Municipal Water Supply and Sewage Treatment:

Costs, Prices and Distortions

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ABSTRACT

Municipal water supply and sewage treatment utilities in Ontario, Canada, are studied in order to establish their costs of supply and evaluate their pricing practices. Prices charged to residential and commercial customers are found to be only a third and a sixth of the estimated marginal cost for water supply and sewage treatment, respectively. For example, the average price to residential customers is $0.32/m^3 while the estimated marginal cost is $0.87/m^3 . The estimated cost parameters are combined with estimated residential and non-residential demands functions in order to calculate approximate welfare losses that arise from over consumption.

JEL classification code: Q25, L32

1. INTRODUCTION

There is a growing concern for the operations of the municipal agencies responsible for supplying potable water and treating sewage (Spulber and Sabbaghi, 1994; Tate and Lacelle, 1995; Burrill, 1997; World Bank, 1997; Parker and Tsur, 1997). This trend has been spurred by a variety of factors: the difficulties of maintaining ageing capital stocks in times of tightening fiscal constraints, the water pollution generated by these agencies, and recognition of the role played by utilities in allocating scarce water resources. A recent report provides the following assessment:

> Canada's water and wastewater system is under pressure: the infrastructure...is severely deteriorating, primarily due to shortages of public funding. If the decline continues, the health of the country's water resources will suffer. At the same time, due to subsidized and below-cost pricing for water and wastewater services, innovative environmental technologies that conserve water resources are failing to find a market. (National Round Table on the Environment and the Economy, 1996, p. 3)

This paper examines the operations of municipal water supply and sewage treatment facilities. While these two types of agencies are often administratively separate in municipal governments, they are considered together here in order to examine the consequences of their combined activities. This paper characterizes their respective production technologies, estimates their marginal costs of supply, examines their pricing policies and computes the approximate welfare losses arising from the instances when their prices diverge from marginal costs. This work is based on a cross-sectional sample of municipal water supply and sewage treatment facilities operating in Ontario, Canada, during 1991.

While a number of authors have been critical of the pricing practices of water supply and sewage treatment facilities (Hirshleifer, DeHaven and Milliman, 1966; Pearse, Bertrand and

MacLaren, 1985; Tate, 1989; Postel, 1993, Winpenny, 1994; National Round Table on the Environment and the Economy, 1996), few have quantified the magnitude of the deviations between actual and optimal consumption levels or the welfare losses associated with these deviations. Renzetti (1992), for example, measures the approximate welfare gain from reforming prices for a single water utility and does not consider sewage treatment costs. The omission of sewage treatment costs is important because the consumption of potable water and of sewage treatment services are likely to be complements. As a result, even if the provision of potable water were priced efficiently, underpricing sewage treatment services would induce overconsumption of both sewage treatment and potable water.

The remainder of the paper is organized in the following fashion: section 2 presents information regarding the operations of municipal water utilities and past economic research. Section 3 reports the estimation of the cost functions for water supply and sewage treatment. It also reports on the estimation of residential and non-residential water demand equations and the aggregate demand for sewage treatment. Section 4 combines the results of the previous section with information on water supply and sewage treatment pricing in order to generate estimates of deviations of observed consumption levels from those predicted under marginal cost pricing and the welfare losses associated with these deviations. Section 5 concludes the paper by considering the reasons for these findings and their implications for government policy.

2. BACKGROUND

2.1. Institutions

Municipal water utilities[2] withdraw water for two basic purposes. First, potable water is provided for final use by the utility's residential, commercial and institutional customers. Second, water provides a critical input to various public functions. The first purpose accounts for the bulk of water supplied, while the second, notably firefighting needs, has a significant influence on the design of water supply networks (and particularly on the pressure levels at which water is supplied). Municipal sewage treatment plants collect water from users (and rainwater in integrated systems) and treat it to some degree before returning it to the natural environment.

Each province is responsible for regulating the pricing behaviour of municipal water utilities under its jurisdiction. However, historically, scant regulatory attention has been paid to the setting of water prices (Pearse, Bertrand and MacLaren, 1985). In most provinces, municipalities inform the provincial government of intended changes to water rates but are not required to go through any kind of approval process (MacLaren, 1985; Percy, 1988). In contrast, most provinces retain and regularly exercise the authority to review and approve new issues of debentures by water utilities. The implication of this lack of regulatory control is that water utilities' accounting and price setting practices have come to vary significantly within and across provinces.

Another important feature of waterworks and sewage treatment facilities has been the level of subsidies and grants provided by all levels of government. While transfers from senior and municipal levels of government have fallen, revenues collected directly from users still account for only a portion of utilities' total costs. In a recent report which examines water utility finances across Canada, it is estimated that the average contribution of user charges to operating and capital costs is only 37% and 66%, respectively (National Round Table on the Environment and the Economy, 1996). Interestingly, a review of urban water supply systems in both developed and developing countries also found that charges to consumers typically cover only an average of 35% of the total cost of supply (Easter et. al, 1993).

Tate and Lacelle (1995) reports on a 1991 national survey of the pricing behaviour of municipal water supply and sewage treatment utilities. With respect to water supply, flat rates for residential customers (which involve a connection fee but no marginal price for water supply) are used by half of the municipalities in Canada. The use of flat rates is most common, however, in small cities and towns; only 25% of cities with population in excess of 100,000 use flat rates. Constant use charges (i.e. a connection fee in combination with a constant marginal price) and declining block rate pricing structure are more common for non-residential customers (approximately 65% of municipalities have one of these types of price structures). With respect to charges for sewage treatment, rates are most commonly either flat (in the case where water supply rates are flat) or defined as a constant percentage of the water supply volumetric rate (although the percentage varies across municipalities). In a very small minority of municipalities (26 of the approximately 960 municipalities which responded to the survey), non-residential sewage rates are based, in part, on the chemical composition of a firm's sewage.

2.2. Past Research

One part of the water supply literature characterizes the technology of water supply and obtains estimates of scale economies (Hayes, 1987; Kim, 1987; Boisvert and Schmit, 1997). Most of these studies find that water utilities enjoy economies of scale or scope[3] over a fairly wide range of output. Kim (1987), for example, estimates a translog cost function using a cross-sectional data set of sixty American water utilities and finds that scale economies are prevalent but that they decline with the size of the utility.

A smaller number of studies addresses the issue of sewage treatment costs. Hanke and Wentworth (1981) employ engineering data on construction and operating costs of representative sewage treatment facilities. The authors regress total cost on output and output squared and find support for the presence of scale economies. Fraas and Munley (1984) estimate separate Cobb-Douglas regressions for capital and operating costs using data from a sample of American sewage treatment facilities. Fraas and Munley find that increases in both flow rates and the concentration of sewage raise costs and that the marginal cost of pollution removal increases at an increasing rate with the percentage of pollutant removed. Neither of these studies includes input prices as explanatory variables in their cost functions.

There are a large number of residential water demand studies. Early studies used single equation models, aggregate data and average cost as a proxy for water's price and found residential water demands to be price and income inelastic (see OECD, 1987 for a survey of this literature). Since then, a number of advances have been made. These include more sophisticated price specifications (Terza and Welch, 1982; Jones and Morris, 1984), the use of microdata sets (Hanke and de Maré, 1982), the inclusion of other prices (such as the price of electricity) as explanatory variables (Hansen, 1996). Residential water demands continue to display relatively small price and income elasticities.

A smaller number of studies examine the commercial and industrial demand for water. Early studies such as Turnovsky (1969) estimate single-equation demand models using data from individual industries or municipalities. Subsequent studies extend the analysis by estimating translog cost functions for the American manufacturing sector. Grebenstein and Field (1979) and Babin, Willis and Allen (1982) use state-level cross-sectional observations and include water as a productive input along with capital, labour, energy and materials. In these two studies, water's price elasticity ranges from 0.0 to -0.801, depending on the industry. Renzetti (1992) examines industrial water demands by considering four separate facets of water use: intake, treatment prior to use, recirculation, and discharge. The data set consists of plant-level observations on water use and expenditures by Canadian manufacturing firms. Intake water's price elasticity ranges from -0.15 to -0.59.

A limited number of studies consider the demand for sewage treatment. Strudler and Strand (1983) examine the relationship between the price of sewage treatment and the residential demand for sewage treatment and estimate the average price elasticity of demand to be -0.07.

Finally, a small number of studies assess the efficiency properties of municipal water supply and sewage treatment pricing rules. Crew and Kleindorfer (1986) and Swallow and Marin (1988) simulate the welfare gains of reforming water prices using hypothetical case studies. Renzetti (1992) estimates the welfare gains from reforming water prices for the Greater Vancouver Water District and estimates potential improvements to aggregate surplus to be approximately 4%.

Recently, several papers in Hall (1996) explore the challenges associated with designing and implementing marginal cost pricing for water utilities. Dinar and Subramanian (1997) survey pricing practices in 22 countries. While the authors in this World Bank report are united in their call for water pricing reform, none of the 22 country case studies provides an estimate of the deviation between the marginal cost of urban water supply or sewage treatment and their respective prices.

3. ESTIMATION MODELS

3.1. Cost and Demand Models

The estimation of the costs of water supply and sewage treatment is done separately as the utilities are administratively, physically and technologically distinct. In both cases, the estimation is based on the assumption that municipal utilities seek to minimize the costs of supplying exogenously determined quantities of output. In their choices regarding input use, water supply and sewage treatment utilities are constrained by exogenously determined market prices, their production technologies and the characteristics of their operating environments. These assumptions imply that the two technologies may be represented by their respective cost functions:

$$C_w = C_w(\, p_1, \ldots p_N, Q_R, Q_{NR}, D\,); \qquad C_s = C_s(\, p_1, \ldots p_N, Q_s, D, Z_1, \ldots Z_F\,) \tag{1}$$

Where the subscript **w** denotes water supply and **s** denotes sewage treatment. For both water supply and sewage treatment, cost is measured as the sum of annual expenditures on labour, energy and capital. All of the utilities in the sample are self-supplied and do not purchase their water from a wholesaler. Under Ontario law, self-supplied utilities do not pay a fee for their raw water supply (Percy, 1988).

It is assumed that the price vector in both cost functions has the same three elements: labour (P_L), energy (P_E) and capital (P_K). In the case of water supply, output is a vector of residential output (Q_R) and non-residential output (Q_{NR}). The non-residential customer class is composed of commercial, industrial and institutional customers. Sewage treatment output (Q_S) is a scalar measure of total recorded annual flow-through. In the case of sewage treatment, Z is a vector composed of a set of dummy variables indicating the type of treatment process employed. Finally, the variable D measures the population density of the municipality.

The data are cross sectional observations of Ontario municipal utilities operating in 1991. These observations are compiled from several sources including national surveys of water utility operations and water utility pricing and municipal financial records that are reported to the provincial government. The result is that there are 77 observations for water supply utilities and sewage treatment facilities. The sample is representative of the province in terms of the distribution of utility size although the sample is skewed slightly towards larger utilities (the average annual output for utilities in the sample is 8.1 million cubic metres while the provincial average is 6.9 million cubic metres). The details regarding the construction of the regression variables are an Appendix.

The structure of each cost function is approximated by a translog functional form. In addition, the water supply and sewage treatment cost functions are estimated separately. Each cost function and N-1 of its share equations are estimated using an iterative, SUR procedure with linear homogeneity in prices and symmetry imposed.

The second step in the estimation involves characterizing the demand for the services of water supply and sewage treatment facilities. Annual aggregate residential water use in each municipality is assumed to be a function of the following variables: price of water for residential customers (P_{RW}), price of sewage treatment for residential customers (P_{RS}), price of electricity for residential customers (P_{RE})[4], average household income (I), number of households (NH) and a vector of weather-related variables (**V**),

$$Q_R = D_R(P_{RW}, P_{RS}, P_{RE}, I, NH, V) \tag{2}$$

Annual aggregate non-residential water use in each municipality is assumed to be a function of the following variables: price of water for commercial customers (P_{NRW}), price of sewage treatment for commercial customers (P_{NRS}), price of electricity for commercial customers (P_{NRE}), value of the manufacturing sector's output (VAL) and number of

$$Q_{NR} = D_{NR}(P_{NRW}, P_{NRS}, P_{NRE}, NF, VAL) \tag{3}$$

manufacturing firms (NF).

A single aggregate demand equation is estimated for sewage treatment services as these utilities do not record residential and non-residential flows separately. Aggregate demand for sewage treatment (Q_S) is assumed to be a function of the price of sewage treatment (P_S), the price of water supply (P_w), the price of electricity (P_E), the average level of household incomes (I), the number of households (NH), the number of firms (NF) and the vector of climate-related (**V**) used in estimating the residential demand for water supply. For each of the three prices in the sewage treatment demand equation, a weighted average of residential and non-residential prices is created using recorded water supply quantities as weights. Thus, the general form of the demand for sewage treatment equation is the following:

$$Q_S = D_S(P_S, P_W, P_E, I, NH, NF, \mathrm{V}) \tag{4}$$

There are 77 observations used to estimate the three demand equations. The residential and non-residential water demand equations and the aggregate sewage treatment demand equation are estimated separately using OLS with all the variables expressed in natural logs. In addition, homogeneity of degree zero in prices is imposed on the estimation coefficients and White's correction for heteroscedastic errors is employed.

3.2. Estimation Results

Table 1 lists the average estimated marginal costs for water supply to residential and non-residential customers and for sewage treatment [5]. It also lists the average values for scale elasticities calculated at the mean of the respective data sets. In the case of water supply, the product-specific scale economy measures are calculated following Kim (1987).

The estimated marginal cost (MC) reported in Table 1 is higher than the estimates reported by other researchers. Renzetti (1992), in a case study of the Vancouver waterworks, records MC that range from $0.53/m^3 to $0.85/m^3. In addition, the estimates presented here are greater than those reported in Kim (1987) and Russell and Shin (1997) where LRMC estimates based on U.S. data range from $0.30/m^3 to $0.56/m^3 (when converted to 1991 Canadian dollars). The reasons for this divergence may be the effects on construction and operating costs of the lower average temperatures and greater temperature variability, higher labour and interest costs and the lower population densities of Ontario municipalities compared to U.S. cities.

Table 1 also indicates that there are scale economies in the technology of water supply and sewage treatment. This finding corresponds to similar results by other researchers. As indicated in the previous section, for example, Kim (1987) finds that scale economies are prevalent but that they decline with the size of the utility.

While not shown in Table 1, the cost function coefficients also provide estimates of the elasticity of cost with respect to density. At the mean of the data set, this parameter has an estimated value for water supply and sewage treatment, respectively, of -0.061 (0.091) and 0.056 (0.170), where standard errors are in parentheses. Water supply's elasticity of cost with respect to density has the negative sign found in other studies (Teeples and Glyer, 1987). However, neither estimated parameter is statistically significant, indicating that population density is not an important factor in explaining the variation in production costs in this sample.

Table 2 reports the average values for the price and income\output elasticities. In all three cases, increases in water supply and sewage prices result in reduced water use. With the exception on non-residential water demands, the elasticities are all quite small. As was suggested in the introduction, consumption of potable water and sewage treatment services are found to be complements. The elasticity associated with the price of electricity, while positive, is only significant in the case of non-residential demands. This may reflect substitution possibilities involved in industrial water use (for example, use of water as a cooling agent instead of refrigeration). This may also indicate that electricity prices are not an important determinant of residential demand for potable water and sewage treatment.

The elasticities that measure the scale of economic activity (income and population for residential demands and value of output and number of firms for non-residential demands) indicate that increases in the level of economic activity increase the demand for both water supply and sewage treatment. The exception is the income elasticity of sewage demand which, while negative, is not significant.

4. EVALUATION OF PRICING POLICIES

Water supply and sewage treatment utilities are commonly criticised for their inefficient pricing practices. Yet, there are few instances in the literature which document divergences between prices and marginal costs of supply. The approach adopted here is to combine the estimated cost and demand equations with data on water supply and sewage treatment utilities' prices to determine the extent to which current consumption levels deviate from those that would be predicted under efficient (i.e., marginal cost) pricing and to measure the approximate welfare losses associated with these deviations.

The deviation and deadweight loss calculations are done separately for both categories of water supply and sewage treatment and for each municipality. The difference between the predicted consumption levels (Q^0) at the observed prices and the efficient level of consumption (Q^*) at marginal cost prices is first determined. Q^0 is calculated by substituting the actual water supply and sewage treatment prices (as well as municipality-specific values of the other explanatory variables) into the estimated demand equations. The value of Q^* is calculated by solving for the intersection of the estimated marginal cost and demand equation.

Table 1: Marginal cost and scale economies for water supply and sewage treatment

	Marginal Cost	Scale Economies
Residential Supply	0.873* (0.153)	1.249* (0.149)
Non Residential Supply	1.492* (0.398)	1.465* (0.074)
Sewage Treatment	0.521* (0.148)	1.364* (0.755)

Notes to Table 1:
1. Marginal cost and scale economies are calculated at the mean values of the data and is measured in \$1991/m^3
2. A scale measure greater than one indicates increasing returns to that output.
3. Figures in parentheses are estimated standard errors. A single asterisk indicates significance at the 0.05 level while a double asterisk indicates significance at the 0.10 level

Table 2: Demand elasticities

VARIABLE	Residential Supply	Non-Residential Supply	Sewage Treatment
P_w	-0.124** (0.081)	-0.593* (0.231)	-0.030 (0.104)
P_s	-0.159* (0.098)	-0.032 (0.124)	-0.033* (0.018)
P_e	0.284 (0.249)	0.625* (0.201)	0.065 (0.108)
Income	0.596* (0.056)	--	-0.251 (0.535)
Output	--	0.457* (0.071)	--
Population	0.953* (0.050)	--	1.178* (0.154)
# of Firms	--	0.648* (0.072)	0.123 (0.134)

Notes to Table 2:

1. Elasticities are calculated using mean values of the data. Figures in parentheses are standard errors.

The deviation for the ith output and the jth municipality (DEV_{ij}) is the difference between predicted and efficient consumption divided by the predicted level of output as shown in (5).

$$DEV_{ij} = \frac{Q^{0}_{ij} - Q^{*}_{ij}}{Q^{0}_{ij}} = \frac{Q^{0}_{ij} - D_{ij}(\hat{MCW}_{ij}, \hat{MCS}_{j}, W_{j})}{Q^{0}_{ij}} \quad for \ \ i = R, NR, S \tag{5}$$

The variable W_j summarises the remaining explanatory variables which enter into the demand equations and j indexes the municipalities in the sample. As was noted in the Introduction, a deviation can occur in one market (for example, residential water demand) due to mispricing in its own market and/or mispricing in another market (for example, in the provision of sewage treatment). Furthermore, the empirical finding that potable water demand and demand for sewage treatment are complements implies that simultaneous underpricing in both markets will be reinforcing and generate larger deviations than would occur if underpricing occurred in only one market.

The deadweight loss associated with the deviation is defined as the difference between estimated marginal costs and the estimated market valuation of service (ie. the inverse demand curve), integrated over the difference between predicted and efficient quantities as shown in (6).

$$DWL_{ij} = \int_{Q_{ij}^{0}}^{Q_{ij}^{*}} [\, MC_{ij}(Q_{ij}, Y_j) - D_{ij}^{-1}(P_{wj}, P_{sj}, W_j)]\; dQ_{ij} \quad for\ \ i = R, NR, S \tag{6}$$

The variable Y_j summarizes the other variables entering into the marginal cost function. The deadweight loss measure is then presented in the following form:

$$WASTE_{ij} = (\, DWL_{ij} / Q_{ij}) \quad for\ \ i = R, NR, S \tag{7}$$

Thus, DEV_{ij} measures the difference between predicted and efficient consumption levels and $WASTE_{ij}$ measures the average deadweight loss per unit of output.

The results presented in Table 3 indicate that substantial divergences between prices and marginal costs are present for the water supply and sewage treatment facilities in the sample under study. In fact, marginal cost exceeds the price of output for water supply and sewage treatment in every municipality in the sample.

These divergences lead to significant deviations between predicted and efficient consumption levels. In the case of residential water-use, for example, predicted consumption levels exceed the efficient level of consumption by almost 50% on average. The range of the deviations across municipalities is 6.1% to 132.2%. This deviation is generated by two re-enforcing factors: the over-consumption of potable water induced by under-pricing water supply and the over-consumption of water supply induced by under-pricing sewage treatment services.

Table 3 also indicates that the largest gap between price and marginal cost occurs in the market for sewage treatment. However, the percentage deviation arising from this difference is not as large as in other markets because of the relatively small own and cross price demand elasticities for sewage treatment. The minimum and maximum observed percentage deviation in sewage treatment are 0.7% and 39.5%, respectively.

The large differences between marginal cost and price and between actual and efficient consumption combine to produce quite large deadweight loss estimates. In the case of sewage treatment, the dollar estimate of average deadweight loss per unit of output actually exceeds the average price per unit of output. Another interesting feature in Table 3 is that, while the proportional difference between marginal cost and price is smallest for non-residential service, the largest percentage deviation in consumption occurs for non-residential customers. The reason for this is to be found in Table 2: the non-residential water demand equation exhibits a significantly larger average value for its price elasticity (-0.593) than does the residential demand equation (-0.124).

The problem of mispricing water resources is most pronounced for small utilities. For the five smallest municipalities in the sample, the average price and marginal cost for residential supply are $0.12 and $1.15 per cubic metre, respectively. Conversely, for the five largest municipalities in the sample, the average price and marginal cost for residential supply are $0.21 and $0.45 per cubic metre, respectively.

Another way to examine the price-marginal cost gap is to divide the sample into those utilities that do not meter household water use and those that do. Utilities which do not meter water consumption display larger average values of the gap between price and marginal cost of residential water supply. In the sub-sample of utilities which do not meter water use, the average value of this gap is $1.35 per cubic metre while the corresponding value for water utilities that do meter water use is $0.99 per cubic metre.

A final way to consider the deadweight loss estimates is to ask how the social loss that they imply is distributed across income groups. Not surprisingly, this is a very difficult question to answer. Wasny (1986) indicates that expenditures on publicly-supplied water decline as a proportion of household income as household income rises. Thus, the finding that municipal water supply is under-priced and is an inferior good would suggest that lower income households benefit more than do higher income households. This conclusion, however, neglects the fact that someone in Canadian society must be paying for this under-pricing. In particular, the distribution of the tax burden associated with the subsidies and grants from other levels of government that under-pricing makes necessary is not known.

There are a number of reasons why water supply and sewage treatment prices are inefficient. The most obvious reason is the lack of metering of residential water use. According to the Environment Canada survey on municipal water pricing practices, approximately half of households living in the municipalities included in the survey do not have their water consumption metered (Tate and Lacelle, 1995).

The second reason relates to the rules used to set prices. Many of the Canadian municipalities that do meter water use follow the pricing rules set out by the American Water Works Association (AWWA, 1991). The AWWA pricing rules are directed at ensuring that sufficient revenue is generated to maintain the financial solvency of the utility and are not designed to guarantee the efficient allocation of water. This is because those prices have relatively little to do with the economic costs of supplying potable water and treating waste water.

The AWWA methodology computes water prices based on the average annual recorded expenditures incurred in system operation (i.e. operation and maintenance and debt-retirement costs). These pricing rules involve the ad hoc allocation of joint capital costs across customer classes and result in prices equal to historical expenditure per unit.

Table 3: Average values for distortion measures

VARIABLE	Residential Supply	Non-Residential Supply	Sewage Treatment
MC ($/m^3)	0.873	1.492	0.521
PRICE ($/m^3)	0.323	0.734	0.128
DEV (%)	47.52	62.87	13.44
WASTE ($/m^3)	0.252	0.312	0.818

Notes to Table 4:
1. The average values of the marginal costs reported in this table differ from those in Table 1 because the values here are calculated from the sub-sample of the data for which complete price information is available.

In addition, prices are typically invariant to distance and time of use. This is despite evidence that water supply costs vary with distance (Kim and Clark, 1987) and with peakloads of output (Renzetti, 1992). Finally, sewage treatment prices are either zero or are expressed as a constant percentage of water supply prices. However, the estimation results indicate that sewage treatment costs are complex functions of input prices, output and operating characteristics.

In addition to these errors in calculating prices, municipal utilities' accounting of their costs is incomplete. Grants and subsidies lead to an underestimation of operating and capital costs. Further, water supply and sewage treatment facilities understate costs in several ways: they do not incorporate depreciation of the capital stock, they do not assign a value to the raw water input withdrawn from the natural environment, they fail to impute the opportunity cost of their land holdings and, finally, they fail to account for the external costs associated with the environmental damages caused by their effluent.

These observations suggest that the deviation and deadweight loss calculations presented here are conservative estimates because the marginal cost estimates are based on utilities' incomplete accounting of the costs of water supply and sewage treatment [6].

5. CONCLUSIONS

Increasing incomes and growing urban populations are putting pressure on municipal water supply and sewage treatment facilities just as provincial and municipal governments struggle to cope with rising deficits and increasingly stringent water quality regulations.

This paper characterizes the technology of municipal water supply and sewage treatment facilities using a cross-section data set of Ontario municipalities and derives estimates of the marginal cost of water supply (for residential and non-residential customers) and sewage treatment. It also estimates aggregate residential and non-residential water demand equations. Using these estimated relationships, it then compares the estimated marginal costs to water supply and sewage treatment prices and calculates the gap between predicted consumption levels and those that would be predicted if utilities followed marginal cost pricing. Finally, the paper estimates the welfare costs of these observed divergences and considers the reasons for these findings.

The most important finding is that prices understate the marginal costs of providing these services by a wide margin. This situation encourages excessive consumption on the part of households and businesses and over-expansion of water supply and sewage treatment facilities. It also discourages technological innovation in water conservation and alternative sewage treatment technologies (Postel, 1993; Gardner, 1997).

It is of little surprise, then, that Canada is the world's largest user of water on a per capita basis. The perception of plentiful supplies of water has been artificially magnified by understating the cost of using that resource. This perception, in turn, has become embedded in residential, commercial and industrial capital stocks and technologies.

Finally, the policy implications of these findings may be considered. The results reported here indicate that water and sewage prices are inefficient. If water utilities are concerned with maximizing social welfare then moving to marginal cost pricing (with an appropriately calculated annual connection fee to recoup any losses implied by marginal cost pricing under increasing returns to scale) is necessary. Interestingly, Environment Canada has recently developed a software program in co-operation with the Canadian Water and Wastewater Association that allows municipal water utility managers to estimate the marginal costs of their operations and to design water rates based on those calculations (Canadian Water and Wastewater Association, 1992).

A major constraint to moving to marginal cost pricing is the absence of meters in a large number of municipalities. Meters should be installed where the benefits exceed the cost. In general, this implies that meters should be installed in cities where population is growing rapidly and where water use is close to capacity (cf. Renzetti, 1992).

In contrast to the problem of a lack of metering, there is some evidence that consumers' willingness to pay for improved water and sewage facilities is not a major constraint facing utility managers. A recent nation-wide survey found that the average household willingness to pay for improved water system reliability was approximately $26.00/month over and above current water supply payments (Rollins, Frehs, Tate and Zachariah, 1996). If prices were raised to capture this expressed willingness to pay, the national water supply industry could raise revenues by in excess of $3 billion.

The cost accounting and pricing of sewage treatment also needs to be reformed. In this regard, it is important to note that the structure of sewage treatment costs is a complicated function of flow rates, input prices and treatment technology, and not simply a constant proportion of water supply costs. As a result, sewage prices should not be tied directly to water supply prices unless metering costs are prohibitive. The estimated demand for sewage treatment and potable water supply suggest that sewage pricing does influence behaviour but this is a particularly understudied area.

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DATA APPENDIX

A. Water Supply and Sewage Treatment Costs

The data are cross sectional observations of Ontario municipal utilities operating in 1991. These observations are compiled from several sources including national surveys of water utility operations and water utility pricing and municipal financial records that are reported to the provincial government. There are 77 observations for water supply utilities and sewage treatment facilities. The sample is representative of the province in terms of the distribution of utility size although the sample is skewed slightly towards larger utilities (the average annual output for utilities in the sample is 8.1 million cubic metres while the provincial average is 6.9 million cubic metres).

The price of labour is represented by the average weekly earnings for all municipal public utility workers as municipal records do not report the earnings of water utility workers separately (OMMA, 1992). The price of energy is represented by the average price of electricity charged in each municipality to industrial customers by the provincial electrical power utility, Ontario Hydro (Ontario Hydro, 1992). In principle, the price of capital should reflect interest rates, depreciation rates and purchase prices of capital equipment. Unfortunately, no data on the costs of capital or depreciation rates were available on a municipality-specific basis. As a result, the price of capital is represented by the average interest rate on each utility's outstanding debt. These data were collected by contacting each utility directly.

Total annual cost to each utility is assumed to be the sum of expenditures on labour, capital and energy. These data are available from the Ontario Ministry of Municipal Affairs which oversees the operations of municipal governments (OMMA, 1992). Total expenditures on capital includes expenditures on debt retirement and capital grants by municipal, Ontario, and federal governments. Expenditures on materials were used to approximate expenditures on energy, since energy is the major portion of materials.

Finally, data regarding annual output levels and the types of sewage treatment used by each municipality are available from Environment Canada's Municipal Water Supply and Sewage Treatment Facilities (MUNDAT) and Municipal Water Use (MUD) databases (Environment Canada, 1991)

B. Water and Sewage Treatment Demands

Water supply and sewage treatment price schedules for each municipality in the sample are available from Environment Canada's Survey of Municipal Water Rates (Tate and Lacelle, 1995). The price for residential water supply is calculated as the marginal price at a level of 20 m^3 per month per household. Environment Canada’s Municipal Water Rates Database calculates marginal water rates at consumption levels of 10, 20 and 30 m^3/month. According to Environment Canada’s Municipal Water-Use Database the average household in municipalities contained in the sample used in this paper consumes approximately 22 m^3 per month. As a result, marginal water supply prices are calculated at a consumption level of 20 m^3 /month.

The rate schedules for sewage treatment for residential customers are also provided by the

Municipal Water Rates Database. In all of the municipalities in the sample, sewage treatment prices are either \$0/ m^3 (in the case of unmetered households) or a fixed percentage of the water supply price (the actual percentage varies across municipalities).

The prices for non-residential water supply and sewage treatment are calculated as the marginal price at a level of 100 m^3 per month. In the case of the aggregate sewage treatment demand, the prices of water supply and sewage treatment are weighted averages of the residential and non-residential prices with the weights being the respective quantities of water consumption. The prices of electricity for residential and non-residential customers are the average rates prevailing in each municipality (Ontario Hydro, 1993).

Income is measured as the average household income in each municipality (Statistics Canada, 1994). Population is the total population in the municipality served by municipal water supply facilities (Environment Canada, 1991). Value and Number of Firms measure the value of output and number of manufacturing firms in each municipality, respectively. These data are available from Statistics Canada's Census of Manufactures (Statistics Canada, 1992) and Environment Canada's Industrial Water Use Survey (Tate and Scharf, 1995).

The temperature and precipitation data are taken from Environment Canada (1994). The first two elements of the **V** vector measure the number of days per year when the mean daytime temperature exceeds 25 and 30 degrees Celsius, respectively, and the last three elements measure the number of days per year when the recorded precipitation is between 5 and 10 mm, between 10 and 25 mm, and in excess of 25 mm, respectively.

C. Water Supply and Sewage Treatment Prices

These observations come from a national 1991 survey of water supply and sewage treatment pricing practices (Tate and Lacelle, 1995). Water supply prices are $/m^3 and sewage treatment costs are calculated as a percentage of water supply price. Out of the total sample of 77 municipalities, 31 have a flat rate price structure for water supply to residential customers and 33 do the same for sewage treatment services to residential customers. In these cases, customers pay a regular fee to gain access to the distribution network but pay a zero marginal price for water supply or sewage treatment. In the instances when utilities charge residential customers a non-zero price for water, constant rates (i.e. quantity-invariant) prices are more common (30 municipalities) than declining block prices (16 municipalities).

With respect to non-residential customers, the use of volumetric charges is more common. Volumetric charges to non-residential consumers are equally divided between constant and declining block structures. One municipality uses increasing block structures. Only 10 municipalities provide flat rate price structures for water supply to non-residential customers.

FOOTNOTES

Lead footnote. The author would like to thank Don Tate, Terry Veeman, Chuck Howe, Lena Höglund, Diane Dupont, participants of the "Water Management" session of the 1997 European Environmental and Resource Economics meetings and two anonymous referees for their valuable comments. Terry Hatton, and Kari Heinrichs provided assistance with the data. Financial support from the Social Sciences and Humanities Research Council is gratefully acknowledged. All errors and omissions are the responsibility solely of the author.

1. There are a variety of ways in which municipal governments organize their water supply and sewage treatment agencies. The differences in organizational structure are not addressed in this paper as all of the utilities in the sample are organized as departments within municipal or regional governments. In addition, there are a small number of privately owned water utilities in Canada (in contrast to the U.S., where a significant portion of the market is controlled by investor-owned utilities). This paper concentrates on publicly-owned utilities.

2. Scope economies refer to the cost savings associated with the joint production of several products. In the case of water utilities, these products are the provision of potable water to residential, commercial, institutional and industrial customers. See Kim (1987).

3. The inclusion of the price of electricity in the residential water demand equation follows Hansen (1996). The price of electricity is also included in the aggregate demand for sewage treatment. In both cases, the purpose for including the price of electricity is to investigate whether it plays a significant role in determining the observed variation in the quantity

demanded. This could occur if the price of electricity influenced the demand for, and rate of utilization, of water-using capital such as pumps, dishwashers, water heaters, etc.

4. The cost functions' and demand equations' estimated coefficients are available from the author.

5. There is another, unrelated, reason why the deadweight loss estimates may be overly conservative. According to Environment Canada's meteorological data, in 1991, Ontario had approximately 10-15% more rainfall than the average annual amount over the preceding 25 years. This would have lead to lower than average water demands and, as a result, lower than average measures of the distortions (and welfare loss) associated with mis-pricing water supplies and sewage treatment. I would like to thank one of the reviewers for raising this point.