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Water Use, Shadow Prices and the Canadian Business Sector Productivity Performance

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'Behind these rather dry figures and groupings lie dramatic tragedies of water scarcity ranging from the need to carry heavy pots of water several kilometres every day to meet household needs, through the destitution of farmers who lose their land because of lack of sufficient water to flush salts from the sol, to the loss of wetlands and estuaries because of upstream water depletion.'
Seckler *et al.* (1999)

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Abstract

This paper develops a production framework that allows for self-supplied water intake, an unpriced 'natural' input. The framework is then exploited to estimate the corresponding water shadow prices and to assess the extent to which water impacts on the multifactor productivity performance of the Canadian business sector's industries. Accounting for water intake leaves the aggregate business sector's multifactor productivity growth virtually unchanged over the 1981-1996 period, but it increases the productivity performance of the largest water-using industries by 0.7 percentage points on average. The shadow price of water intake amounts to $0.73 cubic metre and varies significantly across industries. While the introduction of water recirculation, a kind of water recycling, does not alter in a significant way most of these results, it reduces the shadow price estimate to $0.55 cubic metre and improves its reliability particularly for the largest water-using industries. Water is found to be a substitute to capital and labour inputs, suggesting that more of these inputs are required to bring about savings in water use.

Keywords: productivity, eco-efficiency, water use

Executive Summary

Human societies relies upon water for a number of purposes. Obviously, access to potable water is critical for survival. In addition, water is used in production of goods and services, growing crops, producing electricity, providing habitat for wildlife, creating recreational opportunities, etc.

Canada is blessed with an apparent abundance of water. That perception influenced the types of technologies that are adopted in industrial facilities and the ways in which industrial-by-products and other residuals are disposed of. The combination of industrial development, population growth, global warming and environmental pollution makes the assumption of limitless of water problematic.

This paper focuses on water use by Canadian businesses over the 1981-1996 period. It asks the following three questions:

1. What is the industrial structure of water use in Canada?

   Canadian businesses use an enormous amount of water annually for a variety of purposes. The Canadian business sector took in 40.9 billion cubic metres in 1996, the most recent year for which water use data consistent with industry productivity data are available. The bulk of water intake is used for not only to produce marketable output (e.g. water is a crucial component of hydroelectric power production, agricultural output, beer, or canned food), but also to receive residuals discharge from the production process (e.g., chemical firms primarily use water to disposed of unwanted chemicals produced as by-products to the main output), the production of high pressure steam and crude oil enhanced recovery. Relatively small amounts of water are used in-plant for sanitation.

   Water use in the Canadian business sector is unevenly distributed. Self-supplied water intake represents approximately 95% of total business sector water intake with the remainder coming from public utilities. Large, self-supplied industries carry out the bulk of water intake at virtually no cost. They are the focus of this study. These industries withdraw water directly from rivers, lakes and groundwater rather relying on municipal water utilities to supply them. Self-supplied water intake requires a permit from a provincial government that, once issued, cannot be transferred to other users and cannot be altered easily. Seven industries—utility, agriculture, paper, primary metal, chemical, mining and refined petroleum—account for 96% of total recorded water intake in 1996 while accounting for about ¼ of nominal gross output.

   Water recirculation, a form of recycling, is an important consideration of water use of the Canadian business sector. Over the 1981-1996 period, recirculation represented on average 40.2% of the whole business sector's water intake, compared to 37.4% for the seven largest water-using industries.

2. What is the value of water?

Although water is the subject of different uses by the business sector, the economic features of industrial water use have not received the same scrutiny as residential water use for example. While some work has been done to model businesses' water demands, little is known about the particular issue of the value of water-use in industrial settings and the factors that influence these values. As a result, while it is commonly believed that industrial water use is a relatively high value application of water, there is actually relatively little empirical evidence to support this.

There are a number of challenges that confront any effort to estimate the value of industrial water use. While there are a limited number of jurisdictions where market transactions may yield information on the price of bulk water sales or leases, in most jurisdictions, self-supplied firms pay virtually nothing for their raw water input. Furthermore, much of the expenditure undertaken by firms to use water (filtration, pumping, on-site storage, etc.) is rarely reported in water use surveys.

One of the contributions of this paper is the estimation of intake water's shadow price within an industry cost structure. We combine information on water, non-water inputs and real output in order to estimate a restricted cost function in which non-water inputs are variable inputs while intake water is treated as a quasi-fixed factor. Intake water is treated as a quasi-fixed factor in order to reflect regulatory constraints that limit water use by self-supplied Canadian businesses. The shadow value of the quantity of intake water is derived from the estimated cost function and provides an estimate of the marginal value of intake water to each industry of the business sector.

This paper's attention is restricted to estimating firms' (private) valuation of their water use. This value should approximate a firm's marginal willingness to pay for intake water and, as such, provides a minimum bound on the firm's valuation of marginal quantities of intake water. The shadow price of water intake is statistically significant and amounts to $0.73 per cubic metre for all industries considered in this study. There is a wide variation of the shadow price across all industries, a reflection of differences in the marginal benefits that arise from the use of water as a 'free' or cheap input. Although the shadow prices are positive for the seven intensive water-using industries, they are significant only for utility, agriculture, chemicals and refined petroleum. Within these four industries, utility, the largest water-using industry, reported the highest shadow price at $0.95 per cubic metre, about twice that of agriculture, the second largest water-using industry.

In addition to contributing to the literature concerned with the value of water in a variety of industries with different water needs, this study also investigates the factors that influence the magnitude of intake water's shadow value in the business sector. One factor that is particularly important is recirculation. Accounting for recirculation, reduced the shadow price dropped significantly from $0.73 per cubic metre to $0.55 per cubic metre. In addition, the shadow price estimates for the majority of the largest water-using industries became more statistically significant, reflecting the importance of water recirculation in the measurement of water use shadow prices.

3. Eco-efficiency

Eco-efficiency measures the extent to which economic activity efficiently uses the environment as a free, or cheap, input. In the context of water use, eco-efficiency can be measured in two different, albeit complementary, ways: a) a partial indicator such as real output per unit of water use and b) a broader indictor—multifactor productivity—which not only accounts for water and non water resources employed in the production process. In this context, multifactor productivity represents the growth in the output that is not accounted by the combined growth of marketed inputs (capital, labour and intermediate inputs) and water intake, a natural input for which no market price is available.

Over the 1981-1996 period, the average annual growth rate of eco-efficiency varied across these seven largest water using industries. Chemical industries, primary metal and paper and allied products reported important eco-efficiency gains (8.6%, 4.5% and 3.4%, respectively), reflecting the presence of a water saving technology. In contrast, other utility and agriculture, the largest water users, reported a slight decline in eco-efficiency (-0.4% and -0.34%, respectively).

Under the broader framework, multifactor productivity growth for the entire business sector is not affected by the introduction of water use. In contrast, for the largest water using industries, accounting for water improves multifactor productivity by five percentage points. This is a reflection of the efficiency gain in water use reported by some important industries.

This story holds even when we account for recirculation. In some sense, this suggests that the measurement framework adopted in this study remains robust to alternate specifications.

I. Introduction

Economic growth, global warming and declining regulatory budgets all contribute to a growing concern regarding water intake in Canada. Water plays an important role in the production processes of Canadian businesses (cooling, producing high-pressure steam, sanitation, as a direct input like in beer production and waste disposal), but a large body of the economic literature has contended that this use has been inefficient (see Renzetti and Dupont 1995). The causes of inefficient use of water are several, but are largely related to improper pricing of water resource. For the most part, firms face virtually a zero price (or a very low minimal one) for their use of water as a natural resource input. This is true both for firms purchasing their water from municipal water utilities and, particularly, those that are self-suppliers of water (i.e., they withdraw directly from either a surface or groundwater source)—the dominant source of water intake in Canada.

The impact of water intake on the productive performance of firms is an important issue for policymakers and productivity analysts interested in sustainable development. However, detailed evaluation is difficult as the price paid for water is either zero or well below its opportunity cost. Because the consumption of water involves true opportunity costs no less than does the consumption of labour, capital or material inputs, the standard multifactor productivity growth measure may be viewed as an incomplete barometer of how well society is allocating its scarce resources. The case for broadening multifactor productivity to multi-resources productivity is self-evident. The ultimate evaluation of sustainable development requires it.[1]

In this paper, we develop an approach to derive shadow values of water as a valuable input in a production process, which produces a socially valuable output (which is sold in the market). The contribution of this paper belongs to the tradition initiated by Solow in that it makes use of economic theory in order to infer from statistical data the information that would otherwise be missing. These shadow values are characterised as the amount producers would be willing, on the margin, to pay for the ability to use water as a free input. The magnitude of these economic benefits can therefore be examined by estimating the private costs that would be incurred in reducing water intake as a free input for a given level of the output.

Despite the ubiquity of water intake across the Canadian business sector's industries, there are surprisingly few studies that are concerned with the estimation of water intake shadow prices. This situation stands in contrast to the exhaustive analysis that has been applied to investigating the role of other forms of natural inputs such as mineral reserves in the productivity performance of mining firms (see Diaz and Harchaoui 1997 and the references therein). To date, the limited amount of work directed towards industrial water demand has been concerned with obtaining estimates of the price elasticity of demand for water and establishing the relationships between water and other inputs (see Renzetti and Dupont 1995 for a review of the literature on water).

1. See for example Gollop and Swinand (2001) in the case of bad outputs, Lasserre and Ouellette (1991) for mining reserves.

Unfortunately, these studies have not paid enough attention to the potential problems that arise from using the existing water prices. Water prices charged to firms are lower than the opportunity cost of the resources needed to provide the water resources. As a result, the demand for water sources is higher than socially necessary. Other contributions in the literature, best represented by Renzetti (1992) and Dupont and Renzetti (1999), devised shadow prices for water intake in the Canadian manufacturing sector for the 1981-1991 period. While their contribution is one of the few attempts that derived the private value for the use of water as a 'natural' input, their methodology imposes stringent assumptions on the technology of firms.[2] Recently, Renzetti and Dupont (2002) have used provincial data for manufacturing to estimate shadow prices for water intake and the factors that influence them, such as water treatment. The prices are found to be quite small, albeit statistically significant.

Our paper adds to the existing literature on industrial water intake in Canada in several ways.

First, we cover most of the Canadian business sector's industries for the 1981-1996 period. This includes some important water-using manufacturing industries such as paper, primary metal, refined petroleum and coal products and chemical. Other industries outside the manufacturing, such as utility and agriculture, which account for the bulk of water intake in Canada, are also considered in this study.

Second, we focus on self-supplied water intake which accounts for 96% of water intake in Canada, the remainder comes from public utilities. Self-supplied industries withdraw water directly from rivers, lakes and groundwater rather than relying on municipal water utilities to supply them. This water resource is more interesting from the public policy perspective because no prices are charges for the services rendered. In contrast, water supplied by municipalities comes at a cost per cubic metre which is already part of the intermediate expenses of our data set.

Third, we use a unified framework to estimate the private shadow prices of water intake and their relationships to the demand for produced inputs and the output. The estimates of the shadow prices depend on both the technological substitution possibilities and the input demand and output supply behaviour underlying industry production processes. We also examine how the introduction of water recirculation into this framework, a form of water recycling, affects the shadow price of water.

Fourth, in addition to the estimates of the elasticities of substitution between water and produced inputs, and the scale economies, we derive a measure of multifactor productivity growth that accounts for water intake. The measurement of the water shadow price and its impact on the economic performance of businesses suggest that efforts to examine these possible links are overdue.

2. To derive the shadow price of water Renzetti (1992) and Renzetti and Dupont (1995) only considered expenditures on intake-related activities such as screening and treatment; these expenditures are in-plant operations and maintenance. The technology underlying water use is therefore assumed to be independent from that for the production of goods. As it will become clear later, our empirical framework does not impose this assumption. A more adequate treatment is provided in Renzetti and Dupont (2002).

The paper is structured in the following way. Section II provides the specification and estimation of our econometric model, while Section III discusses the data and provides background information on water intake by Canadian businesses. Section IV presents the empirical results and ascertains their robustness to the introduction of water recirculation—a sort of water recycling—into the framework. Concluding remarks are drawn in Section V.

II. The analytical framework

Self supplied industries use water as a natural free input in their production process (see Pearse *et al*. 1985). In order to capture industries' willingness to pay for water intake, it is instructive to begin with a characterisation of the industry's cost structure, a representation of how produced inputs and unpriced water intake are used in the production process.

We consider a restricted (or short-run) cost function in which self-supplied water is treated as a quasi-fixed input. This characterization of the technology is motivated by the existing regulatory constraints that restrict firms' ability to alter intake water quantities. The short-run cost function takes the general form $G(Y,w,W,D,t)$ where Y is the output;[3] w is the nominal price vector of conventional inputs (labour, L; capital, K; intermediate inputs, U) and W is the quantity of water intake; D is a vector of dummy variables corresponding to fixed effects for each industry; and t is a time trend. The total cost function measures the expenditures made by an industry on all costly inputs, i.e. labour, capital, and intermediate inputs. It does not include the cost of water pollution associated with effluent discharge because this information is not available. Under this framework, firms are assumed to choose their inputs so as to minimise the short-run cost function. The choice is conditioned on the level of output and the volume of water use, which may not be altered in the short run.[4] Another way to motivate this kind of specification of the technology is as follows: the variable W is included in the cost function on the realisation that conventional inputs and a natural input are used to produce output Y, or, conversely, that the 'environment' is used as a free of charge input used by producers when they intake water. However, if private producers had to pay a price for water intake in the same way as they pay for market inputs, they would probably use water more sparingly, substituting paid inputs for it.

Our approach focuses on private production costs. The associated private shadow values z of water intake i.e. the cost saving from using water as a free input, may be measured as the cost effects $-\frac{\partial G}{\partial W} = z$. This shadow value reflects the marginal amount the producer would be willing to pay for the right to increase W. From a reverse perspective, z represents the input costs that would be incurred on the margin if a decrease in W was imposed. So, we expect that $z > 0$.

Applying Shepard's lemma to $G(Y,v,W,D,t)$ generates the associated input demand equations and the input cost shares s_j (j = capital (K), labour (L), and intermediate inputs (U)). The

3. The study did not consider pollution emission associated with water use because of the lack of adequate data.
4. Self-supplied water requires a permit from a provincial government that, once issued, cannot be transferred to other users. Moreover, these permits specify a maximum annual water withdrawals that sets an upper bound on firms' water intake.

framework allows us to gain insights into a variety of cost elasticities that capture the existence of economies of scale in the Canadian business sector and the extent to which water intake impacts on conventional inputs.

Scale economies $SE,$ a measure of output cost elasticity is defined as

$$SE = \left(\frac{\partial \ell nG}{\partial \ell nY} \right)^{-1} \equiv \varepsilon_{G,Y}^{-1}. \tag{1}$$

If SE is equal to (is greater than) (is less than) 1, the technology used exhibits constant (increasing) (decreasing) returns to scale.

The estimated elasticities of substitution between water intake W and the produced input $j = K, L, U$ are given by

$$\varepsilon_{W,j} = \frac{\partial \ell nG}{\partial \ell nW} + \frac{\left(\frac{\partial^2 \ell nG}{\partial \ell nW \partial \ell nw_j} \right)}{\left(\frac{\partial \ell nG}{\partial \ell nw_j} \right)}. \tag{2}$$

The cross-price elasticities shown above, based on Allen partial elasticities of substitution, are calculated on the assumption that output is fixed while all other inputs are allowed to vary. If $\varepsilon_{W,j}$ is positive (negative), water is a substitute (complement) to the input j.

Turning now to the productivity framework, traditionally, the parametric approach to productivity measurement disentangles any movement along the cost function due to overall scale economies from the shift of the cost function due to technical change. In addition to these components, our framework allows for water intake which captures the shift in the cost function that results from an efficient (inefficient) use of water by businesses. Formally, multifactor productivity change is defined as

$$\dot{MFP} = \dot{Q} - \sum_j s_j \dot{x}_j, \tag{3}$$

where Q and x_j are, respectively, the output and the input j in constant prices.

Total differentiating $G = \sum_j w_j x_j$ with respect to time and substituting the expression $\sum_j s_j \dot{x}_j$ in (3) we get:

$$\dot{MFP} = \left(1 - \varepsilon_{G,Y}\right)\dot{Y} - \dot{G} - \varepsilon_{G,W}\dot{W}, \tag{4}$$

where $\varepsilon_{G,W}$ and $\varepsilon_{G,W}$ are, respectively, the elasticities of G with respect to output that water intake.

Equation (4) decomposes multifactor productivity growth into its two basic factors: First, the conventional parametric productivity growth $\left(1 - \varepsilon_{G,Y}\right)\dot{Y} - \dot{G}$ (i.e., a shift in the cost function due to technical change $\left(-\dot{G}\right)$ and a movement along the cost function due to scale economies $\left(1-\varepsilon_{G,Y}\right)\dot{Y}$. Second, the effect of water intake $\dot{W}$ and its shadow price captured through $-\varepsilon_{G,W}$.

III. Econometric implementation

1. The specification

The basic building block of our model is a non constant returns to scale translog cost function normalised by the price of intermediate inputs. We assume that the technology of the industry is represented by a translog cost function of the following form:

$$\begin{aligned}\ell nG_{it} &= \alpha_i + \alpha_Y \ell nY_{it} + \frac{1}{2}\alpha_{YY}\left(\ell nY_{it}\right)^2 + \alpha_W \ell nW_{it} + \frac{1}{2}\alpha_{WW}\left(\ell nW_{it}\right)^2 \\ &+ \sum_{s=K,L,U} \alpha_{Ys}\ell nY_{it}\ell n(w_{ist}) + \sum_{s=K,L,U}\alpha_{Ws}\ell nW_{it}\ell n(w_{ist}) + \alpha_{YW}\ell nY_{it}\ell nW_{it} \\ &+ \sum_{s=K,L,U}\alpha_s \ell n(w_{ist}) + \frac{1}{2}\sum_{s=K,L,U}\sum_{s'=K,L,U}\alpha_{ss'}\ell n(w_{ist})\ell n(w_{is't}) \\ &+ \alpha_t t + \alpha_{tt}t^2 + \sum_{s=K,L,U}\alpha_{ts}\ell n(w_{ist})t,\end{aligned} \tag{5}$$

and the derived share equations are

$$s_{ist} = \alpha_i + \alpha_{Ys}\ell nY_{it} + \alpha_{ws}\ell nW_{it} + \sum_{s=K,L,U}\alpha_{ss'}\ell n(w_{ist}) + \alpha_{st}t, \ \mathrm{s} = K,L,U. \tag{6}$$

The subscript s denotes the variable inputs K,L,U -capital, labour, intermediate input-while i is an industry index and α_i is an industry fixed effect. In this framework, labour input, measured in terms of hours worked, is assumed to be optimally adjusted within a year. A similar assumption is made for the intermediate inputs and capital services.

Using the equations (2) and (5), the elasticities of substitution between water and other types of inputs have the following specification

$$\varepsilon_{W,s} = \alpha_W + \alpha_{WW}\ell nW_{st} + \alpha_K \ell nw_K + \alpha_L \ell nw_L + \alpha_U \ell nw_U, \ \text{for } s = K,L,U.$$

The estimation model consists of equation (5), from which we construct the shadow prices of water intake and a variety of measures of the technology structure, along with the share equations for normalised capital, labour and intermediate inputs. The share equation of intermediate inputs is obtained residually because of the constraint that variable cost shares must sum to one.

We have pooled time-series and cross section data for 36 two-digit Canadian industries for the years 1981, 1986, 1991 and 1996 to estimate the model. Estimating the model as a pooled system not only adds structure to the model (additional degrees of freedom) but also imposes cross-equation restrictions to allow a fully integrated cost structure and input-demand model, facilitating more efficient estimates. Seemingly unrelated regressions (SUR) techniques were used for estimation, since the equations share common parameters. SUR also ensure that estimates are not sensitive to the choice of the numeraire (here a Fisher price index of intermediate inputs) since they achieve maximum likelihood estimates.

2. Description of the data

2.1. The data sources

The data set is based on an extended version of Statistics Canada's publicly available KLEMS database developed on an experimental basis to support research themes on productivity and environmental issues.[5] The Environmental KLEMS (E-KLEMS) database is based on two different sources driven by the input-output tables, thereby facilitating their integration.

First, data on the value of gross output and the costs of labour, capital services and intermediate inputs, as well as their Fisher chain price indices come from the Canadian productivity accounts. These accounts produce a consistent data set on inputs cost, Fisher chain volume indices of output and inputs (KLEMS data) and productivity measures for a number of Canadian business sector industries over the 1981-1997 period.

Household survey data are used to disaggregate total hours into hours worked by different types of workers classified by demographic variables such as age and education. Assuming that workers are paid proportionately to the value of their marginal products, labour input is calculated as a weighted sum of hours worked by different types of workers, weighted by relative wage rates.

The capital input estimates are computed in accordance with a service flow concept for physical capital assets. The rental price of capital used to derive the flow of services of 28 category of assets is composed of an external rate of return (the three-month Treasury Bill rate), capital gains, depreciation rate and tax parameters such as the corporate income tax and investment tax credits. Estimates of capital services represent an aggregation of capital stock across assets where the weight for each asset type is based on the share of property income estimated to be accruing to that asset type in each industry averaged over 2 years. Property income in each industry is allocated to asset types by employing estimates of the rental price of each asset type.

Out of the 47 two-digit industries that make up the business sector, we retained only 37 of them whose measurement of output is suitable for productivity measurement.[6]

The second source of information, obtained from Statistics Canada's environment accounts (see Statistics Canada 1997a, b), comprises data for the years 1981, 1986, 1991 and 1996 on water intake, water use, water recirculation and water discharge at a detailed industry level. These data, which cover both publicly supplied and self-supplied establishments of the Canadian business

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5. KLEMS stands for capital (K), labour (L), energy (E), materials (M) and services (S).
6. Finance and real estate, insurance, amusement and recreational service, accommodation and food services, health and social service, business service, personal and household service and educational service have been excluded.

sector, are based on a series of joint Environment Canada/Statistics Canada surveys on industrial water use in Canada.

Publicly supplied establishments receive water from a water utility whereas self-supplied establishments receive water directly from the natural bodies of water (streams, lakes, or groundwater). The expenditures associated with water intake depend on whether the firm is publicly or self-supplied. If the firm is connected to a public utility, then it must pay the utility's annual connection fee and its per unit charges for water intake, which are part of the intermediate inputs reported in this study.

A self-supplied firm does not face an external cost for its water unless it is located in British Columbia, Saskatchewan and Nova Scotia which are the only provinces in Canada that charge royalties for direct water abstractions (see Tate and Scharf 1991). In general, natural resources royalties are treated in the Canadian system of national accounts (CSNA) as a payment for using the services of a natural primary input and, as a result, are part of capital compensation.[7] But in the case of water royalties no information is presently available in the CSNA.

All water-using firms also face expenditures related to their internal water use. There are the costs of water treatment prior to use (e.g., minerals must be removed if water is to be used to produce high-pressure steam) and expenditures associated with water treatment prior to discharge. These expenditures are considered as intermediate expenditures associated with water use in our dataset. Because water is jointly utilised with labour, capital and other types of intermediate inputs, these expenditures alone cannot be considered as the unique source of information to estimate water intake shadow price (unless one assumes a separable technology, which is arguably a stringent assumption).

We appended data on water intake from self-supplied sources to the data on output and input for the 37 industries which have an output measure reliable for productivity analysis. Out of these industries, we excluded the fishing and trapping industry which does not seem to use water. Table 1 lists the 36 industries along with their descriptive statistics.

2.2. Analysis of the data

The E-KLEMS used in this paper is a panel dataset of 144 observations consisting of data on costs and volumes on produced inputs and output, and water intake as a priceless natural input for 36 industries for the years 1981, 1986, 1991 and 1996.

Table 1 provides the average levels of total cost and average annual growth rates of real output, water intake, and real prices of conventional inputs and cost shares for the period 1981-1996.

7. This is the case for oil and gas royalties, for example. See Diaz and Harchaoui (1997).

Table 1. Summary statistics, 1981-1996

Industry	G ($ millions)	s_K	s_L	s_U	$\dot{\omega}_K$	$\dot{\omega}_L$	$\dot{\omega}_U$	$\dot{K}$	$\dot{L}$	$\dot{U}$	$\dot{Y}$	$\dot{W}$
					Percentage							
Agricultural and related service	29.32	0.24	0.21	0.55	-4.21	2.22	1.48	-1.93	0.71	1.57	2.32	2.66
Logging and forestry	8.07	0.12	0.33	0.55	1.53	-0.10	-0.50	-1.99	0.31	4.16	2.87	1.88
Mining	11.73	0.34	0.26	0.40	1.40	2.78	1.93	-0.35	-1.39	0.25	1.40	0.58
Crude petroleum and natural gas	21.58	0.66	0.09	0.25	6.05	4.91	8.46	2.82	2.51	3.10	3.88	-1.43
Quarry and sand pit	1.05	0.27	0.28	0.45	0.92	1.76	-1.23	0.67	0.60	2.08	2.12	1.34
Services incidental to mineral	4.49	0.18	0.35	0.47	1.55	0.82	-1.00	1.42	2.49	1.22	0.90	-0.76
Food	38.81	0.12	0.15	0.74	1.91	0.82	-0.52	0.89	0.53	1.46	1.15	0.44
Beverage	5.70	0.26	0.20	0.54	3.13	0.77	-1.12	-1.47	-1.48	1.11	0.41	-1.98
Tobacco products	1.99	0.28	0.15	0.57	7.19	0.61	-4.68	-2.47	-4.18	-0.28	-1.64	-4.43
Rubber products	3.11	0.08	0.32	0.60	2.75	2.38	3.20	1.39	-0.03	2.77	3.63	-5.96
Plastic products	5.57	0.14	0.24	0.62	2.71	1.05	1.84	5.10	4.43	5.77	5.26	-3.31
Leather and allied products	1.15	0.09	0.32	0.59	3.19	0.34	-9.75	-2.13	-4.81	-4.91	-4.81	-5.77
Primary textile	3.04	0.16	0.23	0.61	2.46	2.31	4.82	-0.55	-2.09	0.10	0.35	-1.77
Textile products	2.90	0.11	0.26	0.63	2.87	1.13	0.00	-0.19	-0.36	0.79	0.27	2.44
Clothing	6.03	0.12	0.31	0.57	2.53	0.80	-1.27	0.40	-1.71	-0.14	-0.25	-2.45
Wood	14.82	0.08	0.26	0.65	2.11	-2.31	1.77	1.70	1.51	3.57	1.56	-6.48
Furniture and fixture	4.10	0.11	0.32	0.57	4.58	0.07	-1.81	0.99	0.96	1.89	1.74	-0.32
Paper and allied products	22.56	0.14	0.22	0.64	2.22	1.26	-0.15	1.13	-0.50	2.11	1.84	-1.56
Printing, publishing and allied	11.66	0.17	0.36	0.47	3.95	-1.17	-1.72	2.37	1.86	1.93	0.64	0.90
Primary metal	23.19	0.07	0.21	0.72	0.84	2.94	0.14	-0.66	-1.87	1.89	2.07	-2.46
Fabricated metal products	17.02	0.12	0.29	0.59	2.83	0.62	-1.41	0.45	1.00	0.93	0.95	-1.59
Machinery (except electrical mach)	10.45	0.14	0.29	0.57	4.53	0.40	0.75	0.84	0.73	2.03	1.60	-0.21
Transportation equipment	53.36	0.08	0.18	0.74	4.05	1.51	4.27	3.71	1.98	6.24	6.01	-3.34
Electrical and electronic products	19.30	0.13	0.25	0.62	2.11	4.35	2.02	3.48	-0.45	7.33	6.94	-1.93
Non-metallic mineral products	6.57	0.16	0.27	0.57	3.17	0.19	-6.97	-2.27	-0.60	0.45	0.13	1.20
Refined petroleum and coal products	20.05	0.05	0.04	0.90	4.58	4.75	-0.49	-1.14	-3.32	0.48	-0.04	-2.74
Chemical and chemical products	22.01	0.19	0.16	0.64	2.84	1.10	0.66	0.35	0.84	1.97	2.20	-6.40
Other manufacturing	6.94	0.13	0.28	0.59	3.42	0.75	-1.64	2.81	1.10	1.54	1.32	-0.15
Construction	80.74	0.08	0.33	0.58	3.20	-0.30	-1.26	1.17	0.76	-0.01	0.08	0.12
Transportation	38.74	0.14	0.36	0.50	0.28	0.43	3.14	1.84	1.64	2.26	2.73	1.18
Pipeline transport	3.19	0.68	0.12	0.20	1.52	3.99	2.11	3.01	1.89	2.99	5.64	0.46
Storage and warehousing	1.23	0.22	0.46	0.32	2.80	0.50	-0.47	1.53	1.79	1.62	1.61	0.90
Communication	22.49	0.35	0.38	0.27	0.57	0.81	5.74	4.72	2.23	5.49	4.95	1.21
Other utility	22.97	0.60	0.20	0.20	-0.75	-0.83	-3.56	1.97	2.60	5.37	2.69	3.09
Wholesale trade	42.71	0.19	0.48	0.34	5.99	1.61	0.59	2.99	2.53	4.54	4.89	1.24
Retail trade	48.36	0.13	0.54	0.33	4.78	0.16	-0.44	3.67	1.84	2.76	2.61	1.30
All industries	637.02	0.20	0.27	0.53	2.44	0.79	0.70	1.78	1.19	2.51	2.49	1.70
The 7 largest water-using industries[a]	196.347	0.23	0.19	0.58	0.02	1.52	-0.13	0.50	0.12	0.02	1.68	1.78

Notes: s_j = input j share in total cost $(j = K, L, U)$. For the sake of illustration, we assumed that the shares sum to one; the symbol '.' represents the average growth rate of the variable over the 1981-1996 period; K = capital services; L = labour services; U = intermediate inputs; Y = gross output; W = water intake.

[a] Agriculture, mining, paper, primary metal, refined petroleum and coal products, chemical and utility.

The average value of gross output produced by these 36 industries between 1981 and 1996 was $637 billion with a wide variation across industries. Construction, transportation equipment and trade industries, representing more than 1/3 in terms of nominal output, are amongst the largest industries of the 36 industries retained in this study. Other industries such as tobacco and leather and allied products are relatively small.

At the aggregate level, intermediate inputs account for more than half of the total cost, whereas the shares of labour and capital averaged, respectively, 27% and 20%. Input cost shares vary substantially among the 36 industries. For example, labour compensation's share ranges from a low of about 4% in refined petroleum products to a high of 54% in retail trade industries. Capital compensation's share of total cost also varies considerably across industries, ranging from 5% in refined petroleum products to 68% in pipeline transport industries and 66% in crude petroleum and natural gas. Generally, capital compensation's share of total cost, with a few exceptions (most notably crude petroleum and natural gas, pipeline transport and other utility industries) is less than labour compensation's share. Intermediate inputs on the other hand, have the largest share in total cost in almost all industries, ranging from 20% in utility to 90% in refined petroleum and coal products.

The aggregate output grew at 2.49% over the 1981-1996 period. This is higher than the 1.78% and 1.19% reported, respectively, by capital and labour inputs, but slightly lower than the 2.51% posted by the intermediate inputs. Combining the information on cost shares and the growth of these inputs yields a 2% growth of combined inputs which, compared to the output growth of 2.49%, gives rise an average multifactor productivity gain of 0.49% (under the constant returns to scale assumption).

The rates of growth of output and inputs shown in Table 1 also vary among industries over this period. In leather and allied products and tobacco products industries, the growth of output was negative. Other industries, such as textile and beverage, show a lacklustre growth of output. A number of industries, such as plastic products, transportation equipment, electrical and electronic products, and communication, experienced output growth rates over 3%. These fast growing industries also reported a rapid growth for capital and labour inputs, and vice versa for other industries with a modest output growth.

The diversity in the growth pattern of output and inputs across industries suggests that industries have experienced different degrees of change in their input mix, in the output and in productivity growth. Similar patterns of negative, small and rapid growth rates are visible in the growth rates of labour, capital and intermediate inputs. The growth rates of input prices, with few exceptions, were generally positive but varied considerably across industries.

Canadian businesses use water for a variety of purposes. These include cooling and transporting intermediate inputs, producing steam, producing electricity, sanitation and, finally, for inclusion in the businesses' output (e.g., beer production). The business sector's water intake reached 40.9 billion cubic metres in 1996, up from 32.5 in 1981. This 1.53% average annual growth of water intake, compared to the 2.49% annual average increase in output, gives rise to a favourable advance in eco-efficiency growth at 0.96% per year—a measure of how efficiently economic activity is using water as a 'free input'.

The distribution of water intake is quite uneven across the business sector. Seven industries account for 96% on average over the 1981-1996 period of the overall water self-supplied. These are utility (65.9%), agriculture (10.1%), paper (7.1%), primary metal (4.7%), chemical (4.5%), mining (1.5%) and refined petroleum (1.2%).

These seven largest water-using industries, which represent 23.8% in terms of gross output of the business sector retained in this study, report some distinct features compared to the remaining industries. With -0.05% on average, these intensive water-using industries posted a moderate decline in eco-efficiency growth (1.78% increase in water intake, compared with 1.68% increase of real output), compared to 0.79% for the business sector (1.70% increase in water intake, compared with 2.49% increase of real output).

These seven industries also rely more on intermediate inputs (58% of gross output, compared with 53% for the business sector) and more on capital input (23% vs. 20%) but less on labour (19% vs. 27%). This is the result of a more favourable increase in the relative prices of intermediate inputs and capital input in comparison to the business sector (0.02% vs. 2.44%, -0.13% vs. 0.7%, respectively, for capital and intermediate inputs). These industries reported a lower growth of output (1.68%) and inputs (0.5%, 0.12% and 0.02%, respectively, for capital, labour and intermediate inputs) than the overall business sector but a significantly higher multifactor productivity growth at 1.5% on average during the 1981-1996 period (under the constant returns to scale assumption).

Eco-efficiency growth varied across these seven industries, with the highest growth posted by chemical industries (8.6%), followed by primary metal (4.53%), paper and allied products (3.4%), suggesting the implementation of water saving technology that promotes water recycling.[8] In contrast, other utility and agriculture, the largest water users, reported a decline in eco-efficiency (-0.4% and -0.34%, respectively).

IV. Results and implications

1. Estimation

The system of equations to estimate consists of the cost function (5) and the share equations for $i = K, L$ and E given by (6). The share equation for intermediate inputs is obtained residually from the constraint that cost shares must sum to one. We have pooled time-series and cross section data for the 37 industries for the period 1981-1996 to estimate the model. Estimating the model as a pooled system adds degrees of freedom, but also imposes cross-equation restrictions taking the form of common parameters. This can be dealt with using seemingly unrelated regressions techniques; we used a non linear version of the procedure.

8. More on water recycling in Section IV.2 below.

Instrumental variables (IV) are also used to take into account potential output endogeneity or errors in variables. The IV technique usually relies on lagged exogeneous variables as instruments. We corrected for first-order autoregressive disturbances (Durbin-Watson tests indicated that autocorrelated errors were present in the cost and input demand equations) making use of lagged values of exogenous variables. Therefore, the correction for autocorrelation of residuals may be interpreted as use of the IV technique. Specifically, incorporating the lagged dependent variable into the cost equation gave the form $\ell n\left(\frac{G_h}{w_{sh}}\right)_t = \beta_{oh}(D_h) + \beta Z_t + \rho \ell n\left(\frac{G_h}{w_{sh}}\right)_{t-1} + u_t$ which in turn implies, after suitable substitutions, the following form $\ell n\left(\frac{G_h}{w_{sh}}\right)_t = \beta_{oh}(D_h)(1+\rho) + \beta(Z_t + \rho Z_{t-1}) + (u_t + \rho u_t)$ where Z_t refers to the vector of right-hand variables in (5), β refers to the corresponding vector of parameters, and ρ is the coefficient of autocorrelation. A similar formula applies to the share equations (6). Our results, available on request, have also employed White's heteroskedastic-consistent covariance matrix to generate standard errors.

2. Implications of water intake on production structures

The substantial diversity in the growth of outputs, inputs and structure of costs among the industries over the period 1981-1996 provides a rich body of data to test econometrically the impact of using water as a free input on productivity performance growth and the related performance indicators of these industries. Therefore, using the parameter estimates of our econometric model, we expect to find our results (elasticities, shadow prices of water and multifactor productivity growth rates) to vary considerably across industries. These inter-industry variations motivate the use of a specification that captures industry idiosyncrasies.

Cost elasticities and shadow prices for water intake are presented in Table 2. The last two rows give a weighted average across the business sector and across the seven largest water-user industries over the 1981-1996 period. The business sector's cost elasticity is 0.76, which is indicative of the presence of scale economies. There is, however, a wide variation across industries ranging from 1.52 in tobacco to 0.58 in refined petroleum products. Tobacco is the only industry that displayed decreasing returns to scale (0.66), all other industries reported reasonable and statistically significant increasing returns to scale. These seven industries are no exception. Their average cost elasticity is slightly lower than the business sector's average (0.76), albeit with a much smaller range (between 0.84 for chemical industries and 0.58 for refined petroleum products).

Table 2 also reports the estimates of technical change, the elasticities of substitution and the shadow prices by industry. The results indicate a moderate but statistically significant technical progress of 5% for the business sector with a wide range across industries. Industries, such as electrical and electronic products and telecommunications, that produce high-tech products reported the highest change in technical progress over the 1981-1996 on average (8% and 7%, respectively). Others, such as wholesale and transportation, also reported as an impressive technical change as these high tech industries over the same period (7%).

Table 2. Average estimates of cost elasticities and shadow prices, 1981-1996

Industry	$\varepsilon_{G,Y}$	ε_t	$\varepsilon_{W,K}$	$\varepsilon_{W,L}$	z (in $ per cubic metre)
Agricultural and related service	0.76 (3.44)	-0.05 (4.67)	0.17 (4.81)	0.18 (5.67)	0.46 (1.75)
Logging and forestry	0.87 (3.19)	-0.06 (4.84)	0.21 (8.13)	0.22 (9.00)	0.91 (2.16)
Mining	0.62 (3.12)	-0.05 (4.40)	0.11 (9.31)	0.12 (9.98)	0.35 (1.12)
Crude petroleum and natural gas	0.86 (2.03)	-0.06 (5.45)	0.36 (3.24)	0.37 (3.73)	0.95 (3.56)
Quarry and sand pit	0.73 (3.37)	-0.06 (4.89)	0.23 (9.52)	0.23 (2.19)	0.86 (2.28)
Services incidental to mineral extraction	0.58 (2.83)	-0.04 (3.33)	-0.16 (3.02)	-0.15 (2.32)	0.55 (1.55)
Food	0.70 (3.31)	-0.05 (4.14)	0.04 (3.58)	0.06 (4.96)	0.15 (0.48)
Beverage	0.52 (2.68)	-0.05 (3.78)	-0.04 (3.62)	-0.03 (2.76)	-0.20 (0.41)
Tobacco products	1.52 (2.26)	-0.03 (2.40)	-0.41 (2.39)	-0.39 (3.29)	0.93 (2.03)
Rubber products	0.85 (2.17)	-0.06 (4.93)	0.23 (9.76)	0.24 (2.86)	1.29 (2.37)
Plastic products	0.91 (3.01)	-0.07 (6.24)	0.53 (4.36)	0.54 (4.32)	0.67 (5.30)
Leather and allied products	0.99 (1.98)	-0.02 (1.65)	-0.63 (4.38)	-0.61 (4.35)	0.92 (3.09)
Primary textile	0.62 (2.98)	-0.04 (3.50)	-0.12 (9.62)	-0.11 (8.69)	-0.34 (1.12)
Textile products	0.77 (3.36)	-0.05 (4.01)	0.01 (0.78)	0.02 (1.81)	0.04 (0.16)
Clothing	0.60 (2.97)	-0.04 (3.70)	-0.07 (5.50)	-0.06 (4.60)	-0.21 (0.60)
Wood	0.86 (1.94)	-0.05 (3.93)	-0.01 (0.91)	0.00 (0.27)	-0.02 (0.03)
Furniture and fixture	0.66 (3.24)	-0.05 (4.34)	0.09 (7.82)	0.10 (8.73)	0.38 (0.98)
Paper and allied products	0.61 (3.09)	-0.05 (4.44)	0.12 (10.02)	0.13 (11.03)	0.49 (1.23)
Printing, publishing and allied	0.72 (3.36)	-0.05 (4.28)	0.08 (6.59)	0.09 (7.29)	0.32 (0.82)
Primary metal	0.86 (2.97)	-0.05 (4.37)	0.09 (8.06)	0.11 (9.48)	0.39 (1.04)
Fabricated metal products	0.59 (3.00)	-0.05 (3.90)	-0.02 (1.46)	-0.01 (0.53)	-0.04 (0.12)
Machinery (except electrical mach)	0.62 (3.03)	-0.04 (3.58)	-0.10 (7.99)	-0.09 (7.12)	-0.33 (0.92)
Transportation equipment	0.95 (1.87)	-0.07 (6.68)	0.62 (5.30)	0.63 (5.73)	0.84 (6.23)
Electrical and electronic products	0.95 (1.75)	-0.08 (7.01)	0.69 (3.51)	0.70 (4.48)	0.75 (6.92)
Non-metallic mineral products	0.76 (3.25)	-0.04 (3.63)	-0.08 (6.90)	-0.07 (6.05)	-0.22 (0.79)
Refined petroleum and coal products	0.58 (2.75)	-0.04 (3.13)	-0.22 (7.86)	0.17 (3.68)	0.48 (2.06)
Chemical and chemical products	0.84 (1.70)	-0.05 (4.64)	0.17 (4.31)	0.18 (5.41)	0.31 (1.70)
Other manufacturing	0.66 (3.24)	-0.05 (4.29)	0.08 (6.75)	0.09 (7.66)	0.30 (0.85)
Construction	0.68 (3.18)	-0.05 (3.74)	-0.06 (4.83)	-0.05 (3.76)	-0.16 (0.50)
Transportation	0.68 (3.25)	-0.06 (4.84)	0.21 (8.34)	0.22 (9.12)	0.79 (2.18)
Pipeline transport	0.87 (2.38)	-0.07 (6.22)	0.52 (4.23)	-0.54 (4.40)	0.52 (5.25)
Storage and warehousing	0.70 (3.32)	-0.05 (4.25)	0.07 (6.09)	0.08 (6.63)	0.26 (0.75)
Communication	0.87 (2.67)	-0.07 (6.25)	0.53 (4.90)	0.54 (4.81)	0.48 (5.33)
Other utility	0.81 (3.48)	-0.06 (5.05)	0.26 (2.01)	-0.27 (2.76)	0.95 (2.66)
Wholesale trade	0.87 (2.70)	-0.07 (6.13)	0.50 (4.23)	0.51 (4.81)	0.48 (5.07)
Retail trade	0.71 (3.33)	-0.06 (4.90)	0.23 (9.47)	0.23 (2.16)	0.88 (2.31)
All industries	0.76 (2.85)	-0.06 (4.81)	0.24 (4.98)	0.21 (4.96)	0.73 (2.19)
The 7 largest water-using industries[a]	0.70 (2.96)	-0.05 (4.37)	0.17 (4.50)	0.06 (5.61)	0.76 (2.24)

Note: [a] Agriculture, mining, paper, primary metal, refined petroleum and coal products, chemical and utility.

$\varepsilon_{G,Y}$ = scale elasticity; ε_t = technical change; $\varepsilon_{W,K}$ = capital-water elasticity of substitution; $\varepsilon_{W,L}$ = labour-water elasticity of substitution; z (in $ per cubic metre) = shadow price of water intake; t statistics are in brackets.

Additional insights on the technology structure of the industries covered in this study can also be found in the results on the elasticity of substitution. Positive cross elasticities indicate substitutability (and vice versa for complementarity); as the price of capital (labour) decreases, for example, the usages of both capital (labour) and water increase. The capital-water and labour-water elasticities are significantly positive for the business sector (0.24 and 0.21, respectively), reflecting that a decline in water intake requires more capital (labour). The substitutability between capital and water has also been found in Dupont and Renzetti (1999) but the order of magnitude of their elasticities are three times higher than ours, reflecting differences in the methodology and the type of data used.

The estimates of the elasticity of substitution vary significantly across industries. For the majority of the seven largest water-using industries, water is a substitute to labour and capital inputs. Utility and refined petroleum and coal products are, however, the two exceptions where labour and capital are, respectively, complement to water. Amongst the seven largest water-using industries, utility reported the highest elasticities of substitution (in absolute terms) (0.26 and -0.27, respectively, for capital and labour), followed by agriculture and chemical products (0.17 and 0.18). Although utility, the largest water-using industry, reported the highest elasticities of substitution, the results do not reveal a direct link between the intensity of water use and the extent to which primary inputs substitute for water.

The shadow price of water intake was significant and amounted to $0.73 per cubic metre for the whole business sector, slightly lower than the one reported by the seven industries ($0.76 per cubic metre). Half of the 36 industries reported positive and statistically significant shadow prices, albeit with different order of magnitude. This reflects different marginal benefits that arise from the use of water as a free input. Although the shadow prices are positive for the seven intensive water-using industries, they are significant only for utility, agriculture, chemicals and refined petroleum. Within this group of industries, utility, the largest water-using industry, reported the highest shadow price at $0.95 per cubic metre, about twice that of agriculture, the second largest water-using industry.[9]

Before proceeding to the multifactor productivity results, it is useful to compare these results to those of Renzetti and Dupont (2002) who reported estimates of shadow prices for intake water using pooled data from three cross-sectional surveys (1981, 1986 and 1991) on plant-level water use by Canadian manufacturing 2-digit industries for each province. These estimates are obtained from the estimation restricted cost function for Canadian manufacturing in which capital, labour, energy, materials and water recirculation and water treatment are variable inputs and the quantity of water intake is a quasi-fixed input.

Their data come from two different sources: First, Statistics Canada's Annual Survey of Manufactures (ASM) at the provincial level for two-digit industries. To derive the estimates of total cost of production by industry, the authors maintain the identity between gross output and total cost of input (assumption of constant returns to scale). Given that the ASM data are published only in current prices, the authors make use of variety of output and inputs price indexes required by their restricted cost function. Under this assumption of constant returns to

9. The confidence intervals for the estimated shadow prices $0.73 per cubic metre for all industries and $0.95 per cubic metre for the seven largest water-using industries are, respectively, 0.55-0.84 and 0.89-1.08.

scale, it follows that the user cost of capital employed to measure the services price of capital is constructed under the assumption of internal rate of return. Second, data on water use come from Environment Canada's Industrial Water Use Survey available at the plant level available on a quinquennial basis. These data are then aggregated to the two-digit industry level for each province to be consistent with the ASM data.

Table 3. Multifactor productivity growth, 1981-1996 (average annual growth rate)

Industry	With water intake	Without water intake
Agricultural and related service	3.0	1.8
Logging and forestry	1.2	-1.0
Mining	3.6	3.3
Crude petroleum and natural gas	4.3	4.5
Quarry and sand pit	4.2	2.6
Services incidental to mineral extraction	1.9	1.4
Food	0.6	0.5
Beverage	-1.5	-1.8
Tobacco products	8.3	7.7
Rubber products	5.2	9.8
Plastic products	3.7	6.1
Leather and allied products	-2.9	-4.0
Primary textile	-2.2	-3.0
Textile products	-3.9	-4.1
Clothing	-6.0	-6.5
Wood	-1.2	-1.2
Furniture and fixture	5.0	5.1
Paper and allied products	7.0	7.8
Printing, publishing and allied	-2.3	-2.7
Primary metal industries	0.0	1.0
Fabricated metal products industries	1.5	1.4
Machinery (except electrical mach)	5.8	5.7
Transportation equipment industries	-0.1	2.7
Electrical and electronic products industries	1.9	3.9
Non-metallic mineral products industries	-4.2	-3.7
Refined petroleum and coal products	-4.1	-6.3
Chemical and chemical products industries	0.9	4.3
Other manufacturing industries	2.2	2.3
Construction industries	-4.1	-4.1
Transportation industries	10.4	9.1
Pipeline transport industries	10.2	9.8
Storage and warehousing Industries	3.1	2.8
Communication industries	7.2	6.0
Other utility industries	3.3	-1.7
Wholesale trade industries	5.0	6.0
Retail trade industries	6.0	6.2
All industries	2.0	2.1
The 7 largest water-using industries[a]	2.2	1.5

Note: [a] Agriculture, mining, paper, primary metal, refined petroleum and coal products, chemical and utility.

Time period, industry coverage, consistency in the data sources, methodological differences and estimation technique make a definitive reconciliation to our results impossible. For example, our data cover a significant portion of the business sector considered by the official Canadian productivity accounts. We not only cover the two-digit industries of the manufacturing sector, but also agriculture, mining, utilities and non financial services industries. Agriculture and utilities are particularly important to consider in any study on water use since these two industries account for ¾ of the overall self-supplied water during the 1981-1996 period. Our data are based on the E-KLEMS database, an integrated and coherent source of information in both current and constant prices that is more adequate for studies on the impact of economic activity on environment at the national level (see Section III.2). For example, the user cost of capital employed in our data is derived on the basis of the external rate of return method, the only way that is consistent with the non-constant returns to scale assumption that underlies our cost function.[10] Finally, even though both of Renzetti and Dupont (2002) and our study employed a Zellner SUR procedure, our IV econometric estimation technique controls for any problem that may arise from spurious correlation and endogeneity.

Turning now to the multifactor productivity growth estimates reported in Table 3. The results reported in Table 3 indicate that the productivity performance of the 36 industries over the 1981-1996 period averaged 2.1% when water is not accounted for, compared with 2.0% when water is part of the input set. When we restrict the sample to the seven largest water-using industries, productivity growth increases from 1.5% to 2.2% on average over the 1981-1996. The largest increase took place in utility industries (from -1.7% to 3.3%), followed by agriculture (from 1.8% to 3.0%).

3. The effect of water recirculation on the results

The empirical framework used so far has only considered water intake obtained from self-supplied sources. While self-supplied water constitutes the most important source of water used by the Canadian business sector, the issue of water recirculation (recycling) has been overlooked so far. But as the data indicate, water recirculation is an important consideration of water use of the Canadian business sector. Out of the 40.9 million cubic metre of self-supplied water used by the Canadian business sector in 1996, 51% have been recycled. This represents an important increase since 1981 when the recirculation ratio was 43.5%. Although this ratio declined quite significantly in 1986 (37.6%) and 1991 (29.6%), recirculation still remains important as it represented 40.2% of water intake of the business sector on average for the 1981-1996 period. Similarly, with 37.4% over the same period, recirculation was equally important for the seven largest water-using industries.

10. This means that the internal user cost method employed by Renzetti and Dupont (2002) is not consistent with their non-constant returns to scale cost function. Only a constant returns to scale cost function, that is, (in the authors' own notation on page 10), $\frac{C}{Q_o} = C(P_i, Q_W, T, Z)$, $i = K, L, E, M, R, T_r$, is consistent with the notion of internal rate of return (see Harchaoui and Tarkhani 2002 for more details).

Given the importance of recirculation, it is critical to examine the following two questions: first, how robust are the results obtained earlier to the introduction of water recirculation in the framework? Second, what is the effect of water recirculation on the shadow prices of water use in Canada? These questions have important implications for the framework used in this paper. Consider first the question whether the account for water recirculation would alter in a significant way the results previously obtained. This clearly would suggest that the model is poorly specified as it is quite sensitive to any alternate assumption regarding the behaviour of the industries with respect to water use, with the result that the estimates will be unreliable or, at best subject, to a great deal of uncertainty. This leads to the second question addressed in this section: does water recirculation affect the shadow price of water use? Intuitively, the more recycling performed on water use, the less businesses will be willing to pay for water. As a result, accounting for water recirculation should reduce the shadow price of water, all things being equal elsewhere.

Our initial empirical framework has been amended along the following two changes: First, water use, defined as the sum of water intake plus recirculation, is substituted for water intake in the estimation of the equation system (5) and (6). Second, a dummy variable was appended to the variable water use in the equation (5) to reflect the fact that water recirculation involves a different type of technology across industries. Under these changes, the total cost function (5) then becomes

$$\begin{aligned} \ell nG_{it} &= \alpha_i + \alpha_Y \ell nY_{it} + \frac{1}{2}\alpha_{YY}\left(\ell nY_{it}\right)^2 + \alpha_W^1 \ell nWU_{it} + \frac{1}{2}\alpha_{WW}^1\left(\ell nWU_{it}\right)^2 \\ &+ \alpha_W^2 \ell nWU_{it} * D_{it} + \frac{1}{2}\alpha_{WW}^2\left(\ell nWU_{it} * D_{it}\right)^2 + \sum_{s=K,L,U}\alpha_{Ys}\ell nY_{it}\ell n(w_{ist}) \\ &+ \sum_{s=K,L,U}\alpha_{Ws}\ell nWU_{it}\ell n(w_{ist}) + \alpha_{YW}\ell nY_{it}\ell nWU_{it} + \sum_{s=K,L,U}\alpha_j \ell n(w_{ijt}) \\ &+ \frac{1}{2}\sum_{s=K,L,U}\sum_{s'=K,L,U}\alpha_{ss'}\ell n(w_{is't})\ell n(w_{ist}) + \alpha_t t + \alpha_{tt}t^2 + \sum_{s=K,L,U}\alpha_{ts}\ell n(w_{ist})t, \end{aligned} \tag{7}$$

where $WU_{it}\left(\equiv W_{it} + REC_{it}\right)$ is water use defined as the sum of water intake $\left(W_{it}\right)$ and water recirculation $\left(REC_{it}\right)$; D_{it} is a dummy variable that takes the value 1 if water recirculation is used and 0 otherwise. The impact of water recirculation on the cost function operates through two channels: first, the more water is recirculated the higher is the total cost G_{it} (a quantity effect); second, the use of a dummy variable D_{it} suggests that with water recirculation, the industry makes use of a different technology compared to the case where it only intakes water. As a result, the shadow price of water use, along with other indicators of the technology structures and economic performance are affected by the combination of these two effects. The corresponding results are reported in Tables 4 and 5.

Table 4. Average estimates cost elasticities and shadow prices with recirculation, 1981-1996

Industry	$\varepsilon_{G,Y}$	ε_t	$\varepsilon_{W,K}$	$\varepsilon_{W,L}$	z (in $ per cubic metre)
Agricultural and related services	0.74 (3.14)	-0.04 (4.55)	0.16 (3.03)	0.17 (3.47)	0.44 (1.82)
Logging and forestry	0.89 (2.41)	-0.06 (3.97)	0.23 (3.24)	0.19 (3.10)	0.88 (2.60)
Mining	0.71 (2.24)	-0.05 (3.10)	0.12 (3.12)	0.17 (2.58)	0.26 (1.99)
Crude petroleum and natural gas	0.89 (2.56)	-0.06 (4.59)	0.29 (2.87)	0.30 (2.63)	0.75 (2.67)
Quarry and sand pit	0.73 (1.99)	-0.06 (3.82)	0.20 (4.04)	0.29 (2.09)	0.83 (2.01)
Services Incidental to mineral extraction	0.67 (1.89)	-0.04 (2.89)	-0.11 (5.05)	-0.20 (2.52)	0.50 (1.60)
Food	0.70 (2.47)	-0.03 (3.57)	0.06 (2.34)	0.10 (3.76)	0.32 (0.96)
Beverage	0.51 (2.01)	-0.05 (3.89)	-0.03 (1.93)	-0.09 (2.06)	-0.07 (0.89)
Tobacco products	1.38 (3.18)	-0.03 (2.05)	-0.33 (2.47)	-0.41 (3.59)	1.04 (2.45)
Rubber products	0.89 (2.14)	-0.05 (3.21)	0.25 (3.87)	0.30 (2.76)	0.99 (2.41)
Plastic products	0.95 (2.76)	-0.07 (4.44)	0.49 (2.24)	0.48 (3.22)	0.66 (4.24)
Leather and allied products	0.98 (2.06)	-0.04 (1.50)	-0.44 (2.12)	-0.56 (3.45)	0.85 (2.88)
Primary textile	0.63 (3.17)	-0.04 (3.27)	-0.18 (3.75)	-0.14 (3.89)	-0.29 (1.89)
Textile products	0.76 (2.61)	-0.05 (3.28)	0.09 (1.57)	0.00 (1.41)	0.10 (0.83)
Clothing	0.63 (2.11)	-0.04 (2.08)	-0.12 (3.42)	-0.04 (3.50)	-0.33 (1.14)
Wood	0.86 (1.58)	-0.06 (3.12)	-0.02 (0.83)	0.05 (1.67)	-0.00 (0.19)
Furniture and fixture	0.67 (2.55)	-0.05 (4.14)	0.11 (2.14)	0.14 (2.83)	0.41 (1.75)
Paper and allied products	0.73 (2.23)	-0.05 (2.67)	0.20 (3.01)	0.11 (3.23)	0.31 (2.09)
Printing, publishing and allied	0.77 (3.31)	-0.04 (3.11)	0.07 (2.47)	0.12 (3.49)	0.28 (1.66)
Primary metal	0.92 (1.05)	-0.05 (2.12)	0.12 (3.17)	0.17 (2.58)	0.23 (2.03)
Fabricated metal products	0.62 (2.46)	-0.07 (2.90)	0.03 (1.79)	-0.06 (0.33)	-0.08 (0.49)
Machinery (except electrical mach)	0.62 (2.49)	-0.04 (3.88)	-0.16 (2.01)	-0.04 (3.42)	-0.37 (0.84)
Transportation equipment	0.94 (1.74)	-0.04 (4.32)	0.59 (3.47)	0.57 (2.83)	0.79 (3.67)
Electrical and electronic products	0.97 (3.05)	-0.06 (5.43)	0.60 (3.34)	0.59 (2.28)	0.69 (2.86)
Non-metallic mineral products	0.66 (2.71)	-0.04 (2.19)	-0.15 (2.83)	-0.10 (3.25)	-0.09 (0.99)
Refined petroleum and coal products	0.69 (3.03)	-0.04 (2.89)	-0.23 (2.17)	0.22 (2.98)	0.29 (2.33)
Chemical and chemical products	0.87 (2.15)	-0.06 (3.11)	0.11 (2.64)	0.24 (4.01)	0.33 (2.23)
Other manufacturing	0.61 (2.47)	-0.03 (4.31)	0.14 (3.29)	0.12 (3.36)	0.33 (1.49)
Construction	0.63 (2.99)	-0.05 (2.43)	-0.08 (4.14)	-0.03 (2.46)	-0.20 (0.73)
Transportation	0.73 (2.53)	-0.04 (3.01)	0.22 (3.55)	0.24 (3.62)	0.93 (3.02)
Pipeline transport	0.81 (1.89)	-0.06 (5.44)	0.47 (1.76)	-0.45 (2.70)	0.64 (2.39)
Storage and warehousing	0.70 (2.44)	-0.05 (1.99)	0.11 (3.20)	0.12 (2.23)	0.25 (1.49)
Communication	0.84 (3.11)	-0.06 (3.56)	0.49 (2.73)	0.51 (2.91)	0.55 (2.65)
Other utility	0.89 (2.71)	-0.06 (3.47)	0.35 (3.35)	-0.19 (3.36)	0.71 (2.08)
Wholesale trade	0.71 (3.09)	-0.04 (3.33)	0.51 (2.44)	0.44 (2.21)	0.55 (3.16)
Retail trade	0.76 (2.39)	-0.05 (2.56)	0.29 (3.58)	0.18 (3.76)	1.02 (2.65)
All industries	0.77 (2.53)	-0.05 (3.33)	0.24 (2.99)	0.19 (2.93)	0.55 (2.08)
The 7 largest water-using industries[a]	0.74 (2.57)	-0.05 (3.41)	0.18 (2.91)	0.07 (2.95)	0.57 (2.06)

Note: [a] Agriculture, mining, paper, primary metal, refined petroleum and coal products, chemical and utility.
$\varepsilon_{G,Y}$ = scale elasticity; ε_t = technical change; $\varepsilon_{W,K}$ = capital-water elasticity of substitution; $\varepsilon_{W,L}$ = labour-water elasticity of substitution; z (in $ per cubic metre) = shadow price of water use; t statistics are in brackets.

Table 5. Multifactor productivity growth with recirculation, 1981-1996 (average annual growth rate in percentage)

Industry	With water use	Without water use
Agricultural and related service	3.9	3.0
Logging and forestry	-2.6	-0.3
Mining	1.3	1.6
Crude petroleum and natural gas	2.5	2.2
Quarry and sand pit industries	2.3	3.9
Services incidental to mineral extraction	0.2	0.7
Food	2.4	2.5
Beverage	-2.2	-1.9
Tobacco products	4.8	5.4
Rubber products	7.2	2.6
Plastic products	0.8	-1.6
Leather and allied products	-6.0	-4.9
Primary textile	-2.9	-2.1
Textile products	-4.3	-4.0
Clothing	-6.0	-5.4
Wood	-2.5	-2.4
Furniture and fixture	4.8	4.7
Paper and allied products	4.2	3.4
Printing, publishing and allied	-2.1	-1.7
Primary metal	-1.2	-2.2
Fabricated metal products	-1.3	-1.3
Machinery (except electrical mach)	6.0	6.1
Transportation equipment	2.0	4.0
Electrical and electronic products	0.7	-1.3
Non-metallic mineral products	-2.9	-3.3
Refined petroleum and coal products	-6.4	-4.2
Chemical and chemical products	2.4	-1.1
Other manufacturing	5.5	5.4
Construction	-4.6	-4.6
Transportation	8.0	9.3
Pipeline transport	10.0	10.0
Storage and warehousing	2.7	3.1
Communication	9.6	10.8
Other utility	3.0	3.0
Wholesale trade	5.0	5.0
Retail trade	4.6	6.0
All industries	**1.6**	**1.8**
The 7 largest water-using industries[a]	**1.3**	**0.8**

Note: [a] These industries are: agriculture, mining, paper, primary metal, refined petroleum and coal products, chemical and utility.

Although there are some changes at the industry level as a result of the introduction of water recirculation, the initial aggregate results for cost elasticity, technical change, capital (labour)-water elasticity and multifactor productivity growth remained virtually intact (see Table 4). There is, however, one important change in the results: the value of the shadow price dropped significantly from $0.73 per cubic metre to $0.55 per cubic metre. In addition, the shadow price estimates for the majority of the largest water-using industries became more significant, reflecting the importance of water recirculation in the measurement of water use shadow prices.[11]

The effect of recirculation on multifactor productivity growth, reported in Table 5, leaves almost intact the story laid out earlier on the basis of the results of Table 3—while multifactor productivity growth for all industries remains almost unchanged for all industries when water is accounted for, it significantly increased for the most intensive water using industries. To some extent this suggests that measurement framework adopted in this study remains robust to alternate specification changes.

V. Conclusion

This paper has specified a model of the production structure where industries make use of conventional inputs and unpriced water intake to produce a given amount of production. The estimation methodology covers a comprehensive portion of the Canadian business sector that includes the largest water-using industries for 1981, 1986, 1991 and 1996.

The primary purpose of this paper is to account for water intake in the production structure of Canadian businesses and to quantify the extent to which it affects productivity performance. The flexibility of the approach undertaken in this paper allowed us to touch on a variety of issues related to water use. These are: a) the technological structures between water intake and the conventional inputs; b) the economies of scale, c) the shadow prices of water intake, and the effect of recirculation on these shadow prices.

We found that when allowance is made for water intake in the production structure multifactor productivity growth of the largest water-using industries increases by 0.7 percentage points on average over the 1981-1996 period, but leaves that of the aggregate business sector virtually unchanged (see Table 3). Water intake is a complement to capital and labour inputs. The shadow price of water intake is about $0.73 cubic metre and varies significantly across industries.

We also found that introducing water recirculation leaves most of the results unchanged which, in some sense, is indicative of the robustness of our framework. However, in accordance with our priors, recirculation brings water’s shadow price down to $0.55 per cubic metre. The difference between these two estimates can be considered as an indication of willingness to pay for water recycling.

11. The confidence interval for the estimated shadow price of $0.55 per cubic metre is 0.48-0.60. This again confirms the fact that accounting for recirculation makes the shadow price estimates less subject to uncertainty.

The discussion of the dimensions of water use in this study was related to the manner in which the quantity of water used by industries is conceptualized and measured by the data collection vehicles. Despite the substantial efforts expended by Statistics Canada's Environment Statistics Accounts in producing the sorts of water use data employed in this paper, there are still significant gaps in our knowledge regarding specific features of water use.

First, the data are almost a decade out of date. Second, it is clear that the use of water is frequently tied closely to water quality—in the sense of water's physical, biological and chemical characteristics. Therefore, if the relationship between the desired quantity of water use and economic factors such as prices is to be modeled and measured then quality of water should be accounted for. Unfortunately, to the best of our knowledge, no available source presently compiles water quality characteristics that can be reflected in our measurement framework.

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