WATER RESOURCES RESEARCH, VOL. 20, NO. 2, PAGES 197–202, FEBRUARY 1984

# Instrumental Price Estimates and Residential Water Demand

C. VAUGHAN JONES

*Department of Economics, University of Denver*

JOHN R. MORRIS

*Department of Economics, University of Colorado at Denver*

Instrumental estimates of two price specifications, one motivated by the consumer decision problem given full information about rates and charges and the other an average price formulation, are developed to correct for measurement error when residential water sales are made at a schedule of rates, rather than at uniform prices. Annual water purchases of single-family residences are regressed on these instrumental price estimates, family income, and household size by ordinary least squares, based on a sample of 326 observations from metropolitan Denver, Colorado, for 1976. The resulting demand estimates are robust to the price concept specified, given proportional variation in all rates and charges, and are consistent with findings in the literature. The overall price elasticity estimates range between −0.14 in a linear model to −0.44 in a log-log model, while the estimated income elasticity varies between 0.40 and 0.55.

When a commodity is sold at a schedule of rates depending on the quantity consumed, econometric analysis must consider questions not encountered for goods offered at uniform prices. What is the relevant "price" to consumers, and how is it measured?

As an approximation, studies of municipal water demand often adopt an average price formulation [*Metcalf*, 1926; *Gottlieb*, 1963; *Bain et al.*, 1966; *Young*, 1973; *Gardner*, 1977; *Male et al.*, 1979]. Another approach suggests the rate schedule impacts demand through two variables, the marginal price, or cost of an additional unit of the good, and a second variable summarizing the contribution of preceding or inframarginal rates and charges [*Agthe and Billings* 1980]; for an exposition, see *Billings and Agthe* [1980]). This inframarginal rate variable, measured as the difference between the consumer's bill and the cost of the quantity purchased valued at the marginal price, can be described as an implicit tax or subsidy associated with decreasing or increasing rate schedules. Based on an analysis of consumer choice given full information about rates, this approach is an extension of marginal price specifications [*Howe and Linaweaver*, 1967; *Hanke and Davis*, 1971; *Danielson*, 1979].

Caution must be exercised in identifying the price from observed purchases. Measurement error in the observed purchase can introduce a corresponding error in the price variable(s), resulting in correlation between an explanatory variable and the disturbance term of the regression. Ordinary least squares (OLS) estimators are neither unbiased nor consistent under these circumstances.

The measurement problem is prior to comparisons or evaluations of alternative price concepts and is addressed in this research. Based on an extensive, cross-sectional sample of microdata from metropolitan Denver, Colorado, estimates of residential water demand are developed which incorporate instrumental price variables for the average price and the variables of the two-part price specification. The sample includes 889 single-family residences randomly selected from customer lists of the 10 largest Denver area water utilities according to a representative sample design. Water use billing data for 1976 are supplemented by information from county tax assessors and responses to a mail questionnaire eliciting information from the head of the household about family size, income, and other factors.

The strategy of instrumental estimation is to identify a new variable or variables correlated with price but orthogonal to the disturbance term of the regression. Following discussion of the general demand specification in the next section, statistical models justifying the choice of price instruments are presented. Average, marginal, and inframarginal price instruments are developed as statistical relations between observed prices or purchases and exact rate information.

These instrumental price estimates and other explanatory variables are regressed on household by household water use. Specifying suitable instruments for average price or the variables of the two-part price specification recovers the consistency property of OLS estimators. The resulting demand regressions suggest comparisons between the average and two-part price specification and support findings of previous research.

Policy implications of this research are considered briefly in the summary and conclusions section. In general, the analysis suggests closer attention to the operating price hypotheses and budgeting behavior of consumers.

## DEMAND SPECIFICATION

The demand equations are OLS regressions of 1976 water use of single-family residences, $Q$, measured in 1000 gallons (3785 liters) on the following:

| | |
|---|---|
| AP | instrumental average price of water, in dollars; |
| MPRICE | instrumental summer marginal water price, in dollars; |
| INFRA | total dollar amount of instrumental estimates of the value of the summer and winter inframarginal rate variables; |
| INCOME | estimated 1976 family income, in dollars × $10^3$; |
| RESIDENTS | number or residents in the household. |

The average price specification

$$q = q(\text{AP, INCOME, RESIDENTS})$$



Paper number 3W1867.
0043-1397/84/003W-1867$05.00

TABLE 1. Income Regression

| | Estimations |
|---|---|
| ASSESS | 2.72 (8.56) |
| DATE | 0.53 (3.36) |
| EDUC | 14.68 (7.83) |
| JOB | −4.38 (4.03) |
| CARS | 24.40 (7.53) |
| Constant | −1000.68 |
| $R^2$ | 0.41 |
| $F$ statistic | 110.41 |
| Sample size | 510 |

The $t$ statistics are in parentheses.

and two-part price specification

$$Q = q(\text{MPRICE, INFRA, INCOME, RESIDENTS})$$

are expressed in linear, multiplicative or log-log, and semilog functional form.

The annual demand formulation has a number of advantages. Usable observations are maximized in annual demand regressions, a consideration since instrumental variables assure only the consistency of estimators. Billing cycles vary from 1 to 3 months by rate class. Within the 21 rate classes of the sample, meter-reading schedules vary by customer. Observations must be deleted in estimating summer or winter demand, since winter/summer billing periods can include later summer/winter water use. With missing observations in explanatory variables, annual regressions are based on 326 residences. Removing ambiguous summer and winter use data reduces the usable sample to between 100 and 200 observations.

Conceptually, price specifications corresponding to components or subperiods of annual demand present issues in some cases. For example, allocation of the inframarginal rate variable between indoor and outdoor water use in summer is problematical. Also, subperiod "average prices" require more information on the part of the consumer, converging to the exact information case represented by the two-part price specification.

Annual water demand includes the variables significant in various subperiod demands. Exploratory winter regressions and previous research show low statistical significance for the winter marginal price in these data (see *Morris and Jones* [1980] for a report on earlier research). While these findings are not conclusive, i.e., because of loss of large-sample properties or heteroscedasticity not detected by standard tests, the summer and winter marginal rates are the same in 14 rate classes of the sample. MPRICE is the summer marginal price and for most households in the sample is also the winter marginal price.

Regression estimates of the parameter associated with the inframarginal rate variable in an average summer and winter month indicate similar effects for this variable in these seasons. Accordingly, the total effect of INFRA is estimated against the seasonal values of the inframarginal rate variable summed over the year.

The income proxy is developed by regression techniques instead of specifying assessed property value or census tract income averages. The questionnaire elicited broad income ranges for 1977. Midpoints of these income ranges, measured in thousands of dollars, were deflated by the Consumer Price Index to 1976 and regressed on the following:

| | |
|---|---|
| ASSESS | assessed property value of the residence, in dollars × $10^3$; |
| DATE | construction date of the residence; |
| EDUC | coded educational level of the head of the household; |
| JOB | coded occupational level of the head of the household; |
| CARS | cars registered at the address. |

INCOME is the linear combination of the products of the estimated coefficients and corresponding explanatory variables displayed in Table 1. As in regressions presented subsequently, $t$ statistics are in parentheses below the estimated parameters, and the coefficient of determination, $F$ statistic, and sample size are listed in the lower panel. Climatic factors were approximately uniform across the sample area in 1976 and were not included in the specification.

## INSTRUMENTAL PRICE VARIABLES

Classically, two categories of error contribute to the disturbance term of OLS regressions. Equation error includes random effects of minor variables omitted from the specification. Measurement error results from deviation of desired or preferred purchases from observed purchases. With a given rate schedule a consumer can choose to buy $q^*$ but be unable to do so, for example, because of low water system pressure. The observed purchase, denoted here by $q$, can differ from $q^*$ because of water meters of varying efficiency or clerical mistakes.

Consider the problem of identifying the marginal price when the desired purchase is related to the observed purchase and an associated error term, or $q = q^* + e$. Figure 1 illustrates a rate schedule with an initial commodity charge $p_{10}$ for purchases less than or equal to $\delta$ and a second rate $p_{11}$ for purchases in excess of $\delta$. The density function of the measurement error is $f(e)$. The observed purchase $q$ is shown in the second block, suggesting that $p_{11}$ is the marginal price. When $e < \delta - q$, an error of size $p_{11} - p_{10}$ is associated with identifying $p_{11}$ as the marginal price. Similarly, if the observed purchase is in the initial block with sufficiently large, positive $e$, an error of size $p_{10} - p_{11}$ is associated with identifying the marginal price as $p_{10}$. Consequently, errors in measuring the marginal price are correlat-

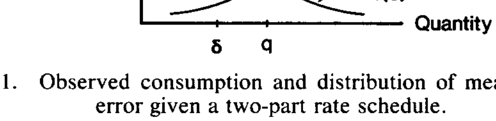


Fig. 1. Observed consumption and distribution of measurement error given a two-part rate schedule.

ed with the disturbance term of the demand regression. A parallel analysis applies for the inframarginal rate variable, which is either zero or $(p_{10} - p_{11})\delta$ in this example, depending on the marginal price.

Consumers may simplify the decision problem, representing the conditions of sale of the commodity by an average price based on customary levels of service. If the two-part price specification is the exact information case, average price specifications seem motivated by typical consumer uncertainty about rates and quantities of water use by household production processes.

Measuring the average price as the unit cost of water the consumer buys, significant econometric problems arise with respect to the specification. The observed average price of $q$ in Figure 1 is

$$\{p_{11}\,[(q^* + e) - \delta] + p_{10}\delta\}/(q^* + e)$$

The presence of the error term in this expression guarantees correlation with the disturbance term of the demand regression. In addition, simultaneity is introduced as the independent variable occurs on both sides of the regression equation.

The correlation procedures for the average and two-part price formulations are based on related statistical models. In general, we have

$$q_i^* = p_i^* A + x_i B \qquad (1)$$

$$q_i = q_i^* + e_i \qquad (2)$$

and either

$$p_i^* = f(q_i^*, R_i) \qquad (3a)$$

or

$$p_i^* = R_i S + w_i \qquad (3b)$$

where $i$ is an index of observations over the sample and, implicitly, $p_i = p_i^* + v_i$.

Equations (1), (2), and (3$a$) or (3$b$) are the structural form of the consumer demand model. Equation (1) relates the desired purchase to the effective (unobserved) price vector $p_i^*$ and a vector of observed exogenous variables $x_i$. Given that multiplication is the dot product, $A$ and $B$ are vectors of parameters to be estimated. The second equation states the desired or preferred purchase is measured with error $e_i$. The third equation pertains to the price instrument. Equation (3$a$) states the relation between quantity and the rate schedule and figures in the instrumental estimation of the two-part price specification. Here, $R_i$ is a vector of exact rate information. Equation (3$b$) applies to the average price instrument and states that the average price in consumer decisions is related to features of the exact rate schedule. Here, implicitly, the observed average price is related to the average price in consumer decisions and an error term $v_i$. $S$ is a vector of parameters to be estimated. The disturbance terms $w_i$, $v_i$, and $e_i$ are assumed to be Gaussian with zero mean and constant variance.

The instrument developed for the two-part price specification involves an averaging procedure familiar in the literature. Average summer and winter water use are computed for each rate class of the sample. A summer or winter marginal price is associated with an estimate $\hat{q}_i$ of typical water use in that season through the rate schedule relation (3$a$). The instrumental estimate of the inframarginal rate variable is the sum of bills for these $\hat{q}_i$ in summer and winter net of the cost of purchasing these amounts valued at the respective marginal prices, including relevant sewer charges.

The consistency of parameter estimates follows if

$$0 = \text{plim}\,[(1/N)\,\Sigma_i\, e_i\,\hat{p}_i] = \text{plim}\,[(1/N)\,\Sigma_i\, e_i\, f(\hat{q}_i, R_i)]$$
$$+ \text{plim}\,\{(1/N)\,\Sigma_i\,[e_i\, f(\hat{q}_i, R_i) - \text{plim}\, f(\hat{q}_i, R_i)]\} \qquad (4)$$

[following *McFadden* et al., 1977]. With similar residences in a rate class, as in surburban subdivisions, averaging observed water use produces more accurate estimates of price than a single observation. Rigorously, plim $\hat{q}_i = q_i^*$ with identical households in a rate class. Relation (4) then holds, since the first limit in the expansion is zero by Kolmogorov's strong law of large numbers.

The rationale for the average price instrument is stated by *Taylor*, [1975, p. 79], who notes that relating the (observed) average price to the "actual tariff schedule" resolves "problems of simultaneity and identification," since "in the short run . . . the tariff schedule is independent of demand". The instrumental estimate developed below is equivalent to a two-stage least squares procedure.

The average price instrument is developed from regressions such as

$$\text{APOBS} = s_0 + \sum_{j=1}^{5} s_j r_j + w_i \qquad (5)$$

where

APOBS the observed 1976 average price of water to a household, in dollars;

$r_1$ annual lump sum charge for any level of water service, including fixed sewer charges, in dollars;

$r_2$ the initial, nonzero commodity charge including differential sewer charges, in dollars;

$r_3$, $r_4$, $r_5$ the difference between rates in subsequent and adjacent blocks, including differential sewer charges, in dollars.

In a simple model,

$$q_1 = a_0 + a_1 p_1^* + e_i \qquad (6)$$

$$p_i = p_i^* + v_i \qquad (7)$$

$$p_i^* = s_0 + s_1 r_1 + w_i \qquad (8)$$

the instrumental regression produces a consistent estimator for $a_1$:

$$\text{cov}\,(q_i, p_i^*)/\,\text{cov}\,(p_i^*, r_1)$$

since sample covariances are consistent estimators of the respective population covariances. The multivariate instrument case produces an analogous solution [see *Judge et al.*, 1980, p. 531–533].

To arrive at a consistent basis of comparison, rate schedules were converted to monthly equivalents by dividing the block intervals by the number of months in the billing cycle. A variety of rate forms were represented in the sample, including increasing, uniform, and the standard decreasing schedules. Most had an initial amount of consumption covered only by a fixed fee and two subsequent rate steps, although as many as four subsequent rate steps applied to

TABLE 2. Average Price Instrument

| | Estimations |
|---|---|
| $r_1$ | −0.002 |
| | (3.08) |
| $r_2$ | 0.575 |
| | (5.65) |
| $r_3$ | 1.511 |
| | (13.12) |
| $r_4$ | 0.360 |
| | (1.08) |
| $r_5$ | 2.610 |
| | (0.59) |
| Constant | −0.116 |
| $R^2$ | 0.29 |
| $F$ statistic | 64.59 |
| Sample size | 804 |

residential customers in some districts. Some of the step variables, in rate schedules without third or fourth distinguishable rate steps, are zero. The rate blocks divided by the months in the billing cycle are approximately equal or can be set equal by construction.

Exogenous variables related to water use were not specified in the average price instrument because increasing as well as declining rate schedules are represented in the sample. Irrigable lot area, for example, is negatively correlated with average price given a declining rate schedule and positively correlated with average price when the commodity charges increase with the quantity of water use.

Table 2 displays the result of regressions of the logarithm of average (observed) price on exact rate information. This semilog model is the equation of best fit.

## RESULTS

Table 3 presents the demand regressions, estimated in three functional forms, by price specification. Here the semilog models are regressions of annual household water use on the logarithms of the explanatory variables. Elasticities associated with explanatory variables are listed by regression in Table 4. These findings support other statistical studies of residential water demand, adopting the two-part price specification, as well as the general literature, and illustrate features that are robust to the price concept specified. Key observations relate to the estimated effect of INFRA and comparisons between the price specifications.

Note the coefficients estimated for INFRA, measured in dollars, and INCOME, measured in thousands of dollars, differ by at most one order of magnitude. The income elasticity estimates are centrally located in the range observed in previous studies, generally from 0.2 to 0.6 (see, for example, *Danielson* [1979] for the evidence on elasticities). While discussed as a component of the "two-part price specification," INFRA is essentially an income variable representing subtractions from or additions to consumer income resulting from changes in rates and fixed charges. The estimated effects of these variables in the regressions in Table 3 imply that $5 increase in lump sum water fees impacts household water use in about the same way as a $500 decrease in consumer income.

Comparable results reported by other demand studies are the focus of critical discussion and analysis of the consumer's decision problem, given a multiple-part tariff or rate schedule. In the *Billings and Agthe* [1980] analysis, the inframarginal rate variable, called "difference" by the authors, is two orders of magnitude larger in its estimated effect than consumer income in linear and multiplicative time series models on Tuscon, Arizona, data. Analogous results for the two-part price specification are reported in Fisher-Kaysen, Koyck, flow adjustment, and stock adjustment dynamic demand models in linear and multiplicative functional form [*Agthe and Billings*, 1980]. These Tuscon regressions are criticized on the basis that the predominantly increasing rate schedules of the sample result in overestimates of the inframarginal rate parameter because of measurement error [*Griffin and Martin*, 1981]. Yet, in reanalysis of the Johns Hopkins Residential Water Use data, *Howe* [1982] estimates an inframarginal rate effect about 35 times that of income. The predominant rate schedule in the Johns Hopkins data, gathered during a controlled statistical experiment in the 1960's, is the declining block.

The contention of this research is that not only are a variety of rate schedules included in the sample, but steps are taken to reduce or eliminate the influence of systematic measurement error on the estimation. In this regard, a

TABLE 3. Demand Regressions with Alternative Price Specifications

| | Full Information Price Specification | | | Average Price Specification | | |
|---|---|---|---|---|---|---|
| Functional Form | Linear | Multiplicative | Semilog | Linear | Multiplicative | Semilog |
| AP | | | | −24.61 | −0.34 | −48.49 |
| | | | | (2.00) | (3.05) | (2.79) |
| MPRICE | −18.96 | −0.21 | −29.22 | | | |
| | (0.94) | (2.04) | (1.91) | | | |
| INFRA | −0.23 | −0.23 | −39.18 | | | |
| | (1.72) | (2.75) | (3.15) | | | |
| INCOME | 3.71 | 0.40 | 65.93 | 3.72 | 0.46 | 73.09 |
| | (7.69) | (3.76) | (4.24) | (7.96) | (2.02) | (6.88) |
| RESIDENTS | 7.52 | 0.14 | 15.30 | 7.67 | 0.17 | 23.69 |
| | (3.32) | (1.94) | (1.43) | (3.30) | (3.44) | (3.21) |
| Constant | 73.86 | 4.42 | 210.68 | 80.66 | 3.46 | −83.04 |
| $R^2$ | 0.26 | 0.25 | 0.28 | 0.26 | 0.23 | 0.23 |
| $F$ statistic | 26.95 | 11.57 | 13.16 | 37.03 | 32.09 | 32.08 |
| Sample size | 326 | 326 | 326 | 326 | 326 | 326 |

TABLE 4. Demand Elasticities of Explanatory Variables

| Functional Form | Full Information Price Specification | | | Average Price Specification | | |
|---|---|---|---|---|---|---|
| | Linear | Multi-plicative | Semilog | Linear | Multi-plicative | Semilog |
| AP | | | | −0.18 | −0.34 | −0.29 |
| MPRICE | −0.07 | −0.21 | −0.18 | | | |
| INFRA | −0.07 | −0.23 | −0.24 | | | |
| INCOME | 0.55 | 0.40 | 0.40 | 0.55 | 0.46 | 0.43 |
| RESIDENTS | 0.15 | 0.14 | 0.09 | 0.15 | 0.17 | 0.14 |

second instrumental procedure for developing the marginal price and inframarginal rate variable was explored. Although providing weaker results, this procedure accounts for differences among residences in a rate class and supports the above findings with respect to the relative magnitudes of the INCOME and INFRA parameters. Observed purchases by household in summer and winter were regressed on exact rate information, family size, family income, and other exogenous variables. This estimated relation was used to predict or identify the effective marginal price and inframarginal rate variable, which, in turn, were specified in equations such as those of the two-part price specification in Table 3. The estimated coefficient of INFRA in an annual regression in linear form is −0.13 with a standard error of 0.05, while the INCOME coefficient is 2.4 and statistically significant at a 5% level, given a two-tailed test.

Multiplicative and semilog functions perform better with respect to the price variables than linear specifications and are consistent with findings of other demand studies employing the two-part price specification. *Billings and Agthe* [1980] estimate a marginal price elasticity of −0.267 and an inframarginal rate or difference elasticity of −0.123 in a static, multiplicative model. The inframarginal rate parameter in their estimate is significant at the 10% level. *Howe* [1982] finds that estimates of the marginal price elasticity are reduced by the augmented specification. When the inframarginal rate variable in a linear demand specification is included, the summer marginal price elasticity in western areas of the United States is estimated to be −0.427. Since MPRICE is the summer marginal price, an approximate conversion between annual and summer marginal price elasticities can be made by multiplying the MPRICE elasticities of Table 4 by 1.67, given that about 60% of annual water use occurs in the summer irrigation season.

Taking the associated confidence intervals into account, the price specifications predict similar consumer responses to a proportional change in all rates and charges. The joint 95% confidence interval around MPRICE and INFRA includes that of AP in regressions of corresponding functional form. Note certain regularity conditions must be assumed in this prediction. Increasing the summer marginal price sufficiently, for example, could induce some consumers to purchase amounts in a lower rate block, thus changing the value of both MPRICE and INFRA, vitiating the prediction. Accordingly, the regression equations predict the consumer response only for limited price variations.

The demand elasticity of RESIDENTS is lower than estimated previously. *Morgan* [1973] found the "people elasticity" to range from 0.25 to 0.57 in linear and logarithmic specifications. Other estimates range as high as 0.6 [*Grima* 1972] or 0.74 [*Danielson*, 1979].

The overall explanatory power of the regressions is typical for OLS estimates on cross-sectional microdata including social and behavioral variables. The $F$ statistic indicates the variables of the average price specification are somewhat more strongly related to the dependent variable than those of the two-part price specification, although both are significant at a 1% level or higher.

## SUMMARY AND CONCLUSIONS

Statistical models of instrumental procedures designed to correct for systematic measurement error are presented for two price concepts, one based on an analysis of the consumer decision problem, given full information about rates, and the average price hypothesis. Instrumental estimates of the marginal price and associated inframarginal rate variable are developed from average water use by rate class during summer and winter. The average price instrument is developed by regressing the observed average price on exact rate information. These instrumental price estimates, household income, and family size are regressed on annual water use data from single-family residences in the Denver metropolitan area for 1976.

Apart from similarities between the elasticities estimated for the explanatory variables and the results of previous studies, two findings stand out in this research. First, the effect of inframarginal rates and fixed charges on residential demand is disproportionately large when viewed from the perspective of the consumer decision problem given full information about rates. Second, this inframarginal rate effect is largely responsible for a type of consistency between the two-part and average price demand specifications. The predicted variation in water use following a proportional change in all rates and fixed charges is similar in both the average and two-part price specifications when allowance is made for confidence intervals associated with the point estimates of the price parameters.

These results are encouraging in view of the requirements of alternative estimation techniques which take into account systematic measurement error. Maximum likelihood methods applied to estimating labor supply response to nonlinear pay schedules assume a given functional form of consumer preferences [*Burtless and Hausman*, 1978]. *Terza and Welch* [1982] discuss application of probit analysis, a method of producing consistent estimates of regression parameters only for electricity or water sales subject to inverted or increasing block rates. Instrumental estimation of price produces results not fundamentally different from simpler OLS approaches to demand estimation. In particular, average price procedures seem suitable for development within an applied context where data deficiencies rule out more exact demand specifications.

Finally, the analysis suggests attention to the actual steps involved in consumer budgeting for water. In adopting an average price hypothesis, consumers may "overestimate" the price of commodities sold at a schedule of rates and, rather than reducing use, can increase consumption with better information about cost conditions [see *Battalio et al.*, 1979]. At the same time, large differences in metered versus unmetered water use [*Howe and Linaweaver*, 1967] suggest limitations to the average price hypothesis. Further research into these issues is supported by the policy significance of price in forecasting demand and in assessing the costs and benefits of utility expansion programs and conservation policies.

## REFERENCES


Agthe, D. E., and R. B. Billings, Dynamic models of residential water demand, *Water Resour. Res.*, *16*(13), 476–480, 1980.

Bain, J., R. Caves, and R. Margolis, *Northern California's Water Industry*, John Hopkins University Press, Baltimore, Md., 1966.

Battalio, R. C., J. H. Kagel, R. C. Winkler, and R. A. Winett, Residential electricity demand: An experimental study, *Rev. Econ. Stat.*, *61*(2), 180–189, 1979.

Billings, R. B. and D. E. Agthe, Price elasticities for water: A case of increasing block rates, *Land Econ.*, *56*(1), 73–84, 1980.

Burtless, G., and J. A. Hausman, The effect of taxation on labor supply: Evaluating the Gary negative income tax experiment, *J. Polit. Econ.*, *86*(6), 1103–1130, 1978.

Danielson, L. E., An analysis of residential demand for water using micro time-series data, *Water Resour. Res.*, *15*(4), 763–767, 1979.

Gardner, R. L., An analysis of residential water demand and water rates in Minnesota, *Water Resour. Res. Bull. 96*, Water Resour. Res. Center, Univ. of Minne. Graduate School, Minneapolis, 1977.

Gottlieb, M., Urban domestic demand for water: A Kansas case study, *Land Econ.*, *39*(2), 204–210, 1963.

Griffin, A. H., and W. E. Martin, Price elasticities for water—A case of increasing block rates: Comment, *Land Econ.*, *57*(2), 266–275, 1981.

Grima, A. P., *Residential Water Demand: Alternative Choices for Management*, University of Toronto Press, Toronto, Canada, 1972.

Hanke, S. H., and R. K. Davis, Demand management through responsive pricing, *J. Am. Water Works Assoc.*, *63*(9), 555–560, 1971.

Howe, C. W., The impact of price on residential water demand: Some new insights, *Water Resour. Res.*, *18*(4), 713–716, 1982.

Howe, C. W., and F. P. Linaweaver, Jr., The impact of price on residential water demand and its relation to system design and price structure, *Water Resour. Res.*, *3*(1), 13–32, 1967.

Judge, G. G., W. E. Griffiths, R. C. Hill, and T.-C. Lee, *The Theory and Practice of Econometrics*, John Wiley, New York, 1980.

Male, J. W., C. W. Willins, F. J. Babin, and C. J. Shillito, An analysis of the water rate structure as a management option for water conservation, *Publ. 112*, Water Resour. Res. Center, Univ. of Mass. at Amherst, December 1979.

McFadden, D., C. Puig, and D. Kirshner, Determinants of the long-run demand for electricity, *Proc. Am. Stat. Assoc.*, 109–117, 1977.

Metcalf, L., Effect of water rates and growth in population upon per capita consumption, *J. Am. Water Works Assoc.*, *15*(1), 1–22, 1926.

Morgan, W. D., Residential water demand: The case from micro-data, *Water Resour. Res.*, *9*(4), 1065–1067, 1973.

Morris, J. R., and C. V. Jones, Water for Denver: An analysis of the alternatives, report, Environ. Defense Fund, Denver, Colo., 1980.

Taylor, L. D., The demand for electricity: A survey, *Bell J. Econ.*, *6*(1), 74–110, 1975.

Terza, J., H., and W. P. Welch, Estimating demand under block rates: Electricity and water, *Land Econ.*, *58*(2), 181–188, 1982.

Young, R. A., Price elasticity of demand for municipal water: Case study of Tucson, Arizona, *Water Resour. Res.*, *9*(4), 1068–1072, 1973.



C. V. Jones, Applied Economic Research Group, University of Colorado at Denver, 1100 14th Street, Denver, CO 80202.

J. R. Morris, Department of Economics, University of Colorado at Denver, 1100 14th Street, Denver, CO 80202.



(Received August 30, 1982;
revised November 1, 1983;
accepted November 22, 1983.)