ILLINOIS AGRICULTURAL ECONOMICS STAFF PAPER

Series E, Agricultural Economics

An estimate of the Demand for Rural Water Service Under Declining Block Rate Price Schedules

by

David L. Chicoine and Ganapathi Ramamurthy

July, 1984

84 E-296

Department of Agricultural Economics
University of Illinois at Urbana-Champaign
305 Mumford Hall, 1301 West Gregory Drive, Urbana, IL 61801

An Estimate of the Demand for Rural Water Service Under Declining Block Rate Price Schedules

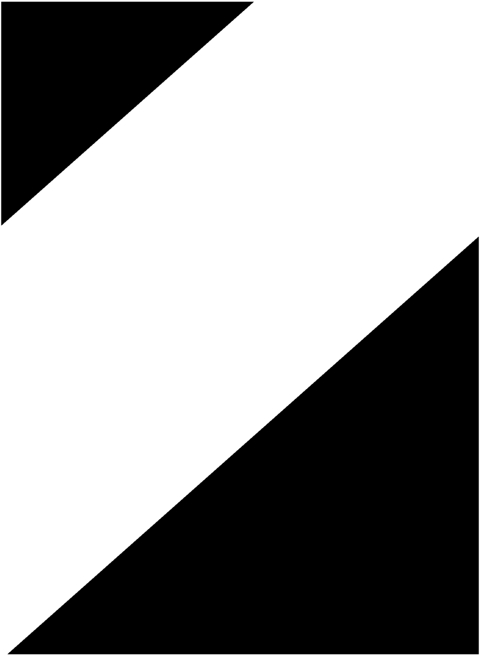
by

David L. Chicoine
Associate Professor

Ganapathi Ramamurthy
Research Assistant

Selected paper presented at the meeting of the American Agricultural Economics Association, August 5-8, 1984, Cornell University, Ithaca, N.Y.

Department of Agricultural Economics
University of Illinois at Urbana-Champaign



An Estimate of the Demand for Rural Water Service Under Declining Block Rate Price Schedules

by

David L. Chicoine and Ganapathi Ramamurthy

ABSTRACT

Using sample household data from Illinois rural water district users, the demand for rural water is estimated considering the declining block rate price schedule used by rural water districts. For goods priced under block rates, demand is a function of marginal price and a price variable accounting for intermarginal price effects. The empirical estimates were generally consistent with expectations except for the second price variable. The estimates of price and income elasticity were -.39 and .18, respectively.

An Estimate of the Demand for Rural Water Service Under Declining Block Rate Price Schedules

Measurement of rural water service demand is taking on increased importance with the trends toward increased rural population and the policy changes restricting federal government capital for rural water system construction (Beal, Ramamurthy and Chicoine). The determination of the demand for rural water is needed to assist the boards of rural water districts 1) manage water supplies--water use forecasts are important in evaluating new supply facility investments, 2) manage water demand--estimate the impact of policies such as price changes and nonprice rationing regulations on water use, and 3) manage revenues--evaluate the impact of rate changes on receipts.

Little research has been undertaken that focuses on rural water demand and several previous studies fail to account for the block rate or multi-part tariff system of pricing water services (e.g., Doeksen, Goodwin and Oehrtman; Hanke and de Mare; Foster and Beattie). With rate schedules where the unit price varies discreetly with the quantity demanded, the amount of water consumed depends upon the whole rate schedule and not upon any single price. Thus, the total expenditure by a household for water is not the simple product of marginal price and quantity demanded. The size of the discreet blocks in the schedule and the within block marginal prices also impact total expenditure.

More recent studies of the demand for residential water have based their analysis on a model of consumer behavior suggested by Taylor and modified by Nordin (Billings and Agthe, Hanke). Here the quantity purchased by a consumer through a multiple-part tariff is expressed as a function of the marginal price faced by the consumer and a second price related factor defined as the difference between the consumer's actual bill and the product of the marginal price and the amount of water purchased (Nordin, p. 719). The second factor reflects the income effects associated with the discreet changes in the water rate schedule. Nordin's analyses, which was a theoretical treatment and considered only decreasing block rate schedules was extended by Billings and Agthe to include increasing block rate schemes. There is also a suggestion that the common practice of using aggregate data, where the quantity demanded and income variables are averages over some unit of observation, have resulted in theoretically inconsistent estimates of demand (Schefter and David).

The objective of this paper is to begin to address these shortcomings. More specifically, using household data from a sample of Illinois rural water district customers, a multiple tariff demand for rural water services is estimated. Demand elasticities for water under the system of declining block rates in these districts are derived. First, the model of consumer behavior under a declining block rate pricing schedule is briefly reviewed along with recent relevant literature. Next the data and empirical model are introduced. The demand estimates are then presented followed by a brief summary.

Water Demand With Block Rates

The demand for goods, like water, sold under block rate schedules that are often declining, has been shown to require the inclusion of two price-related variables in addition to an income variable and other demand shifters. In addition to marginal price, which is the per unit price in the discreet pricing block where consumption occurs, a second price variable is required to account for the income effects associated with block rate pricing (Nordin, Griffin and Martin).

The general demand model for rural water priced with a block rate schedule is:

$$Q = f(P, D, Y, X)$$

where:

Q = monthly water consumption of a rural water customer (thousands of gallons),

P = marginal price (dollars per thousand gallons),

D = difference; actual water expenditure less what would have been paid if all water was purchased at the marginal price (dollars),

Y = personal household income (dollars per month), and

X = vector of household characteristics (e.g., occupation, household size, measures of household technology).

Nordin demonstrates in the case of declining block rates the proper definition of the second price variable is the difference between the consumer's actual bill and the outlay that would have been made had the entire quantity of water been bought at the per unit price in the marginal block. This second price related variable (D) could be viewed as the difference in consumer surplus between what would occur under uniform marginal pricing and the consumer surplus actually captured by the consumer. Nordin suggests 1) D be perceived as a lump sum that must be paid before the demanded units can be purchased at the marginal price and 2) in a linear demand function, the coefficient on D should be equal in magnitude but opposite in sign to that on household income "because a one-unit increase in D has the same effect as a one-unit increase in the lump-sum subtraction from income" (p. 720).

The use of marginal price (P) alone in a study of demand for water sold under a block rate schedule as in Doeksen, Goodwin and Oehrtman and Hanke and de Mare will lead to erroneous results. With D excluded, the income effects of different block rate schedules with the same marginal price will not be properly accounted for.

The difference price related variable (D) has been incorporated in empirical water demand studies by Billings and Agthe and by Howe. Both studies obtained the expected negative sign on the coefficient of D, the difference variable, but these coefficients in both studies were significantly different than the coefficient on the income variable. Schefter and David suggest this theoretically inconsistent outcome may be the result of estimating demand functions with aggregate data measured across communities.

Studies of urban residential water demand have reported price elasticities ranging from -0.15 (Hanke and de Mare) to -0.66 (Billings). Doeksen, Goodwin and Oehrtman report a price elasticity in their study of rural water demand in Oklahoma of -0.4. Income (Y) is expected to be positively related to water consumption because of the normal good characteristics of water. The income elasticity of urban water consumption was reported as 0.11 by Hanke and de Mare in their study of Malmo, Sweden. Doeksen, Goodwin and Oehrtman found income positively related to water consumption for rural water district customers in their Oklahoma study.

The number of persons in a household, and the level of water-using household technology are both expected to increase the amount of water used. Studies of both urban residential and rural water demand have found household size positively related to water consumption (e.g., Hanke and de Mare; Foster and Beattie; Doeksen, Goodwin and Oehrtman). Previous research has indicated the use of modern conveniences as dishwashers, a second bathroom, etc. also contributes to a larger water use (e.g., Batchelor; Hanke and de Mare). Non-domestic use of water by rural water district customers will increase water consumption. Farmers watering stock, for example, would be expected to have a higher water demand than other rural water district customers, other things equal.

Data and Empirical Model

A 1983 telephone survey of 100 customers of Illinois' 59 rural water districts provides household level data to estimate the demand for rural water services. The surveyed customers were drawn from the universe of water district users with a stratified random sampling procedure. The 59 districts provide potable water only to farmers and other rural residents in the open countryside. No incorporated municipalities are served. The survey data on household characteristics were matched with monthly consumption and expenditure data from the records of the nine districts serving the sampled customers. Water rate schedules were obtained from the districts so marginal prices (P) could be determined and difference variables (D) calculated. Missing observations caused the sample size to fall to 77.

The consumption and expenditure data are monthly for 1982 so the data consists of a time series over 12 periods across the 77 households for a total of 924 observations. The demand for rural water was estimated using the following pooled time series and cross-section model:

$$Q_{it} = B_0 + \sum_{t=1}^{11} B_{1t} M_t + B_2 \, RES_i + B_3 \, ALTSRC_i + B_4 \, DISH_i + B_6 \, NUMRES_i + B_7 \, BATH_i + B_8 \, P_{it} + B_9 \, D_{it} + B_{10} \, INC_i + e_{it}$$

where:

Q_{it} = water consumption by household i in month t,

M_t = monthly binary variable where t=1 for Jan., 2 for Feb.,..,11 for

RES_i = type of residence binary variable with farm=1, 0 otherwise,

$ALTSRC_i$ = existence of an alternative onsite source of water, 1 if yes, 0 otherwise,

$DISH_i$ = 1 if household i has a dishwasher, 0 otherwise,

$NUMRES_i$ = household size measured by number of persons,

$BATH_i$ = number of bathrooms in household i,

P_{it} = marginal price paid by i^{th} household in month t,

D_{it} = difference between household i's water bill in month t and P_{it} times Q_{it},

INC_i = monthly income of household i, and

e_{it} = random vector distributed as $N(0,\sigma^2 I)$.

Using ordinary least squares, the demand for rural water services was estimated, employing only those observations where consumption was beyond the first block in the rate schedule. In the first block, P_{it}=0 and the customer pays a minimum fixed fee with the right to consume a given quantity of water. Of the nine districts serving the sample of water district users, five had first blocks of 1,000 gallons. The other four rate schedules had first blocks of 2,000 gallons. This reduced the number of observations to 797.

Demand Estimates

The empirical estimates of the demand for rural water services are presented in Table 1. The signs on the coefficients of household income, price, household size, and number of bathrooms are as expected and significantly different from zero. The coefficients on the dishwasher, farm/

Table 1. Estimated Rural Water Service Demand[a]

Dependent Variable	Model 1	Model 2	Model 3	Model 4
Household Income (av./mo.)	.0006 (5.39)*	.0006 (5.34)*	.0005 (5.43)*	.0005 (5.35)*
Marginal Price	-.5863 (12.53)*	-.5927 (12.67)*	-.5757 (13.17)*	-.5822 (13.33)*
Difference	.0126 (0.65)	.0153 (0.79)	.0166 (0.89)	.0192 (1.05)
Household Size	.5995 (9.13)*	.5938 (9.03)*	.6114 (9.50)*	.6056 (9.39)*
Number of Bathrooms	1.1927 (8.51)*	1.1900 (8.47)*	1.1242 (8.75)*	1.1190 (8.68)*
Dishwasher 1=yes, 0 otherwise	-.3057 (1.37)	-.3141 (1.40)	---	---
Farm/Nonfarm 1=farm, 0 otherwise	-.1188 (0.42)	-.1129 (0.40)	---	---
Other Water Source 1=yes, 0 otherwise	.0510 (0.24)	.0471 (0.22)	---	---
M1, 1=January 0 otherwise	.0809 (0.18)	---	.0806 (0.18)	---
M2, 1=February 0 otherwise	-.0771 (0.17)	---	-.0801 (0.18)	---
M3, 1=March 0 otherwise	.5067 (1.17)	---	.5101 (1.17)	---
M4, 1=April 0 otherwise	-.2012 (0.46)	---	-.2002 (0.46)	---
M5, 1=May 0 otherwise	.3825 (0.89)	---	.3845 (0.90)	---
M6, 1=June 0 otherwise	.6286 (1.43)	---	.6163 (1.45)	---
M7, 1=July 0 otherwise	.7894 (1.84)**	---	.7871 (1.83)**	---
M8, 1=August 0 otherwise	.5780 (1.34)	---	.5793 (1.34)	---
M9, 1=September 0 otherwise	.6352 (1.48)	---	.6345 (1.48)	---
M10, 1=October 0 otherwise	-.1761 (0.41)	---	-.1773 (0.41)	---
M11, 1=November 0 otherwise	.0638 (0.15)	---	.0636 (0.15)	---
Constant	2.1482 (4.18)*	2.4609 (5.87)*	2.0858 (4.17)*	2.4018 (5.98)*
Adjusted R^2	.41	.41	.41	.41
F	30.18	69.49	35.76	110.90
RSS	4761	4851	4773	4864
N	797	797	797	797

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

* Significant at the .05 level.

** Significant at the .10 level.

nonfarm and other domestic water source binary variables are not statistically different from zero. These three variables were excluded from the estimates reported in Model 3 and Model 4. The insignificant coefficient on the farm/nonfarm variable suggests no significant difference in water demand between the farm and the nonfarm customers of Illinois rural water systems. The dominance of cash grain agriculture suggesting little use of water for livestock, etc. could explain these results.

As suggested by Judge et al., an F-test is used to test for time series effects or if a seasonal pattern exists in water consumption. The critical value of the F-ratio did not allow the rejection of the null hypothesis that there are no time series effects. Thus, for estimation purposes the observations can be treated as one sample. Accordingly, the monthly binary variables are excluded from Models 2 and 4.[1]

Theory suggests the coefficients on Difference and Household Income should be equal in magnitude and opposite in sign in a linear demand model since each measures a pure income effect. The coefficient on the difference variable reported in Table 1 is positive, which is opposite that expected, but it is not statistically different from zero. An insignificant coefficient on the difference variable has been reported in other studies (Howe, p. 716). One explanation for the insignificant coefficient on Difference is the low proportion of income it absorbs. On average, the difference variable absorbs .34% of income which may be too small to have any significant impact on consumer's perception of income. Monthly water

---

[1]See Judge et al., pp. 484-485. The calculated F-ratios for Models 1 and 2 and 3 and 4 are 1.34 and 1.35, respectively. The critical value at the 95 percent level for the respective calculated values are 1.83 and 1.75.

outlays were on average approximately 1.3% of the monthly income of Illinois rural water district customers. There is some evidence that surveyed customers with larger monthly water bills had a substantially more accurate perception of their monthly outlay for water than customers with smaller bills. Customers paying more than $20 per month underestimated their actual average monthly bill by 1.6 percent while customers paying $10 or less per month overestimated their actual average bill by 44.9 percent(Chicoine, Grossman and Quinn).

Howe (p.714) argues that because of the surrogate nature of Difference and its ex post construction there is no reason to expect empirical outcomes to be consistent with theoretical expectations. In addition, Foster and Beattie present arguments and some evidence that challenge the appropriateness of the marginal price-difference demand model and its perfect knowledge postulate in analyzing consumer price response behavior for potable water. Because of a general lack of knowledge by consumers on marginal block prices, the complicated nature of typical block rate schedules for water services and the complex format of water bills, consumers may be most aware of total outlays and consumption and respond accordingly.

The adjusted R^2 for the estimated demand in Model 4 is .41. Specifically, for Model 4, the coefficient on household income indicates that an increase in income of $100 per month would result in monthly water use increasing 50 gallons, on average. The coefficient on Household Size suggests each additional person adds 605 gallons to monthly water consumption, other things equal. This is similar to the impact of increased household size on water use reported in a study of Oklahoma rural water demand

(Doeksen, Goodwin and Oehrtman). For an additional bathroom, water use increases 1,000 gallons per month, on average.

The estimated elasticities of rural water demand for own price, income and household size are -.39, .18 and .37 respectively. The price elasticity is similar to elasticities reported in studies of rural and urban water demand (e.g., Doeksen, Goodwin and Oehrtman; Billings and Agthe). Price elasticities for goods sold under block rate schedules must be interpretted with care. Price changes can be expected to change both the marginal price and the difference factor. For example, if the rate schedule shifts upward uniformly, the marginal price elasticity describes the entire impact. Changes in the size of the blocks would have elasticity with respect to the difference factor describing the entire impact of the price change. In between these extremes both elasticities must be considered.

The insignificant coefficient on Difference in Table 1 indicates the impact of price changes over the range of the rate schedules studied are described entirely by the marginal price elasticity. The elasticity of -.39 indicates an inelastic demand for water at the mean of Q_{it} and P_{it}.

Summary and Implications

A model of rural water demand, where the pricing schedule is a block rate system should conceptually include two price related variables, as well as income and other determinants of demand. The price factors are the marginal price and the difference between the actual payment for water and what the payment would have been if all units were purchased at the marginal price. Using household level data from a sample of Illinois rural water district customers, a demand for rural water service was estimated. While the marginal price had the expected negative significant sign on its coefficient, the coefficient on the second price variable was not significant and had an opposite sign than expected. These results may be associated with the small proportion of household income accounted for by the difference price variable. Rural water demand was shown to not exhibit any seasonal variation.

The estimated price elasticity of demand for rural water was -.39 while the income elasticity was estimated to be .18. The price elasticity suggests that by increasing the price of water, a rural water system will increase its total revenues. Also, for the range of water prices studied ($5.00 to $1.25 per 1,000 gallons), a price change will not result in a dramatic change in quantity of water demanded. Thus, small price changes will not be effective policies in allocating a short water supply. Additional efforts are needed to empirically test, using household level data, the two price demand models suggested by theory.

References

Batchelor, R. A. "Household Technology and the Domestic Demand for Water," Land Economics 51(August 1975):208-223.

Beale, Calvin L. The Revival of Population Growth, in Nonmetropolitan America. Washington, D.C.: ERS-USDA, 1975.

Billings, R. Bruce, "Specification of Block Rate Price Variables in Demand Models," Land Economics 58(August 1982):386-394.

Billings, R. Bruce, and Donald E. Agthe. "Price Elasticities for Water: A Case of Increasing Block Rates," Land Economics 56(February 1980):73-84.

Chicoine, David L., Margaret R. Grossman and John A. Quinn, Rural Water Districts in Illinois WRC-84-185, Water Resources Center, Urbana, IL.: University of Illinois (April 1984).

Doeksen, Gerald A., H. L. Goodwin, and Robert L. Oehrtman. "Estimating Demand and Demand Elasticities for Water in Rural Areas," paper presented at the meeting of the Southern Agricultural Economics Association, Nashville, TN: (February 5-8, 1984).

Foster, Henry S. and Bruce R. Beattie. "Urban Residential Demand for Water in the United States," Land Economics 55(February 1979):43-58.

Griffin, Adrian H. and William E. Martin. "Price Elasticities for Water: A Case of Increasing Block Rates: Comment," Land Economics 57(May 1981):266-278.

Hanke, Steve H. and Lennart de Mare. "Residential Water Demand: A Pooled, Time Series Cross Section Study of Malmo, Sweden," Water Resources Bulletin 18(August 1982):621-625.

Howe, C. W. "The Impact of Price on Residential Water Demand: Some New Insights," Water Resources Research 18(August 1982):713-716.

Judge, George G., R. Cater Hill, William Griffith, Helmut Lutkepohl, and Tsoung-Chao Lee. Introduction to Theory and Practice of Econometrics. New York, NY (John Wiley & Sons, 1982).

Nordin, John A. "A Proposed Modification of Taylor's Demand Analysis: Comment," The Bell Journal of Economics 7(Autumn 1976):719-721.

Ramamurthy, Ganapathi and David L. Chicoine. "Capital Costs of Rural Water Systems: An Empirical Approach," Water Resources Bulletin 20(April 1984): 255-260.

Schefter, John E. and E. L. David. "Estimating Residential Demand Under Multi-Part Tariffs Using Aggregate Data," unpublished mimeo (1983).

Taylor, L. D. "The Demand for Electricity: A Survey," The Bell Journal of Economics 6(Spring 1975):74-110.