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ABSTRACT

Demand for rural water service is estimated using micro-level data from a sample of Illinois rural water district customers. An instrumental-variables approach is applied to correct for simultaniety bias resulting from block pricing practices using marginal price and Nordin's difference variable to account for lump-sum income effects implicit in discrete pricing structures. Price and income elasticities were -.36 and .19, respectively for the instrument model.

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In response to the need to avoid costly policy errors, econometric studies of water service demand have become more common in recent years. Some articles have been concerned, in part, with the correct method of specifing price in demand functions for water sold under block pricing schedules since Nordin demonstrated that utility maximizing consumers with perfect information are expected to respond to marginal price along with a lump-sum income effect associated with intramarginal prices and price schedule breakpoints (e.g. Foster and Beattie 1981b; Griffin, Martin and Wade; Billings; Opaluch; and Charney and Woodard). The issue focuses on whether or not consumers are aware of the block pricing structure and hence respond to marginal price and lump-sum income change or are aware only of total spending and total consumption and hence respond to average water price (also see Polzin).

The proper model of consumer behavior is an empirical question that must be addressed in each individual case. Studies of water service demand for urban areas, while limited, are much more common than analyses of the demand for water services expressed by farmers and other rural residents served by rural water districts (e.g. Andrews and Gibbs; Hanke and de Mare; Howe, and Jones and Morris). Two exceptions are the study of Oklahoma rural water demand by Doeksen, Goodwin and Oehrtman and Illinois rural water demand by Chicoine and Ramamurthy. Early studies of the demand for residential water service were handicapped by the lack of micro-level data (e.g. Foster and Beattie 1979; Billings and Agthe). There is some evidence that theoretically inconsistant empirical demand estimates may be associated with the use of aggregate data (Schefter and David). The ideal data for demand estimation is micro-data on a cross section of consumers who face different block pricing schedules (Opaluch).

An issue in the empirical study of water service demand that is not unanimously recognized, nor is there widespread agreement of its importance, is the potential for simultaneity bias with ordinary least squares (OLS) parameter estimates. This potential has been recognized by some authors but few empirical studies evaluate the implications of the simultaniety issue and no studies of rural water demand recognize this as a potential problem (e.g. Howe and Linaweaver; Terza and Welch; Opaluch). This paper presents a comparison of demand parameters from OLS estimates after instrumental variables correction for price endogeneity bias. The data used in the estimates are observations on rural water district customers.

The following section reviews 1) the specification and estimation of rural water service demand under declining block rate pricing schemes, and 2) the basis for the simultaniety issue. Next the data and model specifications are briefly discussed. The empirical results are then presented, followed by a concluding summary section.

Demand Specification Under Block Rates

Incorporating Nordin's lump-sum income effect, the linear demand function for potable water is of the form:

$$Q = B_0 + B_1 P_x + B_2 MP + B_3 D + B_4 Y. \qquad (1)$$

Here Q is the units of water purchased, P_x represents a price index for other relavent goods, MP the marginal price of water in the block of consumption, D the lump-sum income effect (demonstrated by Nordin to be the difference between total expenditure on water less what the water bill would have been if MP prevailed in all pricing blocks, i.e. $D = (P_1 - P_2)\, Q_1$ for a two block rate structure) and Y total consumer income. For decreasing block rates, the income effect is the amount of consumer surplus captured by the seller because of the block pricing scheme and will be positive in value. Under a multiple block pricing structure, the monthly bill (B) of a consumer can be expressed as:

$$B = \begin{cases} SC + MP_1 Q = B & \text{if } 0 < Q < BP_1 \\ SC + (MP_1 - MP_2)BP_1 + MP_2 Q = B_2 & \text{if } BP_1 < Q > BP_2 \\ \quad \vdots & \\ SC + \sum_{i=1}^{n-1} (MP_i - MP_{i+1})BP_i + MP_n Q = B_n & \text{if } BP_{n-1} < Q \end{cases}$$

where SC is a fixed monthly service charge, ($MP_1, \ldots, MP_n$) are marginal prices, ($BP_1, \ldots, BP_{n-1}$) are the breakpoints of the block rate schedule, and B_i is monthly spending by a consumer on water consumption in block i. With declining blocks $MP_i < MP_{i-1}$ for all i. Commonly, customers are given the right to consume a specific amount of water for the SC without incurring any additional charges. First block BP's frequently range from 1,000 to 4,000 gallons per month.

Under declining block rates, the difference between B and what would occur under uniform marginal pricing is the tariff borne by the consumer or the loss in consumer surplus for the privilege of purchasing water in the ith block at MP_i. For increasing block rates, the difference between B and expenditures if all water consumed were bought at MP represents a savings to the consumer. Implicit is a subsidy for water consumed in the intramarginal blocks. Accordingly, the value of D will be negative with increasing block pricing structures and positive with declining block rate pricing schedules. Thus, the sign of the coefficient on D in empirical demand estimates is expected to be negative for declining block rates and increasing block rate prices, a priori (Nordin). With both types of block pricing schemes the absolute value of the estimated parameter on D should equal the coefficient on consumer income (Y)(Howe).

The simultaneity problem in estimating the demand for water services and other block priced goods arises because the price paid by a customer is determined, from the institutional structure of pricing schemes, by the quantity of water bought by the customer. Henson presents a formal statement of the resulting correlation between the explanatory variables in block rate price demand functions and the error term, which violates the classical assumptions for applying OLS (Judge, et al.). With block rate pricing structures, causality goes from price to quantity and from quantity to price. Consumer's choose the amount of water bought depending on some measure of price faced, and the price paid depends on the amount of water consumed. OLS estimates of coefficients also may be biased and inconsistent because of the price variables ex post calculation from observed consumption levels and the rate schedule if consumption is measured with error. Measurement error will lead to the assignment of the wrong marginal price.

Under declining block rate schedules, the price coefficient may be biased away from zero and the coefficient on D may be biased toward zero (Henson).

There is neither unanimous recognition of these potential problems nor any consensus on their importance in the study of demand for water and other good priced using the administrative rate schedules. For example, Taylor (p. 79) suggests that problems of simultaneity are resolved because in the short run individual consumer demand is independent of the price schedule. Foster and Beatie (1981a) expanded on this notion pointing out the difference between consumer's perception of block rate schemes and the block rate schedules as institutionally determined. Howe and Linaweaver statistically rejected the notion that observed price-quantity relationships for potable water were merely a reflection of administered pricing systems in their pioneering 1967 empirical demand analysis. Jones and Morris found simpler OLS approaches not fundamentally different from instrumental estimation of price in studying Denver area urban water demand. However, Henson found evidence of simultaniety bias in the OLS estimates of the demand coefficients for electricity sold under block rate pricing schemes.

Instrumental Variables Procedure. Consistent coefficient estimates may be obtained by an instrumental variables procedure. One approach to developing appropriate instrumental variables that is attractive because of it's simplicity has been employed by Hewlett, and more recently Taylor, Blattenberger and Rennhack, in the analysis of electricity demand and by Billings in a study of demand for water. The instruments for both marginal price (MP) and Nordin's difference variable (D) are derived from the definition, for the ith consuming household, of D:

$$D_i = B_i - MP_i * Q_i \qquad (2)$$

where all arguments are as previously defined. With observations on both B and Q, estimates of MP and D can be derived by rearranging (2) and applying OLS across rate schedules to:

$$B_{ij} = a_j + b_j * Q_{ij} + e_{ij} \qquad (3)$$

where i equals observations on each consumer under pricing structure j. Here the estimate on a_j represents D for jth rate structure and the estimate on b_j is MP for the "average" consumer subject to the jth pricing schedule.

Since both MP and D are limited to one value for every consumer under a particular rate structure, the inference is that all consumers subject to the same pricing schedule are consuming in the same block. In other words, all consumers under the jth schedule face the same marginal price and hence, possess the same difference variable. If this were indeed the case, the adjusted R^2 from the estimations of (3) for each schedule should approach one. Substitution of these estimated values for MP and D into demand equation (1) frees the model of any asymptotic covariance between these two explanatory variables and the error term. Also, problems arising from errors in the measurement of Q are driven to zero because the marginal price instrument does not vary with quantity, eliminating the possibility of assigning a "wrong" marginal price ex post from the rate schedule.

Any simultaniety resulting from quantity dependent prices is eliminated by the use of a marginal price that is constant for all consumers subject to the same price schedule. If the instrumental marginal price (MPI) is variant only over rate schedules and not over quantities consumed, no feedback of quantity on price can occur. In essence, the multi-price block rate scheme is condensed to a "one-price" schedule. The exogeneity of MP and D can be tested using a procedure due to Hausman. Under the null hypothesis of no correlation between explanatory variables and the error term, the difference between the OLS estimators using MP, and D, and MPI and the D instrument (DI) are asymptotically chi-square distributed with degrees of freedom equal to the number of possibly endogenous variables.

Data and Demand Estimates

The data to estimate the demand for rural water services and examine the simultaniety issue are from a survey of stratified, randomly sampled, Illinois rural water district users. The sample was drawn from the universe of rural water district customers where the water system was assisted financially by the Farmers Home Administration (FmHA), USDA and served no municipality or incorporated area. The sample of 100 users came from nine of the 59 FmHA financed Illinois rural water districts that were not associated with an incorporated community. Actual monthly consumption and expenditure records from district files for 1982 were matched with the survey data and MPs were obtained ex post from district rate schedules (see Chicoine, Grossman and Quinn). Missing observations, measurement problems and including only observations where consumption is beyond BP_1 reduced the sample size to 641 monthly observations over 54 customers.

The demand for rural water was estimated using a cross-sectional model. Previous analyses showed no seasonality in consumption so the monthly observations are treated as one sample (Chicoine and Ramamurthy). The empirical demand for rural potable water estimated with the Illinois rural water district household data is:

$$Q_{id} = B_0 + \sum_{d=1}^{8} B_{1d}S_d + B_2MP_i + B_3D_i + B_4INC_i + B_5NUM_i + B_6BTH_i + e_i \qquad (4)$$

where Q_{id} is monthly water consumption in household i under rate structure d, S_d is a rate structure binary variable where d = 1,..., 8, MP_i is the marginal price in the block of consumption for the ith household, D_i equals the difference between household i's water bill and MP_i times Q_{id}, INC_i is the monthly income of household i, NUM_i is household i's size measured by number of persons, BTH_i is the number of bathrooms in household i and e_i is the error term. Using OLS, the demand for rural water was estimated with those observations beyond the first block where MP_i 0. In the first block households can consume up to BP_1 quantity of water with the payment of the minimum charge (SC). Previous research has shown household size and household technology to be important positive demand shifters and are expected to be positively related to water consumption (Hanke and de Mare; Doeksen, Goodwin and Oehrtman; and Batchelor). Cross price elasticities are assumed zero in the short run. The inclusion of the rate structure binary variables (S_d) is to test for behavioral differences associated with the configuration of the pricing schedule. One district was omitted from the estimations and used as the reference pricing scheme. Of the nine districts serving the sample users, five had BP_1s of 1,000 gallons. The others had BP_1s equal to 2,000. All had declining block rate shedules. MPs (per 1,000 gallons) in second blocks ranged from \$1.50 to \$10.00; third block MPs ranged from \$1.25 to \$5.00. The number of blocks varied between two and five.

<u>Demand Estimates</u>. The empirical estimates of rural potable water demand are presented in Table 1. Models B and D use MPI and DI for the marginal price and the difference variables. Estimates of (3), to obtain the instruments, for the nine rate schedules have adjusted R s above .95 in six cases and only one below .80. This indicates that the estimated marginal price (MPI), as well as the difference variable, approach the "true" values, as previously discussed. When the model was estimated using

Table 1. Rural Water Demand Estimates[a]

Variable	Model A	Model B	Model C	Model D
MP	-.7399 (9.49)*	-	-.5794 (12.98)*	-
D	.1849 (8.80)*	-	.0286 (1.19)	-
MPI	-	-.4738 (7.38)*	-	-.5529 (9.33)*
DI	-	.0402 (.83)	-	-.0164 (.27)
INC	.0006 (6.81)*	.0006 (7.19)*	.0005 (4.43)*	.0006 (.27)
NUM	.2692 (7.85)*	.3392 (9.90)*	.6205 (9.39)*	.7505 (11.11)*
BTH	1.3665 (11.09)*	1.3637 (10.41)*	1.068 (7.66)*	1.279 (8.58)*
S1, 1=district 1 0=otherwise	2.3476 (5.69)*	.1233 (.28)	-	-
S2, 1=district 2 0=otherwise	1.6559 (5.96)*	.0947 (.29)	-	-
S3, 1=district 3 0=otherwise	1.8152 (6.25)*	.2034 (.33)	-	-
S4, 1=district 4 0=otherwise	1.7942 (5.55)*	-1.7080 (2.93)*	-	-
S5, 1=district 5 0=otherwise	2.4554 (8.38)*	1.2249 (3.21)*	-	-
S6, 1=district 6 0=otherwise	1.7782 (6.58)*	-1.4569 (1.23)	-	-
Constant	5.050 (1.48)	1.8957 (4.02)*	2.4743 (5.57)*	1.5710 (2.60)*
Adjusted R	.41	.38	.40	.35
F	55.01	47.95	89.42*	70.05*
SSE	4872	5141	3681	4043

a. Dependent variable is the quantity of water purchased per month in thousands of gallons. The absolute value of t statistics are in parenthesis. SSE = sum of squared error.

* Significant at the .05 level.

the price and difference instruments with the rate binary variables, (S_d), the design matrix was singular so the inverse did not exist. This occured because the instruments do not vary within rate schedules causing a perfect linear relationship between the instruments and the binary variables. To stabilize the design matrix, S_8 and S_7 were eliminated by trail and error with the results reported in Model B. To be consistent, only $S_1, \ldots, S_6$ are included in the estimate of Model A.

As suggested by Judge et al., an F-test is used to test for the significance of the structural variation in the rate schemes on water consumption. For Models A and C, the critical value of the F-ratio allowed for the rejection of the null hypothesis that there is no impact from structural variation in pricing schemes indicating the rate structure dummies need to be included in the specification of water demand. This was not the case for the instrument variable models. The calculated F-ratios between Models A and C, and B and D are 1.41 and .67 respectively. Because of multicollinearity problems, the estimated parameters in Model B are likely not reliable. As indicated previously, the correlation between the instruments for MP and D and the rate structure dummies is quite strong. Model D includes the instruments and excludes the rate dummies.

The signs on the coefficients of household income, household size and number of bathrooms are as expected and significantly different from zero. These coefficients are also reasonably stable across the alternate model specifications. An increase in income of $100 per month would result in monthly water use increasing 60 gallons, on average. The income elasticity of .19 is comparable to elasticities reported in the literature. The coefficient on household size suggests each additional person adds from 300 to 700 gallons to monthly water consumption. This is similar to the impact of household size on rural water consumption reported by Doekson, Goodwin and Oehrtman for Oklahoma. For an additional bathroom, water use increases up to 1,300 gallons per month, on average. The adjusted R s range between .41 and .35.

The coefficients on MP are negative and significant in all estimates. Casual comparison of the coefficients on price in Model C and Model D suggests the price coefficient in Model C is bias away from zero, as expected. The price elasticities for these two respective estimates are -.406 and -.357. These compare reasonably well with previous research (e.g.

Doeksen, Goodwin and Oehrtman). The coefficient on the difference variable has the opposite sign than expected and is statistically different than the coefficient on household income (F-ratio = 57.90)(Model C). The simple correlation between water consumption and the difference variable is .23. In general, higher values on D are associated with more household income for the sample of Illinois rural water district users. The expected direction of the bias for the coefficient on D, because of simultaniety problems, is toward zero. For the instrument model (Model D), the sign on D1 is consistent with theoretical expectations, but is not statistically significant, and is not equal in absolute magnitude to the coefficient on income at the .05 level. The coefficient on D1 is larger than that of income.

Other studies of domestic water demand have also reported theoretically inconsistent results with coefficients on the difference variable generally reported as substantially larger than coefficients on income (Howe; Billings and Agthe; Jones and Morris). Howe argues that because of the surrogate nature of this variable and its ex post construction, there is no reason to expect empirical outcomes to be theoretically consistent. Henson points out that the income effect associated with block rate pricing should not be expected to conform with theoretical expectations since it is a trival fraction of monthly income. These results support Foster and Beattie's (1981a) arguments challenging the appropriateness of the Nordin demand model for empirical analysis of goods sold under discrete pricing structures. Their argument is based on the lack of information held by consumers on the complicated block rate pricing schedules for water.

Procedures identified by Hausman can be used to test the hypothesis that there is no simultaniety problems with OLS estimates of water demand and that the price variables are not endogenous because of the institutional pricing structure. The test is implemented by comparing a weighted change in the parameters, for the whole model, between the OLS estimates of the model (4) estimated with and without the instrument variables for marginal price and the difference variable. The test was conducted for Model C and Model D. The critical value at the 95 percent confidence level is 5.9914. The calculated value of 215.37 suggests rejection of the null hypothesis of no correlation between explanatory variables and the error term. This indicates that the OLS estimates are not consistent and that a simultaniety problem exists in the Illinois rural water district household data.

This finding is not consistent with the conclusion drawn by Howe and Linaweaver in their 1967 study and with Taylor's contention that in the short run consumer's behavior is independent of block rate price schedules. However, casual observation of Models C and D support Henson's observation that OLS estimates of demand using price variables measured ex post from rate schedules are reasonably close to estimates using instrument marginal price and difference variables. Jones and Morris made a similar observation in comparing OLS demand estimates of potable water for the Denver area. They conclude that for their household level data, instrumental estimation of price produced results not fundamentally different from simpler OLS approaches.

While the Hausman test identified a statistical difference between Model C and D regarding price endogeniety, the more theoretically consistent coefficient on the difference variable makes Model C warrantable. These results suggest the instrumental approach deserves additional attention in empirical analysis of the demand for rural water services. The estimation of the instruments is an area for consideration. A suggested improvement on the approach to estimating instruments would be to account more directly for the intra-rate variation in estimating the coefficients of (3). Direction for these modifications may be in the literature studying the demand for electricity (e.g. McFadden and Puig).

Summary and Conclusions

The empirical analysis of the demand for rural water service was estimated using household level data from a sample of customers served by the Illinois Farmers Home Administration financed rural water systems. An instrumental variables approach was employed to correct for potential simultaniety bias in OLS estimates associated with the institutional, discrete pricing structure under which water is sold. The estimated model incorporated the full information specification suggested by Nordin and included a marginal price and a lump-sum income effect or difference variable. The results were consistent with the limited literature on water demand, in general, and rural water demand, in particular. A price elasticity of -.36 was reported for the instrumental estimate. The income elasticity of rural water demand was found to be .19.

The demand analysis raises some questions about the appropriateness of the full information assumptions implicit in the Nordin marginal price-expenditure difference model. Consumers may respond to a simpler model of behavior relying on information about total expenditures and total water consumption. The analysis found a significant bias in OLS estimates of rural water demand using price variables calculated at observed consumption levels. The instrumental-variables technique, applied to actual rate schedules, was shown to provide more theoretically consistent estimates and warrants additional attention in future research.

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