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"Public Versus Private Water Delivery: A Hedonic Cost Approach"

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PUBLIC VERSUS PRIVATE WATER DELIVERY: A HEDONIC COST APPROACH

Susan Feigenbaum and Ronald Teeples*

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Abstract

Previous econometric studies of the relative cost performance of government versus private-regulated utilities have compared cost of water delivery functions estimated for each of the two groups of suppliers. This methodology can erroneously attribute cost variations to ownership form if a misspecification of each group's cost function exists and results in the omission of variables that vary systematically with ownership. Our study addresses several of these specification issues by (1) adopting a multidimensional definition of firm output, (2) explicitly testing the validity of various assumptions about water delivery technology, and (3) including previously omitted factor price effects of electrical energy and purchased versus own-water inputs. Using a translog cost function specification, we find that representation of the technology of both government and private water operations by a generalized Cobb-Douglas production function is appropriate, but only if the definition of utility output reflects service-mix attributes as well as volume of delivered water. We adopt a hedonic output function which includes such variables as level of water treatment, percent of water metered, degree of excess storage capacity, percent of water inputs purchased and density of service area to reflect differences in the quality of water inputs as well as the mix of services provided in each firm's exclusive service district. The resulting hedonic cost function estimates yield significant improvement over nonhedonic formulations in explaining variations in utility operating costs. Based on our specification of the water delivery production process, we find that no significant differences exist in the cost-of-service functions of private-regulated versus government water utilities.

Policymakers, faced with unprecedented resistance to public sector expansion, have rekindled debate about the merits of government versus private supply of public service activities. Crucial to this debate is evidence concerning the impact of ownership form on the cost efficiency of firm operations. Previous empirical studies have generated evidence for water and electric utility industries (see, for example, Peltzman, 1971; Meyer, 1975; Crain and Zardkoohi, 1978). Utilities are of particular interest because the relative costs-of-service for government versus private firms may well depend on the degree to which Averch-Johnson effects in private, rate regulated, operations outweigh efficiency losses associated with the generally greater attenuation of private property rights in government enterprises. Furthermore, researchers have suggested that, because of the comparative ease in defining utility output, such firms are especially suited for an empirical examination of the impact of ownership form on cost-of-operation.[1]

Estimates from previous studies have led to conflicting conclusions as to whether utility cost structures vary systematically with type of firm ownership. We suggest that the inconclusiveness of these empirical results may be at least partially explained by differences in the econometric specification of utility production processes. Specifically, we argue that the alternative utility cost models used to date suffer from at least one of the following weaknesses: (1) improper measurement of firm output as a scalar value representing delivery volume; (2) an arbitrarily imposed specification of production technology; and (3) omission of relevant factor prices. In this paper, we address these weaknesses by using a hedonic cost function model to compare the operation costs of private versus government water delivery systems.

Section I presents a general cost-of-service function for water delivery which reflects the multidimensional nature of water utility output. Section II discusses the data used to generate parameter estimates for this function, the variables included in our model, and predictions about the direction of impact of these variables on firm costs. Section III reviews our results and derives from them several conclusions concerning water delivery technology and the effect of ownership on service costs.

I. PRODUCTION AND COST FUNCTIONS FOR WATER DELIVERY

Previous utility studies have typically adopted a generalized Cobb-Douglas production function to explicitly model a firm's production process.[2] In the classic specification, utility output (Y) is produced from two inputs -- labor (L) and capital (K). A utility's production technology is thus represented by:

$$Y = AK^{c}L^{d} .$$

Several problems arise in applying this production model to activities in the water industry. By focussing solely on capital and labor inputs, this production specification ignores many of the variable factor inputs -- including energy and water -- actually used in water operations. Furthermore, a generalized Cobb-Douglas production function, which imposes strict homogeneity and unitary elasticities of substitution on the production process, may be an invalid characterization of the technology available to water utilities. Finally, and perhaps most importantly, the above production function specifies a single homogeneous output (Y) for the firm. For water utilities, Y is typically measured in terms of delivery volume (millions of gallons per year). In fact, utilities do not "produce" water in the sense that a uniform manufactured product is generated from a given set of inputs. Water companies transform the location (in space and time) of water and improve upon the quality of water inputs. Water utilities differ greatly in the quality and accessibility of water inputs and in the service mix demanded within their exclusive market areas. The resulting multidimensional nature of utility service must be explicitly controlled for in any attempt to measure the effect of ownership on operation costs,[3] particularly when there exist systematic differences in input prices and water service mix across ownership forms.

To overcome limitations inherent in the generalized Cobb-Douglas production function, we use a more general production specification of the form[4]

$$Q(Y; z_1, z_2, z_3, \ldots, z_m) = f(K; L; E; W)$$

where $Q(\ )$ = an index of output

Y = volume of delivered water (in millions of gallons per year)

z_i = i^{th} service attribute associated with delivery of Y

K = capital input

L = labor input

E = energy input

W = water input.

Firm output is represented by an index Q which reflects both the volume (Y) of delivered water and various service dimensions (z_i) associated with this water provision. Our specification assumes that "bundles" of water volume, quality and service attributes can be consistently aggregated by the function Q( ) such that each firm's output mix is comparable to that of any other firm in terms of an index Q.[5] Because of the continuous nature of each of the service dimensions, this aggregation approach is preferable to a multiproduct firm model that would treat different combinations and levels of service attributes as distinct goods.[6]

The nature of production technology available to a water utility to provide any given volume (Y) and service mix (combinations of different levels of z_is) is represented by the function f( ). The form of f( ) is left unspecified and alternative specifications are empirically evaluated via examination of firm cost data, below.

A Hedonic Cost Function for Water

Subject to conditions stipulated by Shepard (1953) in his development of duality theory, there exists a cost function C( ) which parallels the production function of the firm. When level of output and factor prices are exogeneously determined for firms, it is preferable to estimate cost functions instead of production functions to gain insight into the nature of firm technology.[7] This indirect strategy is applicable to water utilities, which are required by law to supply all of the output that is demanded at regulated rates, are regulated in their service dimensions and typically act as pricetakers in factor markets. Hence, we characterize utilities as controlling their operating costs primarily through their choice of input mix.[8] Therefore, we estimate a cost function consistent with the above production function to shed light on the technology of water delivery and the relative costs-of-service of private versus government operations.

We adopt the hedonic cost function used by Spady and Friedlaender (1978) in their examination of the regulated trucking industry. Their model is particularly useful for our purposes because it modifies the conventional econometric approach to variations in output quality to reflect the fact that trucking, like the water industry, is subject to rate regulation. In such situations where prices are not market determined, the estimation of hedonic functions which rely on prices to provide an aggregate index of product quality variations is problematic.[9] In addition to rate regulation, trucking firms and water utilities face similar regulatory constraints which make the volume of output, service mix, and quality dimensions of output exogenous to individual firms. These regulatory constraints assure that the estimated parameters of the Spady-Friedlaender hedonic cost function reflect only input price effects and are free of simultaneity bias.

The Spady and Friedlaender analysis specifies a "quality-separable hedonic cost function"[10] of the form:

$$C = C(\,Q(\,Y;\, z_1, z_2, \ldots, z_m);\, r_1, r_2, \ldots, r_n)), \tag{1}$$

where costs (C) are a function of (hedonic) output (Q) and factor prices (r_i). Q( ), our index of firm output, is assumed to be homogeneous of degree one with respect to the volume scalar (Y), so that

$$Q(\;) = Y \cdot g(z_1, z_2, \ldots, z_m), \tag{2}$$

where g( ) is a hedonic function which aggregates the service dimensions provided by the firm and Q( ) is our output index which aggregates both firm volume and service mix. The price (r_i) per unit of input i, will not only vary according to conditions in regional factor markets, but will often vary systematically with utility ownership.[11]

To estimate parameters for this hedonic cost function, we use a translog approximation, which does not dictate a priori the form of the implied production function:[12]

$$\begin{aligned} \ln C(\;) = {} & b_0 + b_1 \ln Q + b_2 (\tfrac{1}{2}(\ln Q)^2) + \Sigma\, c_i \ln r_i \\ & + \tfrac{1}{2}\, \Sigma\Sigma c_{ij} \ln r_i \ln r_j + \Sigma\, d_i \ln Q \ln r_i \end{aligned} \tag{3}$$

where

$$\ln Q = \ln Y + \ln g(z_1, z_2, \ldots, z_m) \tag{4}$$

We approximate the log of the hedonic function g( ) by[13]

$$\ln g(\;) = \Sigma\, a_i \ln z_i. \tag{5}$$

Substituting (5) and (4) into (3), we arrive at the final form of our hedonic cost equation, which is estimated using a nonlinear, maximum likelihood technique. To ensure that the resulting cost function is well-behaved and homogeneous of degree one in factor prices, we impose the following standard parameter constraints:

$$\Sigma\, c_i = 1\;;\; \Sigma\, d_i = 0\;;\quad c_{ij} = c_{ji}\;;\; \Sigma\, c_{ij} = 0 \;\text{ for all } j.$$

This cost function is used to test both for the proper specification of the implied water delivery production function and for any significant differences in the cost-of-service equations of government and private operations.[14] If, for example, water delivery technology exhibits unitary elasticities of substitution with respect to its inputs, then such technology could be represented by a restricted version of the cost equation (where $c_{ij} = 0$ for all i,j). Similarly, by restricting additional parameters of the function, we can impose homotheticity ($d_i = 0$ for all i) and/or homogeneity ($d_i = 0$ for all i and $b_2 = 0$) on the production process.[15] Finally, a nonhedonic specification of the cost function can be estimated simply by constraining $a_i = 0$ for all i. Each of these sets of restrictions is examined below in order to shed light on the actual production structure of water operations. For each possible production specification, we also test whether there is a statistically significant difference in the cost-of-service functions of government and private firms.

II. SPECIFYING A HEDONIC COST FUNCTION FOR WATER DELIVERY

As we noted above, variations in service quality or service-mix of water companies are likely to create differences in the operating costs of utilities, even for those with identical output volume. Thus, for example, we would expect that it is more costly to

(1) deliver highly treated water rather than pass through unprocessed water;[16]

(2) supply water at metered rates rather than provide unmetered, flat rate deliveries;

(3) supply more densely developed service areas, which require more hydrants, higher water pressure and greater peak capabilities for fire protection;

(4) engage in large-scale storage operations to capture water run-off and/or protect against temporary fluctuations in water supply or demand conditions.

(5) service many small metered users rather than a few large users (total volume held constant);[17]

To control for these differences in the activities of water utilities, we include the following quality and service attributes in our hedonic cost function:[18]

z_1 = index of level of water treatment

z_2 = percent of water metered

z_3 = total metered customers/miles of line

z_4 = storage capacity/average daily production

z_5 = average size (in gallons) of metered account.

In addition, we define a sixth output characteristic, z_6, to represent the percent of water input purchased from wholesale water suppliers. Theoretically, it would be preferable to treat water inputs in the same manner as other factors of production by including a price for water in our cost function and leaving the choice of input level endogenous to the firm. However, it is not an industry practice to explicitly value utility-owned surface and ground water resources at prices that reflect the water's physical quality and ease of access.[19] In fact, only the explicit costs of wholesale water purchases are included in a utility's reported cost-of-service. Therefore, inclusion of percent of water input purchased as a service attribute is an attempt to correct the distortion created by using reported costs to proxy the true economic cost of primary water inputs used in firm operations. Lack of information about the true economic cost of utility activities forces us to follow the conventional approach which relies on accounting cost measures of firm operating and administrative outlays to represent utility cost-of-service (C).

Three input prices -- capital, labor and energy -- are explicitly included in the cost function. We define as our input prices:

r_1 = hourly wage rate of labor

r_2 = price per kilowatt of electric power

r_3 = price of new units of capital service.

Data

Comprehensive cost-of-operation and employee wage data for the year 1970 have been made available by the American Water Works Association for 57 private and 262 government water operations, nationwide.[20] Input prices are derived from these sources in conjunction with data published by the Department of Energy (electricity prices) and Engineering News Record (construction cost indices). Excluded from our study are companies that engage strictly in pass-through activities (e.g., aqueduct systems). The Data Appendix provides a detailed explanation of each variable included in our cost function estimation.

III. ESTIMATION RESULTS

Table IA. reports parameter estimates for our general cost-of-service function (Model I.), generated from pooled, government and private firm observations. Our results indicate that cost-of-service is positively, and significantly, affected by level of water treatment (a_1), percent of water metered (a_2), customer density (a_3) and amount of purchased water (a_6). Average size of metered account (a_5) has a negative, statistically significant effect on operation costs. Only the excess storage measure, which had the predicted positive impact, was insignificant at the five percent level. Using a likelihood ratio test,[21] we tested the hypothesis that the parameters of Model I were identical for government and private operations and found that we could not reject this hypothesis at the five percent significance level (see Table IB.).

Model II estimates reflect the imposition of unitary elasticities of substitution ($c_{ij} = 0$ for all i,j), while Models III and IV further incorporate, respectively, homotheticity ($d_i = 0$ for all i) and homogeneity ($d_i = 0$ for all i and $b_2 = 0$). In all three of these restricted models, we were unable to reject pooling of government and private enterprises at the five percent significance level (see Table IB.).

To test whether the production specifications of Models II-IV are significant constraints on our general cost-of-service function, we performed likelihood ratio tests based on the pooled (government and private) estimates of Models I-IV. As Table IB. indicates, we could not reject the constraints imposed by any of the restricted models at the five percent significance level. Thus, water delivery technology appears to be homogeneous with respect to the hedonic output index and to exhibit unitary elasticities of substitution. Moreover, there is no significant, systematic difference in the relative efficiency of government versus private firms.

When we compare these estimates from our hedonic cost-of-service function with results derived from a nonhedonic production specification (with output specified simply in terms of volume Y), we find one significant difference. The nonhedonic estimates, presented in Tables IIA. and IIB., indicate that the implied water delivery production function is not homogeneous. Thus, a generalized Cobb-Douglas production specification appears to be appropriate only when output is defined in hedonic terms to reflect the multidimensional nature of water delivery. While the hedonic cost-of-service function indicates that there are significant economies of scale (with respect to hedonic output Q( )) for utilities of all sizes, the nonhedonic cost model concludes that economies of scale (with respect to volume (Y)) are exhausted as firms expand their volume. When we compute the scale economies index proposed by Christensen and Greene[22] for the homogeneous hedonic cost function (Model IV), we find that water delivery exhibits scale economies of .1355 with respect to the hedonic output index Q( ). In contrast, the scale economies exhibited by the nonhomogeneous, nonhedonic function decline with firm volume and are exhausted in the top five percent of the sample's output range (diseconomies setting in at approximately 45,000 million gallons per year).[23] These results indicate that the diseconomies of scale attributed to increased delivery volume in the nonhedonic formulation can, in reality, be explained by concurrent expansions in service activities.

While the hedonic and nonhedonic cost models differ in their conclusions about the implied production technology of water operations, they are consistent in their support for the hypothesis that there is no systematic difference in cost-of-service equations for government versus private companies. As in the hedonic model, we could not reject pooling the two types of firms for any of the four nonhedonic specifications at the five percent significance level (see Table IIB.).[24]

To test whether our hedonic specification is, in fact, superior to the nonhedonic formulation, we performed a likelihood ratio test of the restrictions imposed by the nonhedonic function for both the homogeneous and nonhomogeneous specifications (Models III and IV). In both cases, we found that the nonhedonic model significantly reduced the explanation of the cost-of-service equation. The hypothesis that our hedonic cost function gave no better explanation than the usual nonhedonic cost formulations was rejected at the one percent significance level.

IV. CONCLUSIONS

Previous studies have drawn conclusions about the relative cost performance of government versus private utilities by comparing cost of water delivery functions estimated for each of the two groups of suppliers. This methodology can erroneously attribute cost variations to ownership form if a misspecification of the cost function exists and results in the omission of variables that vary systematically with ownership. Our study addresses several of these specification issues by adopting a multidimensional definition of firm output, explicitly testing the validity of various assumptions about water delivery technology, and including the factor price effects of electrical energy and purchased versus own-water inputs.

Our results indicate that representation of the production process of both government and private water operations by a generalized Cobb-Douglas production function is appropriate only if the multidimensional nature of water delivery is incorporated into the model. Inclusion of these service mix attributes of utility output, via a hedonic cost function, yields significant improvement in explanation of variations in utility costs-of-service. The costs of labor, energy and purchased water inputs are also statistically significant in explaining the reported operating expenditures of utilities, although the cost of new capital is apparently an insignificant determinant of such outlays. In neither the hedonic nor nonhedonic cost formulations do we find significant differences in the cost functions of government versus private operations.

TABLE IA.

HEDONIC COST FUNCTION ESTIMATES

(t-values in parentheses)

Coef.	Variable	Model I.	Model II.	Model III.	Model IV.
b_0	CONSTANT	-4.9224 (-1.5983)	-2.4547 (-1.3037)	-2.6873* (-3.0826)	-3.5879* (-9.7265)
b_1	Q	0.6553* (2.5841)	0.6391* (2.5250)	0.6734* (3.8932)	0.8655* (52.7200)
b_2	$\frac{1}{2}Q^2$	0.0201 (1.1723)	0.0212 (1.2050)	0.0190 (1.1225)	
c_1	r_1	-0.9692 (-0.3984)	1.0087 (1.3199)	0.7227* (6.3900)	0.7279* (6.3885)
c_2	r_2	-0.0311 (-0.0231)	-0.0804 (-0.1331)	0.1634 (1.9357)	0.1675** (1.9940)
c_3	r_3	2.0003 (1.0282)	0.0717 (0.1113)	0.1139 (1.2878)	0.1046 (1.1700)
c_{11}	$\frac{1}{2}r_1^2$	-0.9722 (-0.9195)			
c_{22}	$\frac{1}{2}r_2^2$	-0.3594 (-0.7344)			
c_{33}	$\frac{1}{2}r_3^2$	-0.7806 (-0.8066)			
c_{12}	r_1r_2	0.2755 (0.5789)			
c_{13}	r_1r_3	0.6967 (0.8301)			
c_{23}	r_2r_3	0.0839 (0.1741)			
d_1	Qr_1	-0.0041 (-0.0478)	-0.0302 (-0.3848)		
d_2	Qr_2	0.0001 (0.0009)	0.0262 (0.4089)		
d_3	Qr_3	0.0040 (0.0590)	0.0040 (0.0614)		

TABLE IA. (continued)

hedonic function g( )

a_1	z_1	0.6049*	0.6054*	0.6072*	0.5970*
		(6.1429)	(6.0279)	(6.1220)	(6.1363)
a_2	z_2	0.6048*	0.5997*	0.6010*	0.5970*
		(6.6478)	(6.4898)	(6.8092)	(7.0795)
a_3	z_3	0.0878**	0.0908**	0.0895**	0.0892**
		(2.3093)	(2.2317)	(2.3738)	(2.4060)
a_4	z_4	0.0754	0.0764	0.0728	0.0727
		(1.9057)	(1.9274)	(1.8898)	(1.8858)
a_5	z_5	-0.4915*	-0.4920*	-0.4926*	-0.5090*
		(-8.0998)	(-7.9180)	(-8.3707)	(-9.1152)
a_6	z_6	0.9756*	0.9723*	0.9744*	0.9538*
		(8.7566)	(8.5513)	(8.8170)	(8.8470)
Estimated Covariance Matrix Determinant		0.09881	0.09935	0.09941	0.09981
Sample Size		319	319	319	319

*Significant at the one percent level

**Significant at the five percent level

TABLE IB.

HEDONIC COST FUNCTION TEST RESULTS

<table>
<tr><th></th><th colspan="2">Model I.</th><th colspan="2">Model II.</th><th colspan="2">Model III.</th><th colspan="2">Model IV.</th></tr>
<tr><td>Maximum Likelihood Ratio: Government/ Private Pooling Test Results</td><td colspan="2">20.16
critical
$\chi^2_{.05}(16)=26.3$</td><td colspan="2">13.28
critical
$\chi^2_{.05}(13)=22.4$</td><td colspan="2">10.26
critical
$\chi^2_{.05}(11)=19.7$</td><td colspan="2">9.34
critical
$\chi^2_{.05}(10)=18.3$</td></tr>
<tr><td>Maximum Likelihood Ratio: Production Function Constraints</td><td></td><td colspan="2">1.82
critical
$\chi^2_{.05}(3)=7.81$</td><td colspan="2">0.20
critical
$\chi^2_{.05}(2)=5.99$</td><td colspan="2">1.28
critical
$\chi^2_{.05}(1)=3.84$</td><td></td></tr>
</table>

TABLE IIB.

NONHEDONIC COST FUNCTION TEST RESULTS

<table>
<tr><th></th><th colspan="2">Model I.</th><th colspan="2">Model II.</th><th colspan="2">Model III.</th><th colspan="2">Model IV.</th></tr>
<tr><td>Maximum Likelihood Ratio: Government/ Private Pooling Test Results</td><td colspan="2">15.76
critical
$\chi^2_{.05}(10)=18.3$</td><td colspan="2">9.38
critical
$\chi^2_{.05}(7)=14.1$</td><td colspan="2">7.54
critical
$\chi^2_{.05}(5)=11.1$</td><td colspan="2">7.40
critical
$\chi^2_{.05}(4)=9.5$</td></tr>
<tr><td>Maximum Likelihood Ratio: Production Function Constraints</td><td></td><td colspan="2">5.18
critical
$\chi^2_{.05}(3)=7.81$</td><td colspan="2">0.94
critical
$\chi^2_{.05}(2)=5.99$</td><td colspan="2">14.20
critical
$\chi^2_{.05}(1)=3.84$</td><td></td></tr>
<tr><td>Maximum Likelihood Ratio: Hedonic vs.Nonhedonic Specification</td><td colspan="2"></td><td colspan="2"></td><td colspan="2">172.98
critical
$\chi^2_{.05}(6)=12.6$</td><td colspan="2">185.90
critical
$\chi^2_{.05}(6)=12.6$</td></tr>
</table>

TABLE IIA.

NONHEDONIC COST FUNCTION ESTIMATES

(t-values in parentheses)

Coef.	Variable	Model I.	Model II.	Model III.	Model IV.
b_0	CONSTANT	4.0337	0.6190	0.1074	-2.3172*
		(1.1082)	(0.3207)	(0.1524)	(-7.1092)
b_1	Y	0.0610	0.1360	0.2243	0.8342*
		(0.2085)	(0.4809)	(1.4030)	(43.4150)
b_2	$\frac{1}{2}Y^2$	0.0758*	0.0790*	0.0721*	
		(3.7289)	(3.8788)	(3.8317)	
c_1	r_1	5.1956	1.1055	0.4479*	0.4478*
		(1.6879)	(1.3129)	(3.1905)	(3.1018)
c_2	r_2	-1.9654	-0.2508	0.3240*	0.3598*
		(-1.1586)	(-0.3880)	(3.1411)	(3.4197)
c_3	r_3	-2.2302	0.1453	0.2281**	0.1924
		(-0.9003)	(0.2011)	(1.9974)	(1.6543)
c_{11}	$\frac{1}{2}r_1^2$	1.2702			
		(0.9059)			
c_{22}	$\frac{1}{2}r_2^2$	-1.2749**			
		(-1.9727)			
c_{33}	$\frac{1}{2}r_3^2$	0.7693			
		(1.3475)			
c_{12}	r_1r_2	0.3870			
		(0.6001)			
c_{13}	r_1r_3	-1.6572			
		(-1.5344)			
c_{23}	r_2r_3	0.8879			
		(1.4132)			
d_1	Yr_1	-0.0855	-0.0809		
		(-0.7354)	(-0.8030)		
d_2	Yr_2	0.0357	0.0719		
		(0.3997)	(0.8996)		
d_3	Yr_3	0.0498	0.0090		
		(0.5509)	(0.1044)		
Estimated Covariance Matrix Determinant		0.16773	0.17047	0.17098	0.17876
Adjusted R^2		0.8758	0.8749	0.8754	0.8701

DATA APPENDIX

The values of all variables except the index of water treatment (z_1) and the three input prices are taken directly from the American Water Works Association, Survey of Operating Data for Water Utilities in 1970. Total cost of firm operation (C_i) is defined to include operating, maintenance and administration expenditures and excludes tax and debt payments as well as annual depreciation.

Our treatment index is generated by applying a set of cost weights to the treatment activities of each utility. The AWWA reports whether utilities engage in the following treatment activities: coagulation, filtration, taste and odor control, disinfection, softening, corrosion control, iron or manganese removal, fluoridation, and other. Our weighting scheme, derived from consultation with the chief engineer of a local water district and a water facility design engineer, takes the form:

$$z_1 = 0.1\,t_1 + 0.2\,t_2 + 0.4\,t_3 + 0.05\,t_4 + 0.15\,t_5 + 0.03\,t_6 + 0.04\,t_7 + 0.03\,t_8 + 0.05\,t_9 \qquad \underline{\text{if } t_3 = 1}$$

$$z_1 = 0.2\,t_1 + 0.3\,t_2 + 0.1\,t_4 + 0.25\,t_5 + 0.05\,t_6 + 0.05\,t_7 + 0.05\,t_8 + 0.05\,t_9 \qquad \underline{\text{if } t_3 = 0}$$

where $t_i = 1$ if utility engages in i^{th} treatment activity; $i = 1,\ldots,9$.
($t_3 = 1$ if utility engages in taste and odor control)

An average hourly wage (r_1) for each utility is computed by weighting a set of regional wage rates generated for eighteen occupational classes in the water industry by the percentage of workers employed in each class by water utilities in the region. Separate wage rate and employment distributions are presented in American Water Works Association, 1974 Survey of Water Utilities Salaries, Wages and Employee Benefits (1975) for five size classes of government and private water operations in nine regions of the country. Hence, our derivation allows firm wage rates to vary with geographical location, type of ownership and size of operation.

Price per kilowatt of purchased electricity (r_2) is derived from industrial rate charges reported for sellers of electric power in Federal Power Commission, Typical Rate Bills, 1970. While these data allow for geographic variations in electric rates, they do not permit variations in rate schedules according to whether the purchaser is government or private. Given the frequency with which water and power are jointly supplied by municipal agencies, we expect that our energy price estimates overstate the cost of energy to government operations.

Price per unit of new capital purchased (r_3) is computed using a regional finance rate multiplied by an index of the cost of utility construction in that region. Regional finance rates are allowed to differ for government versus private operations so that they may reflect the tax preferred treatment of government debt instruments. These rates are generated by weighting the average yields on various debt instruments used by each type of firm in each region during 1970 by the relative magnitude of each type of new debt. Yields are reported in the AWWA Survey of Operating Data for Water Utilities in 1970. Regional utility construction indices for 1970 are provided in McGraw-Hill, Engineering News Record (March, 1981).

NOTES

[1] Not only have these studies indicated the ease with which utility output may be defined and measured (see, for example, Meyer, p.393; Crain and Zardkoohi, p. 400), but they have also noted the neat categorization of utilities into two ownership categories — public and private. In this paper, we show how the first assumption can significantly effect ones conclusions about the production technology of utilities. Likewise, we argue (but defer proof to a later paper) that the second assumption may result in incorrect assessments about the relative efficiency of alternative ownership forms. In reality, many government utilities have incentive structures that result in less attenuation of property rights than in strictly regulated private operations. The legal form of the enterprise will not always be a good indicator of either property rights attenuation or the existence of Averch-Johnson effects.

[2] Crain and Zardkoohi (1978) assume a generalized Cobb-Douglas production function for water with capital and labor as inputs into the production process. Neuberg (1978) uses a total cost function for electricity distribution which is consistent with the Cobb-Douglas specification but includes average wage rate as its only input price (price of capital services is assumed constant over all firms); at the same time, he estimates an average cost function which permits nonhomogeneity. Meyer (1975) adopts a cost function for electric utilities which is quadratic in firm output and omits factor prices. Christensen and Greene (1976) explicitly test for the proper production specification of the Nerlove (1963) model of electricity generation by using a translog cost function that includes fuel, capital and labor factor service prices. However, unlike the first three studies, this latter study does not examine the relative efficiency of government and private utilities.

[3] Neuberg (1978) expresses similar concern about the impact of variations in service mix on utility costs in his analysis of municipal versus investor-owned electric power distribution systems. However, his econometric approach to the problem differs markedly from the following analysis.

[4] Our model of water delivery production and cost structures closely parallels the hedonic cost function approach used by Spady and Friedlaender (1978) in their study of the trucking industry.

[5] This approach is similar to Lancaster's (1966) characterization of a good as a vector of properties; in our analysis, these properties are represented by our service attributes. Neuberg (1978) prefers to view these attributes as indicators of differences in firm technology which shift firm costs. Our approach leads to the aggregation of various service dimensions and volume levels into a composite output index which permits a host of different $(Y,z_1,..,z_m)$ vectors to generate the same level of firm "output" and have the same impact on firm costs.

[6] Since our service characteristics are continuous variables, the use of a multi-product model where outputs are differentiated by their associated service mix could conceivably lead to an infinite number of firm outputs. Moreover, Neuberg (1978) argues that since these service attributes are interdependent and cannot be separately priced and sold, it would be inappropriate to employ a joint-product model to characterize utility activities.

[7] See Christensen and Greene (1976), p.658.

[8] The assumption that only input mix is endogenous to the regulated utility underlies much of the methodology previously used to test for significant differences in firm cost performance. We are currently working on an extended model of the water utility industry which allows for the endogenous determination of utility volume, service-mix, input mix, rate structure and non-sale revenues.

[9] For a more detailed discussion of the problems inherent in applying the traditional hedonic approach to regulated industries, see Spady and Friedlaender (1978), p.160.

[10] As Spady and Friedlaender (1978, p.161) indicate, this specification is somewhat restrictive in that it assumes that the mix of service attributes offered by the firm is independent of relative factor prices. While factor prices do effect the optimal input mix and the level of the firm's output index Q( ), this level of output may be attained by a variety of volume and service combinations.

[11] The average capital and wage rates for government operations were significantly lower than for their private counterparts in our sample. Because we were unable to differentiate energy rates for the two ownership forms, we were unable to test for significant differences in electricity charges. However, we would expect these differences to exist, if only because government water companies often are joint producers of electricity which they may buy from themselves or from companion agencies at favorable rates.

[12] We have adopted the Christensen and Greene (1976) translog formulation which, unlike the Spady and Friedlander (1978) model, does not take the sample mean as the point of approximation for the translog estimation.

[13] Spady and Friedlaender (1978) use a translog approximation for the hedonic function g( ) which allows for interaction effects between the service indicators. We initially adopted this specification and found that these interaction terms were, as a group, insignificant at the five percent level. Largely because of this finding and the fact that the interaction terms introduced severe multicollinearity into the model, we decided to omit the service attribute interaction terms from our final estimation. Our specification implies that the impact on firm output (and, hence, costs) of changes in the level of a service attribute is constant and independent of the level of any other service activity.

[14] Our methodology tests for the <u>relative</u> cost efficiency of government versus private-regulated utilities. It assumes that decision makers are equally proficient (technically) but that they may differ in their cost minimizing behavior due to institutional differences in incentives and constraints. Furthermore, it assumes that such incentives and constraints are uniform within each of the two ownership classes (see ftnt 1, above).

[15] See Christensen and Greene (1976), p.661.

[16] To the extent that purchased water has been processed prior to purchase and pass through, we would expect that its price would reflect the costs of such processing. Such "out-of-house" treatment would be less expensive than comparable in-house processing only if there existed economies of scale in treatment activities.

[17] We suggest that it is the average size of metered accounts, rather than the average size of all accounts, which affects delivery costs. The administrative cost of flat rate delivery is negligible regardless of the amount of water consumed by flat rate users.

[18] Because the translog approximation requires the logging of all variables, we must transform those indices (z_1, z_4, and z_6) which take on values of zero in the data set. We have added one to their values to correct for this problem. This approach is suggested by Spady and Friedlaender (1978, p.164).

[19] While some companies can use a gravity-powered system in which the source of primary water input is at a higher elevation than its users, others must "lift" subterranean water to higher surface elevations in order to access user-delivery locations. If primary water inputs were properly priced to reflect these differences in energy potential, then cost differences between companies might be reduced to unique topological characteristics of their service areas. However, water inputs are not generally priced through a bidding process that capitalizes energy savings.

[20] See American Water Works Association, **Operating Data for Water Utilities** 1970 and 1965 and **1976 Employment Survey of Water Utilities;** Federal Power Commission, **Typical Electric Bills, 1970;** and McGraw-Hill, **Engineering News Record,** March, 1981.

[21] Since our nonlinear routine yields maximum likelihood estimates, we can test parameter restrictions with a maximum likelihood ratio test. The log of the ratio of the estimated covariance matrix determinant of the restricted model to the estimated determinant of the unrestricted model, multiplied by the number of observations (319), is distributed asymptotically as chi-squared with degrees of freedom equal to the number of parameter restrictions. See Christensen and Greene (1976), p.663.

[22] Christensen and Greene (1976, p.661) define this scale economies measure to equal one minus the eleasticity of firm costs with respect to output. This measure will take on negative values for diseconomies of scale.

[23] The scale economies measure for a homothetic, unitary elastic production function will equal $1 - (b_1 + b_2 \ln Y)$. Our estimates yield SCE = $0.7757 - 0.0721(\ln Y)$.

[24] The results concerning pooling were borne out by both a maximum likelihood ratio test and a Chow test.

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