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Economic Instruments for Water Management: The Case for Industrial Water Pricing

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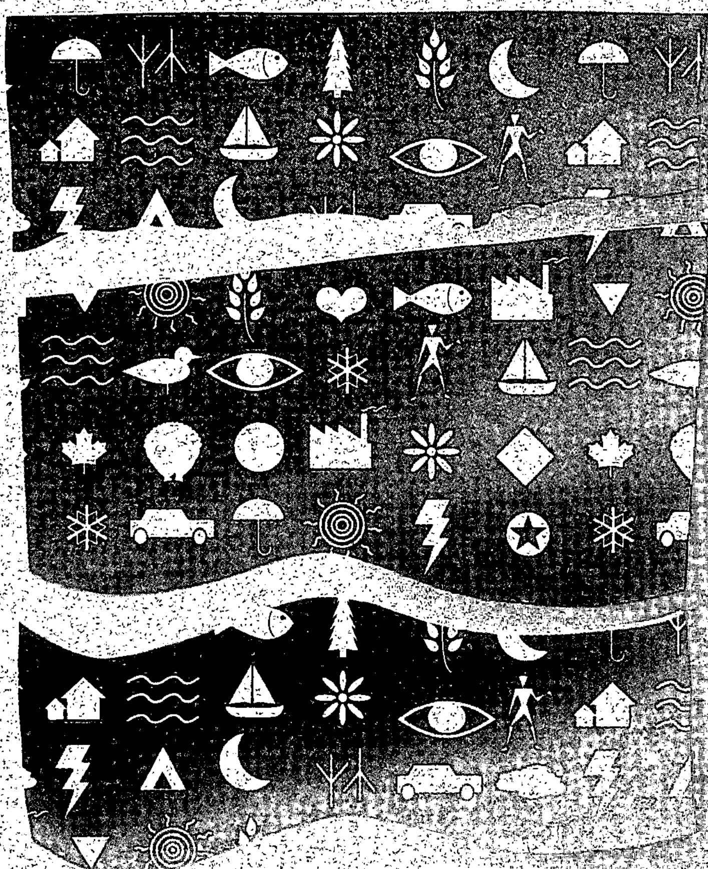

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Economic Instruments for Water Management: The Case for Industrial Water Pricing

D.M. Tate, S. Renzetti* and H.A Shaw†

* Department of Economics, Brock University, St. Catharines
† Formerly with Water Planning and Management Branch

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Abstract

An econometric analysis is undertaken in order to assess the efficacy of one policy instrument (the price of water) in controlling the quantity of water used by manufacturing firms in Canada. Industrial demands for water are estimated using data from two cross-sectional surveys on manufacturing water use and expenditures conducted by Environment Canada in 1981 and 1986. Single-equation demand functions are estimated in double-log form. The price of water is found to be an important factor in determining the quantity of water used by firms for most industries. Estimated price elasticities for intake water range from -0.500 to -1.202.

Résumé

On entreprend une analyse économétrique servant à évaluer l'efficacité d'un instrument de politique (la tarification de l'eau) pour influer sur la quantité d'eau consommée par les industries au Canada. Les consommations d'eau des industries sont estimées à partir de données provenant de deux enquêtes transversales menées par Environnement Canada en 1981 et 1986 et portant sur la consommation d'eau des industries et sur les dépenses qui en découlent. Les fonctions de demande à équation unique sont estimées sous forme bilogarithmique. On a constaté que la tarification de l'eau constitue un facteur important pour déterminer la quantité d'eau consommée par la plupart des industries. L'élasticité de la tarification estimée pour l'eau consommée varie entre -0,500 et -1,202.

CHAPTER 1

Introduction

The 1990s in the Canadian environmental field are likely to be marked by a search for new means of approaching problems, not necessarily to discard traditional approaches, but to augment them with fresh insights. In the water resource field, one such insight, although not particularly "new," involves the role of economic factors, especially price, in influencing the level of resource use. Although the case in favour of pricing was promoted actively by the Inquiry on Federal Water Policy, and later found some prominence in the Water Policy itself, there is still a great deal of work required to entrench pricing as an integral part of water management. This work includes research.

PURPOSE OF THE REPORT

This paper outlines the results of a study of the relationship between industrial water use and its price. The regular five-yearly surveys of industrial water use by the Inland Waters Directorate have, as one aim, the collection of information on the cost of water to industrial plants. The need to examine the relationship between this cost and the level of water demanded underlies this aim.

Economic data on water costs were collected for both 1981 and 1986. A report analyzing the 1981 data was prepared by Renzetti (1987) under contract with the Inland Waters Directorate, Environment Canada, but the report has not been released. With the completion of the 1986 data compilation, and the need for this type of information, it seemed appropriate to repeat Renzetti's 1981 work using 1986 data and to publish the two sets of results together. It is important to note that the two surveys have been treated separately. Subsequent research will examine an integrated, or time series, analysis of the data.

BACKGROUND

In addition to being an interesting research problem in its own right, this project has implications for several current water management issues. Industry uses enormous quantities of water, both as a basic productive input and for the deposition of waste. One implication of the current management emphasis on sustainable development is the need to conserve water supplies in some areas and to reduce waste loadings in others. Despite the current management focus on regulation, both conservation and waste reduction will almost certainly fail without the incorporation of economic incentives for improved water use. One of the first steps in using economic actions to govern water use is to obtain a firm understanding of the relationships between use and price, or, in economic terms, the water demand function. An estimated demand function will indicate the degree to which a firm or industry will respond to water price changes (e.g., by increasing recirculation), and it will provide estimates of the value that firms assign to water use.

Closely related are the implications of the economics of water use for publicly funded infrastructure. A wide array of possibilities exist for reducing demands on infrastructure through industrial water pricing, again implying the need for reliable data on water demand functions. Technological change is unlikely without the presence of effective economic incentives.

Finally, as public funds experience ever increasing (and competing) demands, means are required to ensure reasonably efficient expenditures. This also suggests a role for water pricing, for, as this report shows, there is a relationship between price and the level of industrial water demand, implying the management option of using price to influence the level of that demand.

CHAPTER 2

Methodology

BACKGROUND

At the outset, we should note that the industrial water use data base, upon which this study is based, is quite comprehensive in its coverage of water quantity and economic factors for large Canadian industrial plants. For the years 1981 and 1986, some 10 000 individual plant water use records exist (Tate and Scharf 1985, 1991). Adding in the previous surveys for 1972 and 1976, which collected no data on water costs, the total number of records ranges between 18 000 and 20 000. Thus, as a data source, the industrial water use survey is very rich, and this study only skims its surface.

The research methodology used views water as an input to industrial productivity. This approach follows a well-established economic tradition of viewing productivity as a function of land, labour, and capital. The "land" portion of this general statement has been interpreted broadly as the input to production of all natural resources. The concept of natural resource depletion may also be covered under the "capital" portion of the statement. The individual firm is assumed to seek to minimize its production costs in the process of producing its planned level of output. In addition to the planned output level, the most important factors influencing the desired level of a given resource are the price of the resource itself, the price of all other inputs, the structure of the firm's productive technology, and the relevant set of government regulations.

Although there has been a wealth of studies on the nature of input demands, only recently have economists begun to examine water demands, and relatively few studies exist in this area. For the most part, water demand forecasts and modelling still rely on the concept that water is a requirement of production that must be met and that can be modelled effectively using fixed coefficients per unit of product. The assumption of a fixed relationship between water use and output (or some other productivity measure), and the lack of attention paid to water price constitute two major flaws in this "coefficients approach" (Whittington 1978; Tate 1984). This approach stands in marked contrast to the one advocated here, namely that water is a demand that can be governed in large part through resource effective pricing arrangements (Boland et al. 1984; Whittington 1978; Kindler and Russell 1984). An important advantage of the methodology used in this paper is that the hypothesis of the irrelevance of price to water use decisions can be tested through direct appeal to market data.

The reasons for this reluctance to look at economic variables like price in the water use context seem clear enough. The perception of water abundance pervades Canadian attitudes to water, although this may be changing slowly with recent environmental awareness. This perception has given rise to traditional engineering approaches, which focus on managing supplies to meet perceived requirements. Both of these factors have led to cheap-water policies, which in some cases, as in the municipal sector (Tate 1989), have often threatened the process of infrastructure renewal. They have also retarded research and data collection on water usage and pricing. More fundamentally, the difficulties involved in questions of water resource ownership have meant that the suppliers (in Canada the provinces) are not interested primarily in pricing isses, and the demanders (e.g., industries) have overused a low-priced resource (Pearse 1988; Pearse and Tate 1991).

As a result of these perceptions and difficulties, most economists, not to mention others, have been skeptical about modelling water demands using econometric approaches. In a report for Resources for the Future, Gibbons (1986, p. 49) stated:

> ... theoretically, the demand and value of water in industrial use could be derived from statistical production functions, but as a practical matter this appears to be a vain hope.

On the other hand, however, a small number of studies have used precisely this production function approach over the past 25 years. The first such studies came in the municipal area (e.g., Howe and Linaweaver 1967; Lee 1969; Grima 1972). For industry, early econometric approaches were developed by Rees (1969) and de Rooy (1970). All of these studies viewed water use in the context of economic decision-making by the firm. They all addressed the empirical question of whether water use is price sensitive. And they all rejected the null hypothesis of no relationship between water use and price. In a public policy context, research results such as these, built up over a long time, contributed to the recognition, at least at the conceptual level, that water pricing would form an important part of future water management (Environment Canada 1987).

PREVIOUS STUDIES

An initial issue that should be addressed briefly relates to the price of water for industrial use. The plants dealt with in this paper are largely self-supplied ones, which do not face water prices determined by the interaction of supply and demand. Thus, a price variable must normally be estimated using data on the cost of the various functions of providing water service. These costs include provincial license fees (if any) water pumping, pre-treatment, recirculation, and waste treatment. These costs are totalled and averaged over total intake to give the most commonly used "proxy" for water price. The justification for this procedure is that average cost is the price generated by internal supply and demand conditions within the plant. De Rooy (1970, p. 51), for example, defended the procedure as follows:

> ... since the product is "internally consumed" there is no need to be concerned with market demand in the usual sense. Demand and supply within the firm will always be identical.

The problems implied by this procedure are outlined below.

Rees (1969) surveyed water use in 230 English manufacturing plants in one of the earlier econometric studies of water demand. This study used a relatively simple regression approach to examine the strength of the price/water use relationship in these plants. For the entire sample, she found that price was statistically significant in explaining the variance in water use, but was often insigificant for individual industries. Also, water was found not to be a critical factor in the location decisions of most firms, the exceptions being the industries using large amounts of water.

De Rooy's (1970) study was among the first North American efforts to examine industrial water demand functions. Using a sample of 30 New Jersey chemical plants, de Rooy calculated single-equation water demand functions separately for water used in cooling, processing and steam production. Water use formed the dependent variable for each equation, with plant output, water price (proxied by the average price of water), and a dummy measure of plant age constituted the independent variables. Estimated price elasticities[1] ranged between -0.354 for processing water and -0.894 for cooling. The use of average water cost as a proxy for price (which is normally not measurable for self-supplied industries) introduced a potential source of bias since quantity demanded thereby appears on both sides of the regression equation. Some of the subsequent studies in the field have attempted to deal with this simultaneity problem.

Grebenstein and Field (1979) used the translog form (see Berndt and Wood 1975) of a cost function for the U.S. manufacturing industry to

[1] Price elasticity refers to the relationship between changes in water demand resulting from changes in its price. Formally, price elasticity equals the percentage change in quantity demanded divided by the percentage change in price. In most cases, price elasticity is negative, denoting the inverse reaction of quantity demanded to changes in price.

analyze the water demand relationship. Productive inputs included capital, labour, energy, materials, and water. The cross-sectional data set consisted of 50 state-level observations on input prices, with the intake price of water being proxied by its average cost. The study used two different series of data for water price, and, depending upon the set used, estimated that intake water made up 1.2% or 1.9% of manufacturing cost. The price elasticity of demand was -0.326 or -0.80, again depending upon the data set used. Interestingly, the study found that water and labour were substitutes for each other in the production process, while water and capital were complements. The latter finding was explained by the fact that water and capital form "bundles" of inputs in many industrial processes. Within each bundle, water and capital are substitutes, but if the price of another input changes, both capital and water move in the same direction to a new equilibrium level, hence the finding of complementarity.

Babin, Willis, and Allen (1982) used a similar methodology, with a more disaggregated data set to calculate translog cost functions at the two-digit SIC (standard industrial classification) level for U.S. manufacturing. This study used state-level observations on input prices for 1973 (again using average water cost as a proxy for price). The water cost share ranged from 0.21% (fabricated metals) to 7.9% (chemicals), and the price elasticities from 0 (food, machinery, electrical products) to -0.66 (paper and allied products). The same water/capital complementarity as observed by Grebenstein and Field (1979) materialized for paper and allied products, fabricated metal products, and minerals, and for a pooled regression of all manufacturing. The study found water/capital substitutability for food and electrical products sectors.

Renzetti (1986) analyzed 372 plant-level observations of water use and water-related expenditures in British Columbia manufacturing firms. The data were part of the 1981 data set analyzed in this paper. The study estimated intake water demand equations both as single equations and as part of a system (one equation each for water intake, water treatment prior to use, water recirculation, and water treatment prior to discharge). The problem introduced by using average cost as a proxy for price (outlined earlier) was addressed by using an instrumental variable, following a procedure outlined by Jones and Morris (1984). The instrumental variable was constructed on the basis of the water rate structures facing the firms. The study found that the level of industrial intake was inversely related to intake water price and the costs of water recirculation, and directly related to the firms' output level.

A study by Ziegler and Bell (1984) examined the use of both average and marginal cost as proxies for water price. They stated (p.4):

> While the use of average cost has resulted in demand functions with good statistical fits, the possibility exists that the substitution of other, more theoretically appropriate measures of price could improve significantly the estimates on both a conceptual and theoretical basis.... The economic theory of the firm suggests that firms will use inputs based on considerations of marginal contributions to revenue relative to marginal contributions to cost.... Self supplied firms do not purchase water in a competitive market, and if they in fact use water on the basis of marginal considerations, the possibility exists that the substitution of a marginal cost variable for average cost can result in better water demand estimates.

Ziegler and Bell used data on 23 large water users in Arkansas to compare the relative efficiencies of using average or marginal costs. Marginal costs were estimated by regressing total intake costs against the square of intake quantity and then taking the first derivative of the resulting function. Then both average cost and marginal cost data sets were used in a regression analysis to explain the level of water demand. Ziegler and Bell concluded that industrial demands are price sensitive and the average cost acts as a better estimator of the true but unknown price of water.

Renzetti (1987) used the approach of Ziegler and Bell (1984) in an attempt to estimate proxies for average and marginal costs of industrial water use. The purpose of doing so was to overcome the simultaneity bias inherent in using a firm's average water cost as a proxy for water price. The method regresses total water intake against total water cost and the square of total water cost. The exact functional form of the equation is set out in Data Sources and Analysis Methods, below. Renzetti found that the resulting regression equations were generally poor with respect to statistical significance, with the conclusion, stated in Renzetti (1987), that the Ziegler-Bell method was no better than the simpler average cost method in minimizing simultaneity bias. Thus, the method was used (Renzetti 1987) "to gain some understanding into the relationship between water use and expenditures." This rationale underlies the latter part of the current paper. Subsequent work by Renzetti (1988) uses more aggregate data and a two-stage least squares estimation technique. The latter involves the use of an instrumental variable to proxy the price of water and to eliminate the simultaneity bias associated with demand estimates where price is a function of quantity. The instrument is constructed from the (nonlinear) industrial water price schedules constructed by municipal water utilities.

In summary, common features of the studies outlined in this section include an attempt to incorporate water into an economic framework of decision-making by the firm; the empirical question of the sensitivity of industrial water use to price changes; and rejection of the hypothesis that industrial water demands are insensitive to the price of water. The limitations that these studies share include the imprecise definition of the price variable, the lack of observations on input prices other than water, and the failure to derive the form of the estimated demand equation explicitly from a model of optimizing firm behaviour (cf. Renzetti 1988 on this last point).

AN OUTLINE OF THE ESTIMATION MODELS

The current study estimates water demand and water cost functions for major industrial sectors in Canada, both nationally and provincially. It includes Renzetti's (1987) work using 1981 data, as well as an update of his (unpublished) results, using 1986 data.

The study, which uses linear regression methods, assumes that firms are cost minimizers, and choose their combinations of inputs to meet this objective. Accordingly, a firm's demand for a given input (e.g., water) depends upon the input price of that variable, the input prices of other variables, and its level of output. The principal data source for the study was the 1981 and 1986 Environment Canada surveys of industrial water use. These surveys did not include the price of productive inputs other than water, with the result that the analysis here excludes consideration of the prices of these other inputs. Therefore, this study assumes that water use is strongly separable[2] from other productive inputs, and that one can estimate water demand functions independently of the demands for other inputs.

Industrial Water Demand Functions

Two basic demand models were calculated using different subsets of the 1981 and 1986 data bases. The first type regressed the quantity of water intake against the price (i.e., average cost) of intake and a measure of plant output. In mathematical terms, equation (1) represents this simple demand function model. This model was calculated for (a) each two-digit SIC group nationally, (b) each three-digit SIC group nationally, and (c) each two-digit SIC group provincially.

$$\ln(Q_{in}) = a_0 + a_1\ln(P_{in}) + a_2\ln(X) + e \qquad (1)$$

where ln = the use of natural logarithms

P_{in} = average cost of water intake

Q_{in} = quantity of plant water intake

X = a measure of plant output:
for 1981, total employee-hours worked
for 1986, total value of shipments

$a_{0,1}$ = coefficients of the regression equation

e = an error term

A minor variation on equation (1) regressed the quantity of gross water use (i.e. the sum of

[2] The idea of separability relates to the structure of the firm's technology and the way in which the use of one input is dependent on the levels of other inputs. If this assumption of separability is inaccurate, then the estimated function's coefficients may be biased due to the omission of relevant explanatory variables (e.g., the price of capital).

intake and recirculation) against the total average cost of water to the firm (i.e., the sum of the total costs of intake, treatment prior to use, recirculation, and discharge divided by gross water use) and a measure of output, as follows:

$$\ln(Q_{gross}) = a_3 + a_4\ln(P_{tot}) + \ln(X) + e \qquad (2)$$

where P_{tot} = total average cost of water to the firm

Q_{gross} = quantity of plant water gross use

$a_{3,4}$ = coefficients of the regression equation

e = an error term

Equation (2) was calculated at the two-digit SIC level nationally.

The second demand model regressed intake against the implied price of four water related components, again measured by average cost. This model (represented by equation (3)) was calibrated for the national two-digit SIC groups.

$$\ln(Q_{in}) = a_5 + a_6\ln(P_{in}) + a_7\ln(P_{trt}) + a_8\ln(P_{rcr}) + a_9\ln(P_{dis}) + a_{10}\ln(X) + e \qquad (3)$$

where P_{trt} = average O&M cost of water treatment prior to use

P_{rcr} = average O&M cost of recirculation

P_{dis} = average O&M cost of waste water treatment

$a_{5..10}$ = coefficients of the regression equation

e = an error term

All of the demand functions were estimated in double log form, the form most commonly used in these types of study. In 1981, the plant output measure consisted of employee-hours worked, while in 1986, due to improvements in data collection, it was value of shipments. The use of average cost as a proxy for price may introduce some simultaneity bias, because a measure of water quantity (the dependent variable) is used implicitly to calculate the price proxies. While this problem is recognized, available resources were insufficient to address it during this project. This remains a question for further research. Concerned readers are referred to Renzetti (1986, 1988), where the simultaneity bias problem was addressed using an instrumental variable estimation procedure.

Data Sources and Analysis Methods

In both 1981 and 1986, the primary source of data was the Inland Waters Directorate (IWD) survey of industrial water use (Tate and Scharf 1985, 1991). As noted earlier, the number of plants in each survey totalled about 5 000. The survey focused on obtaining data on the plants' water use, water-related costs, labour employment, and the nature of products. In 1981, the expenditure data were augmented using IWD files on municipal water rates, thereby augmenting the number of plants in the analysis by some 15%. The 1986 data set included only those firms with complete data; no attempt was made to augment it using outside sources. Analysis proceeded on the basis of two- and three-digit SIC groups; these groups are implicit in the tables of Chapter 3. In a few cases, Renzetti (1988) formed industrial composites to obtain sufficient measurements to calculate his regression equations. This procedure was used most frequently in the provincial analyses. It was not used in 1986.

The econometrics computer program SHAZAM (White 1978) was used to estimate the linear regression analyses of the paper. All of the demand equations were estimated using ordinary least squares (OLS) with a correction for the presence of heteroskedastic errors. The non-normal errors arise from the differences in the scale of the industrial operations in the data set. The plants selected for inclusion in the water demand functions were those that contained non-zero values for the water cost components, because of the logarithmic transformations used in the analysis. This restriction was not applied to the water cost functions that used untransformed data, as explained in the previous section. However, a zero cost associated with a non-zero water use in any category was considered unrealistic and was treated as a missing value in that category.

CHAPTER 3

Analytical Results

AN OVERVIEW OF INDUSTRIAL WATER DEMAND AND ITS COST

To provide a contextual framework for the presentation of industrial water demand, Tables 1 and 2 summarize the results for manufacturing from the 1986 and 1981 industrial water use surveys. (The figures in Tables 1-4 were derived from the complete survey tables: as they were rounded, they may appear not to total correctly.) In 1986, manufacturing plants withdrew a total of 7 984 million cubic metres from ambient water bodies (Table 1), and had a gross water use totalling 15 796 million cubic metres. Accordingly, water recirculated within the surveyed plants totalled 7 813 million cubic metres. In other words, recirculation effectively doubled industrial water supplies. Water consumption totalled 405 million cubic metres, or approximately 5.1% of total withdrawal, whereas about 7 579 million cubic metres was discharged back to the ambient water bodies. The consumptive use rate[3] of 5.1% is unchanged from 5.0% in 1981.

The 1986 survey results present an interesting contrast to 1981 in that both the total gross water use and water intake fell, by 24% and 20% respectively. It is tempting to suggest that water reuse efficiency increased during the period. However, the use rate[4], which is the conventional indicator of water reuse, actually fell by 12%. Nor does the answer lie in changes in the activity level by the manufacturing sector, since employment in the surveyed plants increased by 4%, from 795 000 to 830 000 (although most of this growth was in the service sector, traditionally one that uses little water). The explanation may lie in a rise of real water prices to industry, as indicated in a limited way in the following paragraph, although this rise is thought to be insufficient to explain this decline in intake. Thus, the fall in water use remains unexplained at this time, except to note that the water use efficiency per unit of product has apparently increased.

Reported manufacturing industry expenditures on water and on capital systems related to water use in 1986 totalled $481 million (Table 3). This represented an increase in nominal terms of 37% from the 1981 total of $351 million (Table 4). In real terms expenditures rose by approximately 12% over the period. In both years, water acquisition constituted the largest water-related cost. This cost consisted of payments to public utilities, in-house operating and maintenance expenses, and, in 1986 only, the payment of provincial licensing fees of $410 million. Waste treatment expenses made up a significant cost component in both years as well. Much of the growth in water cost over the five-year period arose in the primary metals industry, which moved from fourth to first position. The explanation for this shift is not addressed here.

INDUSTRIAL WATER DEMAND FUNCTIONS

National Water Intake

The analysis began with estimations made at the highest level of aggregation, the national two-digit SIC level, using only the price of intake water (P_{in}) and plant output measures (Q) as independent variables. The intake water demand functions were estimated using ordinary least squares in double log form, with the natural log

[3] The consumptive use rate is an index of water consumption by a plant or industry. The calculation is

$$\frac{(intake - discharge) \times 100\%}{intake}$$

[4] i.e., gross water use divided by water intake times 100%.

Table 1

Water Use in Canadian Manufacturing, 1986 (millions of cubic metres)

Industry group	Total intake	Recirculation	Gross use*	Consumption†	Total discharge
Foods	564	148	712	24	540
Beverages	63	107	169	12	51
Rubber products	23	67	90	2	21
Plastic products	30	66	96	3	27
Primary textiles	95	30	125	2	93
Textile products	13	12	25	2	11
Wood products	56	8	64	2	54
Paper and allied products	3 029	2 979	6 008	200	2 829
Primary metals	1 718	1 350	3 068	43	1 675
Fabricated metal products	25	114	139	1	24
Transportation equipment	117	237	354	4	114
Nonmetallic mineral products	90	70	160	18	72
Refined petroleum and coal products	487	1 068	1 555	33	454
Chemicals and chemical products	1 674	1 558	3 232	59	1 615
Total	7 984	7 813	15 796	405	7 579

Source: Tate and Scharf (1991).
*Gross use = total intake + recirculation.
†Consumption = total intake - total discharge.

Table 2

Water Use in Canadian Manufacturing, 1981 (millions of cubic metres)

Industry group	Total intake	Recirculation*	Gross use	Consumption†	Total discharge
Food and beverage	430	117	547	31	399
Rubber and plastics	54	744	798	7	47
Textiles	124	50	174	6	118
Wood products	73	57	130	4	69
Paper and allied	2 899	4 612	7 511	159	2 740
Primary metals	2 719	1 692	4 411	38	2 681
Metal fabricating	30	130	160	1	29
Transportation equipment	109	73	182	3	106
Nonmetallic mineral products	83	530	613	15	68
Petroleum and coal products	563	1 457	2 020	34	529
Chemicals and chemical products	2 853	1 284	4 137	197	2 656
Total	9 936	10 747	20 683	494	9 442

Source: Tate and Scharf (1985).
*Recirculation = gross use – total intake.
†Consumption = total intake – total discharge.

Table 3

Water Costs by Cost Component, Manufacturing, 1986 (thousands of dollars)

Industry group	Water acquisition	Intake treatment	Recirculation	Discharge treatment	Total
Food	30 308	4 375	4 811	6 516	46 010
Beverage	9 836	2 449	759	504	13 548
Rubber	1 819	766	759	504	3 455
Plastics	2 516	515	1 162	261	4 454
Primary textiles	3 007	1 355	441	777	5 580
Textile products	2 113	350	226	77	2 766
Wood products	2 603	309	265	81	3 258
Paper and allied products	22 700	20 338	8 400	38 058	89 406
Primary metals	100 757	9 857	26 960	33 746	171 320
Fabricated metal products	3 949	583	625	3 125	8 282
Transportation equipment	13 908	2 650	2 503	12 106	31 167
Nonmetallic mineral products	5 761	825	1 685	490	8 761
Refined petroleum and coal products	6 347	6 157	3 685	8 744	24 933
Chemicals and chemical products	22 899	18 429	14 892	12 067	68 287
Total	228 424	68 958	67 160	116 673	481 215

Table 4

Water Costs by Cost Component, Manufacturing, 1981 (thousands of dollars)

Industry group	Water acquisition	Intake treatment	Recirculation	Discharge treatment	Total
Food and beverage	26 978	6 046	3 461	6 480	42 965
Rubber and plastics	3 691	1 058	1 990	649	7 388
Textiles	3 764	1 628	386	635	6 413
Wood products	1 846	446	376	379	3 047
Paper and allied products	14 554	35 209	7 326	52 519	109 608
Primary metals	16 181	9 168	3 950	11 680	40 979
Metal fabricating	2 882	331	854	1 933	6 000
Transportation equipment	8 061	1 226	1 491	7 330	18 018
Nonmetallic mineral products	4 840	877	1 543	447	7 707
Petroleum and coal products	4 873	6 123	5 606	11 598	28 200
Chemical and chemical products	21 237	24 044	19 438	15 850	80 569
Total	108 908	86 156	46 422	108 498	350 984

Source: Tate and Scharf (1985).

Table 5

Estimated Water Demand Functions, National Two-Digit SIC Industries, 1986

(estimated equation: $\ln(Q_{in}) = a_0 + a_1\ln(P_{in}) + a_2\ln(Q) + e$)

Industry (SIC)	Constant	$\ln(P_{in})$	$\ln(Q)$	R^2	F	D.F.
Food (10)	1.701 (1.750)	-0.562 (-8.965)	0.527 (8.970)	0.426	95.8	255
Beverage (11)	-4.499 (-3.281)	-0.570 (-3.868)	0.925 (10.974)	0.756	80.0	51
Rubber products (15)	-4.070 (-1.430)	-0.557 (-2.747)	0.896 (5.186)	0.639	20.4	22
Plastic products (16)	4.588 (2.139)	-0.600 (-4.047)	0.316 (2.393)	0.205	10.8	76
Primary textiles (18)	-6.453 (-2.458)	-0.697 (-4.326)	1.024 (6.249)	0.756	48.9	31
Textile products (19)	-3.186 (-0.676)	-0.683 (-1.482)	0.837 (3.095)	0.372	5.5	15
Wood products (25)	-2.609 (-0.883)	-0.912 (-8.987)	0.700 (3.938)	0.688	56.1	50
Paper and allied (27)	-8.723 (-4.317)	-0.702 (-9.389)	1.166 (9.504)	0.846	256.9	93
Primary metals (29)	-6.557 (-4.090)	-0.769 (-6.475)	1.026 (10.486)	0.760	132.4	83
Metal fabricating (30)	0.929 (0.625)	-0.795 (-5.118)	0.536 (5.886)	0.372	31.2	102
Transportation equipment (32)	-0.352 (-0.249)	-0.704 (-5.130)	0.621 (7.414)	0.542	56.1	93
Nonmetallic mineral products (35)	-7.440 (-5.634)	-0.690 (-11.596)	1.060 (12.751)	0.797	211.0	107
Refined petroleum and coal (36)	-10.513 (-1.466)	-1.202 (-4.234)	1.134 (3.044)	0.762	18.6	11
Chemicals and chemical products (37)	-1.484 (-1.074)	-0.877 (-12.015)	0.703 (8.253)	0.648	143.4	155

Note: All equations exceed the 1% level of statistical significance.

of the quantity of intake water as the dependent variable. In the tables presented here, the figures in parentheses are t-ratio values; beside each equation coefficient appear the F and adjusted R^2 ratios, and the degrees of freedom (D.F.) for the t ratio.

The results of this first analysis (Tables 5 and 6) are quite satisfactory, as shown by the signs of the equation coefficients, and the t and F ratios. All of the F values, for both years, show significance above the 1% levels, as do the t ratios on the price and the output coefficients. The

Table 6

Estimated Water Demand Functions, National Two-Digit SIC Industries, 1981

(estimated equation: $\ln(Q_{in}) = a_0 + a_1\ln(P_{in}) + a_2\ln(Q) + e$)

Industry	Constant	$\ln(P_{in})$	$\ln(Q)$	R^2	F	D.F.
Food and beverage (10)	4.463 (13.21)	-0.579 (-15.93)	0.468 (16.91)	0.463	308.2	711
Rubber and plastics (16)	6.979 (8.799)	-0.359 (-6.131)	0.214 (3.494)	0.215	27.6	193
Textile products (18)	5.648 (5.501)	-0.508 (-5.783)	0.383 (5.044)	0.407	34.3	95
Wood products (25)	-2.806 (-1.310)	-0.378 (-3.327)	0.951 (5.678)	0.517	24.5	42
Paper and allied (27)	-9.266 (-7.187)	-0.229 (-6.536)	1.551 (16.25)	0.793	270.3	139
Primary metals (29)	-4.224 (-3.962)	-0.270 (-4.797)	1.174 (13.29)	0.775	182.2	103
Metal fabricating (30)	3.429 (3.428)	-0.292 (-4.097)	0.535 (6.599)	0.313	35.0	147
Transportation equipment (32)	4.638 (6.961)	-0.460 (-4.682)	0.419 (8.145)	0.440	64.0	158
Nonmetallic mineral products (35)	2.432 (5.193)	-0.564 (-9.141)	0.597 (15.15)	0.660	201.5	205
Refined petroleum and coal (36)	-3.841 (-2.71)	-0.179 (-2.271)	1.262 (9.627)	0.752	57.1	35
Chemicals and chemical products (37)	0.173 (0.233)	-0.148 (-10.68)	0.840 (13.78)	0.617	234.0	287

Note: All equations exceed the 1% level of statistical significance.

adjusted R^2 ratios show that this simple form of water demand function explains up to 85% of the total variance in industrial water intake. (The R^2 values reported in all tables are adjusted R^2s.[5]) From 1981 to 1986, the number of groups included in the analysis rose from 11 to 14, as the food and beverage, the rubber and plastics, and the textile industries were split in a revised classification system. This classification change, combined with a revised measurement of the output variable, improved the R^2 measure slightly for most industries and by over 10% in six of the groups. To improve the R^2 measures further, other sources of variation (e.g., plant age, technology levels, production process/product mixes) would have to be included.

As predicted, the signs for the price variable are uniformly negative, showing an inverse relationship between price and quantity of intake. The positive signs on the output coefficients

[5] The apparent high levels of significance may be due to the definition of price used in this paper. Defining price as average expenditures implies that the quantity of water will enter the regression on both sides of the equation, leading to the possibility of artificially high F and R^2 values.

Table 7

Estimated Gross Water Demand Equations, National Two-Digit SIC Industries, 1986

(estimated equation: $\ln(Q_{gross}) = a_3 + a_4\ln(P_{tot}) + a_5\ln(Q) + e$)

Industry (SIC)	Constant	$\ln(P_{tot})$	$\ln(Q)$	R^2	F	D.F.
Food (10)	1.296 (1.271)	-0.877 (-11.750)	0.546 (8.852)	0.504	130.7	255
Beverage (11)	-3.514 (-2.329)	-0.891 (-7.833)	0.866 (9.307)	0.801	103.7	51
Rubber products (15)	-4.528 (-1.594)	-0.845 (-4.188)	0.924 (5.149)	0.781	40.2	22
Plastic products (16)	3.615 (1.628)	-0.805 (-7.028)	0.393 (2.845)	0.445	31.5	76
Primary textiles (18)	-8.39 (-3.028)	-0.899 (-4.581)	1.144 (6.551)	0.789	59.0	31
Textile products (19)	-1.963 (-0.471)	-1.13 (-4.738)	0.761 (3.171)	0.617	13.1	15
Wood products (25)	-2.589 (-0.744)	-0.898 (-7.548)	0.724 (3.444)	0.628	43.2	50
Paper and allied products (27)	-9.536 (-5.174)	-0.981 (-11.728)	1.225 (11.011)	0.871	314.7	93
Primary metals (29)	-7.725 (-4.838)	-0.776 (-6.813)	1.129 (11.642)	0.775	143.7	83
Fabricated metal products (30)	0.539 (0.315)	-0.493 (-3.229)	0.601 (5.746)	0.288	21.6	102
Transportation equipment (32)	-2.639 (-1.555)	-0.824 (-6.764)	0.774 (7.848)	0.575	63.8	93
Nonmetallic mineral products (35)	-9.302 (-6.395)	-0.781 (-11.413)	1.186 (12.963)	0.798	211.9	107
Refined petroleum and coal (36)	-6.25 (-1.174)	-1.162 (-7.635)	0.986 (3.543)	0.913	59.3	11
Chemicals and chemical products (37)	-3.07 (-2.027)	-1.048 (-13.605)	0.829 (8.879)	0.702	183.4	155

Note: All equations exceed the 1% level of statistical significance.

show the expected direct variation of intake with plant output.

The double-log form of estimation means that the coefficient of the price variable measures the price elasticity of water demand (which is assumed to be constant). The fact that the absolute values of these elasticities fall between 0 and 1 confirms the results of previous studies. The elasticities for some of the major water users (e.g., paper and allied products, primary metals) are relatively high, indicating that increases in water price would have a substantial impact on water demand. This conforms with economic theory, which predicts that the absolute magnitude of the demand elasticity will increase as an

Table 8

Estimated Gross Water Demand Equations, National Two-Digit SIC Industries, 1981

(estimated equation: $\ln(Q_{gross}) = a_3 + a_4\ln(P_{tot}) + a_5\ln(Q) + e$)

Industry (SIC)	Constant	$\ln(P_{tot})$	$\ln(Q)$	R^2	F	D.F.
Food and beverages (10)	4.236 (12.33)	-0.678 (17.98)	0.497 (17.67)	0.511	373.2	711
Rubber and plastics (16)	5.370 (7.949)	-0.915 (-14.77)	0.327 (6.100)	0.613	149.3	185
Textile products (18)	5.754 (5.539)	-0.838 (-7.409)	0.348 (4.419)	0.499	48.7	94
Wood products (25)	-2.278 (-2.279)	-0.727 (-5.366)	0.906 (5.841)	0.636	38.5	41
Paper and allied (27)	-8.259 (-6.304)	-0.635 (-9.775)	1.437 (14.44)	0.836	332.6	128
Primary metals (29)	-2.916 (-2.584)	-0.469 (-6.394)	1.081 (12.02)	0.813	222.6	100
Metal fabricating (30)	3.311 (3.332)	0.882 (-9.389)	0.503 (6.176)	0.524	80.8	143
Transportation equipment (32)	4.421 (5.532)	-0.708 (-5.759)	0.443 (7.136)	0.431	61.3	157
Nonmetallic mineral products (35)	1.358 (2.371)	-0.666 (-10.87)	0.699 (14.52)	0.681	221.5	205
Refined petroleum and coal (36)	-6.938 (-3.242)	-0.425 (-3.672)	1.521 (9.489)	0.852	98.6	32
Chemicals and chemical products (37)	-0.696 (-1.002)	-1.059 (-17.79)	0.867 (15.23)	0.739	391.9	280

Note: All equations exceed the 1% level of statistical significance.

input's share in total costs rises. In one case, (i.e., refined petroleum and coal in 1986), the price elasticity is greater than one, indicating that a given percentage rise in price, on average, would lead to a greater than proportional change in intake demand. This finding is unusual in the industrial water demand field.

Not only are the price elasticities highly significant statistically but they appear to have risen over the five-year period of study. Conventionally, water demand has been tied to the nature of a firm's fixed capital stock and thus relatively insensitive to the price of (minor) inputs like water. The observed increases in price elasticity may indicate the growing importance of the use of previously "free" environmental resources. It may also result from the increase in real expenditures referred to above. As plant managers spend more on water acquisitions, they are likely to become more concerned about water conservation as a means of reducing expenditures.

National Gross Water Use

Tables 7 and 8 report (for 1986 and 1981) the results of a second analysis to determine water demand functions for Canadian industries.

Table 9

Estimated Water Demand Equations with Added Explanatory Variables, National Two-Digit SIC Industries, 1986

(estimated equation: $\ln(Q_{in})=a_5 + a_6\ln(P_{in}) + a_7\ln(P_{trt}) + a_8\ln(P_{rcr}) + a_9\ln(P_{dis}) + a_{10}\ln(Q) + e$)

Industry (SIC)	Constant	$\ln(P_{in})$	$\ln(P_{trt})$	$\ln(P_{rcr})$	$\ln(P_{dis})$	$\ln(Q)$	R^2	F	D.F.
Food (10)	6.731	-0.232	-0.067	-0.231	-0.345	0.219	0.561	11.7	42
	(3.061)	(-1.96)	(-0.783)	(-2.281)	(-4.149)	(1.713)			
Beverage (11)	NO INFORMATION								
Rubber products (15)	NO INFORMATION								
Plastic products (16)	12.807	-2.35	0.689	0.804	0.674	0.006	0.062	1.1	6
	(1.609)	(-1.741)	(1.067)	(2.115)	(1.061)	(0.015)			
Primary textiles (18)	-81.74	2.371	0.419	0.351	-0.236	5.72	0.732	4.3	6
	(-1.378)	(1.037)	(0.449)	(0.365)	(-0.297)	(1.543)			
Textile products (19)	NO INFORMATION								
Wood products (25)	NO INFORMATION								
Paper and allied (27)	-6.66	-0.273	-0.332	-0.052	-0.0271	1.06	0.902	58.1	31
	(-1.939)	(-2.208)	(-3.739)	(-0.732)	(-0.247)	(5.132)			
Primary metals (29)	-16.692	-0.237	-0.107	-0.043	-0.074	1.601	0.897	27.2	15
	(-3.746)	(-0.815)	(-0.636)	(-0.205)	(-0.452)	(6.525)			
Metal fabricating (30)	-5.8	-0.675	-0.196	0.225	0.116	1.017	0.659	7.2	16
	(1.299)	(-2.309)	(-0.576)	(0.857)	(0.653)	(3.688)			
Transportation equipment (32)	2.185	-0.135	-0.104	0.022	-0.12	0.543	0.504	3.6	13
	(0.649)	(-0.236)	(-0.622)	(0.084)	(-0.671)	(2.669)			
Nonmetallic mineral products (35)	-8.708	0.274	-1.087	-0.104	-0.064	1.091	0.949	26.9	7
	(-1.465)	(0.726)	(-3.75)	(-0.835)	(-0.166)	(2.963)			
Refined petroleum and coal (36)	-20.363	-1.2	-0.063	0.152	-0.195	1.628	0.795	8.0	9
	(-1.313)	(-2.323)	(-0.073)	(0.396)	(-0.429)	(1.96)			
Chemicals and chemical products (37)	3.043	-0.511	-0.274	-0.074	-0.117	0.467	0.839	40.7	38
	(1.419)	(-4.9)	(-3.359)	(-1.342)	(-1.445)	(3.604)			

In contrast to the equations of Tables 5 and 6, this set of equations treats gross water use (i.e., the sum of intake plus recirculation) as a function of total water cost (i.e., expenditures for intake, pre-treatment, recirculation, and waste treatment). In a sense this analysis is somewhat broader in nature, in that it relates the industries' gross water use to their (total) average water costs rather than examining the intake quantity – price relationship.

In all cases but two (wood and fabricated metal) in 1986, the adjusted R^2 value improved through this second analysis, in some cases increasing over 20%. This implies that the second analysis is substantially better than the first in

Table 10

Estimated Water Demand Equations with Added Explanatory Variables, National Two-Digit SIC Industries, 1981

(estimated equation: $\ln(Q_{in}) = a_5 + a_6\ln(P_{in}) + a_7\ln(P_{trt}) + a_8\ln(P_{rcr}) + a_9\ln(P_{out}) + a_{10}\ln(Q) + e$)

Industry (SIC)	Constant	$\ln(P_{in})$	$\ln(P_{trt})$	$\ln(P_{rcr})$	$\ln(P_{dis})$	$\ln(Q)$	R^2	F	D.F.
Food and beverage (10)	4.535 (13.43)	-0.520 (-14.82)	-0.066 (-5.056)	-0.073 (-5.368)	-0.040 (-3.450)	0.421 (15.75)	0.518	154.0	708
Rubber and plastics (16)	6.311 (6.290)	-0.720 (-7.051)	-0.068 (-1.567)	-0.075 (-1.769)	0.007 (0.188)	0.289 (4.145)	0.541	23.6	91
Textile products (18)	4.938 (6.956)	-0.625 (-8.544)	-0.111 (-2.978)	-0.030 (-1.190)	0.179 (-5.332)	0.200 (3.911)	0.532	43.5	182
Wood products (25)	-2.479 (-1.507)	-0.648 (-4.969)	-0.101 (-1.330)	-0.040 (-0.414)	-0.081 (-2.104)	0.840 (6.513)	0.729	24.1	38
Paper and allied (27)	-3.815 (-2.794)	-0.490 (-7.775)	-0.083 (-3.011)	-0.233 (-0.178)	0.044 (1.900)	0.102 (10.78)	0.854	152.5	125
Primary metals (29)	-3.005 (-2.389)	-0.428 (-4.693)	-0.025 (-0.638)	0.004 (-0.144)	-0.055 (-1.703)	1.014 (10.54)	0.811	88.3	97
Metal fabricating (30)	3.934 (4.361)	-0.840 (-7.751)	0.007 (0.157)	-0.046 (-1.500)	-0.005 (-0.212)	0.420 (5.602)	0.480	27.7	140
Transportation equipment (32)	5.067 (7.601)	-0.765 (-6.285)	-0.092 (-1.835)	-0.068 (-1.879)	0.002 (0.692)	0.344 (6.809)	0.513	34.4	154
Nonmetallic mineral products (35)	2.735 (5.859)	0.557 (-9.061)	-0.017 (-0.729)	-0.056 (-1.985)	-0.078 (-3.555)	0.515 (12.23)	0.687	91.7	202
Refined petroleum and coal (36)	-3.833 (-1.771)	-0.661 (-4.700)	-0.020 (-3.361)	0.136 (3.362)	-0.004 (-9.51)	1.181 (7.207)	0.825	33.1	29
Chemicals and chemical products (37)	1.403 (2.198)	-0.824 (-14.61)	-0.071 (-2.238)	0.074 (3.208)	-0.022 (-1.297)	0.641 (12.18)	0.746	166.9	277

explaining the variation of water use. As indicated earlier, this may be due, in part, to the different specification of the plant output variable. In one case, refined petroleum and coal, the equation explains over 90% of the variance in gross water use. The F values are all very highly significant in statistical terms, a finding that has important implications for policy purposes, as discussed later in this paper.

Most of the average price elasticity values fall into the inelastic range (i.e., absolute values between 0 and 1). But most are also over 0.5, indicating that a water price change could have a relatively large impact in water use. For refined petroleum and coal, this impact would be larger in percentage terms than the percentage change in price. For most industrial groups, the absolute elasticities rose between 1981 and 1986, indicating a growing sensitivity to water price.

Adding Explanatory Variables

Adding explanatory variables is another means of extending Table 5. Economic theory maintains that a firm's input demand equations should include the price of other inputs as independent variables. The survey data collected in both 1981 and 1986 do not allow this type of analysis, but will allow the analyst to include the prices of other water inputs, in the form of the average costs of the other categories of water use: treatment prior to use (P_{trt}), recirculation (P_{rcr}), and treatment prior to discharge (P_{dis}),. The dependent variable, again, is the natural log of the quantity of intake water. The results of this set of regression analyses are given in Tables 9 (1986) and 10 (1981).

Theoretically, one can anticipate the signs of the independent variables. As in the analyses outlined earlier, the sign of the output variable should be positive, since water intake varies directly with output. Intake and discharge also vary directly, which should make the signs of P_{in} and P_{dis} negative. Intake and recirculation are expected to be substitutes, and therefore the sign on P_{rcr} should be positive. The expected sign on P_{trt} is unclear, since some firms may treat all of their water (suggesting complementarity with input), while some may choose between treated and untreated water (suggesting substitutability).

The results of this analysis are encouraging in some respects, disappointing in others. In 1986, in all cases, the adjusted R^2 values with the enhanced equations are higher than those which use only one price variable (cf. Table 5). However, for four industries the data were insufficient to allow estimation of the enhanced equation, thereby weakening somewhat its increased explanatory power. However, in 1981, the addition of the other independent variables tended to lower the adjusted R^2s of the equations (cf. Tables 6, 8, and 10). This loss is attributable, in part, to correlations among the explanatory variables, so that the additional variables provide little additional explanatory power.

Considering the enhanced equation by itself through time, the R^2 values generally increased between 1981 and 1986. In four cases, this value was over 0.8, denoting the relatively large explanatory power of the enhanced equation. The F statistics for both years indicate, again, that the overall equation is very highly significant.

As noted, there are also negative results indicated in Tables 9 and 10. First, the t values fell during the period of analysis, and in many cases indicate coefficients not even significant at the 5% level. Second, there were fewer data in 1986 because many of the questionnaires were incomplete with respect to the four cost components or the output measurement. Third, the anticipated signs were often not found (Table 11). The worst case occurred in 1981 in conjunction with recirculation, when 8 of 11 signs were negative instead of positive, indicating complementarity with water intake. This may be due to the poorer quality of the recirculation data or due to the specification of the price of the recirculation variable. Alternatively, the estimation results may reflect the true state of firms' water-use technology; for example, each cubic metre of water is recirculated a preset number of times.

Table 11

Analysis of Signs of the Independent Variables in Relation to the Anticipated Signs

Variable	Hypothesis verified 1981	Hypothesis verified 1986	Hypothesis unverified 1981	Hypothesis unverified 1986
Output	11	10	0	0
Intake	10	8	1	2
Discharge	7	8	4	4
Recirculation	5	3	5	8

In both years, the signs of the P_{trt} variable are predominantly negative. This suggests that most firms view water intake and treatment prior to use as complementary, further suggesting that most firms find the ambient water quality inferior for use without treatment.

The relatively poor showing of the added price variables is probably attributable to the low response rates for questions eliciting this information on the Industrial Water Use Surveys. Since the information on these variables cannot be estimated or otherwise supplemented, the relatively poor results at the two-digit national level (i.e., the most aggregated) indicates that to continue to include them in further analyses would not be fruitful at this point, although a future pooled cross-sectional time series approach might prove more useful. Consequently, the remainder of the analyses presented in this paper focus on the national three-digit and the provincial two-digit levels of analysis, and include only the price of water intake (P_{in}) and the indicator of firm output (X) as independent variables.

Demand Functions at a Finer Level of Detail

The data allow the calculation of water demand functions at a finer three-digit SIC level. These may be useful to planners working with specific industries or industrial complexes. For 1986 (Table 12), equations were calculated for 54 industrial subgroups. Of these, 39 were statistically significant at the 5% level or better, as indicated by the F statistic. The majority (49) of the equations showed a negative price elasticity, which ranged from near 0 (five industries between 0 and .1) to over 1 (SICs 152, 181, 192, 199, 297, 358, 361, and 373). Two equations (SICs 105 and 107) had positive price elasticities, but neither of these was statistically significant. The majority (43 of 54) of the t statistics for the P_{in} variable proved significant at the 5% level, or better.

The signs of the output variable were uniformly positve, indicating the increase of water intake with output. Most of the coefficients varied between 0 and 1, but fifteen proved greater than 1, implying that, on average, a given percentage increase in output will produce a greater than proportional increase in water intake. The small sample sizes (see the D.F. statistics) in some of the groups mean that the equations are tentative at this point (i.e., until a cross-sectional time series analysis can be performed) but the overall results for 1986 are quite good.

The analysis for 1981 (Table 13) was also encouraging from the viewpoint of showing the variation of water use with price. Most industries had statistically significant price coefficients ranging between 0 and -1. The price coefficients for SICs 186, 295, 323, 326, and 354 were not significantly different from 0. The output coefficients were uniformly positive, and all but five SICs (105, 181, 182, 326, and 327) were significant at the 5% level, or better.

For both years, the estimated price coefficients reported in Tables 12 and 13 show a larger range of values than do those at the broader, two-digit level of aggregation (cf. Tables 5 and 6). This suggests that aggregating upwards leads to a loss of information, since the two-digit analysis includes an average of the three-digit one. The food industry (SIC 10) for 1986 is a case in point. Table 5 establishes the two-digit price coefficient at -0.56; according to Table 12, the range of variation is from statistical insignificance (SICs 105-107) to -0.81 (SICs 108). Finally, between 1981 and 1986, there was a slight tendency for the absolute values of the price elasticities to increase. For the three-digit groups that were directly comparable, 17 experienced an increased elasticity greater than 10%; conversely, 10 fell by greater than 10%.

Interprovincial Comparisons

Breaking the data down into provincial areas allows the investigation of regional patterns in the water demand coefficients (Tables 14 to 23). The relatively small industrial bases of several provinces permitted compilation within only three, or fewer, industry sectors. Also compilation was done at the two-digit SIC level. For both years, the empirical results were quite good, with highly significant F and t tests for the most part. Most of the coefficients displayed the anticipated sign. The few exceptions occurred in connection with industries that had a limited number of degrees of freedom (i.e., small sample size). None of these were statistically significant.

Table 24 synthesizes the provincial analyses by compiling the ranges around the national averages for each SIC group. As noted previously, a striking increase in price elasticities (in absolute value) took place over the five-year period. The range of variation also increased through the period. The output elasticities and the R^2 coefficients exhibited less of a tendency to increase uniformly.

The results also suggest that "regional" patterns exist. For example, the estimated coefficients for Ontario industries do not resemble those of their Quebec counterparts, and the results for Prairie provinces are not especially close to those of other regions. Table 24 demonstrates that the national results for any industry consist of an average over a substantial range of provincial results. For example, in the beverage industry in 1986, the national price elasticity of -0.570 falls within a wide range, from -1.085 to -0.110.

Table 12

Estimated Water Demand Functions, National Three-Digit SIC Industries, 1986

(estimated equation: $\ln(Q_{in}) = a_0 + a_1\ln(P_{in}) + a_2\ln(Q) + e$)

Industry (SIC)	Constant	$\ln(P_{in})$	ln(Q)	R^2	F	D.F.
Meat and poultry products (101)	7.34 (3.737)	-0.354 (-2.587)	0.204 (1.717)	0.129	5.8	67
Fish products (102)	-0.815 (-0.300)	-0.55 (-4.062)	0.69 (4.001)	0.593	21.4	28
Fruit and vegetable products (103)	0.862 (0.410)	-0.432 (-2.108)	0.625 (5.013)	0.483	15.4	31
Dairy products (104)	3.397 (2.188)	-0.4372 (-4.020)	0.425 (4.495)	0.477	22.0	46
Flour, prepared cereal food, and feed (105)	-0.220 (-0.019)	0.174 (0.192)	0.629 (0.961)	0.120	0.5	9
Vegetable oil mills (106)	-47.27 (-2.01)	-0.207 (-0.711)	3.296 (2.510)	0.594	6.1	7
Bread and other bakery products(107)	-0.525 (-0.144)	0.116 (0.361)	0.661 (3.058)	0.388	5.1	13
Sugar and sugar products (108)	-8.203 (-1.652)	-0.805 (-4.082)	1.079 (3.595)	0.851	26.8	9
Other food products (109)	-3.598 (-1.176)	-0.709 (-3.059)	0.841 (4.665)	0.504	130.7	37
Soft drinks (111)	-3.415 (-3.363)	-0.175 (-2.015)	0.886 (14.187)	0.919	102.8	18
Distillery products (112)	-8.274 (-0.745)	-0.776 (-1.421)	1.136 (1.645)	0.627	6.9	7
Brewery products (113)	0.0609 (0.604)	-0.173 (-1.265)	0.7 (13.132)	0.945	86.9	10
Wine products (114)	0.343 (0.094)	-0.93 (-1.976)	0.554 (2.296)	0.463	6.6	13
Tire and tube (151)	-6.56 (-1.506)	-0.869 (-1.464)	0.99 (3.699)	0.843	14.5	5
Rubber hose and belting (152)	-24.997 (-1.14)	-2.249 (-2.155)	1.997 (1.586)	0.469	2.8	4
Other rubber products (159)	-3.676 (-0.762)	-0.411 (-1.779)	0.889 (2.896)	0.554	7.8	11
Foamed and expanded plastic (161)	-4.836 (-0.39)	-0.131 (-0.182)	0.931 (1.2)	0.18	1.4	4
Plastic pipe and fittings (162)	1.666 (0.207)	-0.052 (-0.11)	0.575 (1.212)	0.333	0.8	10

Table 12 (continued)

Industry (SIC)	Constant	ln(P_{in})	ln(Q)	R^2	F	D.F.
Plastic film and sheeting (163)	7.81 (1.491)	-0.004 (-0.009)	0.226 (0.734)	0.153	0.3	11
Other plastic products (169)	7.932 (2.971)	-0.671 (-3.823)	0.084 (0.505)	0.208	7.3	48
Man-made fibre and filament (181)	-4.293 (-0.886)	-1.186 (-2.729)	0.833 (2.542)	0.861	25.8	8
Spun yarn and woven cloth (182)	-5.029 (-1.379)	-0.552 (-3.068)	0.951 (4.282)	0.592	17.0	22
Carpet, mat, and rug (192)	-12.699 (-1.778)	-1.231 (-2.762)	1.341 (3.403)	0.529	6.6	10
Other textile products (199)	-4.89 (-0.534)	2.572 (1.055)	1.228 (1.8)	0.242	1.6	4
Sawmill and planing mill products (251)	-2.609 (-0.883)	-0.912 (-8.987)	0.701 (3.938)	0.688	56.1	50
Pulp and paper products (271)	-6.155 (-3.47)	-0.37 (-7.055)	1.126 (11.083)	0.817	150.9	67
Other converted paper products (279)	3.212 (1.116)	-0.701 (-4.129)	3.8 (2.134)	0.494	13.1	25
Primary steel (291)	-11.032 (-6.00)	-0.573 (-4.988)	1.321 (12.21)	0.889	121.2	30
Steel pipe and tube (292)		NO INFORMATION				
Iron foundries (294)	-10.15 (-2.667)	-0.788 (-2.062)	1.233 (5.182)	0.650	17.7	18
Nonferrous metal smelting and refining (295)	12.929 (4.366)	-0.767 (-2.037)	0.039 (0.257)	0.254	2.4	8
Aluminum rolling casting and extrusion (296)	11.124 (2.25)	0.03 (0.08)	0.017 (0.057)	-0.153	0.0	15
Copper and alloy rolling casting and extrusion (297)	-6.25 (-2.699)	-1.092 (-5.114)	0.96 (7.028)	0.940	40.2	5
Fabricated structural metal (302)	3.763 (0.512)	-0.721 (-1.398)	0.319 (0.708)	0.054	1.4	13
Stamped, pressed, and coated metal (304)	2.065 (1.255)	-0.685 (-3.042)	0.466 (4.731)	0.328	13.7	52
Wire and wire products (305)	-2.019 (-0.644)	-0.731 (-3.207)	0.75 (3.84)	0.485	17.5	35
Aircraft and aircraft parts (321)	2.379 (0.446)	-0.321 (-0.755)	0.504 (1.678)	0.073	1.4	11
Motor vehicles (323)	-13.479 (-2.82)	-0.584 (-1.603)	1.225 (4.667)	0.984	127.4	4

Table 12 (continued)

Industry (SIC)	Constant	$\ln(P_{in})$	$\ln(Q)$	R^2	F	D.F.
Motor vehicle parts and accessories (325)	-2.871 (-1.496)	-0.698 (-3.835)	0.768 (6.675)	0.554	43.3	68
Railroad rolling stock (326)	17.314 (1.063)	-0.761 (-1.461)	-0.453 (-0.459)	0.040	1.1	4
Shipbuilding and repair (327)	NO INFORMATION					
Hydraulic cement (352)	0.771 (0.176)	-0.573 (-9.122)	0.635 (2.53)	0.900	45.9	10
Concrete products (354)	-4.36 (-1.026)	-0.067 (-0.378)	0.876 (3.321)	0.376	5.5	15
Ready-mix concrete (355)	-4.839 (-3.196)	-0.737 (-9.326)	0.885 (8.884)	0.853	97.0	33
Glass and glass products (356)	-14.76 (-2.8)	-0.199 (-0.713)	1.516 (4.818)	0.692	13.4	211
Abrasive products (357)	-7.532 (-1.233)	-0.998 (-7.154)	1.057 (2.739)	0.927	45.3	7
Lime products (358)	-10.387 (-0.038)	-1.517 (-0.196)	1.169 (0.072)	0.167	0.1	3
Other nonmetallic mineral products (359)	-4.866 (-1.626)	-0.733 (-3.947)	0.903 (4.936)	0.692	25.7	22
Refined petroleum (361)	-10.513 (-1.466)	-1.202 (-4.234)	1.134 (3.044)	0.762	18.6	11
Industrial chemicals (371)	-2.264 (-0.96)	-0.809 (-6.463)	0.79 (5.258)	0.762	74.5	46
Plastic and synthetic resin (373)	4.239 (1.00)	-1.178 (-4.94)	0.347 (1.353)	0.675	17.6	16
Pharmaceutical and medicine (374)	6.967 (2.20)	0.041 (0.174)	0.216 (1.154)	0.109	0.8	15
Paint and varnish (375)	-5.332 (-1.454)	-0.75 (-2.73)	0.915 (4.2)	0.486	9.5	18
Soap and cleaning compounds (376)	1.859 (0.546)	-0.573 (-3.475)	0.509 (2.485)	0.501	8.0	14
Other chemical products (379	-3.273 (-0.913)	-0.777 (-3.865)	0.812 (3.662)	0.427	16.3	41

Table 13

Estimated Water Demand Functions, National Three-Digit SIC Industries, 1981

(estimated equation: $\ln(Q_{in}) = a_0 + a_1\ln(P_{in}) + a_2\ln(Q) + e$)

Industry (SIC)	Constant	$\ln(P_{in})$	$\ln(Q)$	R^2	F	D.F.
Meat and poultry products (101)	5.367 (7.280)	-0.487 (-5.638)	0.419 (7.044)	0.414	46.5	127
Fish products (102)	0.694 (0.534)	-0.583 (-6.806)	0.771 (7.233)	0.646	63.2	66
Fruit and vegetable processors (103)	1.607 (1.528)	-0.164 (-1.822)	0.805 (9.551)	0.614	48.7	58
Dairy products (104)	4.890 (8.476)	-0.585 (-9.921)	0.420 (8.773)	0.518	91.8	167
Flour and cereal products (105)	7.166 (5.620)	-0.681 (-2.527)	0.147 (1.468)	0.216	5.0	27
Miscellaneous food products (108	0.767 (0.716)	-0.783 (-7.933)	0.707 (8.353)	0.587	80.5	10
Beverages (109)	4.660 (6.292)	-0.442 (-4.150)	0.507 (8.064)	0.419	50.7	136
Rubber products (162)	0.067 (0.048)	-0.325 (-2.358)	0.805 (7.297)	0.656	47.7	47
Fabricated plastic products (165)	7.296 (9.174)	-0.774 (-9.205)	0.126 (2.057)	0.383	44.8	139
Cotton yarn and cloth mills (181)	7.271 (2.269)	-0.813 (-4.337)	0.217 (0.911)	0.689	16.5	12
Wool yarn and cloth mills (182)	9.559 (5.168)	-0.714 (-2.105)	0.038 (0.271)	0.234	2.1 (NS)	5
Man-made fibre, yarn, and cloth mills (183)	-1.298 (-0.858)	-0.937 (-6.849)	0.798 (6.900)	0.810	80.0	35
Carpet, mat, and rug plants (186)	3.311 (0.932)	0.144 (0.318)	0.706 (2.641)	0.295	3.5 (NS)	10
Miscellaneous textiles (189)	0.639 (0.183)	-0.587 (-2.759)	0.746 (2.711)	0.378	7.7	20
Wood industries (251)	-3.759 (-2.052)	-0.816 (-6.400)	0.974 (6.827)	0.707	50.6	39
Pulp and paper mills (271)	-4.073 (-2.216)	-0.382 (-5.815)	1.192 (8.975)	0.731	111.0	79
Miscellaneous paper converters (274)	-0.458 (-0.285)	-0.515 (-3.086)	0.774 (6.287)	0.505	25.5	46
Iron and steel mills (291)	-5.226 (-2.736)	-0.376 (-3.120)	1.232 (8.241)	0.855	89.5	28
Steel pipe and tube mills (292)	3.583 (1.898)	-1.118 (-4.934)	0.463 (3.261)	0.746	24.5	14

Table 13 (continued)

Industry (SIC)	Constant	$\ln(P_{in})$	$\ln(Q)$	R^2	F	D.F.
Iron foundries (294)	-4.997 (-1.458)	-0.769 (-4.517)	1.176 (4.249)	0.602	25.2	30
Non-ferrous metal smelting and refining (295)	-6.835 -2.466)	-0.063 (-0.377)	1.418 (6.558)	0.839	55.6	19
Fabricated structural metals (302)	0.109 (0.055)	-0.807 (-5.285)	0.667 (4.294)	0.731	32.2	21
Metal coating and plating (304)	5.445 (3.569)	-0.676 (-2.862)	0.362 (2.982)	0.185	6.6	47
Wire and wire products (305)	-2.347 (-1.485)	-0.643 (-4.360)	0.945 (7.345)	0.653	56.4	57
Aircraft and aircraft parts (321)	5.973	-0.753	0.332	0.255	6.0	27
Motor vehicles (323)	-4.481 (-2.120)	-0.459 (-1.063)	1.051 (6.772)	0.803	31.5	13
Motor vehicle parts (325)	6.565 (7.518)	-0.939 (-6.512)	0.198 (2.667)	0.450	39.5	92
Railroad rolling stock (326)	6.618 (1.291)	-0.123 (-0.237)	0.369 (0.925)	0.200	1.1 (NS)	5
Shipbuilding and repair (327)	6.641 (1.516)	-1.289 (-1.905)	0.244 (0.698)	0.462	5.7	9
Cement mfg. (352)	-2.323 (-0.589)	-0.403 (-2.981)	1.022 (3.385)	0.702	19.8	14
Concrete products (354)	1.603 (1.018)	-0.072 (-0.299)	0.702 (5.294)	0.465	14.0	28
Ready mix concrete	1.604 (1.879)	-0.195 (2.251)	0.727 (9.332)	0.533	48.3	81
Glass and glass products (356)	4.678 (3.214)	-0.648 (-2.550)	0.432 (3.846)	0.579	16.1	20
Abrasives mfg. (357)	6.979 (8.799)	-0.359 (-6.131)	0.214 (3.494)	0.215	27.6	193
Lime mfg. (358)	-3.537 (-1.218)	-0.918 (-5.162)	1.004 (4.389)	0.797	36.4	16
Misc. nonmetallic (359)	6.876 (4.794)	-0.630 (-3.364)	0.260 (2.327)	0.286	8.6	36
Petroleum refineries (365)	-1.574 (-0.593)	-0.543 (-4.198)	1.013 (5.098)	0.708	36.1	27
Plastics and synthetic resins (373)	0.351 (0.130)	-0.390 (-2.754)	0.871 (4.213)	0.532	14.6	22
Pharmaceuticals and medicines (374)	-0.556 (-0.281)	-0.522 (-2.278)	0.808 (5.154)	0.451	17.0	37
Paint and varnish (375)	-2.724 (-1.036)	-0.588 (-1.979)	0.993 (4.628)	0.465	13.2	26
Soap and cleaning compounds (376)	7.301 (6.598)	-0.669 (-2.927)	0.207 (2.081)	0.433	10.9	24
Industrial chemicals (378)	-0.992 (-0.969)	-0.734 (-8.809)	0.922 (10.83)	0.805	193.2	91
Miscellaneous chemical products (379)	-0.996 (-0.819)	-0.906 (-8.282)	0.852 (8.261)	0.730	91.6	65

NS = not significant.

Table 14

Estimated Water Demand Functions, British Columbia Two-Digit SIC Industries, 1986 and 1981

(estimated equation: $\ln(Q_{in}) = a_0 + a_1\ln(P_{in}) + a_2\ln(Q) + e$)

Industry (SIC)	Constant	$\ln(P_{in})$	ln(Q)	R^2	F	D.F.
Food (10)	-5.901 (-1.768)	-0.506 (-2.241)	0.991 (4.823)	0.627	20.4	23
Beverage (11)	-3.005 (-0.943)	-1.085 (-1.94)	0.744 (4.322)	0.713	9.7	7
Plastic (16)	1.841 (0.124)	-0.488 (-0.982)	0.487 (0.503)	0.094	0.7	6
Wood industries (25)	-15.000 (-3.019)	-1.086 (-8.097)	1.391 (4.838)	0.769	39.2	23
Paper and allied (27)	-7.582 (-2.846)	-0.162 (-0.948)	1.262 (8.019)	0.877	43.9	12
Primary metals (29)	-15.110 (-2.506)	-0.694 (3.54)	1.502 (-1.03)	0.929	33.5	5
Fabricated products (30)	-5.886 (-0.972)	-1.747 (-1.686)	0.804 (2.297)	0.465	3.6	6
Other nonmetallic mineral products (35)	-6.657 (-0.746)	-2.393 (-1.768)	0.738 (1.091)	0.657	7.7	7
Chemical and chemical products (37)	-52.995 (-1.933)	-0.575 (-1.281)	3.880 (2.221)	0.705	7.0	5

Note: Insufficient data were available to calculate equations for the remaining industrial groups. Equations for 1981 are contained in Renzetti (1986), but are not included here because they were calculated using a different functional form than the one used in this paper.
NS = not significant.

Table 15

Estimated Water Demand Functions, Alberta Two-Digit SIC Industries, 1986 and 1981

(estimated equation: $\ln(Q_{in}) = a_0 + a_1\ln(P_{in}) + a_2\ln(Q) + e$)

Industry (SIC)	Constant	$\ln(P_{in})$	ln(Q)	R^2	F	D.F.
		1986				
Food (10)	9.631 (4.083)	-0.717 (-3.497)	0.058 (0.406)	0.354	6.5	20
Beverage (11	-11.486 (-1.043)	-0.11 (-0.231)	1.381 (2.007)	0.541	4.5	6

Table 15 (continued)

Industry (SIC)	Constant	$\ln(P_{in})$	$\ln(Q)$	R^2	F	D.F.
		1986				
Paper and allied (27)	-22.748 (-2.971)	-0.634 (-2.411)	1.964 (4.311)	0.966	71.2	5
Primary metals (29)	-2.97 (-0.973)	-1.476 (-4.968)	0.741 (4.033)	0.947	36.7	4
Fabricated products (30)	5.269 (0.777)	0.104 (0.068)	0.29 (0.701)	-0.289	0.3	6
Other nonmetallic mineral products (35)	-8.378 (-1.565)	-0.625 (-3.641)	1.125 (3.452)	0.810	13.7	6
Refined petroleum and coal (36)	-26.124 (-17.771)	-0.273 (-1.299)	1.974 (24.995)	0.995	378.2	4
Chemical and chemical products (37)	6.996 (1.752)	-1.387 (-5.142)	0.171 (0.678)	0.774	23.2	13
		1981				
Food and beverage (10)	2.188 (1.282)	-0.441 (-4.637)	0.669 (6.490)	0.444	32.9	78
Textiles (18)	8.937 (3.536)	-1.144 (-6.202)	0.098 (0.346)	0.866	26.9	6
Wood products (25)	-2.176 (-1.013)	-0.227 (-0.230)	0.946 (7.786)	0.958	34.8 (NS)	1
Paper and allied (27)	-11.71 (-2.234)	-0.197 (-1.283)	1.737 (4.229)	0.842	19.7	5
Primary metals (29)	3.690 (1.364)	-1.299 (-2.777)	0.437 (2.006)	0.612	9.7	9
Metal fabricating (30)	3.572 (0.840)	-0.832 (-1.019)	0.461 (1.418)	0.579	9.9	11
Transportation equipment (32)	9.838 (3.373)	-0.995 (-1.749)	0.026 (0.106)	0.354	2.4 (NS)	3
Nonmetallic mineral products (35)	2.210 (1.441)	-0.4559 (-3.693)	0.641 (5.322)	0.644	190.4	207
Petroleum and coal products (36)	-4.838 (-0.77)	-0.317 (-1.082)	1.269 (2.655)	0.606	5.6 (NS)	4
Chemical and chemical products (37)	-0.513 (-0.227)	-0.436 (-2.063)	0.952 (4.849)	0.737	36.0	23

Note: Insufficient data were available to calculate equations for the remaining industrial groups.
NS = not significant.

Table 16

Estimated Water Demand Functions, Saskatchewan Two-Digit SIC Industries, 1986 and 1981

(estimated equation: $\ln(Q_{in}) = a_0 + a_1\ln(P_{in}) + a_2\ln(Q) + e$)

Industry (SIC)	Constant	$\ln(P_{in})$	$\ln(Q)$	R^2	F	D.F.
		1986				
Food (10)	11.985 (3.243)	-0.474 (-1.968)	0.081 (0.350)	0.148	2.0	11
Beverage (11)	-9.209 (-2.523)	-0.507 (-1.688)	1.247 (5.705)	0.926	19.8	3
Other nonmetallic mineral products (35)	-1.66 (-0.386)	-0.379 (-1.906)	0.7 (2.515)	0.366	3.3	8
Chemical and chemical products (37)	0.54 (0.049)	2.059 (0.704)	0.678 (0.926)	-0.323	0.6	3
		1981				
Food and beverages	8.966 (10.29)	-0.645 (-4.037)	0.105 (1.446)	0.311	9.1	34
Primary metals + metal fabricating	-1.149 (-0.405)	-0.846 (-3.311)	0.780 (3.342)	0.764	10.7	4
Nonmetallic mineral products	-3.279 (-1.11)	-0.133 (-0.369)	1.106 (4.119)	0.722	11.4	6
Petroleum and coal + chemicals and chemical products	-2.667 (-0.536)	-0.496 (-2.443)	0.932 (2.479)	0.523	3.7 (NS)	3

Note: Insufficient data were available to calculate equations for the remaining industrial groups.

Table 17

Estimated Water Demand Functions, Manitoba Two-Digit SIC Industries, 1986 and 1981

(estimated equation: $\ln(Q_{in}) = a_0 + a_1\ln(P_{in}) + a_2\ln(Q) + e$)

Industry (SIC)	Constant	$\ln(P_{in})$	$\ln(Q)$	R^2	F	D.F.
		1986				
Food (10)	8.259 (2.55)	-0.498 (-1.27)	0.163 (0.801)	0.081	1.4	8
Fabricated products (30)	-0.937 (-0.106)	-1.958 (-0.970)	0.587 (1.126)	-0.083	0.8	6

Table 17 (continued)

Industry (SIC)	Constant	$\ln(P_{in})$	$\ln(Q)$	R^2	F	D.F.
		1986				
Other nonmetallic mineral products (35)	-0.681 (-0.067)	-0.5 (-2.207)	0.703 (1.14)	0.494	3.0	4
		1981				
Food and beverages (10)	0.583 (0.561)	-0.719 (-7.045)	0.778 (9.406)	0.649	59.3	61
Rubber and plastic products (16)	2.054 (0.713)	-0.198 (-0.981)	0.653 (2.570)	0.559	4.2 (NS)	3
Textile products (18)	6.562 (1.647)	-0.200 (-0.721)	0.244 (0.771)	0.120	1.7 (NS)	8
Paper and allied (27)	0.111 (0.299)	-2.110 (-2.717)	0.584 (2.104)	0.444	5.8	10
Primary metals (29)	-3.257 (-0.529	-0.188 (-0.552)	1.107 (2.083)	0.772	12.8	5
Metal fabricating (30)	2.907 (0.667)	0.288 (0.165)	0.604 (1.416)	0.700	1.3 (NS)	7
Transportation Equipment (32)	0.704 (0.108)	-1.891 (-0.414)	0.584 (1.381)	0.113	1.4 (NS)	4
Nonmetallic mineral products (35)	4.232 (1.971)	-0.552 (-1.584)	0.493 (2.582)	0.430	5.9	11
Petroleum and coal + chemicals (36 + 37)	-0.777 (-0.307)	-0.890 (-1.981)	0.932 (3.784)	0.606	12.5	13

Note: Insufficient data were available to calculate equations for the remaining industrial groups.
NS = not significant.

Table 18

Estimated Water Demand Functions, Ontario Two-Digit SIC Industries, 1986 and 1981

(estimated equation: $\ln(Q_{in}) = a_0 + a_1\ln(P_{in}) + a_2\ln(Q) + e$)

Industry (SIC)	Constant	$\ln(P_{in})$	$\ln(Q)$	R^2	F	D.F.
		1986				
Food (10)	-3.761 (-1.87)	-0.722 (-6.318)	0.839 (7.0)	0.586	61.1	85
Beverage (11)	-7.722 (-3.454)	-0.786 (-2.958)	1.104 (8.104)	0.837	47.2	18
Rubber (15)	-0.013 (-0.004)	-1.189 (-2.369)	0.608 (2.729)	0.618	13.2	15

Table 18 (continued)

Industry (SIC)	Constant	$\ln(P_{in})$	$\ln(Q)$	R^2	F	D.F.
Plastics (16)	6.233 (1.86)	-0.591 (-2.708)	0.215 (1.05)	0.146	4.4	40
Primary textiles (18)	-14.44 (-3.285)	-0.424 (-1.641)	1.519 (-1.641)	0.841	43.4	16
Textile products (19)	-17.718 (-1.236)	-0.056 (-0.056)	1.689 (2.04)	0.237	2.1	7
Wood industries (25)	2.951 (0.359)	-1.171 (-5.056)	0.36 (0.712)	0.723	14.1	10
Paper and allied products (27)	-9.508 (-2.38)	-0.827 (-5.473)	1.191 (4.907)	0.849	90.8	32
Primary metal (29)	-7.756 (-3.617)	-0.709 (-4.216)	1.116 (8.585)	0.817	90.4	40
Metal fabrication (30)	3.526 (1.711)	-0.857 (-4.023)	0.388 (3.115)	0.309	13.8	57
Transportation equipment (32)	-1.044 (-0.683)	-0.718 (-4.343)	0.66 (7.194)	0.582	59.4	84
Nonmetallic mineral products (35)	-6.462 (-2.728)	-0.773 (-9.068)	0.988 (6.699)	0.835	112.5	44
Refined petroleum and coal (36)	6.435 (0.824)	-1.138 (-3.459)	0.279 (0.649)	0.882	12.2	3
Chemical and chemical products (37)	-3.124 (-1.457)	-0.884 (-8.36)	0.809 (6.218)	0.634	77.2	88
			1981			
Food and beverages	5.845 (10.90)	-0.633 (-8.712)	0.356 (8.211)	0.394	86.0	257
Rubber and plastics	7.045 (9.156)	-1.099 (-9.799)	0.137 (2.352)	0.467	52.8	116
Textile products	7.811 (6.310)	-0.953 (-4.947)	0.182 (1.978)	0.498	16.9	30
Wood products	-3.998 (-1.412)	-1.136 (-4.286)	0.971 (4.586)	0.751	16.1	8
Paper and allied products	-5.636 (-3.007)	-0.615 (-7.512)	1.197 (8.374)	0.846	154.6	54
Primary metals	-3.597 (-2.274)	-0.188 (-3.815)	1.085 (8.410)	0.838	125.1	46
Metal fabricated products	3.578 (2.705)	-0.818 (-6.302)	0.477 (4.367)	0.505	40.8	76
Transportation equipment	5.861 (7.385)	-0.794 (-5.974)	0.299 (4.565)	0.476	51.4	109

Table 18 (continued)

Industry (SIC)	Constant	$\ln(P_{in})$	$\ln(Q)$	R^2	F	D.F.
Nonmetallic mineral products (35)	0.725 (1.256)	-0.669 (-8.949)	0.725 (14.78)	0.783	198.1	107
Petroleum and coal (36)	-3.665 (-1.01)	-1.175 (-4.997)	0.982 (3.858)	0.846	25.7	7
Chemicals and chemical products (37)	3.496 (4.178)	-0.917 (-11.51)	0.500 (7.14)	0.670	154.5	149

Table 19

Estimated Water Demand Functions, Quebec Two-Digit SIC Industries, 1986 and 1981

(estimated equation: $\ln(Q_{in}) = a_0 + a_1\ln(P_{in}) + a_2\ln(Q) + e$)

Industry (SIC)	Constant	$\ln(P_{in})$	$\ln(Q)$	R^2	F	D.F.
		1986				
Food (10)	-3.2 (-1.567)	-0.548 (-3.787)	0.801 (6.636)	0.463	29.9	67
Beverage (11)	10.355 (0.087)	-0.909 (-1.387)	0.597 (2.172)	0.606	7.1	8
Rubber (15)	-9.909 (-1.558)	-0.59 (-2.388)	1.215 (3.276)	0.731	7.8	5
Plastic (16)	(167.007) (1.829)	-0.831 (-2.548)	0.143 (0.582)	0.219	3.7	19
Primary textiles (18)	-2.598 (-0.6)	-0.645 (-2.416)	0.798 (2.989)	0.578	9.9	13
Textile products (19)	-3.377 (-0.904)	-0.358 (-0.772)	0.921 (4.197)	0.727	9.0	6
Wood industries (25)	-16.683 (-3.517)	-0.605 (-2.826)	1.618 (5.518)	0.861	19.6	6
Paper and allied products (27)	-6.34 (-1.597)	-0.6 (-3.365)	1.05 (4.187)	0.757	49.3	31
Primary metal (29)	-1.159 (-0.291)	-1.082 (-3.738)	0.645 (2.546)	0.608	21.1	26
Fabricated products (30)	-1.954 (-0.702)	-1.193 (-4.03)	0.684 (3.859)	0.642	18.9	20
Transportation equipment (32)	7.655 (0.889)	-0.363 (-0.637)	0.18 (0.346)	-0.416	0.3	5
Other nonmetallic mineral products (35)	-7.754 (-3.505)	-0.64 (-3.554)	1.086 (7.884)	0.739	40.6	28

Table 19 (continued)

Industry (SIC)	Constant	$\ln(P_{in})$	ln(Q)	R^2	F	D.F.
Refined petroleum and coal (36)	NO INFORMATION					
Chemical and chemical products (37)	-1.182 (-0.394)	-0.913 (-7.277)	0.655 (3.468)	0.754	50.1	32
			1981			
Food and beverage (10)	0.619 (0.897)	-0.732 (-11.13)	0.742 (12.28)	0.674	177.6	169
Rubber and plastics (16)	0.294 (0.145)	-0.593 (-4.515)	0.696 (4.301)	0.496	26.1	49
Textile products (18)	1.526 (0.947)	-0.604 (-3.707)	0.662 (5.242)	0.582	33.7	45
Wood products (25)	-8.538 (-2.959)	-0.853 (-5.138)	1.333 (5.907)	0.789	34.6	16
Paper and allied products (27)	-6.569 (-2.875)	-0.439 (-3.045)	1.327 (7.232)	0.810	75.5	33
Primary metals (29)	-3.812 (-1.631)	-0.292 (-1.465)	1.172 (5.891)	0.755	45.6	27
Metal fabricated products (30)	3.473 (2.516)	-1.294 (-4.804)	0.380 (3.251)	0.624	24.2	26
Transportation equipment (32)	3.132 (1.578)	-1.121 (-1.766)	0.421 (3.739)	0.501	10.0	16
Nonmetallic mineral products (35)	5.085 (4.419)	-0.228 (-0.909)	0.4242 (4.626)	0.409	13.1	33
Refined petroleum and coal (36)	0.812 (0.531)	-0.409 (-1.341)	0.874 (0.825)	0.268	1.9 (NS)	3
Chemicals and chemical products (37)	-3.764 (-3.756)	-1.033 (-13.02)	1.031 (12.02)	0.886	91.6	73

NS = not significant.

Table 20

Estimated Water Demand Functions, New Brunswick Two-Digit SIC Industries, 1986 and 1981

(estimated equation: $\ln(Q_{in}) = a_0 + a_1\ln(P_{in}) + a_2\ln(Q) + e$)

Industry (SIC)	Constant	$\ln(P_{in})$	ln(Q)	R^2	F	D.F.
		1986				
Food (10)	14.675 (1.397)	-0.743 (-3.268)	-0.311 (-0.467)	0.623	9.3	10

Table 20 (continued)

Industry (SIC)	Constant	$\ln(P_{in})$	$\ln(Q)$	R^2	F	D.F.
Wood industries	16.402 (0.614)	-0.502 (-1.034)	-0.407 (-0.256)	0.200	0.8	3
		1981				
Food and beverage, rubber, plastics and textiles	6.644 (2.286)	-0.222 (-1.435)	0.371 (1.542)	0.180	3.1 (NS)	17
Wood, paper and allied	-4.262 (-0.543)	-0.519 (-2.322)	1.132 (1.973)	0.727	15.7	9
Primary metals, fabricated metals, nonmetallic minerals	-1.289 (-0.768)	-1.178 (-4.467)	0.719 (5.236)	0.890	33.3	6

Note: Insufficient data were available to calculate equations for the remaining industrial groups.
NS = not significant.

Table 21

Estimated Water Demand Functions, Nova Scotia Two-Digit SIC Industries, 1986 and 1981

(estimated equation: $\ln(Q_{in}) = a_0 + a_1\ln(P_{in}) + a_2\ln(Q) + e$)

Industry (SIC)	Constant	$\ln(P_{in})$	$\ln(Q)$	R^2	F	D.F.
		1986				
Food (10)	5.624 (1.693)	-0.509 (-2.792)	0.278 (1.268)	0.525	9.3	15
Paper and allied (27)	-8.921 (-1.154)	0.886 (0.64)	1.644 (2.510)	0.732	5.1	3
		1981				
Food and beverage, rubber, plastics, textiles	0.261 (0.199)	-0.759 (-7.607)	0.753 (7.354)	0.665	53.6	51
Wood, paper and allied	1.839 (0.243)	-0.825 (-1.252)	0.682 (1.002)	0.751	8.6	3
Primary metals, fabricated metals and nonmetallic minerals	0.905 (0.389)	-0.532 (-3.843)	0.685 (3.452)	0.817	36.8	14
Refined petroleum and coal, chemicals, etc.	-3.265 (-0.814)	-0.665 (-1.053)	1.108 (2.681)	0.755	11.8	5

Note: Insufficient data were available to calculate equations for the remaining industrial groups.

Table 22

Estimated Water Demand Functions, Prince Edward Island Two-Digit SIC Industries, 1981

(estimated equation: $\ln(Q_{in}) = a_0 + a_1\ln(P_{in}) + a_2\ln(Q) + e$)

Industry (SIC)	Constant	$\ln(P_{in})$	$\ln(Q)$	R^2	F	D.F.
Food	1.618 (0.935)	-0.644 (-1.469)	0.753 (3.917)	0.665	10.9	8

Note: Insufficient data were available to calculate equations for the remaining industrial groups for 1981 or any of the equations for 1986.

Table 23

Estimated Water Demand Functions, Newfoundland Two-Digit SIC Industries, 1986 and 1981

(estimated equation: $\ln(Q_{in}) = a_0 + a_1\ln(P_{in}) + a_2\ln(Q) + e$)

Industry (SIC)	Constant	$\ln(P_{in})$	$\ln(Q)$	R^2	F	D.F.
		1986				
Food (10)	17.04 (0.570)	0.461 (0.312)	-0.325 (-0.186)	-0.600	0.1	5
Nonmetallic mineral products (35)	14.92 (4.61)	-2.349 (-9.815)	-0.541 (-2.479)	0.973	54.5	3
		1981				
Food and beverages (10)	-0.578 (-0.205)	-0.780 (-3.307)	0.847 (3.534)	0.650	21.4	20
Wood, paper, metals, petroleum and chemical composite	1.947 (0.274)	-1.050 (-1.687)	0.561 (0.803)	0.855	24.7	6

Note: Insufficient data were available to calculate equations for the remaining industrial groups.

Table 24

Comparison of Price and Output Elasticities among the Provinces, Two-Digit SIC Industries, 1986 and 1981

Industry	No. of provinces	Price elasticity National	Price elasticity High	Price elasticity Low	Output elasticity National	Output elasticity High	Output elasticity Low	R2 National	R2 High	R2 Low
1986										
Food (10)	10	-0.562	-0.743	-0.018	0.527	0.991	0.058	0.426	0.665	0.148
Beverage (11)	5	-0.570	-1.085	-0.110	0.925	1.381	0.597	0.756	0.926	0.541
Rubber products (15)	2	-0.557	-1.189	-0.590	0.896	1.125	0.608	0.639	0.731	0.618
Plastic products (16)	3	-0.600	-0.831	-0.488	0.316	0.487	0.143	0.205	0.618	0.094
Primary textiles (18)	2	-0.697	-0.645	-0.424	1.024	1.519	0.798	0.756	0.841	0.578
Textile products (19)	2	-0.683	-0.358	-0.056	0.837	1.689	0.798	0.372	0.727	0.237
Wood products (25)	4	-0.912	-1.171	-0.502	0.700	1.618	0.360	0.688	0.861	0.200
Paper and allied (27)	5	-0.702	-0.827	-0.162	1.166	1.964	1.050	0.846	0.966	0.732
Primary metals (29)	4	-0.769	-1.476	-0.694	1.026	1.502	0.645	0.760	0.929	0.608
Metal fabricating (30)	5	-0.765	-1.958	-0.857	0.536	0.804	0.290	0.372	0.642	0.289
Transportation equipment (32)	2	-0.352	-0.718	-0.363	0.621	0.660	0.180	0.542	0.582	0.416
Nonmetallic mineral products (35)	7	-0.690	-2.393	-0.379	1.060	1.086	-0.541	0.797	0.973	0.365
Refined petroleum and coal (36)	2	-1.202	-1.138	-0.273	1.134	1.974	0.279	0.762	0.995	0.365
Chemical and chemical products (37)	5	-0.877	-1.387	-0.884	0.703	3.880	0.171	0.647	0.774	0.323
1981										
Food and beverages (10)	8	-0.579	-0.780	-0.441	0.468	0.991	0.105	0.463	0.665	0.311
Rubber and plastics (16)	4	-0.359	-1.099	-0.198	0.214	0.696	0.137	0.215	0.559	0.094
Textiles (18)	4	-0.508	-1.144	-0.200	0.383	0.662	0.098	0.407	0.866	0.120
Wood (25)	4	-0.378	-1.136	-0.227	0.951	1.391	0.946	0.517	0.958	0.751
Paper and allied (27)	5	-0.229	-2.110	-0.162	1.551	1.737	0.584	0.793	0.877	0.444
Primary metals (29)	5	-0.270	-1.288	-0.188	1.174	1.502	0.437	0.775	0.929	0.612
Metal fabricating (30)	5	-0.292	-1.747	-0.288	0.535	0.804	0.380	0.313	0.700	0.465
Transportation equipment (32)	4	-0.460	-1.891	-0.794	0.419	0.584	0.026	0.440	0.501	0.113
Nonmetallic mineral products (35)	6	-0.564	-2.393	-0.133	0.597	1.106	0.424	0.660	0.783	0.409
Refined petroleum and coal (36)	3	-0.179	-1.175	-0.317	1.262	1.269	0.874	0.752	0.846	0.268
Chemicals and chemical products (37)	4	-0.148	-1.033	-0.436	0.840	3.880	.0500	0.617	0.887	0.670

CHAPTER 4

Conclusions and Policy Implications

The issue of economic factors as they relate to water use is an important current consideration in Canada. These factors lie at the heart of both providing incentives for more rational water use (e.g., resource conservation) and permitting full cost recovery of infrastructural expenditures. Thus reseach that helps throw light on the economics of water use is important not only in its own right, but also from a policy and decision-making viewpoint. The estimated demand equations indicate the sensitivity of industrial water use to changes in the level of water prices and can also be used to estimate the value assigned to water use by firms. The latter type of information could be used by provinces interested in setting water use royalties.

CONCLUSIONS

This paper has presented the results of a project undertaken over five years to conduct an econometric analysis of the nature of Canadian industrial water demands. This work replicated the research by Renzetti (1986), broadening it to include all Canadian provinces. The data used derived from the Environment Canada surveys of industrial water use for 1981 and 1986 (Tate and Scharf 1985, 1991).

The literature review showed that the economic theory of input demand is firmly established, having been applied to many industries and inputs. This body of literature forms an appropriate theoretical framework for analyzing industrial water demand and costs. Such analyses have, however, been late to develop because of the common perception that water is a free good, and the resultant lack of economic data on water use.

The types of analyses undertaken here involved the estimation of industrial water demand functions. These demand functions were estimated using linear multiple regression analysis. The equations took the double-log form with the quantity of industrial water demanded as the dependent variable, and the average costs of water intake, treatment prior to use, recirculation, and waste discharge, as well as a plant output measure, as the explanatory variables. Limitations on the data prevented the estimation of the water demand equations as part of a wider analysis of all plant inputs, and the use of an instrumental variable estimation procedure. As a result, the use of average costs as price proxies may introduce a simultaneity bias in the estimated regression equations. Despite this problem, the relatively simple econometric models used provided fairly high levels of explanatory power. For most industries and provinces, the price of intake water and the level of the firm's output explained much of the variance in industrial water demand.

POLICY IMPLICATIONS

Public policy in Canada has exhibited an almost total disregard for the potential uses of economics in carrying out the tasks of water management. While financial instruments and benefit/cost methodologies have been part of the tool kit of water managers across the decades, there is a virtual absence of any consideration of the incentive creation mechanisms of water pricing, effluent discharge fees, and the like. The root causes of this situation relate to the traditional perception that water is (or should be) a free good, and the resultant hypothesis that industrial water use is insensitive to price. Various works (e.g., FCM 1985) have given the lie to the "water as a free good" argument, and it is not addressed further here.

The results of this paper establish conclusively that price is an important variable in industrial water use. This finding should underlie a whole new approach to industrial water management. It suggests, for example, that water charges would initiate water conservation through technological changes (such as the movement to greater levels of recirculation) and, over the longer run, progressive transformation in a firm's capital stock. It also suggests that strategies for pollution control should incorporate economic instruments such as effluent discharge fees or marketable permits. Finally, it means that analyses of future industrial water will almost inevitably fail unless they consider substantively the role of water price.

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