A Longitudinal Study of Water Recycling in Manufacturing Plants[1]

Joel Bruneau[2] and Steven Renzetti[3]

January, 2012

Abstract

Industrial water use is an important part of most developed economies' total water use and one which is differentiated from other sectors' water use by the prevalence of recycling. Previous research applied to cross sectional surveys has identified the role of input prices and the scale of plant operations in determining the volume of water recirculated. We, on the other hand, employ longitudinal data to investigate the frequency of recirculation (that is, whether manufacturing plants recirculate or not). Our analysis of the data from several cross sections from Canada's Industrial Water Survey data shows that, while there are a number of plants that either never or always recirculate water, there is a sizable minority of plants who at times are observed to be recirculating and at other times are observed not to be recirculating. In order to investigate these phenomena, we construct a 'pseudo-panel' of data (Deaton, 1985) and estimate both a fixed effects and GMM model of recycling frequency. Our estimation model provides insights into industrial water recycling. In particular, water-related input prices and, in the case of the GMM estimator, the scale of plant operations are found to be significant in explaining the likelihood of recirculation.

---

[1] This paper was supported in part by Environment Canada under research contract K1531-06-1002. We are grateful to Michel Villeneuve, Diane Dupont and Hui Zhu for their help and comments. This paper reflects the opinions of the authors and does not reflect the policies of Environment Canada.

[2] Department of Economics, University of Saskatchewan joel.bruneau@usask.ca

[3] Department of Economics, Brock University and corresponding author steven.renzetti@brocku.ca

Introduction:

Manufacturing plants routinely recirculate water to meet their process and cooling needs. This ability and willingness to recirculate water distinguishes manufacturing plants from most households and agricultural producers. The volume of recirculation carried out in the manufacturing sector can be quite significant. For example, an increase in the volume of recirculated water of 1% by manufacturing firms in Canada would release enough water to supply the inhabitants and businesses of a city of 500,000 people.

A key focus of recirculation research is to determine the factors that influence a plant's decision whether to recirculate water. The motivation behind our analysis is two-fold. The first is that the factors influencing firms' water recirculation decisions have received relatively little empirical analysis to date. Understanding these factors may be important in designing water management schemes as well as in predicting future water demands.

The second motivation arises from the observation that environmental regulations in many countries may encourage socially inefficient decision-making regarding all facets of industrial water use including recirculation. This may be because the prices for industrial intake water and water discharges are not required to reflect their social opportunity cost (OECD, 2003). In Canada, for example, the absence of fees for direct water withdrawals and the under-pricing of publicly supplied water have promoted excessive water use and discouraged conservation (Renzetti, 2007). It is important to understand the factors influencing industrial water use - including internal recirculation - before assessing the potential efficacy of alternative policy instruments for promoting efficient water use.

The purpose of this paper is to analyze the factors that influence a plant's decision whether to recirculate water. We use a data set created by combining cross sectional surveys that track plant-level water use activities in 1986, 1991 and 1996. This longitudinal approach is new to the literature as all previous studies have only utilized cross-sectional data. The advantage of a longitudinal approach is that it can provide some insight into the amount of "churning" that has taken place. As we will show, plants routinely turn their recycling activities on and off. Cross-sectional data, not only cannot identify this effect, but tends to obscure it. The main obstacle to our analysis, however, is that the cross sectional surveys did not sample the same set of manufacturing plants. As a result after combining several of the cross sections we have a ‘pseudo panel’ (Deaton, 1985). Thus, we estimate a fixed effects model and, following Inoue’s (2008) criticism of this approach, a GMM model with this dataset in order to test whether input prices and differences in technology across plants assist explain observed variation in recycling frequencies.

Literature Survey

There are two streams in the literature which considers the economic dimensions of industrial water use including water recirculation. The first considers aggregate water use patterns. For instance, Bruneau and Renzetti (2010) show that aggregate industrial water intake in Canada fell by 17% between 1981 and 1996. This was despite the fact that real industrial output rose by 29% over the same period. At the same time however, industrial water recirculation fell by 25%, an even greater decrease than intake water. Thus, one implication of these observations is that the amount of water consumed by industrial activities (i.e. the difference between intake and discharge) rose by 21%. This suggests that policies that encourage more water recirculation may have unexpected consequences in terms of increase water consumption.

The second stream of the literature employs econometric models to examine firms’ decisions regarding water and other inputs. Early efforts are surveyed by Renzetti (2002). The most recent efforts to estimate industrial water demands while accounting for water recirculation are Dupont and Renzetti, 2001; Chao-Hsien et. al, 2006; Féres, 2007; and, Renzetti and Villeneuve (2010).

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 having decided 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 cross sectional 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.

Bruneau, Renzetti and Villeneuve (2010) employ the 1996 cross sectional Canadian Industrial Water Use Survey in order to estimate a Heckman two-stage model of recirculation water demand. 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.

These studies provide some insights into manufacturing firms' water recirculation decisions. They are, however, limited by their data and modeling strategies. Dupont and Renzetti (2001) explain why the observed volume of water recirculation but 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. Finally, Bruneau et al (2010) employ a two-stage model which illustrates how different factors may influence the decisions whether to recirculate and how much to recirculate but only use a single year’s cross sectional data.

Data:

The data used in this study come from the *Industrial Water Use Survey* (IWUS) provided by Statistics Canada. The survey reports establishment level data covering water related activities within manufacturing plants across Canada. Data include water uses, quantity and sources of intake water and discharge, treatment activities for both intake and discharge, operating and maintenance expenditures on each category of water use, and the type, quantity, and purpose of water recirculation and recycling activities. The survey also includes information about the location of the plant, the size of its labour force, and the primary manufacturing activity of the plant (Scharf, Burke, Villeneuve and Leigh, 2002).

Water that is recirculated or reused 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”. Recycling activities are recorded depending on the purpose of recirculation. Plants can recycle water for *process purposes* only, for *cooling recirculation* only or for both purposes. Process water includes all water which comes in direct contact with products and/or materials. It can be consumed in milling and special processes or included in the final output. Cooling water, on the other hand, does not come in direct contact with products, materials or by-products of the processing operation. It includes bypass water used for cooling or in the production process and water used for the production of steam for either process operations or electric power. A third category “*other recirculation*”, accounts for sanitary services.

If plants reported recirculation, they report how much and for what purpose. There are three ways to characterize these water recirculation activities at the plant level. The first is *recirculation volume*. This is the amount of recirculation (in cubic meters) that a plant engages in within a year. All of the econometric studies to date (including Bruneau, Renzetti and Villeneuve, 2010) seek to explain observed variations in recirculation volumes. Alternately, one can look at the r*ecirculation rate*. This is the ratio of recirculated water to total intake volume and measures the intensity of recirculation activities. However, as we show below, a large fraction of plants do not recirculate water at all. To identify the extent to which this occurs and to examine the factors influencing this decision, this paper focuses on the third way to characterize recirculation-related activities: the *recirculation frequency*. This is the proportion of plants within a given sub-sector or geographic area that report some recirculation activities in a particular period.

The IWUS was conducted in 1976, 1981, 1986, 1991, and 1996 with new surveys covering 2005 and 2007 soon to be released. Unfortunately, only the 1986, 1991 and 1991 surveys contain questions related to input expenditures. Thus, we use these three surveys to construct our database. Another complication is that the coverage of the surveys differed across years (that is, the same firms were not always surveyd) and, thus, it is impossible to create a panel dataset from these surveys. Rather, we combine the three cross-sections to produce a repeated cross-section or 'pseudo panel' dataset (Deaton, 1985). However, the short panel does allow us to identify some patterns that emerge amongst the plants that appear in all three surveys.

Recirculation Frequencies

In the case of plants which have been surveyed in all three time periods, we may investigate the pattern of recirculation activities that have taken place. We begin our analysis by summarizing recycling frequencies. We first identify plants that are common to each of the three surveys and restrict our analysis to these plants. The IWUS is quite large (approximately 5000 plants are surveyed in each cross section) with the number of plants common to the 1986–91–96 surveys at 2725. We then record recirculation activities for each plant in each year (denoted as Y for YES and N for NO). We separate recirculation into *process*, *cooling*, and *total recycling*. These are reported in Table 1. The first rows show the total number of plants that reported some recycling in each of the survey years. As shown, recycling frequency changes over time and across activities. Recirculation frequency is higher for cooling than for process recycling. Recirculation frequency was highest in 1986 among the plants in our sample, falling in 1991, and then rebounding somewhat in 1996.

The first observation we can take from the data is that, at a minimum, 544 plants of the 2725 plants in our sample that had recirculated water in 1986 reported no recirculation in 1991. The actual number of plants that stopped is actually higher than 834 since some plants began recirculating water in 1991 (see below). For processing purposes, at least 536 plants that had not recirculated in 1986 stopped recirculation while for cooling purposes at least 549 plants ceased recirculation. In each category, at least 20% of plants that recirculated water in 1986 did not in 1991.

Since recycling frequencies rebounded in 1996, some of these plants may have re-started their recirculation activities. We can check this by tracking the sequence of recirculation choices. The three time periods provide eight possible permutations of Y or N. We separate plants into four broad categories. Data are reported in table 1.

The first category shows the fraction of plants that either recirculated water or reported no recirculation at all in each of the three periods. This category constituted 41% of the plants with only 10% of plants failing to recirculate any water at any time. 27% of plants have never recirculated water for process purposes while only 13% of plants did not recirculate water for cooling purposes.

The second category shows the fraction of plants that began recirculation within our sample periods (NYY and NNY). About 15% of plants that did not recirculate in 1986 began recirculating some water by 1996. About 19% of plants began process recycling with two-thirds of these beginning in 1996.

The third category shows those plants that stopped recycling by 1996 but which had recirculated some water in 1986 (YNN and YYN). This constitutes about one quarter of all plants with slightly higher rates for processing and cooling purposes separately. In each category, the number of plants that ceased recirculation was highest in 1991. Note that, even though the total number of plants that recycled in 1996 was higher than in 1991, there were still a large fraction of plants that had stopped. Aggregate data simply obscures this experience of individual plants.

The fourth category shows that 18% of plants switched recirculation efforts over the three periods (YNY and NYN). About 14% of plants stopped in 1991 then re-started recirculation efforts in 1996. About 4% started in 1991 then stopped in 1996.

Similar patterns outlined above can be found in geographically disaggregated data[4]. We find similar patterns for each of Canada's ten provinces. Though provinces do differ, with some having a greater fraction of plants that recirculate, the breakdown into the eight combinations of Yes and No is remarkably consistent across the country. It does not appear to be the case that plants in different provinces are more likely to stop, start, or switch any more than in other regions of Canada. However, the pattern for 2-digit industries does differ. For instance, in the *Wood Industries*, 27% never changed, 7% started recirculating, 46% stopped, and 20% switched. But in *Chemical and Chemical Products Industries*, 51% did not change, 13% started, 20% stopped, and 16 percent switched. So the industry and the technologies used in those industries do matter. The potential roles of provincial regulations and technological differences are examined in the econometric model below.

Another way to look at this phenomenon is to consider conditional probabilities. We ask 'what is the probability that a plant recycles in period *t+1* given its behaviour in period *t*'? Our results are presented in table 2. First we identify the total number of recyclers in 1986. We then identify, of these, the number that recycled in 1991. For total recirculation, there were 1957 plants that recycled in 1986 and only 1123 of these that continued in 1991(calculated as the sum of plants with YYY and YYN status). Hence only 57% of plants that recycled in 1986 continued into 1991. Using 1991 as the base year we see that 74% of plants that recycled in 1991 continued into 1996 (calculated as the sum of plants with YYY and NYY status). Pooling these results together shows that 64% of plants continue recycling into the subsequent period. We can also ask what fraction of plants that did not recycle in the base year began to recycle in the next period. Not surprisingly, the conditional probability is lower at around 42%. Together, the conditional probability of recycling is about 1.5 times higher if the plant had recycled in the previous period then if it had not.

We can also take a longer view and ask what fraction of plants that have recycled in both 1986 and 1991 also recycled in 1996 compared to those who did not recycle in either 1986 or 1991. This captures conditional probabilities of plants that have shown a consistent behaviour over multiple periods. Results are in the last column of table 2. For

---

[4] Results are available from the authors.

total recycling, 76% of plants that recycled in 1986 and 1991 also recycled in 1996 whereas only 44% of plants that did not recycle in either 1986 or 1991 did recycle in 1996. If we restrict comparison to plants that have experience only in 1991 (NYY and NYN), the conditional probability of recycling in 1996 is only 65%. So accounting for two periods of previous experience raises the probability of recycling.

It is also interesting to note that the duration of time that a plant does not recycle does not seem to lower the probability that they will begin. In other words, failure to recycle in the past does not seem to reduce the likelihood that a plant will recycle in the future. However, the longer the experience with recycling, the greater the likelihood that the plant will continue to recycle in the future.

The tables above provide some insight in terms of recycling behaviour over time. Perhaps the most surprising set of results, given the likely capital-intensive nature of the decision to recirculate water internally, is the frequency with which plants move in and out of the state of being a recycler. However, these data do not tell us *why* plants are changing their recirculation behaviour. The plants may change recirculation decisions because they change size, face higher prices, face new prices for non-water inputs, or face new water regulations. As mentioned in the literature survey, Bruneau et al (2010) and others have investigated recirculation behaviour using single cross sectional surveys and provided some insight into the factors influencing recirculation decisions. In what follows, we broaden our investigation by pooling three cross sections (1986, 1991 and 1996) to investigate further the determinants of recirculation behaviour[5].

Econometric Model

We are interested in explaining the observed behaviour of Canadian manufacturing plants regarding the decision whether to recirculate water. It is clear from the discussion in the previous section that some plants never recirculate, some always recirculate and others switch between states.

The main constraint imposed on our analysis stems from the nature of the IWUS sampling procedures. The same individual plants were not observed in each survey and,

---

[5] When the 2005 and 2007 IWUS cross sections become available, we will go further and estimate a dynamic discrete choice model of recirculation decision-making. This model is not feasible with only three cross sections of data.

thus, we do not have a true panel dataset. Instead, because different plants are surveyed in 1986, 1991 and 1996, we have a series of repeated cross sections or what has become known as ‘pseudo-panel’ data. For this type of dataset, Deaton (1985) suggests tracing aggregated cohorts of similar individuals (households or firms) and estimating economic relationships based on the constructed cohort data rather than on individual observations. Thus, following Baltagi (2008), we posit a linear relationship between y_{it} and a vector of explanatory variables x_{it}. In order to characterize the relationship, we begin with a series of T independent cross-sections of I observations:

$$y_{it} = x_{it}^{'}\beta + \mu_i + \nu_{it} \quad t = 1,\ldots,T \quad i = 1,\ldots,I$$

If each cross section contained observations on the same individuals, then panel data estimation techniques would be appropriate. Instead, suppose that each cross section surveys a different sample (e.g. different households within a given city or different firms within a region). Then the dataset would not provide repeated observations of the same individual units across time and panel techniques would not be appropriate. Instead, define a set of C cohorts. Each individual observation belongs to exactly one cohort. In repeated cross sections of households, it has been common to define cohorts based on gender and year of birth because these are observable and do not change. As will be discussed below, the firms’ industrial classification will form the basis for our definition of cohorts. Now, averaging over the observations in each cohort yields

$$\overline{y_{ct}} = \overline{x_{ct}^{'}}\beta + \overline{\mu_{ct}} + \overline{\nu_{ct}} \quad c = 1,\ldots,C \quad t = 1,\ldots,T$$

Where the bar denotes the average value over all individuals belonging to cohort c at time t. Because we are concerned with the discrete choice of whether the plant is observed to be recycling water at time t, the averaging of the binary dependent variable leads to it being interpreted as the proportion of plants in the cohort which are observed to be recycling at time t[6]. Further, it can be expected that the $\overline{\mu_{ct}}$ will likely be correlated with

---

[6] It should be acknowledged that it is somewhat unusual to assume that a binary indicator variable is a linear function of explanatory variables as the linear function can take on any value while the indicator must be either 0 or 1. As Gassner (1998) points out, however, the use of Deaton’s constructed cohorts and

the x_{it} and, as a result, a random effects specification would lead to inconsistent estimates. Thus, a fixed effects specification is required along with the assumption that $\overline{\mu_{ct}} = \overline{\mu_c}$. Thus, our equation specification becomes

$$\overline{y_{ct}} = \overline{x'_{ct}}\beta + \overline{\mu_c} + \overline{\nu_{ct}} \quad c = 1,\ldots,C \quad t = 1,\ldots,T$$

For the estimation of our model, we have organized the individual manufacturing plants into cohorts based on their 3-digit industrial classification. This implies that there are 3 time periods and 55 cohorts in each time period with an overall sample of 165 observations. The average size of each cohort is about 277 plants. Baltagi (2008) discusses the trade-off that may exist in the definition of each cohort. This is because the larger the number of cohorts, the smaller the number of individuals in each cohort. On the one hand, increasing the number of cohorts may improve the efficiency of the estimator. On the other hand, increasing the number of cohorts may imply that n_c (the number of individuals in the c^{th} cohort) is smaller and this may imply that the cohort mean may be a poor estimator of the population cohort mean.

The right-hand side variables in our estimation model are those that economic theory predicts will influence a representative plant's decision-making regarding whether to recirculate water: input prices, the scale of operations, and the plant's technology. With respect to input prices, the IWUS does not report the costs of non-water inputs but does provide information regarding the costs of water use. Specifically, the IWUS provides observations on plants' operating and maintenance expenditures for each of water intake, water recirculation, and water 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.

---

their use in the subsequent estimation yields a relationship between the share of 1's and the average of the explanatory variables.

Another significant feature of the IWUS 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. The last explanatory variable is a binary variable indicating whether plants treated their intake water prior to using it. This variable serves to differentiate amongst the various uses of water across manufacturing plants. Those plants using water primarily for cooling must treat their water in order to remove impurities while those plants using water primarily for process purposes do not require the same degree of pre-use water treatment.

Thus the following model is estimated first using a fixed effects procedure with a correction for the measurement errors arising from the construction of the observation cohorts:

$$\overline{RCRDUM}_{ct} = \sum_i \beta_i \overline{P_{ict}} + \beta_{tr} \overline{TREAT}_{ctr} + \sum_j \beta_j \overline{PROV_{cj}} + \beta_T T + \overline{\mu}_c + \overline{\nu}_{ct}$$

$$c = 1, \ldots, C \quad t = 1, \ldots, T$$

Where $\overline{RCRDUM}_{ct}$ is the proportion of plants within cohort c that is recycling water at time t, the $\overline{P}_{ict}$ are the average prices of water intake, recirculation and discharge in the cth cohort at time t, $\overline{TREAT}_{ctr}$ is the proportion of plants within cohort c that is treating water prior to use at time t, $\overline{PROV}_{cj}$ are provincial dummy variables and T is a time trend. The equation is estimated using the PPREG program (Zurab and Chiburis, 2006) written for STATA. Recently, Inoue (2008) demonstrated that Deaton's FE estimator may be consistent but inefficient. He suggested a GMM estimator that is robust and efficient. Thus, we follow Gyimah-Brempong and Asiedu (2009) in applying the Inoue

GMM estimator. This is done by employing the xtivreg2 program (Schaffer, 2010) written for STATA.

Estimation Results

Table 3 summarizes the results of the estimation. The first column provides the estimated coefficients and standard errors for Deaton's FE estimator while the second provides the estimated coefficients and standard errors for Inoue's GMM estimator. In both cases, the estimation results are largely consistent with economic theory and our expectations.

If we first consider the FE estimates, we see that recirculation's own price is significant and has a negative effect on likelihood of recycling. Similarly, the price of water discharge has a positive effect: increasing the cost of treating water prior to discharge (e.g. in order to meet environmental standards) increases the likelihood of a plant recycling. The negative and significant coefficient on the price of intake water does not conform with our expectations. One expects that the higher the price of intake, the greater the incentive to recirculate water. This is the result found in other studies that look at the volume of recirculation. Our estimation instead looks at the frequency of recirculation, not its intensity. We find that higher water prices lead to a higher fraction of plants that cease recirculation. It may, in fact, be the case that those plants that continue to recirculate, recirculate more water. One explanation may be that plants that face higher intake prices choose to invest in technologies that lead to reduced gross water use. Gross water is the sum of intake plus recycled water. Thus, production would require less water and less recirculation. It is possible that the net decrease in gross water use leads to recirculation so small as to be unnecessary. Certainly, this issue merits further investigation in future research.

Considering the other explanatory variables, we see that the scale of operations (as represented by the number of production workers) is not a significant factor while the need to treat water prior to its use is a significant factor. The latter finding is most likely due to the desire on the part of plants to retain valuable treated water through recirculation. Several Provincial dummies are significant. These may be picking up differences in provincial water-related regulations (or even perhaps the tax treatment of capital investments) or overall differences in water availability. Finally, the time trend is positive and significant indicating an overall trend towards recycling becoming more likely.

There are a number of differences between the FE and GMM estimates. While the coefficient on the number of workers is almost the same, it is significant in the case of the GMM estimator. The other important difference concerns the price of intake. In the case of the GMM estimator, its coefficient is positive and significant. This suggests a substitute relationship between intake and recirculation as has been found in previous studies (Dupont and Renzetti, 2001). Finally, the time trend's coefficient is negative and significant for the GMM estimator.

Conclusions

Industrial water use is an important part of most developed economies' total water use and one which is differentiated from other sectors' water use by the prevalence of recycling. This feature means that encouraging greater industrial water recirculation is a potentially important form of water conservation that could provide water for other sectors. Previous research efforts have applied econometric models to cross sectional surveys and identified the role of input prices and the scale of plant operations in determining the volume of water recirculated. As our analysis of the data from several cross sections from Canada's Industrial Water Survey data shows, however, is that there are remarkably complex patterns of behaviour observed over time. Perhaps most surprising was the finding that, while there are a number of pants that either never or always recirculate water, there a sizable minority of plants who at times are observed to be recirculating and at other times are observed not to be recirculating.

The fact that the IWUS does not survey the same individual manufacturing plants precluded us from estimating a true panel model. As an alternative, we employed two estimation models. We first followed Deaton's prescription to estimate a fixed effects model employing a 'pseudo panel' of cohort-level data. Despite the information lost in creating these cohorts, our model still provided insights into industrial water recycling. We also addressed Inoue's (2008) critique of the Deaton approach by estimating a GMM model. In particular, water-related input prices were significant and, in the case of the

GMM model, the scale of plant operations was found to be significant in explaining the likelihood of recirculation.

Environment Canada has carried out but not yet released the 2005 and 2007 Industrial Water Use Surveys. Once those cross sections are released, we will have five cross sections and this may allow us to estimate a dynamic model that will explicitly account for plants' moving in and out of water recycler status.

Table 1: Number of Plants that Recycle: 1986–91–96

		TOTAL RECYCLING		PROCESS RECYCLING		COOLING RECYCLING	
TOTAL PLANTS	**2725**	# recyclers	Share of plants	# recyclers	Share of plants	# recyclers	Share of plants
1986 survey		1957	0.72	1356	0.50	1811	0.66
1991 survey		1413	0.52	820	0.30	1262	0.46
1996 survey		1638	0.60	1062	0.39	1464	0.54
STATUS							
NO CHANGE IN STATUS		**1126**	**0.413**	**1039**	**0.381**	**1025**	**0.376**
Recycled in all 3 periods	Y Y Y	857	0.314	310	0.114	660	0.242
Did not Recycle in any period	N N N	269	0.099	729	0.268	365	0.134
BEGAN RECYCLING		**397**	**0.146**	**503**	**0.185**	**436**	**0.160**
Recycled in 1991 and 1996 but not in 1986	N Y Y	188	0.069	175	0.064	197	0.072
Recycled in 1996 only	N N Y	209	0.077	328	0.120	239	0.088
STOPPED RECYCLING		**716**	**0.263**	**797**	**0.292**	**783**	**0.287**
Recycled in 1986 only	Y N N	450	0.165	599	0.220	491	0.180
Recycled in 1986 and 1991but not in 1996	Y Y N	266	0.098	198	0.073	292	0.107
CHANGED STATUS		**486**	**0.178**	**386**	**0.142**	**481**	**0.177**
Recycled in 1986 and 1996 but not in 1991	Y N Y	384	0.141	249	0.091	368	0.135
Recycled in 1991 only	N Y N	102	0.037	137	0.050	113	0.041

Notes to Table 1:

1. Source: Environment Canada, Industrial Water Use Survey, 1986, 1991, 1996.
2. Process recycling includes “other recycling”.

Table 2: Conditional Probabilities of Recycling in Period 1986–91–96

	Base Year 1986	**Base year 1991**	**COMBINED**	**Base year 1986+1991**
TOTAL RECYCLING				
Number of recyclers in YEAR t	1957	1413	3370	1123
of which recycled in t+1	1123	1045	2168	857
Condition probability of recycling	**0.57**	**0.74**	**0.64**	**0.76**
Number of non-recyclers in YEAR t	768	1312	2080	478
of which recycled in t+1	290	593	883	209
Condition probability of recycling	**0.38**	**0.45**	**0.42**	**0.44**
Ratio of probabilities	1.52	1.64	1.52	1.72
PROCESS RECYCLING				
Number of recyclers in YEAR t	1356	820	2176	508
of which recycled in t+1	508	485	993	310
Condition probability of recycling	**0.37**	**0.59**	**0.46**	**0.61**
Number of non-recyclers in YEAR t	1369	1905	3274	1057
of which recycled in t+1	312	577	889	328
Condition probability of recycling	**0.23**	**0.30**	**0.27**	**0.31**
Ratio of probabilities	1.64	1.95	1.68	1.96
COOLING RECYCLING				
Number of recyclers in YEAR t	1811	1262	3073	952
of which recycled in t+1	952	857	1809	660
Condition probability of recycling	**0.53**	**0.68**	**0.59**	**0.69**
Number of non-recyclers in YEAR t	914	1463	2377	604
of which recycled in t+1	310	607	917	239
Condition probability of recycling	**0.34**	**0.41**	**0.39**	**0.40**
Ratio of probabilities	**1.55**	**1.64**	**1.53**	**1.75**

Notes to Table 2:

1. Source: Environment Canada, Industrial Water Use Survey, 1986, 1991, 1996.
2. Process recycling includes “other recycling”.

Table 3: Estimation Results

Variable	**FE**	**GMM**
Number of workers	0.000049 (0.00028)	0.000051* (0.000012)
Price Intake	-139.577* (46.102)	35.628* (15.814)
Price Recirculation	-35.5071* (19.302)	-4.4855* (1.8234)
Price Discharge	8.73480* (4.4607)	3.5065* (1.5031)
Treatment	0.898523* (0.1193)	0.36253* (0.00802)
Prov (Nfld)	0.406238 (1.1854)	-0.06249 (0.03308)
Prov (NS)	-1.29233* (0.6045)	0.02325 (0.01996)
Prov (NB)	0.480704 (0.8282)	-0.04084* (0.02018)
Prov (Que)	-0.61727 (0.3618)	0.04345* (0.01087)
Prov (Ont)	-1.07856* (0.3518)	0.04714* (0.01025)
Prov (Man)	-3.10432* (0.9629)	0.04785* (0.01892)
Prov (Sask)	-1.72488 (1.2457)	-0.10667* (0.02241)
Prov (Alb)	1.42644* (0.5443)	0.06416* (0.01498)
T	0.45706* (0.1725)	-0.16617* (0.05941)
LLF	-41026.72	
Wald χ^2 (14)	1722.51	237.99
Prob > χ^2	0.00	0.00

Notes to Table 3

1. Asymptotic standard errors are in parentheses. Coefficients significant at 5% are denoted by *

References:

Baltagi, B. (2008) *Econometric Analysis of Panel Data* 4th ed. New York: John Wiley and Sons.

Bruneau, J. and S. Renzetti (2010), “Water Use Intensities and the Composition of Production in Canada. *Journal of Water Resources, Planning and Management*, 136(1): 72-79.

Bruneau, J., S. Renzetti and M. Villeneuve (2010) “Analysis of the factors influencing water recirculation decisions by Canadian manufacturing firms” *Canadian Journal of Agricultural Economics*, 58(4):515–530.

Cai, A. (2008) “Knowledge Spillover and Firm Size Heterogeneity” University of British Columbia, Department of Economics. Paper downloaded from website http://grad.econ.ubc.ca/aprilcai/ November 20, 2009.

Chao-Hsien L., C. Liang-Ching and C. Li-Mei (2006) “Industrial Water Demand with Water Reuse” *Journal of the American Water Resources Association* 42(3): 593-601.

Deaton, A. (1985) “Panel Data from Time Series of Cross-Sections” *Journal of Econometrics* 30: 109-126.

Dupont, D. and S. Renzetti (2001) “The Role of Water in Manufacturing” *Environmental and Resource Economics* 18(4): 411-432

Féres, J. (2007) *Assessing the impact of water policy instruments on the Brazilian water-using sectors* PhD dissertation, University of Toulouse

Gassner, K. (1998) “An estimation of UK telephone access demand using Pseudo-Panel data” *Utilities Policy* 7: 143–154.

Gyimah-Brempong, K. and E. Asiedu (2009) “Remittances and Poverty in Ghana” paper presented at African Economic Conference 2009 “Fostering Development in an Era of Financial and Economic Crises” November 11-13, 2009, Addis Ababa, Ethiopia. File downloaded June 7, 2010 from website http://www.uneca.org/aec2009/papers/AEC2009RemittancesandPovertyinGhana.pdf

Inoue, A. (2008) “Efficient estimation and inference in linear pseudo-panel data models” *Journal of Econometrics* 142: 449-466.

OECD (2003). “Improving Water Management: Recent OECD Experience”, *OECD Observer Policy Brief*, March 2003, avaialble on-line at www.oecd.org/publications/Pol_brief.

Renzetti, S. (2007) “Are the Prices Right? Balancing Efficiency, Equity, and Sustainability in Water Pricing” in K. Bakker, ed. *Eau Canada: The Future of Canada’s Water*, Vancouver: UBC Press, pp. 263-279.

Renzetti, S. (2002) *The Economics of Water Demands*, Kluwer Academic Press, Norwell, Massachusetts.

Schaffer, M. (2010) “xtivreg2: STATA module to perform extended IV/2SLS, Gmm and AC/HAC, LIML and k-class regression for panel data models” File downloaded June 8, 2010 from website http://ideas.repec.org/c/boc/bocode/s456501.html

Scharf, S., D. W. Burke, M. Villeneuve and L. Leigh (2002) *Industrial Water Use, 1996*. Minister of Public Works and Government Services Canada, Ottawa, Ontario.

Zurab, S. and R. Chiburis (2006) “PPREG: Efficient estimation of regressions based on pseudo-panel data: STATA ado-file with help and documentation” File downloaded January 10, 2010 from website: http://econ.worldbank.org/programs/poverty/toolkit

Appendix: Instrumental Variable Estimation

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. Similarly, there are costs incurred to internally recirculate water and to discharge water but there are no market prices for these activities.

We construct the implicit prices of water intake (P-IN), recirculation (P-RCR), and discharge (P-DIS). There are several options available to us to do this. For example, we could use either the computed unit cost or marginal cost of each of these activities but either of these may be a function of the quantity of water used and, thus, doing this would likely introduce a simultaneity bias into the estimation of the recirculation equation. Instead, the approach adopted here follows Renzetti (1992) and Féres (2007). The marginal cost of each activity (water intake, water recirculation and water discharge) is first found by regressing its total cost on its quantity and quantity squared of water:

$$\begin{aligned} &TC_{ijt} = a_0 + a_1 Q_{ijt} + a_2 (Q_{ijt})^2 + e_{ijt} + u_{ijt} \quad i = \text{Intake, Recirculation, Discharge} \\ &\widehat{MC}_{ijt} = \widehat{a_1} + 2\widehat{a_2} Q_{ijt} \end{aligned} \tag{A-1}$$

Where i indexes the type of water use, j indexes the individual plant and t indexes the time period. Next, an instrument variable is constructed and substituted to represent the computed marginal cost in the recirculation equation. 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 correlated with its value but orthogonal to the volume of water recirculated and, thus, uncorrelated with the error term (υ_i) in equation (5) Specifically, the explanatory variables in each of 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 (TREATdum) and whether the plant treats its water prior to discharge (DISCHARGEdum):

$$\begin{aligned} \widehat{MC}_{ijt} = b_0 + \sum_l b_{1l} SICdum_{ilt} + \sum_k b_{2k} REGdum_{ikt} + b_3 TREATdum_i + \\ b_4 DISCHARGEdum_i + w_{ijt} \end{aligned} \tag{A-2}$$

i = Intake, Recirculation, Discharge

The instrumented marginal costs are estimated using OLS on the entire dataset. Table A1 reports the results of the instrumental variable estimation. As has been commonly noted, 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

	Marginal Cost of Intake	Marginal Cost of Recirculation	Marginal Cost of 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 estimated marginal cost derived from the regression equation $TC = a_0 + a_1Q + a_2Q^2$. TC measures total reported cost and Q is total reported volume of water.
2. The figure in parentheses is the estimated standard error