Self-selection bias and manufacturing firms' demand for water recirculation[1]

by

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Abstract

Relatively little is known of the factors which might influence firms' water recirculation decisions. This paper estimates an econometric model that accounts for potential self-selection bias and considers two facets of firms' recirculation behaviour: first, the discrete decision of whether to recirculate and, second, the decision of how much to recirculate. The model is estimated by applying the Heckman two-stage estimation procedure to data from Environment Canada's Industrial Water Use Survey. In the first stage, long run factors such as relative water scarcity and production technologies are found to influence the decision whether to recirculate water. In the second stage, the imputed prices of intake water and water recirculation as well as the scale of operations are found to influence the choice of the optimal quantity of water to recirculate.

Introduction

The ability to recirculate water within a production process is an important characteristic of many manufacturing processes and one feature that distinguishes industrial water use from most other instances of water use. However, many manufacturing firms choose to carry out no recirculation and, of those firms that do recirculate water, the percentage of water recirculated varies across time and across sectors. For example, the overall recirculation rate in the Canadian manufacturing sector has varied considerably over time with the ratio of recirculated water to intake water falling from 1.08 in 1981 to 0.93 in 1991 and rising to 1.15 in 1996. Furthermore, as Table 2 demonstrates, individual manufacturing subsectors vary significantly in their frequency and intensity of recirculation[3] (Scharf, Burke, Villeneuve and Leigh, 2002).

It is important to clarify what is being discussed here. Internal water recirculation is generally not considered to be the same thing as water reuse. Recirculation refers to using the same water more than once within a specific production process or within the same industrial facility. An example would be a closed-loop cooling system within a factory where the same cubic metre of water is used repeatedly to cool equipment or intermediate outputs. Water reuse refers to using water more than once but in quite different applications and different locations. For example, watering a golf course with treated sewage water is considered water reuse but not water recirculation. Our concern in this paper is with explaining observed variations in water recirculation within Canadian manufacturing facilities.

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[3] Frequency of recirculation refers to the proportion of firms in a sector which are observed to recirculate water while intensity of recirculation refers to the ratio of recirculation to water intake for a sector.

The motivation behind our analysis of industrial water recirculation is two-fold. The first is that the factors influencing firms' water recirculation decisions are poorly understood as this facet of industrial water use has received little empirical analysis to date. Changes in recirculation activities, given the large demands for water in manufacturing, can have significant impacts on water availability for ecological and human needs. The second is that Canada's regulations governing industrial water withdrawals and discharges may encourage socially inefficient decision-making regarding all facets of industrial water use including recirculation. This paper employs a cross-sectional survey of Canadian manufacturing plants to estimate an econometric model that seeks to explain observed variations in manufacturing water recirculation practices.

The remainder of this report is organized in the following fashion. The next section provides background information related to the efficiency of Canada's water regulations, previous research efforts and to the features of the Industrial Water Use Survey. Section 3 presents an econometric model of industrial water recirculation and discusses the results of estimating the parameters of that model using the IWUS data. Section 4 provides concluding remarks.

Background

(a) Water Recirculation in Canadian Manufacturing

Manufacturing water use in Canada is the second largest water intake category reported by Environment Canada exceeded only by water intake for thermal electric power. Table 1 shows total water intake by sector for 2005. Water intake by manufacturing plants was approximately 7,800 million cubic meters (MCM), sixty percent more than that used for agriculture or for municipal purposes (though there are major differences across provinces).

Recirculation of water by manufacturing plants is widespread. Table 2 shows intake and recirculation volumes within manufacturing for 1986, 1991 and 1996. Generally, the bigger the intake volume, the more water is recirculated although not necessarily proportionally more. On average, each cubic meter of water taken in is recirculated at least once. Overall, intake volumes have decreased somewhat as have the volume recirculated. The recirculation intensity (ratio of recirculated water to intake volumes) is close to 1 though has risen slightly from 1986 to 1996. Table 2 also shows the recirculation frequency. This is the fraction of manufacturing plants that reported a positive recirculation volume in the survey year. The fraction of firms that recirculate water fell from 73 percent in 1986 to 53 percent in 1996. This suggests that, for those plants that continued to recirculate water, their intensity of recirculation rose significantly. Both recirculation rates and frequencies differ significantly across industries and across provinces.

Increased recirculation in manufacturing is one possible way to reduce the ecological impact of human activities on the aquatic ecosystem or to release water for other uses. For instance, if recirculation intensities increased by only 5 percentage points, or the fraction of plants that recirculated water increased by only 5 percentage points, then the demand for intake water could fall by as much as 390 MCM based on 2005 manufacturing intake volumes. This would supply enough water for approximately 7 million dairy cows (Canada had only about 1 million head in 2008 (Statistics Canada

2009)). Alternately, it would supply close to all the water used by the 2.6 million people and thousands of businesses in Toronto in 2004 (Environment Canada)[4].

(b) Policy Environment

Under the Canadian Constitution, provincial governments have most responsibility for matters relating to natural resource use and regulation (Nowlan, 2005). All provincial governments have established permit-based systems to regulate direct water withdrawals and to control depositions of wastes in surface and groundwater bodies. Provincial governments also have the authority to regulate municipalities' setting of water prices. Since all manufacturing firms in Canada are either self-supplied or purchase water from a municipal water supplier, provincial water-related regulations form the institutional context within which firms' water-use decisions are made.

For the purposes of this research, the most important feature of this regulatory environment is that it does not promote efficient decision-making regarding industrial water use (see for instance Dupont and Renzetti, 1999; Nowlan, 2005; Renzetti, 2007). The permits issued to firms withdrawing water directly from surface or groundwater bodies do not confront them with the full social costs of their decisions as the fees levied for the permits cover only the administrative costs of issuing the permits. Firms are also not charged for their wastewater discharges as provinces employ command and control-style water quality regulations. Similarly, previous research (Renzetti, 1999) has demonstrated that municipal water and sewage prices diverge significantly from the social marginal cost of supply. These features combine to mean that industrial water users do not face the full social costs of their intakes and their discharges. Thus, to the extent

[4] Environment Canada's Municipal Water Pricing Survey reports total average daily intake in Metro-Toronto of 1,074,915 cubic meters. This is about 392 MCM per year.

that recirculating water leads to a reduction in either intake or discharges, firms' private assessment of water-related savings will fail to reflect social net benefits and may be inefficient. This is because intake and discharge are under-priced but the costs of recirculation are borne entirely by the firm. This suggests that firms will not recirculate as much as is socially efficient.

These arguments provide a second source of motivation for investigating manufacturing firms' water recirculation decisions. In addition to seeking to add to the relatively small body of empirical papers that have previously considered this issue, this paper is motivated by a concern for the efficiency of water allocation in Canada. The existing policy environment distorts firms' decision-making regarding water recirculation as the costs and benefits to the firm diverge from those to society. In addition, it would be valuable to know whether these potentially inefficient decisions are sensitive to economic instruments such as reformed municipal water prices, water withdrawal fees and effluent charges.

(c) Literature Survey

The analysis of water demands has been unevenly applied with most of the effort going to study recreational, agricultural and residential water demands (Griffin, 2006; Young, 2005). While industrial water recirculation has been studied by engineers and systems analysts (Lens et al, 2002), relatively little analysis has been carried out to understand the economic dimensions of industrial water use. Early efforts are surveyed by Renzetti (2002) and de Gispert (2004). The most recent efforts to estimate industrial water demands are Dupont and Renzetti (2001), Reynaud (2003) and Chao-Hsien et. al (2006).

Manufacturing water recirculation

Within the set of industrial water demand studies, a small subset of papers has addressed the specific issue of the factors influencing firms' decision-making regarding internal water recirculation. Dupont and Renzetti (2001) estimate a cost function for the aggregate Canadian manufacturing sector that includes water intake and recirculation as variable inputs. The authors found that the own-price elasticity of water recirculation is -0.66. As well, the relationship between water intake and recirculation is stronger when water intake is process-related rather than related to cooling and steam production. The Dupont and Renzetti model, however, is restricted to explaining the observed volume of water recirculated conditional on firms deciding to engage in some positive amount of recirculation.

Chao-Hsien et. al (2006) model water demands in the Taiwanese integrated circuit industry using a combined engineering process-econometric model. The authors assume firms calculate the optimal water recirculation rate as a function of internal water costs and external water prices. Once internal water costs are estimated from a cross-sectional sample of 25 firms, a relationship between optimal water intake and external water prices is derived. Simulation results demonstrate that plants' optimal water recirculation rates depend on the price of water intake, the form of technologies for water recirculation and water discharge regulations. Féres (2007) uses a survey of approximately 500 manufacturing firms in the state of São Paulo, Brazil, to estimate an endogenous switching regression model of manufacturing water intake demands. The model estimates two water intake demand equations: one for those firms that choose to recirculate water and one for those that choose not to recirculate. The estimated model indicates that the discrete decision whether to recirculate water is positively related to the price of intake water but negatively influenced by the cost of capital.

These studies provide some insights into manufacturing firms' water recirculation decisions. They are, however, limited by their modeling strategies. Dupont and Renzetti (2001) explain why the observed volume of water recirculation does not explain the binary decision of whether or not to engage in water recirculation. On the other hand, Féres (2007) models the discrete decision whether to recirculate but does not but does not explain the observed volume of water recirculation.

Recirculation decision-making model and estimation

(a) Decision-making model

Neoclassical economics assumes that firms choose inputs in order to minimize the cost of producing a given amount of output. This leads to conditional input demands being modeled as functions of input prices, the level of output and the firm's production technology. A more general approach also begins with the assumption of cost-minimizing behaviour but further assumes that firms' decision-making regarding input use (in this case, internal water recirculation) may take place in two stages: first, the firm makes the decision whether to recirculate water internally at all and, second, for those firms that have decided to recirculate, how much water to recirculate. Thus, firms are said to be *self-selecting*: whether to be a 'recirculater' and, conditional on that decision, how much to recirculate.

There are several reasons for adopting this more general perspective. First, this approach allows us to assess the two decisions separately and to examine whether a given factor might influence the two decisions differently. Second, the approach provides two possible explanations for observing a plant failing to recirculate water in a given period: that a firm never recirculates (i.e. the decision at the first stage was 'no') or that the firm sometimes recirculates but is not currently doing so (i.e. that the decision at the first stage was 'yes' but the optimal choice in the second stage is zero).

The Heckman two-step model is an econometric model used to estimate the influence of factors in cases with two decision-making stages (Cameron and Trivedi, 2005, ch.16). The Heckman model has been extensively used and provides a framework that allows us to generalize the neoclassical model of input demands. This generalization accounts for the preponderance of zero recirculation observed in the data. The general format of the Heckman model is the following. Let y_2^* represent the variable of interest (such as the optimal volume of water recirculation). Further, suppose there exists a second latent variable y_1^* and that the outcome y_2^* is observed only if $y_1^* > 0$. More formally,

$$y_1 = \begin{cases} 1 & if\ y_1^* > 0 \\ 0 & if\ y_1^* \leq 0 \end{cases} \tag{1}$$

$$y_2 = \begin{cases} y_2^* & if\ y_1^* > 0 \\ - & if\ y_1^* \leq 0 \end{cases} \tag{2}$$

Then, we specify a linear model for the latent variables:

$$\begin{aligned} y_1^* &= x_1'\beta_1 + \varepsilon_1 \\ y_2^* &= x_2'\beta_2 + \varepsilon_2 \end{aligned} \tag{3}$$

It is well understood that OLS estimates of β_2 will biased if ε_1 and ε_2 are correlated. Self-selection bias occurs when characteristics of recirculators and non-recirculators are different and some unobserved characteristics of recirculating plants are correlated with explanatory variables. For example, firms facing higher costs of treating water prior to its discharge may be more inclined to recirculate water internally in order to avoid these costs. This situation may cause a correlation between these explanatory variables and the error terms. This situation results in biased estimates of regression coefficient estimates when the model is estimated with ordinary least squares.

The Heckman procedure corrects for this potential bias by introducing an additional explanatory variable in the OLS estimation of the vector of coefficients β_2 using the positive values of y_2^*:

$$y_{2i} = x_{2i}'\beta_2 + \sigma_{12}\lambda(x_{1i}'\hat{\beta}_1) + \upsilon_i$$

The second term on the right hand side contains the estimated inverse Mills ratio $\lambda(x_{1i}'\hat{\beta}_1)$. The correlation between the two errors can be tested using the statistic $\rho = \hat{\sigma}_{12} / \hat{\sigma}_2$. A finding of ρ not equal to zero indicates that a sample selection correction is not required[5].

(b) Data

[5] An alternate sample selection model known as a double hurdle estimates the two equations simultaneously. Estimation of this model was attempted but it would not converge as is not infrequently the case.

The Industrial Water Use Survey (IWUS) reports plant-level data covering water related activities within the manufacturing sector across Canada. Data includes water uses, quantity and sources of intake water and discharge, treatment activities for both intake and discharge, and the type, quantity, and purpose of water recirculation activities. The survey also includes information about the location of the plant, the size of its labour force, and primary manufacturing activity of the plant (Scharf, Burke, Villeneuve and Leigh, 2002).

This paper employs the data collected from the 1996 version of the survey (the most recent year in which plant-level observations are available). Recirculated water is defined in the survey as "water which is discharged from the plant or from a particular process within the plant, and which is subsequently recycled into the same process or into a different process within the plant". Recirculation activities are recorded depending on the purpose of recirculation. Plants can recirculate water for process purposes only, for cooling recirculation only, for both purposes, or for neither. A third category, "other recirculation", accounts for sanitary services.

A significant feature of the dataset concerns the information it provides to characterize the scale of operations of each plant. The survey requests the value of shipments but the response rate to this question was very low (only 21%). Further, the plants responding to the question typically had higher levels of water intake and number of workers than non-responders. Thus, restricting the sample to firms providing positive value of output data would have led to a non-representative sample. This necessitated our use of number of workers as a proxy for scale of plant operations. All plants provided information on number of workers. Cai (2008) argues that the number of workers is the most commonly employed proxy for missing value of output data in empirical studies regarding the manufacturing sector.

(c) Estimation

The Heckman two-stage selection model contains two equations: the decision equation in which the discrete choice of whether to recirculate is modeled and the recirculation equation in which the continuous choice of the volume of water to recirculate is modeled[6]. The decision equation is estimated using a Probit model where the dependent variable is binary taking the value of 1 if the plant is observed to recirculate a positive volume of water and a value of 0 otherwise. Our choice of regressors for this equation is guided by two principles. The first is that, given the capital-intensive nature of water recirculation, it can be expected that the decision whether to recirculate will be guided by major long-term factors such as a plant's scale and production technology as well as local water supply conditions. The second is that identification is assisted by avoiding having the same right-hand side regressors in the two equations (Cameron and Trivedi, 2005). Thus, the explanatory variables include the scale of the plant (represented by the number of workers employed at the plant) and several dummy variables that characterize the plant's location, its industrial classification and whether the plant treats its raw water supply prior to use. The price of water is not included in the first equation since most manufacturing facilities directly withdraw water from the environment (as opposed to relying on municipal water supplies) and, thus, face little or no external price for their water.

The recirculation equation is estimated using OLS. The dependent variable is the volume of water recirculated and the sample is restricted to those plant's reporting

[6] Table 4 provides descriptive statistics for all the variables used in the estimation models

positive recirculation volumes. Given that plants are recirculating some positive quantity of water, the appropriate right-hand side variables are those that economic theory predicts will influence the marginal decision of how much water to recirculate: input prices, the scale of operations, and the plant's technology. The IWUS provides observations on expenditures related to water intake, recirculation, and treatment prior to discharge. In making decisions regarding these activities, manufacturing plants do incur costs associated with pumping, treating, and storing intake water but usually face no external prices with the exception of publicly-supplied plants which face an external price for intake water. Thus, there is some discretion regarding the most appropriate way to represent the 'price' that firms consider when making these water-related decisions. The construction of the implicit prices of water intake, recirculation, and discharge is detailed in the appendix. Estimation of the decision equation and the recirculation equation is carried out using STATA's Heckman two-stage routine. There are 5532 observations used in the decision model's Probit equation and 3574 observations used in the recirculation model's OLS equation.

Estimation results

Decision Equation

Table 3 reports the estimated coefficients and t-statistics of the decision equation and the recirculation equation. Generally, the estimation results are in accordance with expectations: larger plant scale and greater need for internal water treatment make it more likely that a plant will recirculate water internally. Plant scale may have a role because of the capital costs or lumpiness of recirculating technology. Further, if a plant must treat raw intake water prior to use, then internal recirculation is a way of avoiding that cost. The industry dummies indicate that generally heavy water users are more likely to recirculate. Positive and significant coefficients are found for Plastics, Textiles, Paper, Petroleum, and Chemicals. Table 2 showed that these sectors had high recirculation rates. Conversely, negative and significant coefficients are found for the Wood, Fabricated Metals and Transportation Equipment sectors. The location dummies also show some patterns. Manufacturing plants in relatively drier (and, thus, water scarce) provinces are more likely to recirculate water. Provinces with positive and significant coefficients are Saskatchewan and British Columbia. Alberta exhibits a positive but insignificant coefficient. This may be because its industry is dominated by chemical and petroleum plants whose effects are picked up by the industry dummies. BC likely has a positive coefficient because it has the highest licence fees for private withdrawals by manufacturing firms and these may promote recirculation (Nowlan, 2005).

<u>Recirculation Equation</u>

Table 4 reports the estimated coefficients and standard errors of the water recirculation equation. Recall that these coefficients are estimated using only those observations which report a positive volume of water recirculated. The first feature to note concerns the Inverse Mills Ratio (IMR) variable. As Table 4 demonstrates, the estimated coefficient on the selectivity variable, is significant, indicating the presence of self-selection bias. The significance of the selectivity variable's coefficient indicates that the expected value of the equation's error would have been nonzero were it not for the inclusion of the selectivity variable in the equation. Thus, if the self-selecting behaviour of firms had not been accounted for by including the IMR variable, the estimated coefficients in the recirculation equation would have been biased. The sign of the coefficient is somewhat surprising, however, as it indicates that for the plants having chosen to be a "recirculator", the probability of such a choice decreases with the water recirculated[7]. This may reflect the differences in factors influencing the decision to recirculate and the decision regarding the volume of water to recirculate. Alternatively, it may reflect something we observe in the raw time series data, which is that some firms are observed to recirculate in one time period but not in others. In our discussion of future work in the Conclusions we return to this point.

With respect to the other explanatory variables, the results are generally in accordance with our expectations. For example, the positive coefficient on the instrumented price (that is, estimated marginal cost) of intake water indicates that plants treat intake water as a substitute for internal water recirculation. The own price has a negative effect on quantity recirculated. Finally, the price of water treatment prior to discharge has a positive effect on recirculation quantities. In addition, the proxy for output has a positive effect on the volume of water recirculated. The industrial sector dummies demonstrate that some sectors (namely heavy water using industries such as Primary Metals, Chemicals and Petroleum) have positive and significant coefficients. All other industrial sector dummies are not significantly different from zero.

Conclusions

It has been acknowledged in policy circles for some time that industrial water recirculation can be an important part of any effort to promote water conservation and

[7] Féres (2007) also estimates a negative coefficient on the IMR variable in his model.

sustainable water use. However, before industrial water recirculation can be promoted, it is necessary to have an understanding of the potential efficacy of the policy instruments that are available to government.

The work reported here allows us to make some initial observations regarding potential efficacy of economic instruments and other policy measures to encourage water recirculation by manufacturing plants. The estimated two-stage model indicates that economic factors such as the size of the plant and the marginal costs of water intake and water recirculation play a role in influencing a firm's optimal volume of water recirculation once the decision to recirculate has been taken. The decision whether to recirculate is influenced by long-run factors such as the chosen technology of product and plant location.

Finally, it is important to emphasize that more work is required. Little research efforts have assessed the economic features surrounding industrial water recirculation. This report has provided some additional insights but it is necessary to expand the scope of analysis to be able to look at the roles of other input prices and environmental regulations in recirculation decisions. It is also necessary to examine the behaviour of firms who switch back and forth between "recirculator" status over time. These will be the subject of our future efforts on this topic.

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Statistics Canada, 2009, Table 003-0032 - Number of cattle, by class and farm type, annual

Table 1: Water Intake in Canada, 2005 (MCM per year)

Region	Thermal	Manufacturing	Mining	Agriculture	Municipal	Rural	Total
Atlantic	x[2]	538	x	21	287	191	**1,036**
Quebec	x	1,833	24	113	1,555	250	**3,776**
Ontario	26,648	3,487	43	174	1,536	176	**32,064**
Prairies	x	675	x	3,592	650	124	**5,041**
BC and North	x	1,246	62	886	754	126	**3,074**
total	**32,137**	**7,779**	**459**	**4,787**	**4,782**	**866**	**50,813**
Share of total	0.63	0.15	0.01	0.09	0.09	0.02	

Notes to Table 1:

1. Source: Environment Canada. Downloaded Jan 19 2009, http://www.ec.gc.ca/Water/en/manage/use/e_wuse.htm

2. x-suppressed to meet the confidentiality requirements of the *Statistics Act.*

Table 2. Trends in Water Use in Canadian Manufacturing Industries, 1986-1996

Industry sub-sector	Intake Volume			Recirculated Volume			Recirculation Intensity			Recirculation Frequency		
	1986	**1991**	**1996**	**1986**	**1991**	**1996**	**1986**	**1991**	**1996**	**1986**	**1991**	**1996**
FOOD	564	347	267	148	193	145	0.26	0.56	0.54	0.65	0.55	0.56
BEVERAGE	63	73	73	107	16	18	1.71	0.22	0.25	0.72	0.71	0.61
TOBACCO	23	21	12	67	56	13	2.86	2.69	1.05	0.78	0.67	0.57
PLASTIC	30	42	13	66	267	39	2.22	6.42	2.92	0.80	0.62	0.57
PRIMARY	95	259	87	30	170	68	0.31	0.66	0.79	0.72	0.54	0.60
TEXTILE	13	14	15	12	20	8	0.94	1.44	0.53	0.88	0.72	0.74
WOOD	56	59	45	8	5	10	0.14	0.09	0.23	0.77	0.37	0.38
PAPER AND ALLIED	3,029	2,912	2,421	2,979	2,181	3,106	0.98	0.75	1.28	0.81	0.51	0.62
PRIMARY METAL	1,718	1,561	1,423	1,350	1,688	1,448	0.79	1.08	1.02	0.70	0.52	0.58
FABRICATED METAL	25	19	19	114	30	8	4.51	1.53	0.42	0.77	0.29	0.35
TRANSPORTATION EQUIP.	117	82	65	237	36	107	2.02	0.44	1.64	0.69	0.42	0.51
NON-METALLIC MINERAL	90	137	102	70	156	92	0.78	1.14	0.90	0.71	0.35	0.56
PETROLEUM AND COAL	487	445	370	1,068	1,012	541	2.19	2.27	1.46	0.97	0.87	0.70
CHEMICAL	1,674	1,313	1,121	1,558	977	1,354	0.93	0.74	1.21	0.76	0.56	0.59
TOTAL	**7,984**	**7,282**	**6,036**	**7,813**	**6,806**	**6,958**	**0.98**	**0.93**	**1.15**	**0.73**	**0.49**	**0.53**

Notes to Table 2:

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1. Source: Environment Canada, Industrial Water Use Survey, various years
2. Water Intake and Recirculation are measured in millions of cubic meters per year.
3. Recirculation intensity is the ratio of Recirculated volume to Intake volume.
4. Recirculation frequency is the proportion of plants reporting positive recirculation volumes.

Table 3: Heckman Two-Stage Estimates

Variable	Decision Equation	Recirculation Equation
Constant	0.2015 (0.0980)	-1.51e+09 (1.41e+08)
P-IN		4.81e+10 (2.24e+10)
P-RCR		-7.87e+08 (9.38e+07)
P-DIS		1.04e+09 (9.55e+08)
Output	0.0005 (0.0001)	3653.695 (855.24)
Treatment	0.1219 (0.035)	
SIC11 (Bev)	0.1216 (0.1228)	-1179006 (2044062)
SIC15 (Rubber)	-0.0869 (0.1353)	-211515.2 (2334802)
SIC16 (Plastic)	0.0298 (0.0068)	335523 (1178950)
SIC18 (Primary Textile)	0.0252 (0.1428)	776653.2 (2397181)
SIC19 (Textile Products)	0.4282 (0.2020)	-1406746 (2946125)
SIC25 (Wood)	-0.3502 (0.0719)	55314.96 (1614291)
SIC27 (Paper)	0.0788 (0.0384)	1931767 (524614)
SIC29 (Primary Metal)	-0.0588 (0.0967)	3559611 (1647403)
SIC30 (Fab. Metal)	-0.5221 (0.0679)	373162.1 (1583768)
SIC32 (Trans. Equip.)	-0.3095 (0.0688)	-736979.3 (1232849)
SIC35 (Minerals)	0.0646 (0.0603)	434096.5 (1035631)
SIC36 (Petroleum)	0.2923 (0.1595)	9707017 (3983638)
SIC37 (Chemicals)	0.0805 (0.0464)	2417731 (1091069)

PROV-NS	-0.0748 (0.1309)	
PROV-NB	-0.3293 (0.1305)	
PROV-QU	-0.1772 (0.1016)	
PROV-ON	-0.0144 (0.1004)	
PROV-MAN	-0.3567 (0.1338)	
PROV-SASK	0.9708 (0.1606)	
PROV-ALB	0.02697 (0.1126)	
PROV-BC	0.5218 (0.1073)	
IMR		-460665.9 (205296)
Wald		1086.96

Notes to Table 3:

1. The dependent variable in the Decision equation is a binary variable with value 1 if the plant recirculates water and 0 otherwise. The dependent variable in the Recirculation equation is the volume of water recirculated.
2. In each cell, the first number is the estimated coefficient and the second is the estimated standard error.
3. IMR is the Inverse Mills Ratio variable

Table 4: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
Output[1]	142.9571	373.9786	100	12000
recirc	1259777	1.41e+07	0	4.54e+08
piniv	.0164874	.0001367	.0162805	.0168518
prcriv	.0569474	.0014915	.0529492	.0590949
pdisiv	.7361264	.0056411	.7211017	.7446938
prdum1	.011769	.1078544	0	1
prdum2	.0358501	.1859331	0	1
prdum3	.0365743	.1877313	0	1
prdum4	.2560203	.4364727	0	1
prdum5	.3693645	.4826764	0	1
prdum6	.0329531	.17853	0	1
prdum7	.0217273	.145805	0	1
prdum8	.0840123	.2774314	0	1
prdum9	.1298207	.3361366	0	1
sicdum10	.2292232	.4203712	0	1
sicdum11	.0219084	.1463977	0	1
sicdum15	.0175629	.1313681	0	1
sicdum16	.0885388	.2841027	0	1
sicdum18	.0157523	.124527	0	1
sicdum19	.0085099	.0918639	0	1
sicdum25	.0827449	.2755212	0	1
sicdum27	.0532319	.224516	0	1
sicdum29	.0392902	.1943022	0	1
sicdum30	.0986783	.2982565	0	1
sicdum32	.0992214	.2989862	0	1
sicdum35	.1316314	.3381202	0	1
sicdum36	.0048886	.0697541	0	1
sicdum37	.1088177	.3114385	0	1
recrdum	.5344921	.498854	0	1
treatdum	.537208	.4986588	0	1

Notes to Table 4:
1. Output is proxied by the number of workers

Appendix: Instrumental Variable Estimation

This appendix describes how the input price variables were constructed. The IWUS database provides information about the total annual expenditures and total volumes associated with water intake and treatment, water recirculation and water treatment prior to discharge. With the exception of a relatively small number of plants connected to public water utilities, there are no external prices to represent the unit costs of these three activities. One can use either the estimated unit cost or marginal cost but either of these may be a function of the quantity of water used and, thus, may introduce a simultaneity bias into the estimation procedure.

The approach adopted here follows Renzetti (1992) and Féres (2007). The marginal cost of each activity is estimated by regressing total cost on quantity and quantity squared of water. Next, an instrument variable is used to represent the computed marginal cost. The instrument is the predicted value of the computed marginal cost after it has been regressed on a set of variables which are expected to be orthogonal to the volume of water recirculated. Specifically, the explanatory variables in the instrumental variable equations are dummy variables for: industry classification (SICdum1 covers SIC categories 10-19 and SICdum2 covers SIC categories 20-29), region (REGdum1is Ontario and Quebec, REGdum2 is Manitoba, Saskatchewan and Alberta, REGdum3 is British Columbia), whether the plant treats its water prior to use and whether the plant treated its water prior to discharge. Table A1 reports the results of the instrumental variable equation estimation. There may be a loss of efficiency in the estimation due to the substitution of the instrument for the computed marginal cost (especially as the only choices for instruments are variables available in the IWUS database) but this is often the case when trying to avoid endogeneity bias problems.

Table A1: Instrumental Variable Estimates

	Intake	Recirculation	Discharge
Constant	0.0162 (0.0024)	0.0591 (0.0204)	0.7447 (0.1074)
Intake treatment dummy	9.08E-05 (2.1E-05)	-0.0011 (0.0002)	-0.0037 (0.0009)
Discharge treatment dummy	7.56E-05 (0.0008)	-0.0009 (0.0065)	-0.0032 (0.0340)
Regdum1	1.51E-05 (0.0004)	-0.0002 (0.0038)	-0.0007 (0.0196)
Regdum2	7.6E-05 (0.0005)	-0.0009 (0.0037)	-0.0039 (0.0196)
Regdum3	5.27E-5 (0.0006)	-0.0006 (0.0045)	-0.0022 (0.0240)
SICdum1	0.0003 (3.03E-5)	-0.0033 (0.0002)	-0.0121 (0.0013)
SICdum 2	4.39E-05 (2.32E-05)	-0.0004 (0.0002)	-0.0018 (0.0010)
R2	0.2086	0.4923	0.2543
F	21.404	36.795	19.043

Notes to Table A1

1. For each of the three equations, the dependent variable is the computed marginal cost derived from the regression equation TC = a0 + a1Q + a2Q2. TC measures total reported cost and Q is total reported volume of water.
2. The figure in parentheses is the estimated standard error