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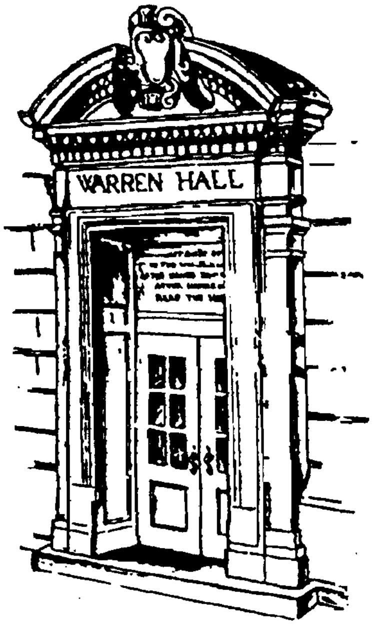

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A Hedonic Approach to Estimating Operation and Maintenance Costs for New York Municipal Water Systems

by

Todd M. Schmit and Richard N. Boisvert

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Abstract

A hedonic cost function is used to isolate the O&M costs for water treatments. For small systems, costs are substantial for some technologies, but not for others. Financial burdens may still be substantial for small systems; rural systems have some cost advantage given input costs relative to urban areas.

A Hedonic Approach to Estimating Operation and Maintenance Costs for New York Municipal Water Systems

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Introduction

The ability of small public water systems to comply with monitoring and treatment requirements under the Safe Drinking Water Act (SDWA) continues to be an open question for national, state, and local policy makers and government officials. National estimates of SDWA compliance costs range anywhere from $1.5 to over $4 billion dollars for existing rules, not including proposed rules such as the enhanced surface water treatment rule, disinfection by-products rule, or radionuclides (CBO, 1995). Based on certain necessary but simplifying assumptions, others have converted these estimated national cost totals onto a household basis (EPA, 1990; and EPA, 1993b). Due to substantial economies of size in water treatment and the extent of existing treatment technologies already in operation, many households served by larger systems will witness only modest increases in water costs (about $10 to $20) as water systems are brought into full compliance. Those served by many smaller systems will not be so fortunate; estimated cost increases run as high as $150 to $400 per household, depending on the type of treatment required (EPA, 1993b). Over 90% of the 57,000 community water systems nationwide serve populations under 10,000 people, a size below which many believe systems are unable to take advantage of economies of size and/or have insufficient resources to finance SDWA requirements at a reasonable cost to consumers (Boisvert and Schmit, 1996; and EPA, 1993b).

Although the national cost projections are based on the best available information, most components are derived from cost engineering relationships. There has been little systematic study of the actual costs of construction and operation of small water systems currently using various treatment technologies. While Stevie and Clark (1978), Logsdon *et al.* (1990) and Schmit and Boisvert (1996) are important exceptions, other previous work (e.g. Bruggink, 1982; Feigenbaum and Teeples, 1983; and Bhattacharyya *et al.*, 1994) focuses primarily on costs for larger systems. This is in part due to the availability of data for larger systems from the AWWA. It is also true that the focus of these cost studies has been on operation and maintenance (O&M) costs because cross sectional financial data for water systems contains little information on the age or level of capital investment.

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The purpose of the research on which this report is based is to contribute to an understanding of public water system treatment costs by accounting explicitly for system size, population densities, factor prices, water source, and water treatment technologies in estimating water treatment cost functions. The differential costs of improved water quality are accounted for in a hedonic fashion reflecting the existing types of water treatment; this approach represents a substantial improvement over past efforts using simplified hedonic quality indices based on the number of treatments. This model specification is made possible through a combination of financial data for New York water systems from the Division of Municipal Affairs and data on current treatment from the FDRS-II national data base. It is true that the focus must still be limited to O&M costs, but both small and large systems are represented in the data. It is only through a comprehensive data set of this kind that the costs of small and large systems can be estimated on an equal footing.

We continue this report with a brief review of the literature on the estimation of water system cost functions, focusing primary attention on hedonic functions for public water supply utilities. This is followed by the development of the O&M cost model and a discussion of the data used for parameter estimation. We then discuss the results of the model and cost differences across treatment alternatives and system size. Finally, we articulate some general conclusions and policy implications.

A Brief Overview of Related Literature

Research into water supply costs and implications of drinking water regulations was underway well before the 1986 amendments to the SDWA (e.g. Clark and Goddard, 1977; Clark and Stevie, 1981; Stevie and Clark, 1982; Bruggink 1982; and Feigenbaum and Teeples, 1983). Some of this early work focused on the relative efficiency of public and private systems. The substantial new monitoring and treatment requirements embodied in the amendments, however, have heightened the interest in this type of research because the cost implications are directly related to the survivability of many small water systems across the country. Numerous national level estimates of the costs of compliance have been completed, but few models have concentrated on estimating the individual system response to various treatment concerns and water quality considerations. There has been some limited evaluation of treatment technologies suitable to small water systems, and they serve as a good starting point for further research (Logsdon *et al.*, 1990; Goodrich, *et al.*, 1992; and Malcolm Pirnie, 1993). For the most part these studies examine the costs for individual treatments and do little to address the costs associated with multiple treatments. These types of comparisons of costs across treatments and system sizes are essential for any meaningful policy analysis and national implications.

As an alternative, one can envision a hedonic approach whereby costs are assumed to be a function of overall water quality, which in turn depends on the types of water treatments. In this way, the additional costs due to treatments or multiple treatments are reflected in an index of water quality. This hedonic approach has received only limited attention, especially with respect to the treatment technology specification. Bruggink (1982), for example, evaluated the comparative efficiency of public and private ownership in the municipal water industry by estimating a multivariate operating cost model. Operating costs were assumed dependent on several production, distribution, regulatory, and ownership variables. Treatment concerns were addressed only through a simplified treatment index variable, reflecting primarily the number of treatments applied rather than specific treatment effects (Bruggink, 1982). Interaction effects with production, water source, and other variables were not included. In addition, the model ignores any differences in product quality and specification of production technology. The results were based on 86 large water systems all serving more than 10,000 people.

In 1988, Holmes examined the relationship between soil erosion and water treatment costs by estimating a water production cost function which included various water quality and economic variables. While from a slightly different perspective of soil conservation policy, environmental quality was viewed as a factor input where variations in quality induce changes in the cost of water. Holmes estimated a Cobb-Douglas (C-D) cost function, appended with a variable representing influent water quality. A two-stage model was presented where ambient water quality was a function of turbidity levels based on sediment loading, stream flow, and reservoir storage capacity. The second stage was then used to estimate treatment costs as a function of production, input prices, and ambient water quality. Unfortunately, actual treatment costs were not available so "typical" costs of specific treatment technologies were used along with firm specific data on whether the technology was used or not. In addition, the C-D specification restricts average costs to decline monotonically even though one may expect an increase in unit costs at upper extreme system sizes. The hedonic water quality component was positive and significant.

Hedonic cost approaches for water utilities continued with Feigenbaum and Teeples (1983) and Teeples *et al.* (1986); they examined the effect of ownership on firm cost structure. A hedonic model was specified incorporating a translog cost function with factor prices and quality adjusted production. The functional form used is adapted from Spady and Friedlaender's (1978) hedonic cost model for the regulated trucking industry. Spady and Friedlaender argued that failing to account for industry characteristics creates serious specification errors and incorrect inferences regarding economies of size.[1] The hedonic coefficients in the cost function can then be seen as representations of technology; and if the technologies affect resulting costs, their inclusion in the specification is necessary for accurate cost predictions and estimates of economies of size.

The quality and service attributes specified by Feigenbaum and Teeples (1983) are limited in terms of treatment technologies as they adopt a treatment index approach similar to Bruggink (1982). In addition, they include service attributes such as metered customers, purchased water, customer density, and storage capacity. The treatment quality attribute was weighted by costs obtained from engineering data for each firm's treatment activities. AWWA data on actual O&M costs for 1970 were obtained for 320 large water supply firms. The hedonic specification was superior to the non-hedonic specification and costs were shown to increase significantly with the level of treatment. Economies of size were estimated at 0.14 for the final hedonic specification imposing unitary elasticities of substitution with respect to inputs, and homotheticity and homogeneity in the production process.[2]

The Model

Here, we adopt a model similar to the one used by Feigenbaum and Teeples (1983), but the hedonic specification is in terms of primary water source and several specific treatment technologies used frequently in New York State. We also incorporate fixed factors of production into the cost specification.

The hedonic indirect cost function to represent public water systems can be derived from a production function of the form:

$$(1) \qquad Q(Y; z_1, z_2, \ldots, z_s) = f(L, E, D, W)$$

where:

$Q()$ = an index of firm output,

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[1] Spady and Friedlaender (1978) favor hedonic representations of outputs and qualities as arguments compared with conventional cost functions with exogenously specified quality adjusted outputs as arguments. The hedonic specification permits various quantity technology combinations to reflect the same level of quality.

[2] Bhattacharyya *et al.* (1994) used similar 1989 AWWA data to examine the relative efficiently between public and private water utilities and came up with an almost identical economies of size level of 0.15.

Y = average daily flow of water delivered,

z_s = water treatment and source attribute associated with Y,

L = labor input,

E = energy input,

D = service area population density, and

W = water input.

Water output is represented by the hedonic output, Q, reflecting both the water production of the system measured in gallons per day (Y) and its associated treatment characteristics (z_s). The production technology applicable to the firm is represented by $f(\ )$, and for our purposes need not be given further specification.

Since public water utilities are for the most part legally obligated to supply all output that is demanded in their service territories at regulated rates, it is reasonable to assume that they operate in the short run to minimize the cost (by adjusting input levels) subject to this demand or output constraint. Under these conditions, and applying the economic duality results, we know that there exists an indirect cost function $C(\ )$ which depends only on exogeneously determined input prices, quality adjusted output Q and a set of fixed factors (Christensen and Greene, 1976).

We define our hedonic cost function similar to the one used by Spady and Friedlaender (1978) for the regulated trucking industry, but we expand the model to include fixed factors. The regulatory constraints imposed on the water supply industry make the volume of water, service mix, and quality dimensions of output all exogenous to the firm, and hence assure that the parameter estimates are free of simultaneity bias (Feigenbaum and Teeples, 1983). The hedonic cost function is of the form:

$$(2)\quad C = C(Q(Y; z_1, z_2, \ldots, z_s); r_1, r_2, \ldots r_i; F_1, F_2, \ldots F_m),$$

where annual O&M costs (C) are a function of the hedonic output (Q), factor prices (r_i), and fixed factors (F_m).

The translog specification of this general form is:

$$\text{(3)}\quad \ln C = b_0 + b_1 \ln Q + b_2\left[\tfrac{1}{2}(\ln Q)^2\right] + \sum_i c_i \ln r_i + \tfrac{1}{2}\sum_i \sum_j c_{ij} \ln r_i \ln r_j + \sum_i d_i \ln Q \ln r_i$$
$$+ \sum_m f_m \ln F_m + \tfrac{1}{2}\sum_m \sum_n f_{mn} \ln F_m \ln F_n + \sum_m g_m \ln Q \ln F_m + \sum_m \sum_i h_{mi} \ln F_m \ln r_i \,,$$

where:

$$\text{(4)}\quad \ln Q = \ln Y + \phi\,(z_1, z_2, \ldots, z_s)\,,\ \textit{and}$$

$$\text{(5)}\quad \phi\ = \sum_s a_s z_s \,.$$

Input prices are denoted by r_i and fixed factors are denoted by F_m. Here, *ϕ( )* is the hedonic function aggregating the various water source and treatment attributes provided by the firm and *Q( )* is the quality adjusted water flow index.[3] To utilize all available information for statistical efficiency in estimation, the cost function is estimated jointly, along with a system of n-1 factor share equations:

$$\text{(6)}\quad \frac{r_i x_i}{C} = c_i + \tfrac{1}{2}\sum_j c_{ij} \ln r_j + d_i \ln Q + \sum_m h_{mi} \ln F_m$$

These share equations are transformations of the partial derivatives of the cost function with respect to input prices. From duality theory, we also know that they are transformations of the input demand functions, and by including them in the system to be estimated, we implicitly embody the assumption of cost minimization.

To ensure that the cost function is homogenous of degree one in factor prices and that the symmetry conditions hold, we impose:

$$\text{(7)}\quad \sum_i c_i = 0;\ \sum_i d_i = 0;\ \sum_i h_{mi} = 0;\ c_{ij} = c_{ji}\,;\ f_{mn} = f_{nm}\,;\ \textit{and}\ \sum_j c_{ij} = 0.$$

Cross equation constraints are imposed so that particular parameters take on the same value in all equations, and to impose (7), the parameters of the n^th share equation are identified analytically from the conditions in (7). Finally, because *Q* cannot be observed, we must substitute equation

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[3] Since the water source and treatment attributes are (1,0) dummy variables, the natural logarithm is avoided for the hedonic component. The implications of this specification is that *Q* is quality separable, and is homogenous of degree one in volume. This latter assumption implies that all else equal, the quantity of output is proportional to water volume. Written differently the hedonic function has the form $Q = Ye^{\sum a_s z_s}$.

(5) into equation (4) and equation (4) into equation (3) to arrive at the final form of the cost equation. Through this series of substitutions, the resulting equation to be estimated is non-linear in its parameters and is estimated using non-linear two-stage least squares The full hedonic specification is estimated, and we test restrictions on unitary elasticities of substitution between the inputs and homotheticity and homogeneity of the production process. A non-hedonic specification is also estimated by restricting $a_s=0$ for all s.

From an empirical perspective, we need data on O&M costs and cost shares and input prices for labor and energy. There is only one fixed factor included; it is the population density of the service area, as measured in people per square mile. The treatment attributes (z_s) include the nature of the primary water source and eight different treatment technologies.

Data Summary

Several sources of data were combined to form a data set for several hundred local governments in New York State and their associated community water systems. One primary source of data was the annual financial reports for all New York municipalities for fiscal years 1987 through 1992 available from the Office of the State Comptroller, Division of Municipal Research and Statistics. Due to its comprehensive and complex nature, transformation of the data to usable SAS data sets was necessary. Combinations of equivalent auditing codes were completed to provide meaningful financial measures across all water systems represented in the data.

Since the emphasis of this research is on community water system (CWS) operations and their relation to the treatment technologies employed, only those annual financial report data for municipalities operating water systems were retained. General municipal level information, such as population and population density, was obtained for these areas and were merged together to form one data set of financial and municipal information for community water systems. In effect, all water system fund accounts, including revenue, appropriation, and general ledger accounts, were included in the data set.

In order to relate this water system financial information to specific system characteristics, data from EPA's Federal Reporting Data System (FRDS-II) were also included in the data set (EPA, 1993a). A component of the summary level FRDS-II data base includes water system classification by ownership type. This classification includes systems operated by private, local government, state government, federal government, mixed public and private, and Native American entities. Only those CWSs owned by local governments were retained. Other data obtained from the FRDS-II data base include such items as the population served, service connections provided, average daily water production and system design capacity, primary water source, and treatments applied to the source water prior to distribution to the service area.

Because water systems in New York are operated by different units of local government or as special districts, some of the FRDS-II data specific to individual operations on a system level basis did not coincide exactly with an entire municipality or unit of local government. This potential difficulty was most frequent for towns, and was much less common in cities or villages. Many town water systems, but not all, are served by several individual special water districts within the town. For example, an original town water system may have been developed to serve a given population and geographic area. Later, additional areas of the town wish to be connected to the CWS and in so doing commonly form their own Water District within that town. Generally, the costs of extending service to this area, as well as annual operating costs, are paid for by that individual district through user fees or property tax assessments. In some cases, water districts are formed within a town and operate separately from the other existing districts. That is, they provide their own sources of water, distribution to service connections, and/or treatment necessary. The problem arises because town financial information covering all water districts is what is reported to the Office of the Comptroller to satisfy its annual reporting requirements. Thus, within this reporting procedure, data for some individual water districts could not be disentangled. So as not to loose the data for these water districts, any town where this problem occurred was treated as one large district and the data were aggregated across water districts. Data from FDRS-II were used to estimate the proportions of water in these aggregated districts that came from surface or ground water sources and that were subject to certain types of treatment.[4]

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[4] This procedure was much more complex then is suggested by this simple scenario. Inconsistencies between FRDS-II systems and town level water districts were especially troublesome. Furthermore, many small systems purchase treated water and therefore the treatments which are applied are not necessarily dictated in the FRDS-II data. As such, it was necessary to eliminate some municipalities from the data set because an accurate correspondence could not be made between the water system information and the municipal financial data. Despite these difficulties, and those normally due to missing or obviously inaccurate data, the final data set includes observations for 36 cities, 112 towns, and 211 villages; for a total of 359 municipal governments. This represents nearly 70% of the municipalities from the initial combined FRDS-II and comptroller data sets and almost 60% of those municipalities which had financial water system data in the initial comptroller data file.

Although one cannot know with certainty, it would appear that these procedures needed to put a consistent data set together would not lead to any systematic bias in the sample. For example, There were initially water system financial data for 615 municipalities; 9% were cities, 35% were towns, and

Finding data for wage and electricity rates (prices for the two major inputs) for individual water systems was much more problematic, as one would not expect to find them in financial data reported to a state agency. By the same token, one might also expect to find some similarity in wage rates across water systems by locality or by region of the state. Therefore, as a proxy for public water system wage rates, county level data on county local government earnings were divided by local government employment to obtain an implicit annual rate of compensation (from the CD-ROM Regional Economic Information System, REIS, 1987-92). This proxy should be highly correlated with local government wage rates and effectively capture the desired effect in the regression by reflecting important differences in wage rates by region and over the five year period. Using community specific electricity rates in the regression was less problematic as these rates would under any circumstances be constant for systems within the service territories of New York's major electric utilities. These data are from the Annual Electric Utility Reports (EIA, 1987-92).

Empirical Analysis

In conducting this econometric analysis, it is important to have a broad representation of water systems in the data set. A good perspective on the variety of water systems included in the sample is evident from the summary statistics in Tables 1 through 3 below.

Some Descriptive Statistics

To begin to understand the data, we can look at system size. The average size of the communities served was slightly over 6,500 persons, but size ranged from a low of only 100 to over 190,000 people (Table 1). This wide range in size is significantly greater than accommodated in previous studies and allows for an analysis of small systems to be conducted on an equal footing with larger ones. Total O&M costs excluding debt service average nearly $355,000 (1992 dollars), and range from under $2,000 to nearly $9 million. On a per capita basis, these costs average about $57, and range from $12 to nearly $450. The cost data also show that labor and labor related expenditures (i.e. employee benefits, etc.) constitute over 40% of the total operation costs on average; the range is from nearly zero to 86%. Table 1 also distributes O&M costs by type of expenditure as reflected in the New York State audit codes.

56% were villages. For the final data set containing 359 municipalities, 10% are cities, 31% are towns, and 59% are villages.

Table 1. Descriptive Statistics For Variables in Cost Function Estimation.

Variable	Description	Mean	Std. Dev.	Min.	Max.
TOTCOST	Total O&M cost excluding debt service (1992 $)	354,901	779,678	1,629	8,948,502
ADMCOST	Administrative costs (1992 $)	57,092	150,121	211	1,566,288
PURCOST	Purification costs (1992 $)	81,018	235,499	114	2,531,345
TRDCOST	Transmission and distribution costs (1992 $)	96,950	312,154	0	4,535,152
SSPCOST	Source supply and pumping costs (1992 $)	60,160	124,895	0	1,595,619
CSUCOST	Common water supply costs (1992 $)	539	8,689	0	343,394
OTHRCOST	Other O&M cost (1992$)	25,016	78,078	0	1,253,607
UNEBCOST	Undistributed employee benefit costs (1992 $)	34,124	85,302	0	1,129,797
TCSTPGAL	Total O&M cost per gallon (1992 $)	0.43	0.38	0.07	5.98
TCSTPCAP	Total O&M cost per capita (1992 $)	56.97	36.29	11.69	448.44
WAGSHARE	Labor cost share of total O&M cost	0.42	0.17	0.00	0.86
POPDEN	Population density (People per square mile)	1,523	1,775	2	13,693
TOTLPOP	Water system population	6,551	16,618	100	192,000
TOTLHU	Water system hookups	1,856	4,372	28	45,503
TOTLPROD	Average daily water production (gpd)	1,227,356	3,784,696	10,000	50,090,000
TOTLDESC	System design capacity (gpd)	2,177,988	5,833,857	42,413	64,000,000
RESRAT	Community residential electric rate ($/kwh)	0.097	0.022	0.021	0.160
GOVWAGE	County government wage rate (1,000's 1992 $)	28.289	3.087	22.126	40.491
Treatment and Water Source Dummy Variables:					
AERTRT	Aeration treatment	0.144	0.351	0	1
DEFTRT	D.E. Filtration treatment	0.064	0.245	0	1
RSFTRT	Rapid Sand Filtration treatment	0.151	0.358	0	1
SSFTRT	Slow Sand Filtration treatment	0.034	0.181	0	1
OFTRT	Other Filtration treatment	0.042	0.200	0	1
UFTRT	Ultra-Filtration treatment	0.090	0.286	0	1
IETRT	Ion Exhange treatment	0.046	0.210	0	1
CFTRT	Coagulation/Flocculation treatment	0.256	0.437	0	1
SURFACE	Surface water source	0.509	0.500	0	1

Note: The average values for the dummy variables are equal to the proportions of the systems with that attribute.
Aeration treatment includes cascade, packed tower, and slat-tray aeration.
Other filtration includes pressure sand and direct filtration.
Coagulation/Flocculation treatment includes processes of flocculation, coagulation, rapid mixing, and sedimentation.
All systems use chlorination and is thus not individually specified here.

Average water production is over 1.2 mgpd, ranging from only 10,000 gpd to over 50 mgpd.[5] On a per capita basis, average water production was approximately 161 gpd, or 45% higher than the average for the state (Boisvert and Schmit, 1996). The range in per capita water consumption for the sample systems is from a low of 127 gpd for the very small systems, to over 260 gpd for the very large systems (Table 2). This range begins slightly above the 111 gpd per capita average for the state, but this is not unexpected because smaller systems are just slightly underrepresented in the sample relative to the state. About half of the systems in the sample have surface water as their primary water source; this is less than the state average of about 60%.

The water quality attributes, as reflected in the specification of the dummy variables, are summarized at the bottom of Table 1. The means of these dummy variables are equal to the proportions of systems currently using the treatment.[6] Chlorination (gas or liquid) is used on all systems in the sample; it is not reported here. Other simple and inexpensive non-SDWA specific type treatments, such as pH control or fluoride addition, were not specified individually and are included along with chlorination as a reference point for the dummy variable regression. Coagulation/Flocculation/Sedimentation processes are used on over 25% of the systems, which is not surprising given their common application in conjunction with rapid sand, ultra, and other filtration, as well as ion exchange. This proportion is similar to the state average of around 30%. Rapid sand filtration is used on over 15% of the systems, with aeration being a close third at over 14%; averages for the state are 10% and 11%, respectively. Somewhat surprisingly, slow sand filtration is used by fewer than 4% of systems, especially given the relatively high proportion of systems serving populations below 10,000 people. For the state as a whole, however, slow sand filtration is used by fewer than 3% of the systems. The remaining treatments listed in Table 1 are all used by fewer than 10% of the sample systems.[7]

Slightly more detail regarding factors affecting water quality by size classification is presented in Tables 2 and 3. The percentage of systems using surface water and multiple

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[5] mgpd = million gallons per day, gpd = gallons per day.

[6] See Boisvert, Tsao, and Schmit (1996) for a more detailed description of the various water treatment technologies.

[7] Specifically, data treatment percentages for diatomaceous earth filtration, ultra filtration, other filtration, and ion exchange were 6%, 9%, 4%, and 5%, respectively; compared with state proportions of 4%, 5%, 6%, and 5%, respectively.

Table 2. Additional Descriptive Statistics by Population Category.

Population Category	Systems		Water Production	Surface Water	Wage Rate	Electric Rate	Population Density	Treatments Applied		
	Number	Percent						Mean	Min	Max
	No.	%	gpdpc	%	$ 000	$/kwh	No/sq mile			
< 500	44	12.26	127	19	26.826	0.102	351	1.13	1	3
500 to 999	83	23.12	159	36	27.061	0.096	543	1.32	1	3
1,000 to 4,999	145	40.39	163	48	28.293	0.095	1260	1.74	1	5
5,000 to 9,999	34	9.47	154	79	29.944	0.101	2865	2.21	1	4
10,000 to 24,999	30	8.36	177	92	29.642	0.098	3376	3.19	1	5
25,000 to 49,999	16	4.46	180	75	30.808	0.098	4065	2.99	1	4
50,000 to 99,999	4	1.11	265	100	30.302	0.096	4165	3.26	3	4
100,000 +	3	0.84	201	100	32.474	0.092	5392	2.67	1	4
All Systems	359	100.00	161	51	28.289	0.097	1523	1.83	1	5

All costs in 1992 constant dollars.

gpdpc = gallons per day per capita, kwh = kilo-watt hour, density measured in people per square mile.

Treatments based on model categories and include chlorination, but no other "aesthetic" treatments.

Table 3. Treatment Frequencies by Population Category.

Population Category	Number of Systems	Percentage of Systems Currently Using Treatments							
		Aeration	D.E. Filtration	Rapid Sand Filtration	Slow Sand Filtration	Other Filtration	Ultra Filtration	Ion Exchange	Coagulation / Flocculation
< 500	44	2.6	0.0	0.0	5.2	0.4	0.0	0.0	5.2
500 to 999	83	3.4	6.0	3.2	0.0	6.4	2.6	2.6	8.3
1,000 to 4,999	145	15.3	6.5	12.3	3.3	4.3	7.2	5.5	19.9
5,000 to 9,999	34	15.5	9.3	30.6	3.1	4.7	8.3	9.3	39.9
10,000 to 24,999	30	38.6	17.5	48.0	10.5	5.3	21.1	7.0	70.8
25,000 to 49,999	16	36.8	0.0	37.9	6.3	0.0	36.8	6.3	74.7
50,000 to 99,999	4	26.1	0.0	0.0	0.0	0.0	100.0	0.0	100.0
100,000 +	3	33.3	0.0	66.7	0.0	0.0	0.0	0.0	66.7
All Systems	359	14.4	6.4	15.1	3.4	4.2	9.0	4.6	25.6

In addition, all systems currently disinfect with either gas or liquid chlorination processes.

treatments increases as system size increases.[8] Treatments such as diatomaceous earth, slow sand, other filtration (including pressure sand and direct filtration), and ion exchange are used exclusively by small to medium-size systems. Treatments such as rapid sand and ultra filtration and aeration are used little by small systems, but frequency of use increases with population.

Estimated Cost Equations

There are 359 systems represented in the sample, and there are six years of data for each system. For purposes of estimation the data were treated as a pooled time series of cross sections. In so doing, econometric estimation of the hedonic O&M cost model was based on a data set with an excess of 2,000 observations. System O&M costs and government wage rates were converted to constant 1992 dollars by the *Index of Average Hourly Compensation, All Employees, Non-farm Business Sector* (BEA, 1987-92), while electricity rates were converted by the *Producer Price Index for Intermediate Materials, Supplies, and Components* (BEA, 1987-92). The estimated equations for the hedonic and non-hedonic specifications are in Table 4.

The hedonic results are particularly encouraging, given that over 90% of the variation in the dependent variable is explained and the coefficients all have the expected signs and for the most part the t-ratios on the parameter estimates are relatively high. The model was tested for unitary elasticities of substitution with respect to the two input variables (Model 2) as well as homogeneity and homotheticity restrictions in the production process. We rejected these restrictions. This provides strong evidence that Model 1 is appropriate, that the input substitution elasticities are not unity for the underlying, but unknown, hedonic water production function, and that the production function is not homogenous in its inputs.[9] Furthermore, since only two input prices (labor and electricity) are specified, it was only necessary to estimate one cost share

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[8] Direct comparison with treatment numbers here and in previous reports, namely Boisvert and Schmit (1996) should be done with care. Boisvert and Schmit (1996) treatment distributions include separate classifications such as fluoride, pH control, and inhibitors, where these are not individually specified here. In addition, the earlier descriptive report separates the components of coagulation, flocculation, sedimentation, etc. into individual classifications. As such, numbers here will be substantially lower than earlier reporting schemes, and constitute only those processes directly involved in meeting SDWA regulations.

[9] An F-test was completed for each specification comparing the unrestricted (Model 1) specifications with the three alternative specifications. In all cases the null hypothesis was rejected at a significance level of $\alpha=.01$. For ease of exposition, only the restricted models imposing unitary elasticities of substitution with respect to the inputs for the hedonic and non-hedonic specifications are reported.

Table 4. Community Water System Annual Operation and Maintenance Hedonic Cost Estimation Results

		Hedonic Specifications				Non-Hedonic Specifications			
		Model 1		Model 2		Model 1		Model 2	
Parameter	Variable	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio
b0	Intercept	3.226	6.21	4.935	9.24	3.052	5.22	4.890	8.21
b1	Average Daily Flow (ADF)	0.386	4.98	0.429	5.28	0.385	4.37	0.407	4.46
b2	1/2 ADF Squared	0.024	4.12	0.021	3.43	0.028	4.18	0.026	3.74
c1	Wage Rate	0.295	9.47	0.027	0.94	0.270	8.12	-0.002	-0.08
c11	1/2 Wage Rate Squared	0.041	15.02	na	na	0.040	14.04	na	na
c2	Electric Rate	0.705	22.62	0.973	34.48	0.730	21.98	1.002	33.41
c22	1/2 Electric Rate Squared	0.041	15.02	na	na	0.040	14.04	na	na
c12	Wage Rate*Electric Rate	-0.041	-15.02	na	na	-0.040	-14.04	na	na
d1	Wage Rate*ADF	0.022	8.05	0.024	8.53	0.024	8.19	0.027	8.84
d2	Electric Rate*ADF	-0.022	-8.05	-0.024	-8.53	-0.024	-8.19	-0.027	-8.84
f1	Population Density	-0.090	-5.36	-0.127	-7.28	-0.088	-5.12	-0.123	-6.93
h1	Wage Rate* Popn. Density	0.013	4.74	0.020	7.46	0.012	4.62	0.020	7.29
h2	Electric Rate*Popn. Density	-0.013	-4.74	-0.020	-7.46	-0.012	-4.62	-0.020	-7.29
a1	Aeration	0.070	1.87	0.051	1.34				
a2	D.E. Filtration	0.396	6.86	0.430	7.29				
a3	Rapid Sand Filtration	0.678	8.88	0.674	8.61				
a4	Slow Sand Filtration	0.114	1.56	0.136	1.81				
a5	Other Filtration	0.390	5.66	0.321	4.58				
a6	Ultra Filtration	0.570	7.72	0.623	8.24				
a7	Ion Exchange	0.479	7.84	0.475	7.61				
a8	Coagulation/Flocculation	-0.145	-2.08	-0.162	-2.28				
Cost Equation:									
R-square		0.912		0.904		0.898		0.890	
RSS		426.569		464.309		494.788		532.388	
Root MSE		0.460		0.480		0.495		0.513	
Wage Factor Share Equation:									
R-square		0.080		0.021		0.085		0.025	
RSS		52.654		56.041		52.452		55.959	
Root MSE		0.161		0.166		0.161		0.166	

Note: Model 1 refers to the original specification, while Model 2 imposes unitary elasticities of substitution with respect to inputs.

Note2: The ADF*Density interaction term and the Density Squared term were removed from the final specification due to relatively high standard errors and low t-ratios.

equation. The regression statistics for the cost share equation are located at the bottom of Table 4.[10]

Further evidence that Model 1 is appropriate is provided in Table 5 where the actual operation O&M costs are compared with those predicted using the model. Across all systems, the mean O&M costs are $56.97, whereas the average of the predicted values is $55.84. This is a difference of less than 2%. For systems in five of the eight population categories listed, the average of the predicted costs are also very close to the average of the actual costs for systems in that size category.

Table 5. Hedonic Cost Function Prediction Statistics.

	O & M Costs Per Capita		
Population Category	Actual Mean	Predicted Mean	Percent Difference
	------------------1992 $---------------		
<500	62.36	56.87	-8.8
500 to 999	56.54	60.25	6.6
1,000 to 4,999	54.54	54.50	-0.1
5,000 to 9,999	56.66	48.59	-14.2
10,000 to 24,999	65.78	57.90	-12.0
25,000 to 49,999	53.71	53..11	-1.1
50,000 to 99,999	64.44	65.62	1.8
100,000+	38.08	49.16	29.1
All Systems	56.97	55.84	-2.0

From Model 1, total O&M costs rise with water volume and input prices, and they fall with a *ceterus paribus* increase in population density, although individual coefficients are hard to interpret given the hedonic structure of the model and interaction variables. With one exception, water treatments add to O&M costs, but the size of the increase varies substantially by treatment classification. The exception is the coagulation/flocculation/sedimentation (CFS) treatment category. This presents little problem, however, because these processes are almost exclusively employed in combination with rapid sand filtration, ultra filtration, other filtration, and ion

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[10] Although the R-square values on the cost functions are quite high, the R-square values on the factor share equations are quite low. This is not unusual in translog cost studies, however, since the estimation method does not simply minimize the sum of squared residuals, but also takes into account the covariance across equations (Spady and Friedlaender, 1978).

exchange to condition the raw water for efficient operation of the other processes. As such, it is the sum of the parameter estimates that determine the net effect on O&M costs. The positive coefficients in these four treatments are larger than the negative coefficient on CFS. Thus, the net effect on costs of CFS combined with any of these four treatments is positive.

Aeration and slow sand filtration imply the lowest incremental treatment costs. For most aeration technologies the need for chemical inputs is low, as are the labor requirements for operation. It is unfortunate that limitations in the data precluded further disaggragation of these technologies. Slow sand filtration, as expected, is the lowest cost among all filtration technologies because there are no chemical or power costs specifically tied to the treatment and minimal maintenance is required (Boisvert *et al.*, 1996). Other filtration, including direct and pressure sand filtration, is slightly more expensive than slow sand, and the relative sizes of the coefficients seem reasonable given the moderately higher operating requirements.

The effect on O&M costs from ion exchange, which is generally used by systems with ground water sources, is about in the middle compared with the other treatment categories. Although ion exchange may be well suited for small systems (exchange units can be installed on an individual or groups of wells), the maintenance of the resin capacity and regeneration materials are relatively costly. Ultra and rapid sand filtration lead to the highest marginal costs. Ultra filtration's higher operating costs stem from continual membrane maintenance including frequent back flushing and soaking of the membranes in cleaning chemicals. Rapid sand filtration's higher water flow rate, periodic back flushing, and increased operator requirements push its O&M costs above all other technologies evaluated here.

Estimating the Marginal O&M Costs of Treatment

In order to summarize our discussion of the use of this cost equation to estimate the marginal O&M costs of operation, we solved Model 1 for each treatment technology for seven system sizes, all of them within the range of data. These system sizes correspond to seven of the twelve categorical size limits EPA has established for policy making purposes (EPA, 1993b). We emphasize the very small through medium size system population levels, but costs for a couple of larger systems were calculated for purposes of comparison (Table 6).

To isolate the marginal costs of treatment, the data in Table 6 are based on the assumption that input prices, population density, and per capita demand are at mean levels for the data. Also, because water systems in the sample tended to use coagulation/flocculation processes in conjunction with rapid sand filtration, ultra filtration, other filtration, and ion exchange, the

Table 6. Simulation of Unit CWS Operation and Maintenance Costs Per Capita by Treatment Technology

Population	Base Case	Aeration			D.E. Filtration			Rapid Sand Filtration		
Served	AC	AC	ME	%	AC	ME	%	AC	ME	%
100	$93.25	$98.19	$4.94	140	$119.67	$26.42	139	$132.52	$39.27	139
500	63.31	66.84	3.53		82.29	18.99		91.61	28.30	
1,000	54.60	57.72	3.11	88	71.38	16.77	88	79.64	25.03	88
3,300	43.47	46.04	2.57	73	57.37	13.90	73	64.26	20.79	73
10,000	36.26	38.47	2.21	63	48.28	12.02	63	54.27	18.01	64
50,000	29.35	31.22	1.87	53	39.58	10.23	54	44.73	15.38	54
100,000	27.31	29.08	1.78	50	37.03	9.72	51	41.94	14.64	52

Population	Slow Sand Filtration			Other Filtration			Ultra Filtration			Ion Exchange		
Served	AC	ME	%	AC	ME	%	AC	ME	%	AC	ME	%
100	$97.15	$3.90	140	$106.82	$13.57	139	$121.98	$28.73	139	$119.40	$26.15	139
500	66.09	2.79		73.04	9.73		83.98	20.67		82.10	18.79	
1,000	57.06	2.46	88	63.19	8.58	88	72.87	18.27	88	71.20	16.60	88
3,300	45.50	2.03	73	50.57	7.10	73	58.62	15.15	73	57.23	13.75	73
10,000	38.01	1.75	63	42.39	6.13	63	49.37	13.11	63	48.15	11.89	63
50,000	30.83	1.48	53	34.55	5.20	53	40.52	11.17	54	39.47	10.12	54
100,000	28.71	1.40	50	32.25	4.94	51	37.93	10.62	51	36.93	9.62	51

All costs expressed in constant 1992 Dollars. AC = Average Cost per Capita, ME = Marginal Effect, % = Percent of ME at 500 people.
Water production per capita, population density, wage rate, and electricity rate assumed at mean levels in the sample data.

cost estimates for these treatments are based on that assumption.[11] Finally, it is important to reiterate that these estimated costs represent total O&M costs, (i.e. distribution, source supply and pumping, and treatment), and not just those associated with treatment. The data in the column labeled ME in Table 6 reflect differences between the per capita costs for a system with that treatment and costs for the base scenario, thus these numbers do represent change in total O&M costs due to a particular treatment.

The per capita O&M costs for systems in the seven size categories for the base case (i.e., systems treating only with chlorination) are shown in Table 6. As expected, average costs decrease as the population served increases. The base system has per capita costs of over $93 when serving only 100 people, while it is half this amount at a system size of only 3,300 people. Per capita costs drop below $30 per capita for a system serving 100,000 people.

The other average cost columns in Table 3 are for when other treatments are added to chlorination. The largest increase is for rapid sand filtration--nearly $40 (42% increase over base) for the smallest system and under $15 (54% increase over base) for the largest. The additional O&M per capita costs at the margin for ultra filtration, diatomaceous earth filtration, and ion exchange are quite similar, ranging from $26 to $29 for systems serving 100 people. The additional costs are about $10 for the largest system. In all cases, these costs at the margin are between 60% and 70% of those for rapid sand filtration. The marginal costs of other filtration, which includes pressure sand and direct filtration, range from a high of about $13.50 (14%) to a low of $5 (18%) over the base case for the smallest and largest systems, respectively. Finally, the marginal costs of adding aeration and slow sand filtration are the lowest marginal effects over the base scenario and ranged from only $5 to $2 over the populations evaluated. While these systems may be more costly in terms of capital components, annual unit operational cost increases seem to be affected much less so. This is evident when comparing across treatments where marginal effects of other treatments are up to seven to eight times that of slow sand filtration and aeration.

While the information in Table 6 effectively captures the marginal additions to O&M costs as treatment processes are added, it is important to comment on one regularity that appears in the estimates. That regularity is that for across all treatments, the marginal effects for systems

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[11] This means that in solving the model for each of these four treatment processes (e.g. any run for which one of the following dummy or categorical variables is set at unity: RSFTRT, UFTRT, OFTRT, IETRT), the variable CFTRT was set at unity. Because of the negative coefficient on this variable in the hedonic component of the model, the inclusion of this variable in this way reduces the estimate of treatment costs for these four processes below what they would have been otherwise.

of any size are a constant proportion of those for a system serving 500 people. The explanation for this result has to do with the structure of the model, the fact that marginal costs are captured by a hedonic function of an exponential form (see footnote 3) and that variables other than system size are held at mean levels. If for each of the system sizes, wages, electricity rates, population densities, etc. are set at mean levels for the corresponding size groups in Table 2 or 3, then the results change. These additional results are in Table 7; to the extent that systems of various sizes might be concentrated in certain regions of the state, particularly for larger systems concentrated in urban areas with higher wage rates and population densities, these results will differ from the figures in Table 6.[12]

Conclusions

The primary purpose of this paper is to demonstrate that an indirect cost function for community water systems with a hedonic specification for water quality can be used to isolate the additional O&M costs needed for various water treatment technologies. For the empirical analysis, data from several sources provided valuable cost and operational information for over 350 municipal systems across New York State, representing a wide range in size, population densities and existing levels of water treatment.

By all conventional measures, the modeling exercise was a success, and additional O&M costs attributable to aeration, ion exchange and several types of filtration processes were identified with some precision for both small and large systems. Thus, this model can be a valuable tool in further research and policy analysis for examining the effects on O&M costs of current EPA regulations associated with the SDWA. The model is the first of its kind to be applicable to small systems. In principal, it can be used to estimate the costs of implementing more than one treatment process, although for the most part, the treatments embodied in the New York State data would not be used in combination with one another. Perhaps if such a model could be re-estimated using a sample of water systems from around the country, a richer combination of treatment processes could be represented. From a policy perspective, it is clear that for some treatment technologies, the additional O&M costs are substantial, particularly for small systems, but for some they are not. Interestingly, two of the treatment technologies that are the least expensive, slow sand filtration and aeration, have been adopted by 3% and 14% of the community water systems statewide, respectively (Boisvert and Schmit, 1996). This is

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[12] Under these assumptions, it is also true that for all treatments, average per capita costs are higher for systems serving 50,000 people than for systems serving 100,000. This was unexpected, but is explained by the fact that water demand per capita is larger for the systems grouped in the 50,000 category than for those systems grouped in the 100,000 population category.

Table 7. Simulation of CWS Unit Operation and Maintenance Costs Per Capita by Treatment Technology

Population	Base Case	Aeration			D.E. Filtration			Rapid Sand Filtration		
Served	AC	AC	ME	%	AC	ME	%	AC	ME	%
100	$78.36	$82.46	$4.10	119	$100.30	$21.94	119	$110.95	$32.59	118
500	61.70	65.14	3.44		80.18	18.48		89.25	27.55	
1,000	53.19	56.21	3.03	88	69.50	16.31	88	77.54	24.35	88
3,300	44.32	46.94	2.62	76	58.51	14.19	77	65.54	21.22	77
10,000	40.78	43.27	2.50	73	54.35	13.57	73	61.13	20.35	74
50,000	48.36	51.50	3.14	91	65.53	17.16	93	74.19	25.83	94
100,000	37.69	40.16	2.48	72	51.27	13.59	74	58.15	20.46	74

Population	Slow Sand Filtration			Other Filtration			Ultra Filtration			Ion Exchange		
Served	AC	ME	%	AC	ME	%	AC	ME	%	AC	ME	%
100	$81.60	$3.24	119	$89.63	$11.27	119	$102.21	$23.85	119	$100.07	$21.71	119
500	64.42	2.71		71.17	9.47		81.82	20.12		79.99	18.29	
1,000	55.58	2.39	88	61.54	8.35	88	70.96	17.77	88	69.33	16.15	88
3,300	46.39	2.07	76	51.57	7.25	77	59.79	15.46	77	58.36	14.04	77
10,000	42.75	1.97	73	47.70	6.92	73	55.59	14.81	74	54.21	13.43	73
50,000	50.84	2.47	91	57.09	8.72	92	67.11	18.75	93	65.35	16.98	93
100,000	39.64	1.95	72	44.58	6.90	73	52.53	14.84	74	51.13	13.44	74

All costs expressed in constant 1992 Dollars. AC = Average Cost per Capita, ME = Marginal Effect, % = Percent of ME at 500 people.
Water production per capita, population density, wage rate, and electricity rate assumed at mean levels by population category.
All scenarios include disinfection by chlorine. Base line, aeration, and ion exchange use ground water sources, all filtration use surface water.
Rapid sand, ultra, and other filtration, and ion exchange include coagulation, flocculation, and sedimentation components.

somewhat surprising given the high proportion of systems across the state serving fewer than 10,000 people. This, however, probably reflects the fact that these systems have yet to install treatments over and above chlorination, rather than the fact that they are using more expensive alternatives.

It is also evident from the analysis that when regional differences in the cost of inputs are accounted for, many small systems located in rural areas may have a cost advantage over systems of a similar size located closer to urban centers. While this may be an advantage for these systems, costs of water treatment to meet the amendments to the SDWA may still be substantial in these areas and still pose a substantial financial burden on these rural local governments.

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