Cook's Distance, corresponding to the distance between a dependent variable value and the value predicted by the model. Performing the same Hausman test now provides a statistic of $X^2(15) = 55.25$. Although still significant, the statistic is 94% lower than in the first trial. The Breusch-Pagan test falls 74% to $X^2(1) = 5810$. Price endogeneity has been reduced to a tolerable level, but heteroskedasticity is still a problem. Meanwhile, the explanatory power has increased from 90.34% to 95.03% by adjusted-R^2. The Akaike Information Criterion has reduced from 698,126 to 640,543, also indicating a better fit. When employed to predict demand for 2005, the mean absolute percent error (MAPE) for this model is 55.05%. The 2005 value for quantity demanded that is predicted by the model averages about 55% above or below the observed quantity demanded by the community in 2005.

Logarithmic Residential Regression

To illustrate the benefits of the 3-sector flexible model, the same data are regressed in a model more common to residential demand estimation. The dependent variable for this estimation is simply the natural log of total quantity demanded after it has been divided by population. Independent variables residential marginal price, average residential fixed price, income, temperature, frequency of precipitation, historical mean temperature, and historical frequency of precipitation, are also expressed as natural logs. Binary indicators for winter averaging and sewer are also included. The model is

$$\ln q = \alpha + \sum_i \beta_i \ln x_i + \sum_j \delta z_j \qquad [11]$$

for per-capita consumption q, independent variables x_i, and indicator variables z_j. Elasticity of q with respect to x_i is simply β_i. Results are presented in Table 4-3. Although the coefficients in table are significant and maintain the expected signs, the overall explanatory power is a weak 10.45%. The results of this regression model are not recommended for any but the crudest purposes. It does appear, for example, that the fixed price variable is influential, but the estimated fixed-price elasticity of –0.105 should not be taken as accurate.

Nonnested Average and Marginal Price

One way to compare the average price specification with the marginal price specification is to test the significance of the part of average price that is missing from marginal price. Another way is to compare the performance of two regressions whose only difference is their price index. To follow the latter tactic, the individual price components are combined into a marginal price and an average price for the residential sector, and a marginal price and an average price for the commercial sector. Marginal price is calculated as the average of p_1 and p_2, and average price is calculated as the sum of p_1 and pd.

Over 18,282 observations, the mean (and standard deviation) of residential marginal price is \$2.66 per 1000 gallons (\$1.81), \$8.65 (\$8.88) for residential average price, \$3.40 (\$2.27) for commercial marginal price, and \$3.75 (\$5.23) for commercial average price. Regressing these prices instead of the price components in two separate versions of Equation [6], each with 87 variables and 16,092 observations, yields adjusted-R^2 statistics of 89.03% for marginal price and 88.96% for average price, giving a small advantage to the marginal price specification. Comparing the Akaike and Schwarz Information Criteria for the two versions, where smaller scores indicate a better fit, the marginal price regression is slightly favored by both. The Akaike Criterion scores marginal price 700,153 and average price 700,243; the Schwarz Criterion scores marginal price 700,830 and average price 700,920.

By all three nonnested measures, then, marginal price is shown to be slightly more explanatory than average price. If these are the only alternatives, marginal price is recommended as the slightly preferred driver of demand. An advantage of using several price components, however, is that they provide a more flexible alternative to the scalar index. Flexibility is all the more attractive in cases such as this, where neither rigid alternative is entirely dominant.

Generalized Least Squares

Returning to the preferred 3-sector model with price components, the exclusion of influential observations provides a more consistent model, but the variances of the errors prove nonconstant. It is plausible that this heteroskedasticity may primarily be attributable to differences between communities. The model is regressed again, but in an iterative process known as generalized least squares (GLS) with panel-specific heteroskedasticity that allows each community to exhibit its own error variance. Results are presented in Table 4-4. The GLS procedure does not provide an adjusted-R^2 statistic, but the predictive power of the model can be assessed via the mean absolute percent error of predictions on the 2005 data. The MAPE for the GLS model is 43.05%, which compares favorably against the 55.05% MAPE of the ordinary least-squares model. Looking more closely, MAPE for the Western region is 41.16%, MAPE for the Southern region is 52.20%, and MAPE for the Midwest region is 23.77%.

Variables of interest appear multiple times in the table results, in levels and square roots and combined with each other. To determine the significance of these variables, Chi-squared (X^2) tests are performed on all instances of each variable. The results of these tests are presented in Table 4-5. All variables are significant to a minimum of 99% confidence.

Price elasticities are calculated as combinations of parameter estimates and variable levels according to equation [7] in Chapter 2. Since this procedure predicts price elasticity for each observation directly from the regression, each observation comes with its own standard error. Price elasticities are presented with their mean standard errors in the first column of Table 4-6. Because the variance of these elasticity estimates is high, they are retabulated for the 90% of observations with the lowest standard error and presented in the second column of Table 4-6. The second column is probably more indicative of the price responsiveness of most communities.

We find that residential marginal price responsiveness decreases significantly in income and historical frequency of precipitation. Residential responsiveness to increasing block rates decreases with increased frequency of precipitation but increases with income. Residential responsiveness to fixed charges decreases with income and historically higher temperatures but increases with contemporaneous temperature. Commercial responsiveness to block rates is increased with historical temperatures, and commercial responsiveness to fixed fees increases with historical frequency of precipitation. Commercial responsiveness to marginal price is clearly the most powerful price effect. Residential and industrial marginal price responsiveness may even be negative (positive price elasticity) when conditioned on the other classifications of price response.

Price elasticities are categorized by region in Table 4-7. Residential price elasticity seems to hinge on the effect of increasing block rates in all regions, although the response to fixed fees is also powerful in the Southern region. In contrast, the commercial sector does not seem to be responsive to increasing block rates outside the Midwest region. Commercial marginal price is the most influential component in all regions. Perhaps surprisingly though, the commercial sector responds somewhat to fixed fees in every region. Industrial demand appears to respond to price only in the Midwest region. Positive industrial price elasticity in the Southern region implies that industry demands more water when it is more expensive. This finding is not expected and may reflect an omitted variable, such as the intensity of self-supply.

Overall, Southern communities appear to be the most price responsive and Western communities the least. The effect of fixed fees is too large to rule out. At the mean, fixed charges explain about half of all price elasticity. The mean average price elasticity across the sample, for fixed charges and low and high marginal prices changing proportionally, is –0.224. The mean marginal price elasticity, for marginal prices changing only, is –0.115. Although these figures are "in the ballpark" of previous estimates, they indicate that previous research may have overestimated price elasticity, or we may have underestimated it. The "elasticities" reported here conform as closely as possible to those estimated by other studies, but in the end there is no canonical definition of a price elasticity that accounts for so many price components.

The present estimation indicates residential price sensitivity to be considerably lower than commercial sensitivity. The multisectoral design also allows estimates of the sectoral shares of total water use. These shares are illustrated in Figures 4-1 to 4-4. Overall, an estimated 78.7% of urban deliveries go to residential uses, 12.2% to commerce, and 4.9% to industry, whereas 3.5% is estimated lost or used publicly. This means that even though commerce is especially sensitive to price, it does not account for enough total demand to have the biggest aggregate effect. Commercial use is estimated to be lowest in the Western region, where residential use predominates, and to be highest in the Midwest. Demand management strategies may therefore require regional specificity.

The use shares in Figures 4-1 to 4-4 are estimated from total use and sector-specific demand drivers. An independent consistency check can be made from the Estimated Use of Water in the United States in 1995 (http://water.usgs.gov/watuse/spread95/usco95.txt). Using an entirely different inventory methodology, the USGS study estimates the mean shares of publicly supplied water supply for the 110 counties containing communities also in this research to be, 74.3% domestic (residential), 17.0% commercial, and 8.7% industrial. This is an interesting validation because it indicates that the econometric procedure has identified the uses of publicly supplied water without using coefficients or sectoral delivery information.

4.3 Dynamic Regressions

Pooled Least-Squares Regression

The results presented in Section 4.2 reveal an underlying structure in water demand, but they do not address the timing of demand adjustments. A linear model in changes is employed to shed light on the dynamics of water demand. It is not necessary or even appropriate that the dynamic model resemble the structural model (Engle et al. 1989). Just as the flexible functional form of the structural model provides a second-degree approximation of the long-run demand function, the dynamic model in linear differences provides a first-degree approximation of annual demand adjustments. The dynamic model is, to slightly rephrase equation [9],

$$\Delta_{12}Q = \alpha + \sum_{i=1}^{13} \beta_i \Delta_{12} x_i + \delta(\hat{y}_{t-12} - y_{t-12}) + \varepsilon . \qquad [12]$$

Here $\Delta_{12}Q$ is the annual difference in total quantity demanded. x_i are independent variables including price components for each sector, population, commercial and industrial activity, average minimum and maximum daily temperatures, and the proportion of days with precipitation. $(\hat{y}_{t-12} - y_{t-12})$ is the ECM term representing the deviation in the previous year from the structural equilibrium, and α, β_i, δ, and ε are estimated parameters, including a stochastic error term.

The model is estimated using the method of least squares on 13,721 observations; the 7 price parameters are tested jointly for significance, and the Breusch-Pagan test of heteroskedasticity is performed. The adjusted-R^2 statistic for the regression indicates 25.45% of variation is explained by the model. The F(7,13,706) statistic of 0.39 on the price parameters indicates a 91.1% likelihood that all prices are insignificant, and the $X^2(1)$ statistic of 149,621 on the heteroskedasticity test overwhelmingly rejects the hypothesis of consistent variance. These statistics are interrelated because a side effect of heteroskedasticity is the overstatement of standard error estimates, which could lead to a rejection of coefficient significance.

Pooled Generalized Least-Squares Regression

As with the structural estimation, the dynamic estimation is improved by the explicit recognition of panel-specific error variance and the use of GLS. Regression results are presented in Table 4-8. Although an adjusted-R^2 statistic is not appropriate to the GLS procedure, a joint significance test on price yields $X^2(7) = 28.68$, rejecting the hypothesis that all price effects are jointly zero. Individual effects of residential marginal price and block pricing, commercial fixed charges, population, commercial activity, average minimum and maximum daily temperature, proportion of days with precipitation, and the ECM term, are all significant.

Recalculating MAPE for the 2005 data with respect to this model reveals a mean of 22.56%, an improvement over the 43.05% MAPE from the structural model. Forecast error is nearly cut in half. This finding is an important illustration of the benefit of an integrated short- and long-run model. MAPE is 22.61% in the Western region, 28.38% in the Southern region, and 8.63% in the Midwest, indicating that the model is especially good at forecasting demand in the Midwest data segment.

Mean elasticities are calculated for each price component and reported in Table 4-9. These are shorter-run (annual) elasticities, rather than the long-run elasticities estimated in the preceding section. The first column of Table 4-9 presents elasticities estimated across the whole sample. The second column presents elasticity means of the central 90% of data. Because these estimates are not combinations of random variables, a standard error is not assigned to each observation, so the subsample in the second column is truncated by extreme elasticity value rather than by extreme standard error. Elimination of the outlying 10% of estimates results in a reduction in standard error of 74%. The second-column estimates are expected to be more representative of most communities.

As in the structural estimation, the strongest price response appears to be associated with commercial marginal price change. Industrial marginal price change is also relatively influential in the short-run. Mean residential marginal price elasticity is positive. This result, although unexpected, is consistent with the structural results. The most conservative interpretation of this result is that residential demand is the slowest to respond to marginal price changes among the sectors evaluated. Residential demand is somewhat responsive to block pricing changes in the short-run and essentially unresponsive to changes in fixed charges. Commercial demand is somewhat responsive to change in block pricing and fixed charges, but not to those components as much as to marginal price changes.

Regional price component elasticities are presented in Table 4-10. Many component elasticities are relatively consistent across regions. Commercial and industrial responsiveness to marginal price change is higher in the southern region. Commercial response to changes in fixed charges is noticeably higher in the western region. Due primarily to differences in the sectoral composition of the regions, overall short-run elasticity is higher in magnitude in the Midwest and negligible or positive (negative response) in the western region. Generally low short-run response to changes in fixed charges implies nearly identical marginal and average price elasticities, around –0.0264 (–0.02638 for average price and –0.02647 for marginal price).

Based on an annual average price elasticity of –0.02638 and a long-run average price elasticity of –0.224, an approximate time path of demand adjustment can be projected. This path is illustrated by Figure 4-5 and presented numerically in Table 4-11. Figure 4-5 tracks the demand response of a community to a hypothetical doubling of all price components. The expected reduction in structural demand of 22.4% materializes very slowly. Only 11.8% of the adjustment takes place over the first year. If this hypothetical change had occurred in 1995, the first year of data in the present research, only about 85.4% of the adjustment would have materialized by the end of the study horizon in 2005. Clearly, demand projections made from structural models could lead to unrealistic expectations of a timely response.

Useful information about nonprice variables can also be taken from the GLS model. On average, each inhabitant added to the population accounts for 4314 gallons of increased monthly demand. Each dollar of commercial growth demands 36.8 additional gallons per month. Industrial growth impacts demand insignificantly in the short-run. Every degree increase in average high temperature adds a mean of 4.0 million gallons to an average city's monthly demand, although a concomitant increase in average low temperature takes off 2.1 million gallons. Each day that experiences at least 0.1 inches of precipitation is worth 1.9 million gallons of demand, without any consideration of reservoir recharge.

Monthly Dynamic Models

The GLS dynamic ECM model is regressed for each calendar month. Resulting parameters are reported in Table 4-12. Average demand responses to the various price components are illustrated in Figure 4-6. A pattern in Figure 4-6 is not immediately discernable. In Figure 4-7, the same components are grouped into an average price (all components) and a marginal price (excluding fixed charges). Figure 4-7 can be qualitatively interpreted in at least three ways. It is possible that the functions are completely random. It appears, though, that price response is lowest in spring months and highest in the summer. It is also possible to discern a 1/4-annual oscillation: each season has its cycle of price response, with troughs in December, March, June, and September, and peaks in February, April, August, and October. The data are not conclusive enough to exclude any of these possibilities. What is evident is that average price is less influential than marginal price in the short run. Since average price is more influential in the long run, it may be that community water demand reacts more slowly to fixed components than to marginal components.

Chapter 5

Conclusions and Discussion

5.1 Insights from Data Collection

Data Availability

A theme in this research has been the uses of information. Customers can use price information to make more efficient consumption decisions. Utility systems can use demand information to better achieve their objectives. Third parties can use price and demand information together to predict future conditions and to estimate benefits and damages. Having gathered price and demand information, we can say something about their accessibility and the challenges of their acquisition.

Marginal price information is generally accessible to urban water customers who have a computer. We found that price schedules are posted online in a great majority of cities. Our own difficulties in obtaining price data reflected primarily the fact that we wanted historical rather than current prices. We can infer from this that the cost of marginal price information is low. If customers have not invested in this information, it is only because the return to investment is also low. We anticipate an imminent increased interest in the marginal price of water as rates grow in relation to household expenditures.

Demand information includes price information, use information, and the presumption of a relationship between the two. Utility systems seem able to provide use data when requested by a state government. Again, interest in gaining the information depends on the value of the resource. States with quickly expanding urban populations are more likely to request use information, and cities are probably similarly motivated. If planning activities do not presently include demand considerations, we expect that they will as soon as scarcity dictates. Over the sample, marginal price growth has outpaced inflation, whereas the growth in fixed charges has not. Economic intuition suggests this observation may be evidence of rising scarcity.

State programs that gather water use information promote awareness of water expenditure, better record keeping, and uniformity of measurement. At present, water accounting standards are not as high as money accounting standards. This is neither because water has no value nor because the technical demands of water accounting are insurmountable. Nevertheless, a lack of regulatory interest can lead to poor record keeping, which reinforces the belief that water use records are unusable. The present research has shown us that existing records can be informative, although more accurate and precise records would be more informative. A clearer link between water production and water delivery would be particularly beneficial.

Expenditures on Water

The representative residential rate schedule across the data included monthly fees of \$6.60 for water service and \$12.52 for sewerage, for which 1200 gallons of use were included. Additional use was metered at \$1.82 for water and \$1.76 for sewer, per 1000 gallons. Block rates were slightly increasing for water but decreasing for sewer, for a net decreasing block rate effect. If water and sewer rates are not explicitly coordinated, they tend to dilute each other. Carefully crafted increasing water rates, for example, are wasted effort if negated by decreasing sewer rates. Summer "conservation" rates tend to be counteracted by winter averaging.

The median resident earned a monthly income of $1836.92. Assuming the mean household size of 2.53 persons, fixed charges for water and sewer only amounted to 0.41% of total income. Adding 12,000 gallons per household (at $15.28 per person) brings water and sewer charges to 1.24% of total monthly income. Variability within the sample is high, but for the median residential consumer, water expenditures were a very small part of the total budget. It is understandable that many residents do not invest in marginal price information.

The representative commercial rate schedule included monthly fees of $26.30 for water and $30.94 for sewer service, for which 2720 gallons were allowed monthly. These charges are insignificant for the average business, which earned $194,818 per month in 1997, even though they might be significant for a smaller firm. Additional gallonage was charged $1.84/1000 for water and $2.00/1000 for sewer in the first block. High volume water blocks decreased somewhat to $1.77 per 1000 gallons. Assuming 17.1% of publicly supplied water went to commerce (including industry), about 0.07 gallons factored into the representative dollar of nonfarm earnings. At $3.77, these 0.07 gallons would have cost $0.000277. In other words, each representative dollar in commercial earnings demanded about 0.03 cents of water as an input. By inference, the representative commercial water customer paid about $54 per month in variable water charges, about equal to monthly fixed charges and still a very small portion of the typical budget. Variation is high, of course. A high-rise office can earn a considerable amount without much water expenditure.

The representative industrial rate schedule included monthly fees of $148.70 for water and $145.42 for sewer service. 11,430 gallons were allowed each month at this price. Additional use was charged at $1.84 per 1000 gallons for water, declining to $1.75 with high usage. The representative industrial sewer price was $2.00 per 1000 gallons, not including additional charges for removing suspended solids or other contaminants. Uncertainty as to the degree of self-supply in industrial water demand, as well as the degree of additional decontamination, precludes a solid estimate of the value of the water input in industry. Logic parallel to that for residential and commercial estimates, however, leads to an estimated 0.047 gallons used per dollar of industrial output, at a cost of about 0.017 cents.

Regional Variability

Pricing elements varied considerably within and across regions. Variability across the sample is a valuable attribute of the data, but regional idiosyncrasy calls into question the generalizability of the results. Regional variation in price policies used, average levels of price components, and even timing and units of measurement, underscores regional differences in attitudes and institutions governing water allocation. Different cities and regions allocate the burden of water provision to different sectors, and these allocation decisions may reflect social norms, efficiency concerns, conservation goals, or costing practices.

Fixed water charges are least in the Northeast cities of the sample, but fixed sewer charges are lower in the Midwest. In the West and Midwest, sewer charges are not much higher for commercial and industrial sectors than for residential, although water charges are lower for residences across the sample. Although mean marginal water price is consistent across the sample, price blocks generally decrease in the Midwest, whereas they remain uniform in New England and the South and increase in the West. Large commercial connections are generally granted a higher minimum volume allowance than residential connections, but not in New England. Reasons behind these regional differences remain largely unexplained. The price components method may shed some light on the relative efficacy of rate regimes, but the analysis here has no ability to capture underlying political realities.

Volume Supplied

The nine states for which volumetric data are obtained represent the geographical extent of the U.S., with a full range of weather and income characteristics. Our findings largely agree with the 1995 results of the Aggregate Water-Use Data System on a state-by-state basis, suggesting a consistency of data gathering across independent efforts.

Despite the high degree of variation in consumption quantity from state to state, no two states' relative consumptions are statistically distinct due to the even greater variability within states. No state's average per capita consumption is statistically distinct from the mean of 6000 gallons per month.

Even so, some subtleties are worth notice. Texas and California cities consume the most water relative to their populations. Alaska and Minnesota consume the least. This may be due to the states' relative natural endowments of water resource, differences in weather, levels of urbanization or industrialization, or other factors. Consumption per commercial output follows the same ordering. The econometric section above attempted to explain why one city uses more water than another, often with clear results, but ultimately some factors will remain beyond explanation.

5.2 Insights from the Analysis

Estimated Price Components

After estimating a representative level of water use for each community, a benchmark interval is defined within which most consumption is assumed to take place. This interval is a way to aggregate multiple block prices, including the implicit marginal price of zero that applies to consumption less than the minimum allowance. Marginal water and sewer prices for consumption within the interval are averaged to produce average marginal price estimates for each observation. The interval is divided in half at the mean, yielding upper and lower average marginal prices. Representative fixed price is calculated as the sum of monthly water and sewer fixed charges divided by the estimated mean consumption.

The mean of average marginal prices estimated to be experienced by the half of all residents consuming the least water is \$2.02 per 1000 gallons. The mean of average marginal prices estimated for residents consuming the most water is \$2.77 per 1000 gallons. The increasing block effect is amplified by the minimum allowance, a region where consumption is unpriced. The mean of average marginal prices for the lower half of commercial consumption is $2.61; for the upper half of commercial consumption it is $3.15. These estimates indicate that marginal price is effectively increasing for both sectors. Residential prices are lower than commercial primarily because a higher proportion of residential consumption occurs below the minimum allowance. High commercial consumption is priced almost the same as high industrial consumption, which averages $3.18 per 1000 gallons at the highest block.

Mean estimated fixed price is $5.73 for residential customers and $0.56 for commercial customers. Even though fixed charges are higher for the commercial sector, estimated consumption is much higher, so that the price per 1000 gallons is considerably lower. A fixed price for industrial customers is not used as an explanatory variable because its value would approach zero at very high consumption levels.

The estimated price components should be more reflective of the price signals experienced by communities than the descriptive price elements described in Chapter 3. Because they are calibrated to each community, they improve on the indices summarized in table 3-3. They incorporate a broad range of water and sewer rate information more succinctly than tables 3-1 and 3-2 so that it can be used in the statistical analysis. The minimum and maximum values and standard deviations of the estimated price components, shown in table 4-2, reveal that Americans really do face a wide diversity of water prices.

Structural Regression Results

Diagnostics

The long-run regression is subjected to a test that prices are exogenous, a test that error magnitudes are consistent across the sample, and a test for influential observations. The interval parameterization described within the "Auxilliary Price Estimation" portion of section 4.2 eliminates algebraic price endogeneity within communities, but endogeneity can still arise across communities because the price components are derived from estimates of use quantity and because of unobserved factors that may influence pricing policy. The results of the first Hausman test strongly suggest that prices are endogenous in the model. This implies that parameter estimates could be biased in an unpredictable direction. The second Hausman test, performed after some 600 influential observations have been dropped, is still positive but highly improved. Bias is a problem in a regression that must be weighed against error variance and the availability of alternatives. Ultimately, the GLS long-run model is the best available despite some evidence of price endogeneity. Using the model to predict values outside the sample is one way to quantify the severity of bias.

Results of the Breusch-Pagan test strongly suggest that error variances systematically vary within the ordinary least squares model. The danger from such heteroskedasticity is that some parameter values that appear insignificant may in fact contribute significantly to the model. Heteroskedasticity also indicates that the empirical model could be improved. Intuitively, some communities could experience higher variance in quantity demanded than others, either because of imprecise records or simply because of dynamics unique to the community such as tourism. The two-step GLS regression allows each community to have its own error variance, as opposed to the sample-wide variance in the ordinary least squares model. This method improves the estimation of parameter significance and refines individual parameter estimates.

Ideally, a good estimation will draw fairly from each data point. Points that lie unusually far from the rest of the data can skew the estimation line. Results of the Cook's Distance test indicate that about 2.5% of observations are inordinately influential. In the context of the present data, it is likely that at least some of these points were measured, reported, or recorded inaccurately. Their omission improves the fit of the model as well as the results of the other diagnostics. The existence of such points is inevitable, and an outlier test such as Cook's Distance is a systematic way to identify them during estimation.

Model Fit

In addition to postestimation diagnostics, model performance is gauged by statistical significance tests and out-of-sample forecasts. In the case of the GLS model, all 117 parameters are tested simultaneously with the Wald test, the results of which indicate likelihood less than 0.01% that the model has no explanatory power. This result is not as satisfying as a regression sum of squares statistic, but the generalized covariance structure precludes a meaningful sum-of-squares metric. The same model with a simple covariance structure explains 95% of variations in the dependent variable. Since heteroskedasticity results in inflated variances, it is reasonable to assume that the GLS model explains 95% or more of variations in quantity demanded. This is a very strong support for the model. The GLS model explains quantity demanded in 2005 with 43% mean error. This is not nearly as impressive, although no model is expected to perform as well outside the sample. The moderate to high predictive error of the structural model is a persuasive argument for the inclusion of a complementary error correction model. Although the structural model is very good at capturing the big picture of water demand, it is not as good at projecting marginal changes.

Parameter Estimates

Table 4-4 reports parameter estimates for 117 regressors, composed of levels, square roots, and combinations of 15 independent variables and an intercept. Each of the 15 independent variables is significant when the model is compared to a restricted model with all instances of the variable excluded. The most significant are residential fixed price, income, and historical precipitation.

The significance of residential fixed price (the measure of fixed charges defined in Section 2.4) is an important result with respect to price specification. It indicates that marginal price alone is an insufficient characterization of the price signal. Fixed charges may have an income effect or a substitution effect. Since fixed water and sewer charges account for less than 1% of the typical personal budget, it is unlikely that the income effect of fixed charges would figure so prominently in the regression model. The significance of the fixed price variable suggests that households form a perception of price from the monthly fees that differs from the marginal price. In fact, the elasticity of residential demand with respect to fixed price dominates the elasticities of the other residential components in the subsample of southern cities.

As expected, an increase in income leads on average to an increase in water consumption. The flexible functional form allows the income effect to vary, showing that the positive effect disappears at high income levels. This indicates that affluent residential sectors can become satiated with respect to water. Marginal price elasticity as well is reduced at high income levels. This is expected as the water bill becomes a smaller proportion of total income.

A history of low precipitation can influence communities to use less water, but residential demand is also reduced when frequent precipitation is expected. Response to the expectation of precipitation is more direct in the commercial and industrial sectors: less water is demanded when more precipitation is expected. Although the mechanism that links historical precipitation to quantity demanded may be complex, the significance of the effect points to deeply held habits in water use across both seasons and geography. Marginal price elasticity is reduced when frequent precipitation is expected.

Long-Run Price Elasticities

The most influential single price component is commercial marginal price. The overall mean marginal price elasticity for the commercial sector is approximately –1. The effect is strongest in the South and weakest in the Midwest, possibly following patterns of commercial landscaping. In contrast, long-run marginal price elasticity is effectively nonexistent for residential and industrial sectors, although residential elasticity with respect to increasing block rates is significant and industrial marginal price elasticity is more pronounced in the Midwest. The case for marginal price specification is not encouraged by these results.

Logarithmic Residential Regression

Water demand regressions with over 100 parameters and a relatively flexible functional form, such as the GLS long-run regression discussed above, are atypical in the literature. With the gain in precision, clarity and simplicity are sacrificed. The logarithmic residential regression is an example of a more common estimated method. No consideration is made of business activity, interactive relationships, or variability in component elasticities.

Basic relationships are more accessible in the logarithmic regression (Table 4-3). The estimated marginal price elasticity is –0.026. Average price elasticity, at –0.131, can be interpreted as marginal price elasticity plus fixed price elasticity. Income elasticity is estimated as 0.034. Although lower than most comparable estimates, these figures all agree in sign with economic expectation. Higher temperatures and higher expected temperatures lead to increased consumption. Increased frequency of precipitation and the expectation of increased precipitation lead to decreased consumption. These, too, are expected. Inclusion of sewer rates lead to a prediction of greater consumption. This coefficient can be interpreted as a place marker for sewer rates that were actually charged to customers, even though sewer rate data is not available for the observation. The practice of winter averaging leads to an increased consumption estimate, although the estimate is not statistically significant. Consumption during nonwinter months under winter averaging regimes is estimated to be higher than during comparable winter months. This estimate may spuriously include seasonality, but nevertheless conforms to economic intuition about the incentives created by winter averaging.

Perhaps the most telling statistic listed in Table 4-3 is the adjusted R-squared statistic of 0.1052. Compared with 3-sector models that explained at least 90% of data variation, this regression explains only 10.52%. On this basis, the residential regression is far inferior to the other long-run models discussed. Reasons could include the loss of flexibility and misspecification of the dependent variable (per capita water use). Although the simpler model can provide some qualitative insights, its applicability to quantitative uses is limited.

Nonnested Test

The significance of fixed price, although suggestive, does not settle the question of price specification. Average and marginal price indices are constructed from the price components and regressed in two parallel estimations. The marginal price regression explains an estimated 0.07% more of the variation in the dependent variable than the average price regression and outscores the average price regression by about 0.013% on Akaike and Schwarz information criteria.

Objectively, the marginal price specification is preferred by the nonnested test, but the margin of preference is extremely narrow. Although a formal hypothesis test cannot be performed on these measures, the explanatory powers of the two price specifications could be seen as approximately equal. Since fixed charges are highly explanatory in the main long-run regression, the marginal price specification is eliminated as the absolutely best price specification because it omits an important variable. Since marginal price performs marginally better than average price, average price is also eliminated as the best possible specification. Perhaps some other combination of the price components is more explanatory than either marginal price or average price, or perhaps a clear picture of water demand structure can only result from decomposed price components. We leave resolution of this issue to future research.

Dynamic Regression Results

The 43% mean predictive error from the long-run model leaves room for improvement. The short-run ECM can help in this regard. Instead of using regression error only to find the model's faults, ECM actively employs past error to improve the model. Postestimation diagnostics parallel to those performed on the long-run model result in similar prescriptions for the ECM, leading to a two-step GLS formulation with outliers excluded. The ECM integrated model halves next-step forecasting error, to 22.56%.

Interpretation of the regression results in Table 4-8 is simpler than for the flexible models because the independent variables enter linearly. Other conditions remaining constant, each additional resident gained by a community results in 4314 gallons per month of additional water use by the end of the first year. Each dollar of commercial growth translates to 0.037 additional gallons per month. Industrial growth is insignificant to water demand in the short run. Industrial growth is probably most often intensive growth (growth by existing facilities), which may only impact water usage over time. A month of higher high temperatures will tend to see higher water demand, as will a month with more drastic temperature swings. A month with more days of precipitation will see lower water demand. These weather variables are the most significant drivers of demand in the short run.

The significance of the lagged error correction (EC) term in the dynamic regression is a finding critical to research methodology. The term is positive and highly significant. When observed consumption falls below the estimated long-run equilibrium, demand increases the following year, representing equilibrium forces adjusting over time. The coefficient value of the EC term is not as important as its value in model specification. Without EC, explanatory value would erroneously be ascribed to the other variables or to random error. With the EC term, the dynamic model is a truly integrated short/long run model.

Over a single year, only residential block rate changes and commercial fixed charge changes induce a significantly negative demand response. Commercial marginal price changes might also have a marginal impact. Residential response to marginal price change may even be marginally positive in the short run. This effect may be a random artifact of the data, or it might reflect a psychological reaction to confusing rate changes.

Viewed as elasticity, commercial marginal price is the price component with the greatest short-run potential, with an estimated mean of –0.48. This estimate is five times the magnitude of the next most elastic component, industrial marginal price, at –0.084. Other components are much weaker in the short run, and no component is statistically elastic, given the high variation of the data. Advice from this formulation dictates that commercial customers are most likely to respond quickly to rate increases. Residential customers respond quickly to sharply increasing block rates, but the block rate increase to residences would have to be greater than commercial rate increases to achieve the same effect. The evidence from residential marginal price suggests that reducing low-volume rates may actually decrease consumption by increasing the contrast against high-volume rates.

To an extent, the results of the nonnested test have discredited the use of marginal price and average price indices. The appeal of simplicity may encourage their continued use, however. In this research, short-run marginal price and average price elasticity are practically identical at –0.0246.

Time Path of Adjustment

The integrated nature of the ECM allows a theoretical projection of demand adjustment over a period of years. In a stylized illustration, demand conditions can be set at equilibrium then all prices can be increased by 100%. The short-run model predicts that consumption will respond somewhat over the first year. After that, the only force is the persistent draw to a new equilibrium, as represented by the EC term. It is an assumption of the model that demand will never fully readjust, because the gravitational pull of the structural equilibrium tapers as excess demand approaches zero. The assumption is realistic in modern contexts because conditions seldom remain static for long.

Over a decade, 85.4% of the theoretical limit of adjustment materializes. This implies that a structural estimate of quantity demanded will be too low, even after 10 years. Such an estimate will profoundly overestimate annual adjustment, so responses to an acute shortage based on the recommendation of a long-run model will tend to be insufficient. On the other hand, a short-run model without an EC or comparable equilibrium term would predict no adjustment past the lags of the model (usually only a year or two). Prediction following from a short-run model would fail to anticipate the effect of momentum from past price changes and thus underestimate total adjustment. Revenue shortfalls could occur from an underestimation of long-run demand adjustment.

Seasonal Dynamics

The role of random error in the monthly dynamic models should not be discounted. The resolution of these models tests the limits of the available data. The best that can be said for the monthly price component elasticities illustrated in Figure 4-6 may be that the mean appears to lie below zero, implying a normal price effect. Combining the components, as in Figure 4-7, adds just enough clarity to encourage the formation of various ad hoc hypotheses. Rigorous testing of these hypotheses would not be conclusive within this research, due to the general weakness of the monthly results, but would be fertile ground for future research.

5.3 Concluding Remarks

In addition to its confirmation of some prior knowledge regarding water demand, this research reveals a number of heretofore unknown findings. Sectoral water use quantities are identifiable purely from aggregate sectoral characteristics. Both residences and businesses respond not only to marginal rates but also to periodic fixed charges on their water bills. Some industrial price responsiveness is discernable even from incomplete data. Regional patterns are evident, but most water demand behavior can be explained in a national model. Communities adapt to price change slowly, over a period of many years. Weather is the most significant influence on water demand in the short run.

The research has its limitations though. The research results are clearly tempered by idiosyncrasies of data, variable selection and definition, methodology, and mathematical assumptions.

Data limitations

- Only about 15% of the nation's large cities are represented in the final econometric analysis.
- Evaporation, system loss, and transfer timing are not accounted for in the model.
- Some volume data are of inconsistent quality.
- Some pricing elements are excluded.
- Some sewer prices are missing.
- Industrial activity is not subdivided into self-supplied and publicly supplied water users.

Limitations in variable selection and definition

- Results may be sensitive to price representation choices.
- Price components show evidence of endogeneity with quantity demanded.
- Household characteristics are not included as explanatory variables.
- Income and economic measures are highly aggregated.

- Frequency of precipitation may not capture the effect of precipitation on water demand.

Methodological limitations

- Statistical regression emphasizes commonalities and de-emphasizes differences across cities.
- Data collection methods favor simpler and more accessible records.
- The error corrections model framework assumes most communities are in equilibrium most of the time.

Mathematical limitations

- The square root functional form imposes less structure on the relationships among data than do ordinary forms used in this type of analysis, but there are impositions present; and sensitivity to functional form is not explored here (by applying alternate functional forms).
- Linear short-run functional form imposes continuity and nonconstant elasticity.

While these limitations do not likely affect the substance of the findings, they undoubtedly reduce the precision of the whole. Since the flexible ECM is a fabric of many fibers, isolated use of individual parameter estimates or other conclusions is not recommended. Use of the whole model to project future demand of a community, region, or the U.S. will likely produce the best water use forecasts available. The best applications of these results can be achieved by anchoring demand using available local/regional information specific to an application area, and then applying the elasticities or slopes generated here to project responses or economic valuations appropriate for the area.

Contributions of local, state, and federal water professionals made this research possible. It will be their continued contribution and cooperation that solves the inevitable future challenges of public water provision nationwide.

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TABLE 3-1
DESCRIPTIVE STATISTICS FOR THE WATER PRICE SAMPLE

VARIABLE		MEAN	STD DEV	MIN	MAX	VARIABLE	PERCENT
Full Sample, 319 Cities							
Residential	Fees	$6.60	$5.10	$0.00	$44.75	Quarterly	12.35%
	First Price	$1.82	$1.25	$0.00	$11.50	Bimonthly	3.23%
	Last Price	$1.94	$1.34	$0.00	$14.58		
	Min Volume	1.20	2.98	0.00	30.00	kGal	54.67%
Commercial	Fees	$26.30	$27.91	$0.00	$211.25		
	First Price	$1.86	$1.30	$0.00	$11.58	West	24.26%
	Last Price	$1.77	$1.10	$0.00	$9.72	South	37.62%
	Min Volume	2.72	9.94	0.00	200.00	New England	5.80%
Industrial	Fees	$148.70	$183.35	$0.00	$1,403.70	Midwest	31.60%
	First Price	$1.84	$1.30	$0.00	$11.58		
	Last Price	$1.75	$1.10	$0.00	$9.72		
	Min Volume	11.43	51.83	0.00	1280.00		
West, 77 Cities							
Residential	Fees	$8.00	$5.91	$0.00	$40.00	Quarterly	2.84%
	First Price	$1.42	$1.08	$0.00	$8.50	Bimonthly	10.35%
	Last Price	$2.02	$1.54	$0.00	$14.58		
	Min Volume	1.18	4.12	0.00	30.00	kGal	33.52%
Commercial	Fees	$31.37	$26.78	$0.00	$173.75		
	First Price	$1.51	$1.09	$0.00	$8.50		
	Last Price	$1.65	$1.17	$0.00	$9.72		
	Min Volume	3.16	16.29	0.00	200.00		
Industrial	Fees	$196.24	$221.68	$0.00	$1,403.70		
	First Price	$1.50	$1.08	$0.00	$8.50		
	Last Price	$1.65	$1.16	$0.00	$9.72		
	Min Volume	11.54	70.15	0.00	1280.00		
South, 122 Cities							
Residential	Fees	$6.92	$3.26	$0.00	$17.26	Quarterly	0.67%
	First Price	$2.07	$1.36	$0.00	$9.49	Bimonthly	0.00%
	Last Price	$2.28	$1.39	$0.00	$9.78		
	Min Volume	1.10	1.51	0.00	13.00	kGal	86.24%
Commercial	Fees	$29.58	$31.12	$0.00	$211.25		
	First Price	$2.10	$1.47	$0.00	$11.58		
	Last Price	$2.06	$1.11	$0.00	$6.73		
	Min Volume	2.96	7.62	0.00	49.30		
Industrial	Fees	$157.45	$169.63	$0.00	$1,231.15		
	First Price	$2.09	$1.48	$0.00	$11.58		
	Last Price	$2.02	$1.09	$0.00	$6.73		
	Min Volume	13.49	49.17	0.00	329.80		

New England, 18 Cities							
Residential	Fees	$3.28	$4.15	$0.00	$16.54	Quarterly	43.23%
	First Price	$1.68	$0.76	$0.00	$3.45	Bimonthly	0.00%
	Last Price	$1.69	$0.97	$0.00	$4.91		
	Min Volume	2.70	4.21	0.00	10.00	kGal	23.93%
Commercial	Fees	$8.14	$12.18	$0.00	$39.51		
	First Price	$1.78	$0.76	$0.53	$3.45		
	Last Price	$1.81	$0.98	$0.48	$4.91		
	Min Volume	2.70	4.21	0.00	10.00		
Industrial	Fees	$38.02	$67.63	$0.00	$246.92		
	First Price	$1.76	$0.75	$0.53	$3.45		
	Last Price	$1.78	$0.97	$0.48	$4.91		
	Min Volume	2.70	4.21	0.00	10.00		

Midwest, 99 Cities							
Residential	Fees	$5.60	$5.76	$0.00	$44.75	Quarterly	28.18%
	First Price	$1.89	$1.23	$0.00	$11.50	Bimonthly	2.27%
	Last Price	$1.52	$0.98	$0.00	$4.83		
	Min Volume	1.07	2.92	0.00	15.00	kGal	37.94%
Commercial	Fees	$22.24	$25.24	$0.00	$144.75		
	First Price	$1.87	$1.24	$0.00	$11.50		
	Last Price	$1.50	$0.98	$0.00	$4.83		
	Min Volume	2.11	6.01	0.00	46.00		
Industrial	Fees	$127.08	$168.86	$0.00	$888.75		
	First Price	$1.83	$1.26	$0.00	$11.50		
	Last Price	$1.48	$0.99	$0.00	$4.83		
	Min Volume	10.71	42.65	0.00	369.12		

TABLE 3-2
DESCRIPTIVE STATISTICS FOR THE SEWER PRICE SAMPLE

VARIABLE		MEAN	STD DEV	MIN	MAX	VARIABLE	PERCENT
Full Sample, 210 Cities							
Residential	Fees	$12.52	$31.21	$0.00	$422.00	Quarterly	3.63%
	First Price	$1.76	$1.34	$0.00	$7.32	Bimonthly	9.08%
	Last Price	$1.33	$1.39	$0.00	$7.20		
	Min Volume	0.84	1.88	0.00	15.00	kGal	67.07%
Commercial	Fees	$30.94	$84.43	$0.00	$1,132.38		
	First Price	$2.00	$1.37	$0.00	$8.79	West	21.20%
	Last Price	$1.99	$1.45	$0.00	$8.79	South	48.86%
	Min Volume	2.95	21.11	0.00	311.00	New England	8.17%
Industrial	Fees	$145.42	$620.95	$0.00	$8,626.50	Midwest	21.21%
	First Price	$2.00	$1.41	$0.00	$10.36		
	Last Price	$1.97	$1.46	$0.00	$10.36	Winter Averaging	17.89%
	Min Volume	21.60	268.35	0.00	4000.00		
West, 46 Cities							
Residential	Fees	$32.13	$62.62	$0.00	$422.00	Quarterly	8.57%
	First Price	$0.85	$1.27	$0.00	$7.20	Bimonthly	5.83%
	Last Price	$0.82	$1.27	$0.00	$7.20		
	Min Volume	0.08	0.75	0.00	8.00	kGal	57.07%
Commercial	Fees	$27.36	$52.12	$0.00	$302.00		
	First Price	$1.58	$1.44	$0.00	$7.20	Winter Averaging	17.43%
	Last Price	$1.55	$1.46	$0.00	$7.20		
	Min Volume	0.99	3.27	0.00	18.60		
Industrial	Fees	$56.25	$129.77	$0.00	$856.41		
	First Price	$1.64	$1.69	$0.00	$10.36		
	Last Price	$1.62	$1.70	$0.00	$10.36		
	Min Volume	0.98	3.25	0.00	18.60		
South, 100 Cities							
Residential	Fees	$8.67	$5.02	$0.00	$28.36	Quarterly	0.00%
	First Price	$2.35	$1.21	$0.00	$7.32	Bimonthly	1.17%
	Last Price	$1.48	$1.47	$0.00	$7.16		
	Min Volume	1.05	1.45	0.00	9.00	kGal	90.27%
Commercial	Fees	$47.05	$111.73	$0.00	$1,132.38		
	First Price	$2.41	$1.28	$0.00	$8.79	Winter Averaging	24.40%
	Last Price	$2.39	$1.39	$0.00	$8.79		
	Min Volume	4.55	29.71	0.00	311.00		
Industrial	Fees	$291.59	$921.59	$0.00	$8,626.50		
	First Price	$2.39	$1.28	$0.00	$8.79		
	Last Price	$2.34	$1.33	$0.00	$8.79		
	Min Volume	42.67	382.75	0.00	4000.00		

New England, 17 Cities							
Residential	Fees	$4.35	$10.59	$0.00	$52.44	Quarterly	7.00%
	First Price	$1.90	$1.32	$0.00	$7.11	Bimonthly	40.80%
	Last Price	$2.10	$1.66	$0.00	$7.11		
	Min Volume	1.74	4.38	0.00	15.00	kGal	7.00%
Commercial	Fees	$16.35	$53.94	$0.00	$279.51		
	First Price	$2.01	$1.45	$0.00	$8.40	Winter Averaging	0.00%
	Last Price	$2.20	$1.76	$0.00	$8.40		
	Min Volume	1.74	4.38	0.00	15.00		
Industrial	Fees	$96.46	$340.65	$0.00	$1,747.83		
	First Price	$2.02	$1.45	$0.00	$8.40		
	Last Price	$2.21	$1.76	$0.00	$8.40		
	Min Volume	1.74	4.38	0.00	15.00		

Midwest, 46 Cities							
Residential	Fees	$4.04	$3.43	$0.00	$16.23	Quarterly	5.90%
	First Price	$1.30	$0.92	$0.00	$4.08	Bimonthly	18.82%
	Last Price	$1.22	$0.89	$0.00	$4.08		
	Min Volume	0.79	1.69	0.00	10.00	kGal	45.32%
Commercial	Fees	$4.83	$7.67	$0.00	$78.86		
	First Price	$1.35	$0.87	$0.00	$4.08	Winter Averaging	10.71%
	Last Price	$1.29	$0.82	$0.00	$4.08		
	Min Volume	1.63	5.08	0.00	30.00		
Industrial	Fees	$7.28	$19.31	$0.00	$255.70		
	First Price	$1.36	$0.86	$0.00	$4.08		
	Last Price	$1.30	$0.82	$0.00	$4.08		
	Min Volume	1.80	5.09	0.00	30.00		

TABLE 3-3
DESCRIPTIVE STATISTICS FOR THE WATER AND SEWER PRICE INDICES (NOMINAL PRICES)

SECTOR		OBS	MEAN	STD DEV	MIN	MAX	% ANNUAL CHANGE
			Marginal Price				
Residential	Water	37158	1.81	0.92	0.00	8.12	2.94%
	Sewer	22927	1.22	1.23	0.00	7.20	3.22%
Commercial	Water	35378	1.75	0.95	0.00	7.53	2.71%
	Sewer	20637	2.04	1.41	0.00	8.79	3.44%
Industrial	Water	32547	1.71	1.05	0.00	9.37	2.99%
	Sewer	17467	1.97	1.47	0.00	10.36	3.93%
			Average Price				
Residential	Water	37048	2.25	0.98	0.33	8.38	2.88%
	Sewer	22927	2.28	2.15	0.00	28.13	4.94%
Commercial	Water	35378	2.08	0.98	0.07	7.92	2.65%
	Sewer	20637	2.42	1.71	0.00	14.15	3.45%
Industrial	Water	32547	2.01	1.07	0.01	9.72	2.92%
	Sewer	17467	2.26	1.85	0.00	17.25	3.69%

TABLE 3-4

VOLUME STATISTICS AGGREGATED BY STATE
(MILLIONS OF GALLONS PER MONTH)

STATE	OBS	MEAN	STD DEV	MIN	MAX
Alaska	96	120.2	17.6	92.4	159.0
California	5,518	1,171.1	2,695.0	3.3	23,170.9
Florida	5,173	408.3	523.0	16.7	3,716.5
Indiana	846	780.9	1,327.9	1.0	6,544.5
Kansas	529	956.5	859.2	2.3	4,071.1
Minnesota	1,188	454.9	575.2	41.2	3,269.7
Ohio	1,584	692.0	1,298.8	83.6	6,936.0
Texas	8,400	1,013.9	2,057.4	25.0	41,568.6
Wisconsin	2,510	453.9	757.9	29.3	5,814.9
Full Sample	25,844	814.3	1,822.9	1.0	41,568.6

TABLE 3-5
POPULATION AND ECONOMIC STATISTICS BY STATE
(YEAR 2001, WITH STANDARD DEVIATIONS BELOW)

STATE	OBS	POPULATION	INCOME ($)	COMMERCE ($000)	INDUSTRY ($000)
Alaska	1	30,533	29,186	667,910	12,306
		.	.	.	.
California	45	204,145	25,431	3,684,298	1,015,970
		(569,350)	(8,406)	(10,700,000)	(2,435,971)
Florida	27	69,741	24,976	1,089,110	189,095
		(54,929)	(5,348)	(971,162)	(266,933)
Kansas	8	168,010	22,831	3,079,615	2,204,643
		(259,884)	(8,169)	(5,109,292)	(3,900,437)
Indiana	6	111,794	26,559	2,352,708	934,054
		(122,290)	(7,065)	(2,430,029)	(1,663,025)
Ohio	8	102,184	29,463	2,215,623	799,530
		(116,251)	(8,558)	(2,322,919)	(502,674)
Minnesota	11	107,876	25,831	1,953,947	903,786
		(203,974)	(10,398)	(3,843,705)	(1,434,887)
Texas	62	147,663	22,398	2,621,281	784,471
		(231,255)	(6,985)	(4,536,898)	(1,917,347)
Wisconsin	20	90,955	24,087	1,529,587	1,093,294
		(126,331)	(5,572)	(1,807,696)	(1,131,442)
Full Sample	188	138,794	24,363	2,483,776	857,695
		(321,933)	(7,434)	(6,105,481)	(1,905,132)

TABLE 3-6
CORRELATIONS AMONG DEMOGRAPHIC VARIABLES

	Population	Income	Commerce	Industry
Population	1			
Income	-0.0567	1		
Commerce	0.981	0.0372	1	
Industry	0.774	-0.0417	0.768	1

TABLE 3-7

MONTHLY VOLUME SUPPLIED RELATIVE TO POPULATION AND EARNINGS, BY STATE

STATE	RELATIVE VOLUME	OBS	MEAN GALLONS	STD DEV	MIN	MAX	USGS 1995	t-SCORE
Alaska	per capita	96	3898.5	570.1	2974.0	5169.2	5689.8	3.14
	per $000	96	177.5	31.3	129.9	259.3		
California	per capita	5134	6203.3	3689.8	7.1	45130.9	6131.9	0.02
	per $000	5134	448.9	356.3	0.8	2770.6		
Florida	per capita	3373	4840.0	5121.1	225.0	40800.9	4516.7	0.06
	per $000	3373	333.6	234.7	12.6	1590.5		
Kansas	per capita	774	5832.1	2040.3	5.0	22073.6	4990.2	0.41
	per $000	774	382.2	166.3	0.3	1025.6		
Indiana	per capita	792	4569.7	1469.0	2539.8	9850.0	2553.5	1.37
	per $000	792	260.5	121.7	85.4	738.0		
Minnesota	per capita	1056	4411.8	1654.8	854.7	12163.6	3796.8	0.37
	per $000	1056	230.5	127.7	30.7	773.1		
Ohio	per capita	1464	4957.4	1516.3	2396.4	16245.2	4180.3	0.51
	per $000	1464	397.9	217.7	80.2	1618.0		
Texas	per capita	8280	7153.9	8335.6	221.9	265270.7	5158.8	0.24
	per $000	8280	540.5	873.2	20.4	33378.5		
Wisconsin	per capita	2126	5113.4	2099.6	2028.5	12908.3	5583.2	0.22
	per $000	2126	323.3	189.0	65.8	1091.7		
Total	per capita	23095	6005.7	5803.8	5.0	265270.7	5094.8	0.16
	per $000	23095	430.3	572.8	0.3	33378.5		

TABLE 3-8
DESCRIPTIVE STATISTICS FOR THE WEATHER AND CLIMATE VARIABLES

VARIABLE	OBS	MEAN	STD DEV	MIN	MAX
min_temp (°F)	15654	50.1	16.1	-9.3	82.5
max_temp (°F)	15654	70.9	17.6	11.4	111.6
rain_fraction	15651	0.19	0.13	0.00	1.00
mean_min_temp (°F)	1356	49.1	16.4	-1.2	78.5
mean_max_temp (°F)	1356	70.3	17.7	17.9	108.2
mean_rain_fraction	1356	0.16	0.087	0.00	0.64

TABLE 4-1
RESULTS OF THE AUXILIARY PRICE REGRESSION

Source	SS	df	MS	Number of obs	=	20949
Model	6.2772e+22	55	1.1413e+21	F(55, 20893)	=	2127.21
Residual	1.1210e+22	20893	5.3653e+17	Prob > F	=	0.0000
Total	7.3982e+22	20948	3.5317e+18	R-squared	=	0.8485
				Adj R-squared	=	0.8481
				Root MSE	=	7.3e+08

Dependent Variable: vol_gal	Coef.	Std. Err.	t	P>|z|
temp•pop	-1846.831	1269.661	-1.45	0.146
rain•pop	-5837.188	3321.01	-1.76	0.079
meantemp•pop	-3037.487	1294.504	-2.35	0.019
meanrain•pop	49296.54	10070.14	4.90	0.000
income•pop	-3.270322	825915	-3.96	0.000
sqrt(temp) •pop	-6712.943	4293.212	-1.56	0.118
sqrt(rain) •pop	-8675.005	8216.662	-1.06	0.291
sqrt(meantemp) •pop	5921.621	4239.06	1.40	0.162
sqrt(meanrain) •pop	84969.52	16837.42	5.05	0.000
sqrt(income) •pop	41.45895	106.8308	0.39	0.698
sqrt(temp•rain) •pop	15028.67	4151.483	3.62	0.000
sqrt(temp•meantemp) •pop	5026.555	2551.538	1.97	0.049
sqrt(temp•meanrain) •pop	-2923.804	7283.819	-0.40	0.688
sqrt(temp•income) •pop	-210.6599	38.80201	-5.43	0.000
sqrt(rain•meantemp) •pop	-11948.53	4153.705	-2.88	0.004
sqrt(rain•meanrain) •pop	-50972.63	9062.229	-5.62	0.000
sqrt(rain•income) •pop	-261.6391	54.51894	-4.80	0.000
sqrt(meantemp•meanrain) •pop	-10819.94	7405.269	-1.46	0.144
sqrt(meantemp•income) •pop	240.1558	39.36418	6.10	0.000
sqrt(meanrain•income) •pop	243.6151	74.4839	3.27	0.001
pop	-1881.421	7544.561	-0.25	0.803
temp•comm	1128.487	614.0532	1.84	0.066
rain•comm	3985.298	1966.016	2.03	0.043
meantem•comm	2511.806	628.4294	4.00	0.000
meanrain•comm	-15112.08	5762.831	-2.62	0.009
sqrt(temp) •comm	9954.461	2233.701	4.46	0.000
sqrt(rain) •comm	18304.2	4569.684	4.01	0.000
sqrt(meantemp) •comm	-16868.32	2183.536	-7.73	0.000
sqrt(meanrain) •comm	-62282.97	9622.06	-6.47	0.000
sqrt(temp•rain) •comm	-7513.505	2194.722	-3.42	0.001
sqrt(temp•meantemp) •comm	-3209.004	1233.535	-2.60	0.009
sqrt(temp•meanrain) •comm	-664.028	3892.356	-0.17	0.865
sqrt(rain•meantemp) •comm	4881.723	2220.761	2.20	0.028
sqrt(rain•meanrain) •comm	26335.95	5450.471	4.83	0.000
sqrt(meantemp•meanrain) •comm	8898.921	3978.168	2.24	0.025
comm	26677.71	4183.859	6.38	0.000
temp•ind	215.8445	352.7126	0.61	0.541
rain•ind	-615.3114	1913.153	-0.32	0.748
meantemp•ind	-1378.108	363.3927	-3.79	0.000
meanrain•ind	-43034.85	6200.685	-6.94	0.000
sqrt(temp) •ind	-3397.366	1845.431	-1.84	0.066
sqrt(rain) •ind	-87.4079	3958.285	-0.02	0.982

sqrt(meantemp) •ind	9601.826	1794.317	5.35	0.000
sqrt(meanrain) •ind	55737.99	7813.575	7.13	0.000
sqrt(temp•rain) •ind	-409.8126	1764.668	-0.23	0.816
sqrt(temp•meantemp) •ind	858.5006	704.6738	1.22	0.223
sqrt(temp•meanrain) •ind	-6690.867	3301.098	-2.03	0.043
sqrt(rain•meantemp) •ind	514.1499	1739.074	0.30	0.768
sqrt(rain•meanrain) •ind	2286.642	6129.679	0.37	0.709
sqrt(meantemp•meanrain) •ind	2659.141	3311.75	0.80	0.422
ind	-31697.19	3245.435	-9.77	0.000
temp	1789268	1968248	0.91	0.363
rain	-9.87e+07	5.58e+07	-1.77	0.077
mean_temp	-1144350	1970477	-0.58	0.561
mean_rain	-7.88e+08	9.49e+07	-8.30	0.000
constant	1.60e+08	2.92e+07	5.47	0.000

TABLE 4-2
DESCRIPTIVE STATISTICS OF ESTIMATED PRICE COMPONENTS

VARIABLE	OBS	MEAN ($)	STD DEV	MIN	MAX
rp1	18282	2.02	1.70	0	10.27
rp2	18282	2.77	1.89	0	12.91
rfp	18282	5.73	7.44	0	43.10
cp1	18282	2.61	1.82	0	11.74
cp2	18282	3.15	2.21	0	11.75
cfp	18282	0.56	4.09	0	60.13
ip	18282	3.18	2.29	0	13.23

TABLE 4-3
RESULTS OF THE LOGARITHMIC RESIDENTIAL REGRESSION

SOURCE	SS	df	MS			
				Number of obs	=	14666
Model	566.12	10	56.61	F(10, 14655)	=	172.21
Residue	4817.8	14655	.3287	Prob > F	=	0.0000
Total	5383.9	14665	.3671	R-squared	=	0.1052
				Adj R-squared	=	0.104
				Root MSE	=	.57336

Dependent Variable: ln(vol_gal / pop)	Coef.	Std. Err.	t	p>|t|
ln(p1)	-0.0261	0.0026	-9.95	0.000
ln(fp)	-0.1050	0.0049	-21.48	0.000
ln(inc)	0.0335	0.0097	3.46	0.001
ln(temp)	0.2926	0.0184	15.88	0.000
ln(rain)	-0.0861	0.0088	-9.80	0.000
ln(meantemp)	0.0195	0.0115	1.70	0.090
ln(meanrain)	-0.0583	0.0074	-7.89	0.000
winterav	0.0496	0.0307	1.61	0.106
summersewer	0.2444	0.0354	6.90	0.000
sewer	0.0953	0.0139	6.85	0.000
constant	7.9386	0.0265	299.19	0.000

TABLE 4-4
RESULTS OF THE GLS STRUCTURAL REGRESSION

Estimated covariances	=	175	Number of obs		=	15446
Estimated autocorrelation	=	0	Number of groups		=	175
Estimated coefficients	=	118	Obs per group:	min	=	4
				avg	=	88.26286
				max	=	120
			Wald chi2(117)		=	147267.79
Log likelihood	=	-310768.6	Prob > chi2		=	0.0000

Dependent Variable: vol_gal	Coef.	Std. Err.	z	p>|z|
rpl•pop	-353.2812	77.09027	-4.58	0.000
rpd•pop	-939.1072	260.4023	-3.61	0.000
rfp•pop	-1841.631	76.77213	-23.99	0.000
inc•pop	360.4981	126.5955	2.85	0.004
temp•pop	-2999.178	4903.742	-0.61	0.541
rain•pop	335.4384	268.364	1.25	0.211
meantemp•pop	-920.1116	4326.875	-0.21	0.832
meanrain•pop	4325.376	434.4768	9.96	0.000
sqrt(rp1) •pop	-1241.231	605.3065	-2.05	0.040
sqrt(rfp) •pop	342.2969	574.1588	0.60	0.551
sqrt(income) •pop	-3874.659	984.1357	-3.94	0.000
sqrt(temp) •pop	7250.64	5954.406	1.22	0.223
sqrt(rain) •pop	-1284.367	1320.732	-0.97	0.331
sqrt(meantemp) •pop	-12076.33	5477.238	-2.20	0.027
sqrt(meanrain) •pop	-1366.474	1897.031	-0.72	0.471
sqrt(rp1) •rpd•pop	41.08461	35.34998	1.16	0.245
sqrt(rp1•rfp) •pop	217.4543	115.1244	1.89	0.059
sqrt(rp1•income) •pop	1087.636	163.463	6.65	0.000
sqrt(rp1•temp) •pop	-1552.071	1032.349	-1.50	0.133
sqrt(rp1•rain) •pop	236.9691	147.2657	1.61	0.108
sqrt(rp1•meantemp) •pop	1555.922	1013.627	1.54	0.125
sqrt(rp1•meanrain) •pop	536.5601	194.7065	2.76	0.006
rpd•sqrt(rfp) •pop	456.6836	51.65978	8.84	0.000
rpd•sqrt(income) •pop	-220.5272	70.48377	-3.13	0.002
rpd•sqrt(temp) •pop	-90.60658	392.2252	-0.23	0.817
rpd•sqrt(rain) •pop	149.4338	60.65452	2.46	0.014
rpd•sqrt(meantemp) •pop	515.2519	385.3337	1.34	0.181
rpd•sqrt(meanrain) •pop	-86.91213	83.62086	-1.04	0.299
sqrt(rfp•income) •pop	3265.97	156.7305	20.84	0.000
sqrt(rfp•temp) •pop	-5489.086	838.4908	-6.55	0.000
sqrt(rfp•rain) •pop	139.1837	135.0182	1.03	0.303
sqrt(rfp•meantemp) •pop	4137.783	815.9111	5.07	0.000
sqrt(rfp•meanrain) •pop	111.16	165.5134	0.67	0.502
sqrt(income •temp) •pop	5146.992	1643.432	3.13	0.002
sqrt(income •rain) •pop	576.3729	243.5815	2.37	0.018
sqrt(income •meantemp) •pop	-1773.933	1551.232	-1.14	0.253
sqrt(income •meanrain) •pop	-5915.63	278.8093	-21.22	0.000
sqrt(temp•rain) •pop	2234.293	2501.9	0.89	0.372
sqrt(temp•meantemp) •pop	5278.047	9120.551	0.58	0.563
sqrt(temp•meanrain) •pop	-6578.194	3436.393	-1.91	0.056
sqrt(rain•meantemp) •pop	-2392.479	2345.652	-1.02	0.308

sqrt(rain•meanrain) •pop	-627.1769	570.4937	-1.10	0.272
sqrt(meantemp•meanrain) •pop	4901.08	3285.3	1.49	0.136
winterav	-314.3201	85.08716	-3.69	0.000
summersewer	625.9992	94.29627	6.64	0.000
pop	12786.48	2786.694	4.59	0.000
cpl•comm	-23.149	4.70769	-4.92	0.000
cpd•comm	131.5046	10.77033	12.21	0.000
cfp•comm	11.04992	2.473564	4.47	0.000
temp•comm	352.8033	235.1142	1.50	0.133
rain•comm	-20.3935	13.49145	-1.51	0.131
meantemp•comm	173.7636	208.4451	0.83	0.404
meanrain•comm	-174.7762	20.11181	-8.69	0.000
sqrt(cp1) •comm	100.5551	32.56897	3.09	0.002
sqrt(cfp) •comm	-33.31919	27.1021	-1.23	0.219
sqrt(temp) •comm	-1103.212	291.7138	-3.78	0.000
sqrt(rain) •comm	-10.21738	63.5341	-0.16	0.872
sqrt(meantemp) •comm	529.3459	269.1919	1.97	0.049
sqrt(meanrain) •comm	519.7936	90.65939	5.73	0.000
sqrt(cp1)•cpd •comm	-69.08758	3.043299	-22.70	0.000
sqrt(cp1•cfp) •comm	-48.83398	8.277532	-5.90	0.000
sqrt(cp1•temp) •comm	27.31417	55.75337	0.49	0.624
sqrt(cp1•rain) •comm	-3.765212	9.448698	-0.40	0.690
sqrt(cp1•meantemp) •comm	-93.58374	53.42835	-1.75	0.080
sqrt(cp1•meanrain) •comm	.8355014	10.35751	0.08	0.936
cpd•sqrt(cfp) •comm	-39.54582	5.81945	-6.80	0.000
cpd•sqrt(temp) •comm	28.33675	16.79344	1.69	0.092
cpd•sqrt(rain) •comm	-1.16947	2.881958	-0.41	0.685
cpd•sqrt(meantemp) •comm	-56.34047	16.12837	-3.49	0.000
cpd•sqrt(meanrain) •comm	3.042669	3.998133	0.76	0.447
sqrt(cfp•temp) •comm	6.891786	26.784	0.26	0.797
sqrt(cfp•rain) •comm	-.8922338	3.616917	-0.25	0.805
sqrt(cfp•meantemp) •comm	2.445444	27.3887	0.09	0.929
sqrt(cfp•meanrain) •comm	-20.08453	5.775752	-3.48	0.001
sqrt(temp•rain) •comm	46.26784	115.2402	0.40	0.688
sqrt(temp•meantemp) •comm	-352.1498	438.3921	-0.80	0.422
sqrt(temp•meanrain) •comm	204.5425	154.729	1.32	0.186
sqrt(rain•meantemp) •comm	-29.54476	109.0495	-0.27	0.786
sqrt(rain•meanrain) •comm	15.57858	27.24564	0.57	0.567
sqrt(meantemp•meanrain) •comm	-182.0553	148.7178	-1.22	0.221
comm	139.7996	135.9979	1.03	0.304
ip1•ind	61.77284	8.901264	6.94	0.000
temp•ind	89.72093	139.2292	0.64	0.519
rain•ind	10.41824	9.53461	1.09	0.275
meantemp•ind	89.19826	117.1734	0.76	0.447
meanrain•ind	-94.10425	15.89858	-5.92	0.000
sqrt(ip) •ind	-295.656	37.47028	-7.89	0.000
sqrt(temp) •ind	54.47479	164.4115	0.33	0.740
sqrt(rain) •ind	17.25155	37.59453	0.46	0.646
sqrt(meantemp) •ind	107.189	153.0163	0.70	0.484
sqrt(meanrain) •ind	460.3521	63.95249	7.20	0.000
sqrt(ip•temp) •ind	32.58604	61.37657	0.53	0.595
sqrt(ip•rain) •ind	-14.963	12.24162	-1.22	0.222
sqrt(ip•meantemp) •ind	66.50664	58.26322	1.14	0.254
sqrt(ip•meanrain) •ind	6.497457	18.49914	0.35	0.725
sqrt(temp•rain) •ind	7.925744	71.88991	0.11	0.912
sqrt(temp•meantemp) •ind	-175.4339	250.338	-0.70	0.483

sqrt(temp•meanrain) •ind	-65.16907	107.1351	-0.61	0.543
sqrt(rain•meantemp) •ind	-22.96826	65.92817	-0.35	0.728
sqrt(rain•meanrain) •ind	-9.651026	20.04175	-0.48	0.630
sqrt(meantemp•meanrain) •ind	-68.13785	98.77496	-0.69	0.490
ind	-318.3549	70.14963	-4.54	0.000
temp	-2.58e+08	1.77e+08	-1.46	0.145
rain	5650070	7762842	0.73	0.467
meantemp	-3.40e+08	1.50e+08	-2.26	0.024
meanrain	6571260	1.21e+07	0.54	0.586
sqrt(temp)	5.74e+08	1.83e+08	3.13	0.002
sqrt(rain)	1.53e+08	3.95e+07	3.87	0.000
sqrt(meantemp)	-3.03e+08	1.67e+08	-1.81	0.070
sqrt(meanrain)	4.17e+08	5.46e+07	7.63	0.000
sqrt(temp•rain)	-2.58e+08	7.54e+07	-3.42	0.001
sqrt(temp•meantemp)	6.46e+08	3.23e+08	2.00	0.046
sqrt(temp•meanrain)	-2.07e+08	9.98e+07	-2.08	0.038
sqrt(rain•meantemp)	2.00e+08	7.09e+07	2.82	0.005
sqrt(rain•meanrain)	-2.61e+07	1.67e+07	-1.56	0.118
sqrt(meantemp•meanrain)	-1.83e+07	9.49e+07	-0.19	0.847
sewer	1.56e+07	3015751	5.18	0.000
constant	-7.01e+08	7.58e+07	-9.25	0.000

TABLE 4-5
SIGNIFICANCE TESTS OF INDEPENDENT VARIABLES

VARIABLE	PARAMETERS	CHI^2 (PARA)
rp1	9	208.18
rpd	8	137.27
rfp	9	1225.40
cp1	8	762.63
cpd	7	726.02
cfp	8	707.28
ip	6	145.40
income	9	1313.47
temp	28	364.43
rain	28	250.07
mean_temp	28	179.07
mean_rain	28	1596.13

TABLE 4-6
STRUCTURAL PRICE COMPONENT ELASTICITIES

VARIABLE	MEAN ELASTICITY	STANDARD ERROR	MEAN ELASTICITY (90% sample)
rp1	0.129	0.037	0.068
rdp	-0.172	0.093	-0.137
rfp	-0.488	0.033	-0.045
cp1	-6.259	0.534	-1.086
cdp	-0.042	0.018	-0.005
cfp	-0.737	0.058	-0.137
ip	0.652	0.628	0.306

TABLE 4-7
STRUCTURAL PRICE COMPONENT ELASTICITIES BY REGION

	WEST	SOUTH	MIDWEST	OVERALL
rp1	0.033	0.072	0.096	
rpd	-0.111	-0.115	-0.204	
rfp	0.039	-0.159	0.088	
cp1	-0.759	-1.724	-0.178	
cpd	0.003	0.025	-0.075	
cfp	-0.210	-0.166	-0.074	
ip	0.124	0.755	-0.597	
ap	-0.071	-0.358	-0.142	-0.224
mp	-0.097	-0.219	-0.175	-0.115

TABLE 4-8
RESULTS OF THE GLS DYNAMIC REGRESSION

Estimated covariances	=	170	Number of obs	=	13721
Estimated autocorrelation	=	0	Number of groups	=	170
Estimated coefficient	=	15	Obs per group: min	=	11
			avg	=	80.71176
			max	=	108
			Wald chi2(14)	=	1680.94
Log likelihood	=	-271746.6	Prob > chi2	=	0.0000

Dependent Variable: d_vol_gal	Coef.	Std. Err.	z	p>|z|
d_rp1	6244940	2890096	2.16	0.031
d_rpd	-5343605	2316329	-2.31	0.021
d_rfp	115069.5	707494.1	0.16	0.871
d_pop	4314.359	931.1467	4.63	0.000
d_cp1	-5536295	3315314	-1.67	0.095
d_cpd	-624841.4	3125448	-0.20	0.842
d_cfp	-4343425	2122903	-2.05	0.041
d_comm	36.78498	13.0232	2.82	0.005
d_ip1	-329617.6	2975386	-0.11	0.912
d_ind	-.7601267	3.441082	-0.22	0.825
d_min_temp	-2056455	219763.6	-9.36	0.000
d_max_temp	4014401	209307.9	19.18	0.000
d_rain	-5.75e+07	5014325	-11.48	0.000
lag_EC	1812257	0067179	26.98	0.000

TABLE 4-9

SHORT-RUN PRICE COMPONENT ELASTICITIES

VARIABLE	ELASTICITY	STANDARD ERROR	ELASTICITY (90% sample)	STANDARD ERROR
rp1	0.085	0.261	0.061	0.068
rpd	-0.025	0.091	-0.014	0.027
rfp	0.005	0.017	0.003	0.005
cp1	-0.640	1.549	-0.483	0.454
cpd	-0.017	0.068	-0.008	0.020
cfp	-0.069	0.420	-0.019	0.025
ip	-0.112	0.243	-0.084	0.086

TABLE 4-10
SHORT-RUN PRICE COMPONENT ELASTICITIES BY REGION

VARIABLE	WEST	SOUTH	MIDWEST	OVERALL
rp1	0.055	0.095	0.098	
rpd	-0.006	-0.022	-0.004	
rfp	0.001	0.005	0.000	
cp1	-0.419	-0.569	-0.358	
cpd	-0.002	-0.013	0.000	
cfp	-0.040	-0.015	-0.013	
ip	-0.068	-0.108	-0.048	
ap	0.0254	-0.0350	-0.0564	-0.0264
mp	0.0259	-0.0367	-0.0528	-0.0265

TABLE 4-11
TIME PATH OF DEMAND ADJUSTMENT

YEAR	Bx	y	x-shock	EC	% Adjust
0	1	1	1	0	0
1	0.77583	0.974	0	-0.0358	11.768
2	0.77583	0.938	0	-0.0293	27.758
3	0.77583	0.908	0	-0.0240	40.850
4	0.77583	0.884	0	-0.0197	51.570
5	0.77583	0.865	0	-0.0161	60.346
6	0.77583	0.849	0	-0.0132	67.533
7	0.77583	0.835	0	-0.0108	73.417
8	0.77583	0.825	0	-0.0088	78.234
9	0.77583	0.816	0	-0.0072	82.179
10	0.77583	0.809	0	-0.0059	85.408
11	0.77583	0.803	0	-0.0049	88.053
12	0.77583	0.798	0	-0.0040	90.218
13	0.77583	0.794	0	-0.0033	91.991
14	0.77583	0.791	0	-0.0027	93.442
15	0.77583	0.788	0	-0.0022	94.631
16	0.77583	0.786	0	-0.0018	95.604
17	0.77583	0.784	0	-0.0015	96.400
18	0.77583	0.782	0	-0.0012	97.053
19	0.77583	0.781	0	-0.0010	97.587

TABLE 4-12
RESULTS OF MONTHLY GLS DYNAMIC REGRESSIONS (STANDARD ERRORS BELOW)

Dep Var: d_vol_gal	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
d_rp1	6630884	8100121	1.48E+07	1.69E+07	-316431.4	3512547	4141300	1.07E+07	8635379	-6493812	-806457.6	-955988.6
	(1.52E+07)	(6413808)	(1.49E+07)	(1.21E+07)	(1.48E+07)	(9630961)	(1.37E+07)	(1.15E+07)	(9059522)	(1.16E+07)	(8789475)	(6423841)
d_rpd	-4936130	4752486	1418199	3044091	-5397522	-2336871	-4606445	-4471322	-5894891	-1744726	126883.8	-4447377
	(1.19E+07)	(6598768)	(1.19E+07)	(1.05E+07)	(1.21E+07)	(8140048)	(1.32E+07)	(9417073)	(8633181)	(8297594)	(7678874)	(5663478)
d_rfp	-753436.8	-11373.75	969307.2	-1039061	-797840.9	2445074	-1839487	265953.5	661142	-463010.1	-747772.8	172033.5
	(3359542)	(1572351)	(3551857)	(2402260)	(4295920)	(3572417)	(2911476)	(2401228)	(2257231)	(2519053)	(1771853)	(1069544)
d_pop	6803.002	3021.356	14002.69	9833.866	15099.26	11337.66	6610.003	3447.659	1469.599	4844.453	963.6422	3706.672
	(3313.344)	(1943.662)	(3128.18)	(3001.525)	(4690.752)	(3542.016)	(3699.064)	(3026.247)	(2481.68)	(2364.423)	(1953.125)	(1613.498)
d_cp1	-8578855	-1.24E+07	-2.39E+07	-1.57E+07	-2618093	-1.40E+07	1.13E+07	4582078	-1.35E+07	4873403	-4114279	376172.8
	(1.76E+07)	(7707004)	(1.65E+07)	(1.34E+07)	(1.85E+07)	(1.11E+07)	(1.40E+07)	(1.20E+07)	(9857273)	(1.04E+07)	(9253953)	(7054555)
d_cpd	-1275116	-5085772	-1.13E+07	-3432806	1399884	-1.70E+07	1.26E+07	4644764	-6733494	-2917808	843008.4	-1280852
	(1.42E+07)	(8267599)	(1.46E+07)	(1.27E+07)	(1.89E+07)	(1.32E+07)	(1.37E+07)	(1.09E+07)	(9410321)	(1.01E+07)	(7961903)	(5844136)
d_cfp	-454594.9	-941964.6	-1025035	-523964	-1.06E+07	-6057163	-7056559	-6232584	-6633162	2521328	-2959770	-8907910
	(1.12E+07)	(5370692)	(8202455)	(5469507)	(8064230)	(7009908)	(8798657)	(7178906)	(6424810)	(4238170)	(7344211)	(6913480)
d_comm	-20.48773	-8.184286	-42.33114	-3.884327	-48.12915	-53.88188	21.74064	78.95188	80.96584	67.72	74.15081	-2.558793
	(49.11433)	(28.35442)	(48.833)	(41.33305)	(58.40729)	(49.73588)	(52.93857)	(41.58546)	(38.90687)	(30.94191)	(28.18918)	(20.98733)
d_ip1	3115384	2366001	1.01E+07	1353006	-7099505	9479057	-1.79E+07	-8239105	6160128	5503093	1622379	1052185
	(1.26E+07)	(6537090)	(1.27E+07)	(1.17E+07)	(1.67E+07)	(1.15E+07)	(1.18E+07)	(1.06E+07)	(7903130)	(8274347)	(7456254)	(5353833)
d_ind	-0.3818651	10.04138	14.2621	10.60062	-13.09597	-29.31898	-64.11248	-53.14491	53.78577	-1.067352	-13.00884	18.67357
	(8.915294)	(7.132607)	(10.77417)	(8.577107)	(17.13542)	(15.25884)	(27.31601)	(21.78282)	(18.04816)	(9.082266)	(10.85749)	(8.077574)
d_min_temp	-314769.9	-2749986	-4155495	-1837594	-4556020	-1086424	-1339302	-155399.4	-3356929	-3423570	-476338.7	-910837.2
	(767612.6)	(421335.4)	(875907.4)	(919094.7)	(1434572)	(1399952)	(1526287)	(1174091)	(896705.7)	(725912.6)	(477725.6)	(388361.5)
d_max_temp	-106153.3	2841762	4726525	9482305	9044304	1.21E+07	1.44E+07	8164708	9031894	7227775	1771336	1279353
	(910991.1)	(435835.8)	(811200.5)	(832520.6)	(1211380)	(1087578)	(1189129)	(924192.7)	(726406.7)	(675908.8)	(404631.5)	(403588)
d_rain_frac	-2.95E+07	-5.79E+07	-6.52E+07	-8.06E+07	-7.51E+07	-8.76E+07	-9.01E+07	-5.43E+07	-5.71E+07	-3.59E+07	-6.4E+07	-2.62E+07
	(1.78E+07)	(1.01E+07)	(1.85E+07)	(2.09E+07)	(2.77E+07)	(2.11E+07)	(1.74E+07)	(1.77E+07)	(1.68E+07)	(1.72E+07)	(1.52E+07)	(1.14E+07)
lag_EC	0.1492591	0.114281	0.266607	0.2427955	0.2412978	0.215767	0.1538825	0.1178402	0.0967155	0.1216507	0.136731	0.0899558
	(0.0311493	(0.017658)	(0.0302971)	(0.0246926)	(0.0316559)	(0.0227076)	(0.0211496)	(0.0174267)	(0.0164368)	(0.0182837)	(0.019191)	(0.0165841)
constant	918534.7	2084559	-2106967	1462267	-1885382	-870709.2	2698101	3667934	2214726	-986776	-1077233	668492.3
	(3375031)	(1968056)	(3547553)	(2978700	(4141865)	(3096209)	(3562817)	(3097398)	(2841144)	(2665739)	(2196940)	(1773119)

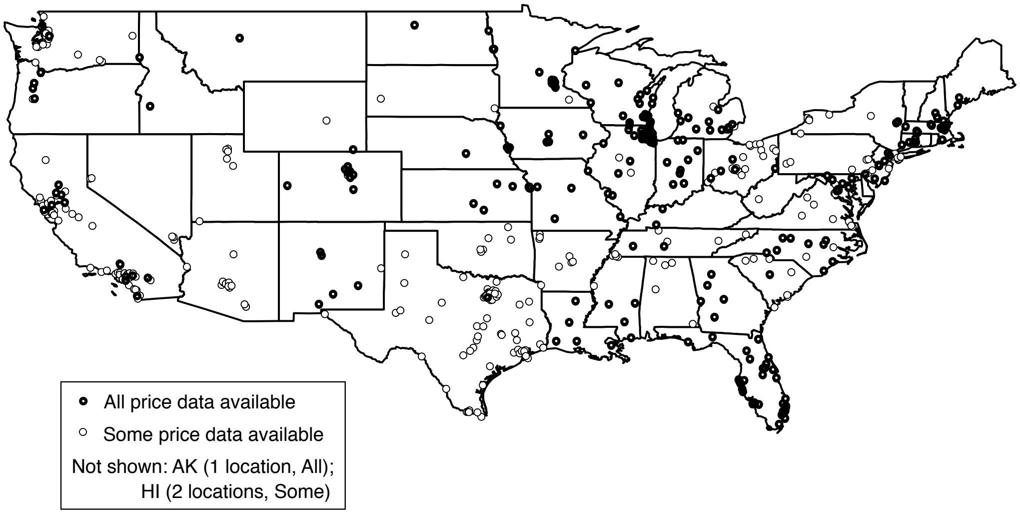

Figure 3-1. Locations Represented in Rate Data

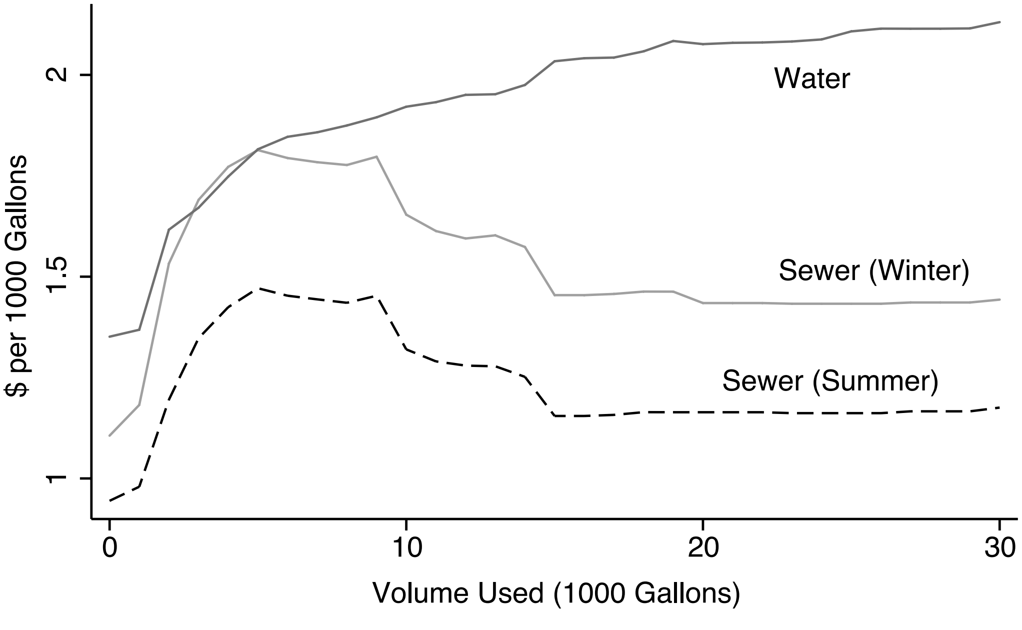

Figure 3-2. Residential Marginal Price by Volume

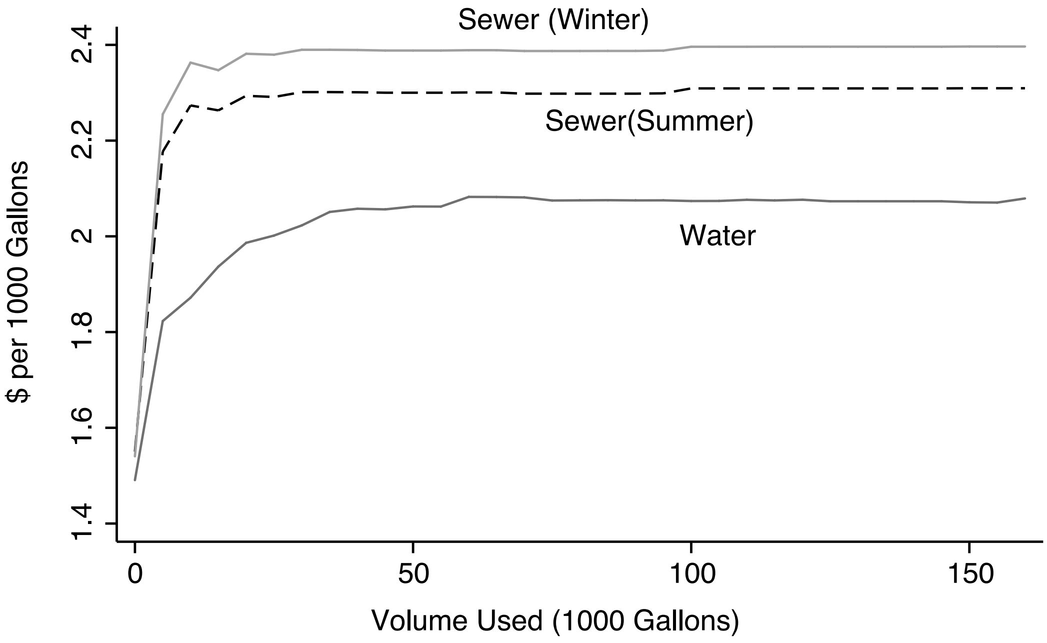

Figure 3-3. Commercial Marginal Price by Volume

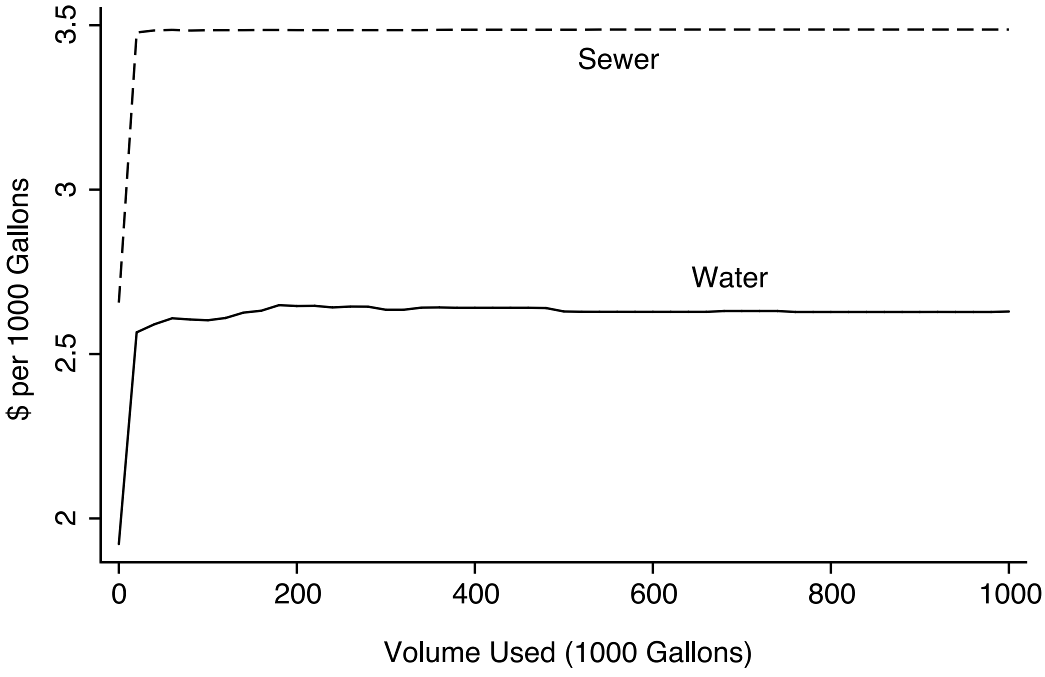

Figure 3-4. Industrial Marginal Price by Volume

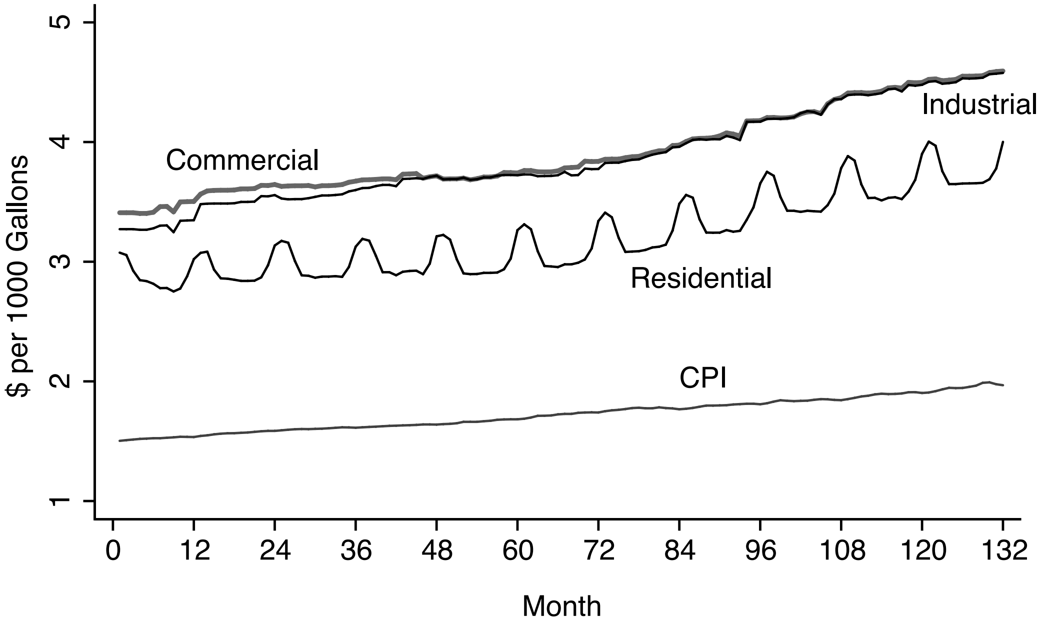

Figure 3-5. Trends in Marginal Pricing Policy

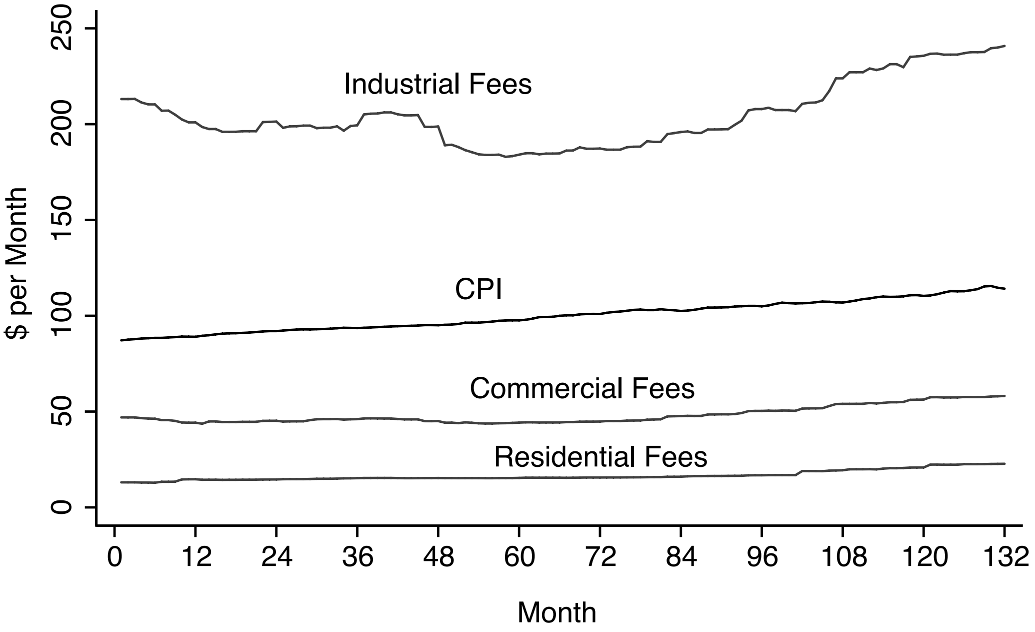

Figure 3-6. Trends in Fixed Charges (CPI=100 for month 66)

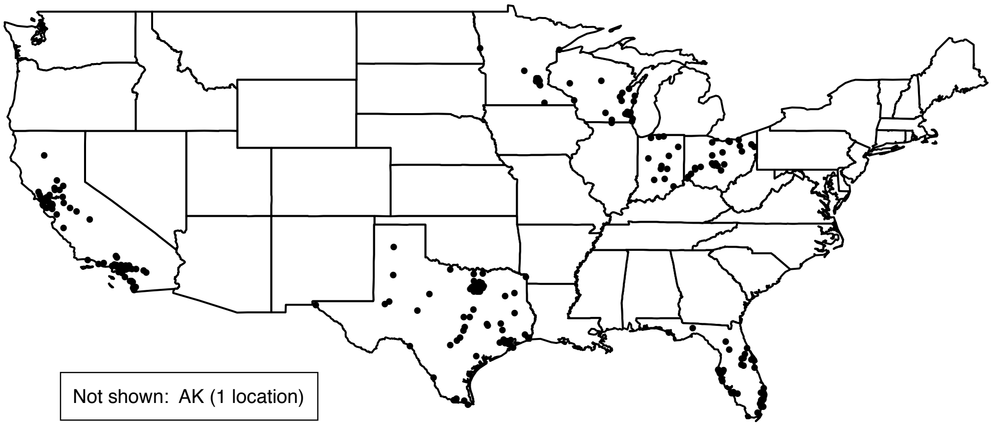

Figure 3-7. Locations Represented in Volume Data

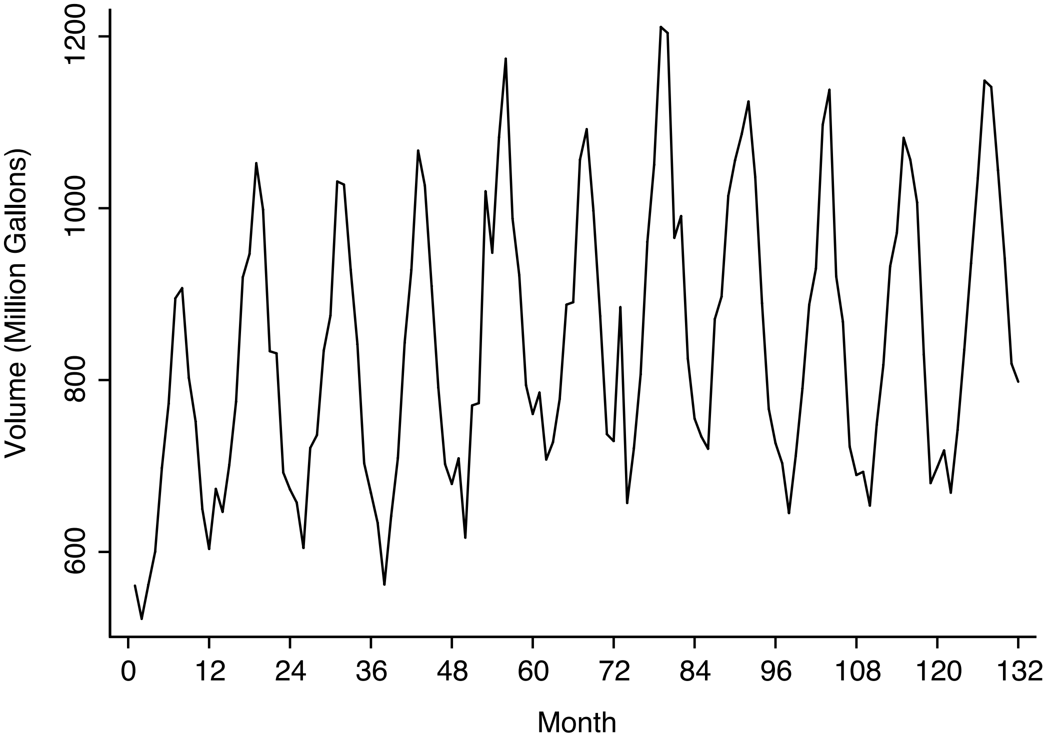

Figure 3-8. Trend in Average Volume Withdrawn

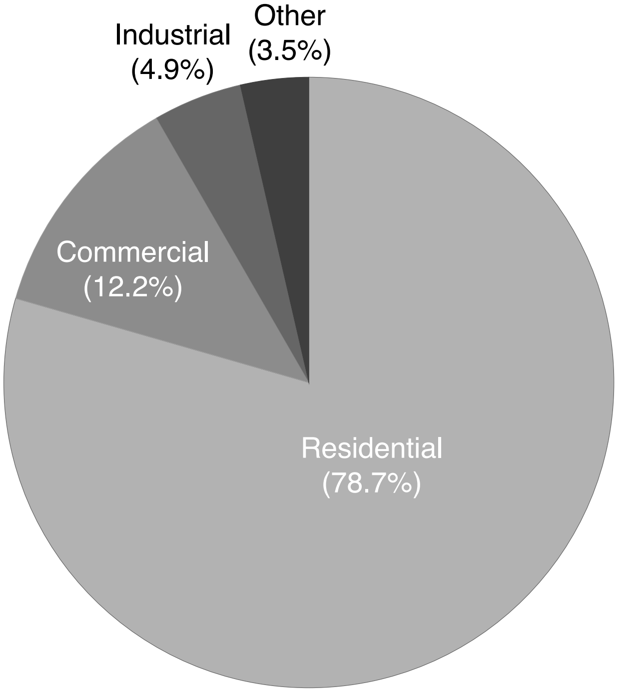

Figure 4-1. Sample Water Use Shares by Sector

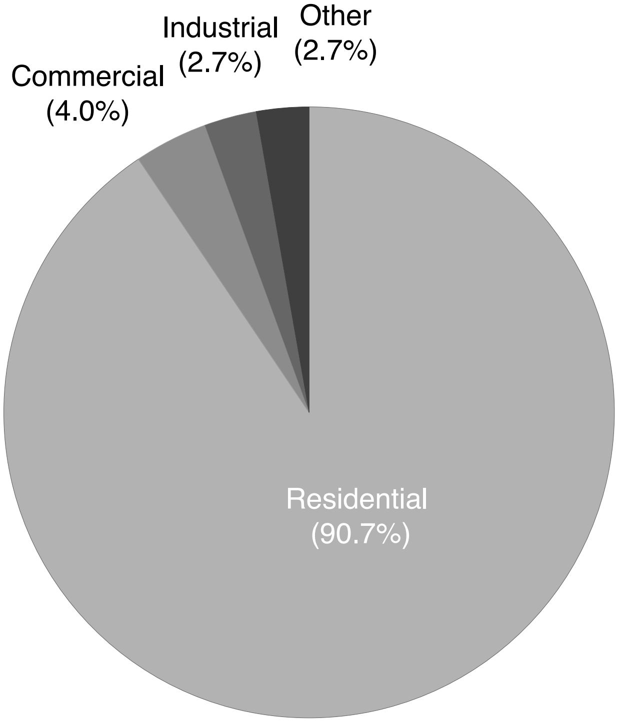

Figure 4-2. Western Region Water Use Shares

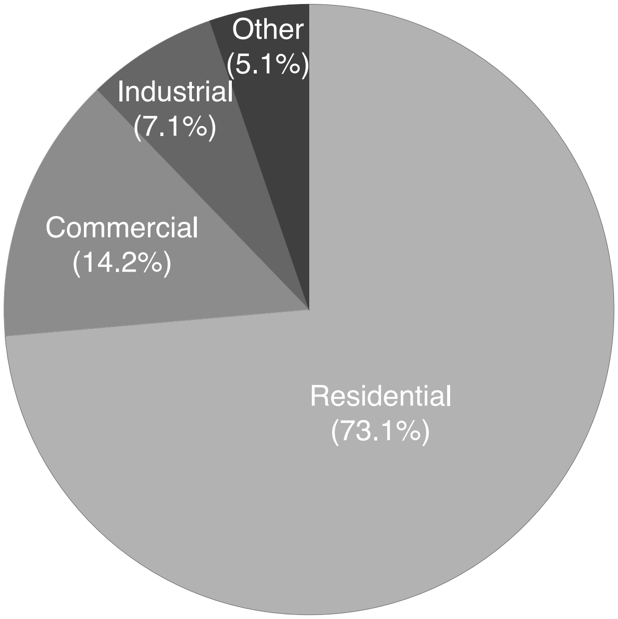

Figure 4-3. Southern Region Water Use Shares

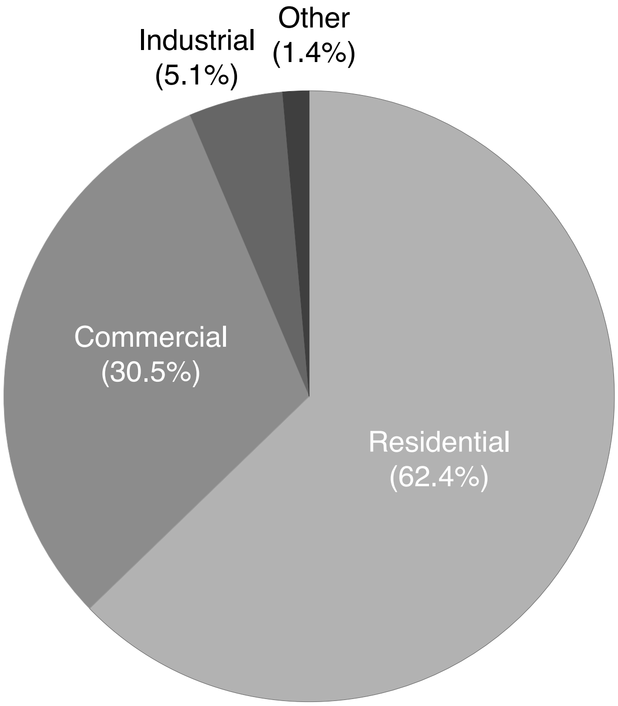

Figure 4-4. Midwest Region Water Use Shares

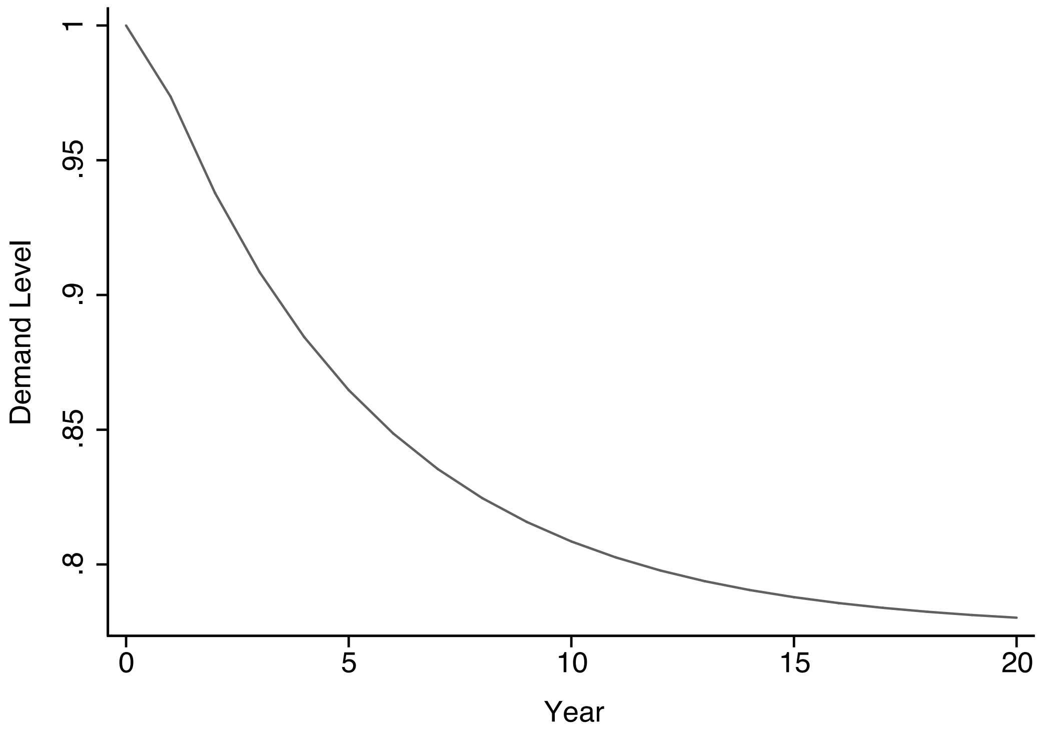

Figure 4-5. Time Path of Demand Adjustment

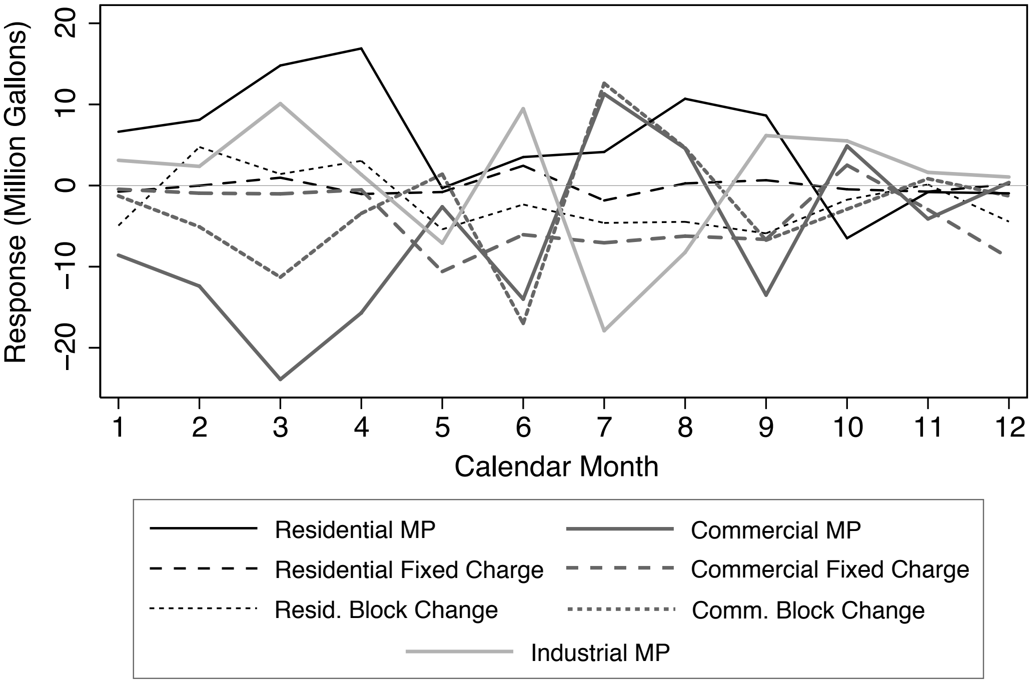

Figure 4-6. Seasonal Demand Response to Price Components

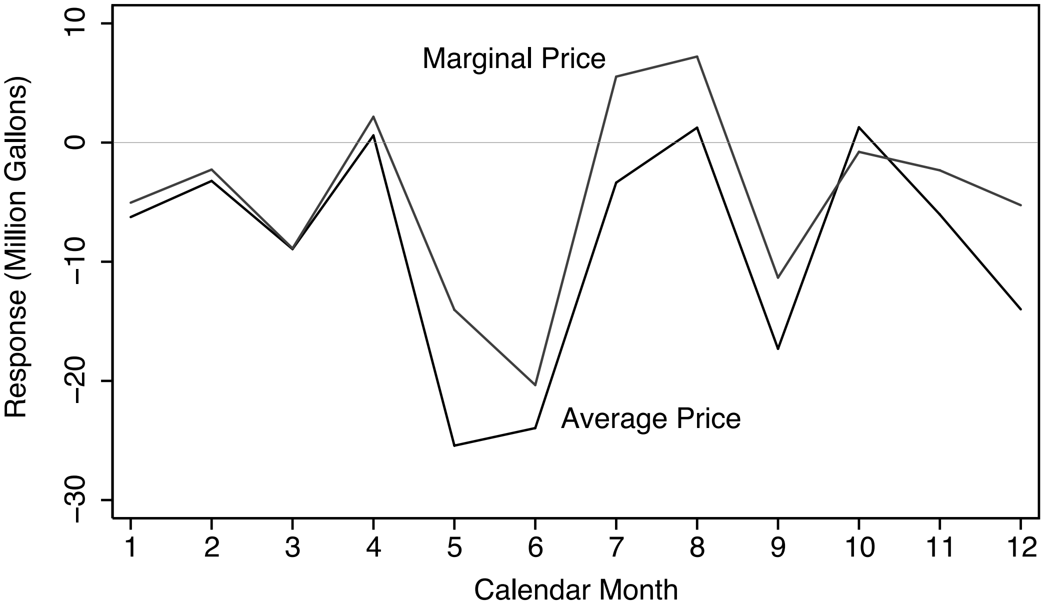

Figure 4-7. Seasonal Demand Responses to Average and Marginal Prices