Effect of Reduction of Pollutant Emissions on the Productivity Performance of Regional Canadian Pulp and Paper Industries

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Abstract

In our study, the productivity performance of the Canadian pulp and paper industry is compared with respect to the choice of measurement for desirable output, the length of time period and with or without pollutant outputs. Input distance function can easily incorporate the non-marketable outputs of biological oxygen demand (BOD) and total suspended solids (TSS) on a quantity basis. This environmentally sensitive approach provides better productivity performance for all regions, indicating the need for adjusting the conventional approach that ignores the pollutant outputs. The results also indicate that industrial technological progress is different in different regions due to variations in regional industry output and technology.

Key words: input distance function, productivity performance, technical change, efficiency, pollutant outputs, pollutant abatement, water effluent, pulp and paper industry.

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1. Introduction

The Canadian Pulp and paper industry has been and is still one of the biggest industries in this country, making a significant[1] contribution to the whole economy and providing a great number of employment opportunities.[2] However, besides those contributions, we should also look at problems that the industry has created its effect on the environment. Apart from the fact that a vast amount of forest resources has been consumed, the main concern has been the significant volume of wastewater generated during the pulping, bleaching and paper making processes and emitted into the natural environment.

This industry effluent discharge, for a long time, could be freely emitted into rivers. The pulp and paper industry is one of the biggest sources of water pollution in Canada. Among the various materials contained in the water effluents, we focus our discussion on total suspended solids (TSS) (kilograms), which measures the wood particles and other materials, and biological oxygen demand (BOD) (kilograms), which measures the oxygen consumption potential of dissolved organic material.

For researchers studying the productivity of the Canadian pulp and paper industry, it is quite easy to observe the marketable outputs and we can get specific quantities and prices of them. Based on common sense, we can call them the "good" outputs. On the other side, as we mentioned above, "bad" outcomes can be recognized also, which are the bad influences on the environment during the production process. But those "bad" outputs are more difficult to assign prices to and their impact may take a longer time to fully reveal itself. So, in traditional measures of economic activities, these undesirable outputs are simply out of the picture.

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[1] In this paper, the word "significant" bears the meaning of "sufficient great or important to be worthy of attention; noteworthy" (Oxford Dictionary), not related to statistical meaning.

[2] According to The State of Canada's Forests – Annual Report 2017 from Natural Resources Canada, the pulp and paper product manufacturing industry contributed 7.188 billion dollars to real GDP (constant 2007 dollars, 2016) and generated around 3.6 billion wages and salaries (dollars, 2015).

However, as effluent regulations were put into action and producers in the Canadian pulp and paper industry actively responded to them, it would seem a less appropriate approach to continue ignoring those "bad" outputs. Among these regulations, one is called Pulp and Paper Regulations, which were first introduced in 1970. As quoted on the government website, these regulations relate to "prescribing certain deleterious substances related to the effluent from pulp and paper mills, authorizing the deposit of limited quantities of those deleterious substances in certain circumstances"[3]. By placing restrictions on the average monthly rate of TSS and BOD, the government has managed to control to some extent pulp and paper industry water pollution.

Now, to comply with these regulations, producers have incurred costs, for example, to install effluent abatement systems. Certainly, these costs are recorded as expenditures of the company but the benefit they bring to society in the form of better environment quality is not recognized, which is an unfair situation. Furthermore, that would lead to underestimation of productivity improvement and efficiency, because now there is more on the cost side, but the decrease of "bad" outputs is not counted as a positive factor on the outcome side. Therefore, it is important to use an environmentally sensitive approach when studying the productivity change.

Hailu (2003) took the environmental factors into consideration when evaluating the productivity performance of Canadian pulp and paper industries. After observing the dramatic changes in the environmental effects of the pulp and paper industry, the author came to realize that failure to take the environmental side into account may be the reason for the very low or negative productivity growth rate estimates from previous studies on the industry. To analyze this issue, the author studied the performance of pulp and paper industries in four Canadian regions, namely Quebec, Ontario, Atlantic & Prairies and BC, based on a panel data set covering the period from 1970 to 1993. The main purpose was to compare the conventional measure of

[3] Pulp and Paper Regulations, SOR/92-269, Minister of Justice, Government of Canada, last amended on June 29, 2012.

Total Factor Productivity (TFP) that ignores the non-marketed benefits of pollution abatement activities with the environmentally sensitive approach, that includes undesirable output reduction. In this paper the same technique is adopted, that is, the input distance function. As a quantity-based technique, distance function can easily incorporate non-marketed outputs while analyzing productivity. Also as what we do here, the pollutant outputs were measured by the quantities of BOD and TSS. Besides these similarities, there are several aspects of our study that are different from Hailu's:

1. Instead of using pooled data for four regions, where only one model was estimated, we perform the estimation for three provinces (BC, Ontario and Quebec) separately. We think it is more reasonable to study the performance province by province because they differ in terms of industry size, years of history and major products etc.
2. We extend the time period to the year 2012, so our sample period is 1971 to 2012 instead of 1970-1993. Also, the data we use are more recently revised.
3. While in Hailu's paper real dollar value was used as the output measure, we considered also physical quantities (tons/year).
4. On the input side, Hailu (2003) had five elements: energy, virgin fiber, non-wood materials and services, production and administration labor, and capital. Our study includes four inputs: energy, materials, labor and capital.

The main conclusion of both Hailu's and our study is that it is very important to take into account the beneficial effects of pollution abatement activities rather than ignoring them when analyzing productivity performance. However, differences appear according to measurement of output, observation period and aggregation level.

Here is how we organize the paper: Section 2 contains a brief introduction on the Canadian pulp and paper industry. Section 3 presents the Canadian Pulp and Paper Effluent Regulations (PPER) and the effectiveness of these government actions and how the industries behave to comply. Section 4 shows the methodology employed in this paper. Section 5 summarizes the panel data sets that we used for the study. Following that, the results are drawn from both the traditional measures (excluding the pollutant outputs) and the environmentally sensitive measures (including the pollutant outputs) in Section 6. Consistent with Hailu's conclusion, the results for our paper show that excluding the undesirable output reduction leads to underestimating significantly the productivity improvement in Canadian pulp and paper industries. Compared with Hailu (2003), our results present larger contribution of pollution decreases to TFP growth. Using tons instead of real dollars also increases the contribution of pollutant decrease to TFP growth.

2. Canadian Pulp and Paper industry

The Canadian pulp and paper industry was born in the early 1800s and has been an important contribution to Canadian GDP. Continually transforming, the industry includes manufacturing enterprises that convert original wood materials into various products including pulp, newsprint, groundwood, printing and writing paper, paperboards, household and sanitary paper and specialty paper etc. From the latter half of 19th century, demand for newsprint was increasing very fast and that helped to boost the industry. Canada is blessed with abundant and renewable wood resources and it was not long before the U.S. began to import newsprint from Canada, and Canada became one of the major suppliers of newsprint to nations around the world. In recent years, reading has transformed from print to electronic devices, which absolutely affected the pulp and paper industry. However, the industry remains an important part of the national economy, especially for many rural and indigenous areas, where the income mainly comes from forest-related jobs. Although located in many Canadian regions, the pulp and paper industry is mostly concentrated in British Columbia (BC), Quebec and Ontario. The 40 pulp and paper and paperboard mills that comprise the industry in 2015 were located in Quebec (11), Ontario (14), British Columbia (8), and the Atlantic and Prairie Provinces (7).[4]

Pulp and paper manufacturing injected around $7.188 billion into Canada's economy (real GDP, constant 2007 dollar) in 2016, which underperformed the whole economy with a decline of 3.5% from the last year ($7.447 billion) while the whole Canadian economy grew by 1.4%. However, the industry remains a big part of the manufacturing industry. In 2016, the total revenue of manufacturing industries was around $664 billion; out of that, more than 4% came from the pulp and paper product manufacturing industry ($26.8 billion).[5]

[4] Statistics Canada, Table 33-10-0032-01 - Business by Industry, by province or territory and the North American Industry Classification System, for the pulp and paper and paperboard mills, semi-annual, June 2015.
[5] Statistics Canada, Table 16-10-0117-01 - Principal statistics for manufacturing industries, by North American Industry Classification System (NAICS) (x 1,000) , province or territory for manufacturing [31-33], annual (dollars),

The Canadian pulp and paper industry provides various kinds of jobs such as foresters, factory workers, engineers, technicians and skilled tradespeople. In rural areas, these job opportunities help to ensure the economic sustainability of the local communities. However, since there is trend towards less demand for paper products, employment in Canadian pulp and paper manufacturing continued to decline. In 2014, the industry accounted for 69,342 jobs, and labor force decreased to 60,233 in 2016, which means that nearly 6.6% of jobs vanished yearly. Of these jobs, close to 70% are located in Ontario (20,333) and Quebec (21,792), and another 14% are located in British Columbia.

Besides the decline in demand, another reason for the employment loss is the advances in technology, as less workers are needed to produce the same level of output. However, the remaining jobs tend to be more skilled and therefore higher paid, so we should also look at wages and salaries together with the numbers of jobs. Wages in pulp and paper manufacturing have increased markedly from 2014 (from around $3.35 billion to about $3.6 billion in 2016), a 5% year-over-year growth. In 2016, average earning (average net annual income per person) for a pulp and paper employee reached around $ 67,000, which is higher than the overall manufacturing sector, in which earning was flat between 2015 and 2016. In British Columbia, the pulp and paper industry generate around $582 million of wages and salaries in 2016. In Ontario and Quebec, the corresponding numbers are $1,317.6 million and $1,029 million respectively.[6] Although there was a slight decline in British Columbia compared to previous year, most of the other provinces have increases in wages and salaries, which makes the overall industry sees a growth in wages and salaries. The higher wages can be contributed by removing less efficient operations and adding advanced, high-value product lines, which can save huge volumes of energy and increase energy efficiency. Some newly introduced techniques can also even reuse the

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modified on July 22 2018.

[6] These figures are collective for The State of Canada's Forests, Annual Report 2017, 2016 and 2015, Natural Resource Canada.

residuals to make new bioproducts, which expands the industry market to some non-traditional products. Overall, as a major employer nationwide, even though the industry's employment is declining, the average wages are rising.

In 2016, newsprint production declined by 4% to 3,353 thousand tonnes, compared to 3,500 thousand tonnes in 2015. The production of printing and writing paper and of wood pulp decreased a slight 1.4% (from 3,041 thousand tonnes to 2,995 thousand tonnes) and 0.3% (from 16,841 thousand tonnes to 16,508 thousand tonnes) respectively. These declines mainly result from the rise of electronic media. However, that is partially offset by increasing customer segments (tissue paper and packaging). Production of wood pulp is quite stable, as increasing overseas demand (from around 9.68 million tonnes in 2014 to over 9.91 million tonnes in 2016, a 2.4% increase) offsets partially decreasing domestic consumption (from 7.57 million tonnes in 2014 to 7,14 million tonnes in 2016, a 5.7% decline)[7]. Production of non-traditional products has emerged, and there is research underway to expand pulp and paper mills so that wastes from the pulp-making process can be used to make new bioproducts.

As one of the world's major pulp and paper product manufacturers, the Canadian industry makes products not only to meet the domestic customers' needs, but also supplies countries and regions around the world. This export-oriented property of the Canadian pulp and paper industry supports the Canadian economy and significantly improves Canada's trade balance. Although the industry exports overall decreased by 4%, from $17.7 billion in 2015 to around $17 billion in 2016, the export market was still huge, around 63.5% of total sales in the pulp and paper product manufacturing industry ($26.776 billion, 2015). In British Columbia, out of $4.8 billion total sales, around $4 billion of pulp and paper products (83%), are exported to the global market. In Ontario, $3 billion out of $8.3 billion (36%) of pulp and paper products are exported, and in Quebec these figures are $6.2 billion of $8.5 billion (73%). Among these products, wood pulp exports fell by 6.1% to $7.2 billion, newsprint fell by 5.6%

[7] Statistical Data, Forest Resource, Natural Resources Canada, 2017.

to $2.2 billion, and print and writing paper fell by 12.3% to $2.2 billion in 2016. The newsprint and print and writing paper exports are in a long-term decline for the same reason as production decline, which is the fast-growing electronic media era. Moreover, globalization has made it more possible for the Canadian pulp and paper producers to explore beyond their traditional markets. The industry has become less dependent on the regional North American market and started to export to Asian countries, mainly China. The U.S. share of exports has declined, but this market is and will continue to be the major destination for Canadian pulp and paper products, given a weaker Canadian dollar and recovering U.S. economy.

To conclude, as more and more customers are turning to digital products instead of print reading and the market for newsprint and printing and writing paper has been continuing to shrink, the industry has been hit hard, especially in the east, where the pulp and paper industry has been more concentrated from long history. However, as transportation develops and people are living a more convenient life, package and tissue markets are expanding, which partially offset the declines in newsprint and printing and writing paper markets. At the same time, the pulp and paper industry is adopting advanced and innovative techniques and transforming the industry structure to face these challenges and opportunities. Non-traditional products such as biochemicals and other new materials are made during the original production process, with new and environment-conscious techniques; they can be used to produce goods such as biodegradable plastics, bio-based pharmaceuticals, personal care products and other industrial chemicals. Efforts have been made in the industry to adjust to changes in market needs, improve financial performance and demonstrate a commitment to an environmentally friendly production process. Following that, ongoing research and development activities will result in increasing need for high skilled and high paid employees.

3. Pulp and Paper Effluent Regulations

To tackle the problem of notorious environmental impact in the Canadian pulp and paper industry, the Pulp and Paper Effluent Regulations(PPER) were developed under the Fisheries Act in 1971, and the pulp and paper sector was the first industry regulated under the Act with an objective of protecting water quality that sustains fish, fish habitat and the use of fisheries resources. To achieve that, the regulations govern the discharge of harmful substances from pulp and paper mills into water frequented by fish and set limits on emission of certain deleterious substances from pulp and paper mills into certain circumstances.[8] The 1971 PPER set limits on the amount of biochemical oxygen demand and total suspended solids and prohibited deposits of effluents that displayed acute lethality to fish. However, these limits were only legally binding to mills that started operation after the Regulations come into force, which represented fewer than 10 percent of the mills in Canada and served as non-enforceable guidelines for mills that were already in operation.

After extensive consultations, the revised framework of Pulp and Paper Regulations came into force on 7 May 1992. This updated PPER was still under the Fisheries Act but set stricter limits for BOD and TSS, while maintaining a similar non-acute lethality requirement as in the 1971 regulations. These new regulations became legally binding on all kinds of mills, including the old, existing ones which account for the biggest share of the whole industries and off-site treatment facilities (OSTFs) to comply with enforceable effluent quality standards. For those mills that were set up before 1971, to comply with the 1992 PPER they would need some time to upgrade their manufacturing process and design and install effluent treatment equipment. Thus, the 1992 PPER also included a system of transitional authorizations (TAs) that give

[8] The maximum amounts of BOD and TSS that can be deposited from a pulp and paper mill during a month, expressed in kilograms, can be determined by the formula $Qm = F \times D \times 1.5 \times RPR$, where D is the number of calendar days in the month; F is equal to a factor of 5 for BOD and 7.5 for TSS, expressed in kilograms per tonne of finished product; RPR is the reference production rate of the mill for all finished products, expressed in tonnes per day. See Pulp and Paper Effluent Regulations, published by the Minister of Justice of Canada at http://laws-lois.justice.gc.ca (2018).

interim limits which could suit case-by-case situations of specific mills with their own abatement plans to meet. Conditions and duration of TAs might differ across mills, however. Individual TAs expired by December 31, 1995 or earlier, and on January 1, 1996 all mills in Canada became subject to the new limits.

In the 2004 and 2008, there were further amendments including adding Environmental Effects Monitoring (EEM) requirements to investigate the causes of and solutions to adverse environmental effects associated with pulp and paper effluents. EEM is a continuous, site-specific oriented program, aiming at providing a more complete and comprehensive understanding of the long-term impact of effluents on the Canadian aquatic environment.

Since the first publication in 1971, in 40 years, the Pulp and Paper Effluent Regulations (PPER) have achieved considerable improvement in pulp and paper effluent quality. From 1970 to 2008, the total discharges of BOD and TSS matter decreased by approximately 90% and 97%, respectively. There has also been increasing compliance with the Regulations, with acute lethality testing increasing from a pass rate on the order of 25% in 1985, to a 78% pass rate in 1996 and a 97.4% pass rate by 2008. In 2014, 99.9% and 99.8% of effluent samples met regulatory requirements for BOD and TSS, respectively.[9] To achieve pollutant abatement, the producers invested to add primary effluent treatment system, such as clarifiers and settling basins, at most mills across Canada, which was the main reason for the total discharges of TSS and BOD to decrease by approximately 60% and 40% respectively between 1970 and 1987. After the amendments to the PPER in 1992, most mills started to implement secondary biological treatment, which contributed to further reduction, especially for BOD matter, which directly resulted in the decrease of the total discharges of TSS and BOD matter to water by around 60% and 90% respectively between 1987 and 1996. Since the mills had already invested in the major

[9] Environment and Climate Change Canada (2016) Canadian Environmental Sustainability Indicators: Managing Pulp and Paper Effluent Quality in Canada.

capital needed to meet the 1992 Regulations, the total TSS and BOD discharges into water have remained stable.[10]

[10] Statues Report on the Pulp and Paper Effluent Regulations, Environment Canada, 2012.

4. Methodology

Our methodology mostly relies on Hailu (2003), and only differs in terms that instead of pooling data for all regions and estimating only once, we estimate province by province. That will be one of the big reasons for the difference in the results that we will elaborate later in the paper, apart from the different data sources.

In order to incorporate the pollutant outputs, the adoption of production models that can cope with multi-output technologies is needed. Since the undesirable outputs are difficult to set prices to and their impact may take longer time to fully reveal, we can hardly get market prices or shadow prices for pollutant outputs, thus methods that can be employed with information on the quantities but not on the prices of pollutant outputs are also required. As a quantity-based technique, distance function can easily incorporate non-marketed outputs while analyzing productivity. It is a representation of multiple-output and multiple-input production technologies. The standard production functions, though they can be also quantity-based techniques, require aggregating outputs into a single index while dealing with multiple-output production processes. However, distance functions can be employed without that need. So, it is more convenient to use distance functions to incorporate non-marketable outputs such as pollutants into productivity analysis. The estimated distance function can be used to compute the level of technical efficiency for a given observation. We can also measure technical change, which is the rate of the shift in the production frontier and further get the productivity growth rate by the distance function. Changes in technical efficiency and technical change are defined by the standard way of proportional changes in quantities, which are inputs in our case. The trade-offs between inputs and outputs contained in the estimated technology can present the shifts in the production frontier or improvements in the positions of an observation against the frontier into equivalent proportional changes in inputs. These proportional changes in inputs can directly translate into proportional changes in costs, for a given set of prices. By measuring the degree of reduction in production costs or increase in welfare, we can analyze the environmentally sensitive productivity without knowing the prices of the inputs and outputs.

Both input and output distance functions require information on input and output quantities. If constant returns to scale (CRS) is imposed, they yield the same results, regardless of whether input-based or output-based approached are used. Following Hailu (2003), input-base measures and input distance functions were chosen for our analysis.

For a production technology in which case the firms use *N* kinds of inputs to produce *M* marketable and unmarketable (pollutant) outputs, Shephard's (1953, 1970) input distance function can be defined as follows:

$$\psi\ (u, x, t) = \sup_{\theta} \left(\theta\colon \left(u, \frac{x}{\theta}\right) \in Y(t), \theta\ \in R_{+} \right) \qquad [1]$$

where x and u represent input and output vectors respectively; t is the time trend variable; and $Y(t)$ is the technology (or production possibility) set at time t. According to the equation, the value of this input distance function measures the maximum level by which the input vectors can be deflated given the level of output vector. The bigger the value is, the more input vector is used to produce a certain amount of output vector, in which case less efficiency is observed. The input distance function has a finite value, and the minimum value is one. It is an increasing and continuous function of x for $u\ \in R_{+}^{M}$. It is concave and homogeneous of degree one in x, and an upper semi-continuous and quasi-concave function of u.[11] The pulp and paper production technology's input distance functional form (Christensen et al. 1973) is represented by the following translog specification:

[11] See Shephard(1970) or Fare and Primont (1995) for more on the characteristics of the function.

$$\ln\psi(u^{kt}, x^{kt}, t)$$

$$= \alpha_0 + \sum_{n=1}^{N} \alpha_n \times lnx_n^{kt} + \sum_{m=1}^{M} \beta_m \times lnu_m^{kt} + (0.5)\sum_{n=1}^{N}\sum_{n'=1}^{N} \alpha_{nn'} \times lnx_n^{kt} \times lnx_{n'}^{kt} + (0.5)\sum_{m=1}^{M}\sum_{m'=1}^{M} \beta_{mm'} \times lnu_m^{kt} \times lnx_{m'}^{kt} + (0.5)\sum_{n=1}^{N}\sum_{m=1}^{M} \gamma_{nm} \times lnx_n^{kt} \times lnu_m^{kt} + \alpha_t \times t + (0.5) \times \alpha_{tt} \times t^2 + \sum_{n=1}^{N} \alpha_{nt} \times t \times lnx_n^{kt} + \sum_{m=1}^{M} \beta_{mt} \times t \times lnu_m^{kt} \qquad [2]$$

where k represents regions (Ontario, Quebec and British Columbia) and t represents time period variable; n indexes the inputs such that the subscripts 1,2,3,4 denotes, respectively, the quantities of labor, capital, energy and material; m indexes the outputs of the industry such that the subscript 1 denotes the marketable output of pulp and paper firms, while 2 and 3 represents the quantities of pollutant outputs TSS and BOD, respectively.

The parameters of the input distant function in equation [2] are estimated by mathematical programming methods, which relies on the minimization of the sum of the deviations of the values of the function from the production frontier that is being estimated, subject to monotonicity, homogeneity and symmetry conditions. This mathematical programming approach to parameter estimation (also known as goal programming) was first introduced by Aigner and Chu (1968). In the specification of the technology, the imposition of weak inequality restrictions on the first derivative signs of the input distant function is required because of the asymmetric treatment of desirable and undesirable outputs. Linear programming is very flexible so that it can impose inequality restrictions, although it does not either account for noise in the data, nor provides statistical measures of goodness of fit or significance. In this sense, compared to econometric techniques, the linear programming approach to parameter estimation allows us to work in sophistication in the specification of the systematic components of the function much more easily. Here, we use the programs written in

SAS to work out the linear programming problem.

Our task in the linear programming problem is to choose the set of parameter estimates that minimizes the sum of deviations of the logarithmic values of the input distance function from zero. Constraints are related to monotonicity, homogeneity, and symmetry conditions. An additional constraint imposed on the problem is that the value of the input distance function, which is ψ in equation [1], is required to be equal to or greater than 1 for all the observed input-output combinations (or for the k = 1, 2, 3 regions and t = 1, …, 42 time periods). Thus, the translog form should be equal to or greater than 0. This ensures that the observations are within the technology frontier. The estimation problem takes the following form:

$$\text{Minimize}(\alpha,\beta,\gamma)\sum_{k=1}^{3}\sum_{t=1}^{42}\ln\psi(u^{kt},x^{kt},\text{t}) \qquad [3]$$

Subject to the following constrains:

$$\ln\psi(u^{kt},x^{kt},\text{t}) \geq 0, \qquad t=1,\dots,42;\ k=1,2,3 \qquad [4]$$

$$\frac{\partial\ln\psi(u^{kt},x^{kt},\text{t})}{\partial x_n^{kt}} \geq 0, \qquad t=1,\dots,42;\ k=1,2,3;\ n=1,\dots,4 \qquad [5]$$

$$\frac{\partial\ln\psi(u^{kt},x^{kt},\text{t})}{\partial u_m^{kt}} \leq 0, \qquad t=1,\dots,42;\ k=1,2,3;\ m=1 \qquad [6]$$

$$\frac{\partial\ln\psi(u^{kt},x^{kt},\text{t})}{\partial u_m^{kt}} \geq 0, \qquad t=1,\dots,42;\ k=1,2,3;\ m=2,3 \qquad [7]$$

$$\sum_{n=1}^{4}\alpha_n = 1, \qquad [8]$$

$$\sum_{n=1}^{4}\alpha_{nn'} = 0, \qquad n'=1,\dots 4 \qquad [9]$$

$$\sum_{n=1}^{4}\gamma_{nm} = 0, \qquad m=1,2,3 \qquad [10]$$

$$\sum_{n=1}^{4}\alpha_{nt} = 0, \qquad [11]$$

$$\alpha_{nn'} = \alpha_{n'n}, \qquad n, n' = 1, \dots 4 \qquad [12]$$

$$\beta_{mm'} = \beta_{m'm}, \qquad m, m'=1, 2, 3 \qquad [13]$$

$$\sum_{m=1}^{3} \beta_m = -1, \qquad [14]$$

$$\sum_{m=1}^{3} \beta_{mm'} = 0, \qquad m' = 1,2,3 \qquad [15]$$

$$\sum_{m=1}^{3} \gamma_{nm} = 0, \qquad n = 1, \dots 4 \qquad [16]$$

$$\sum_{m=1}^{3} \beta_{mt} = 0, \qquad [17]$$

Since we estimate the parameters province by province, we can omit the variable k here, which represents the provinces. Furthermore, in order to compare our results with Hailu's, we also did the shorter time period (1971-1993) estimation. We furthermore changed the unit of marketable output from tonnes per year to Hailu's constant dollars measurement to see what the differences would be. Therefore, we get 24 sets of parameter estimates in total. That is, the number of provinces (3, Ontario, Quebec and British Columbia) multiplied by two time periods (2, 1971-1993 and 1971-2012), multiplied by two output measurement approaches (2, conventional and environmentally sensitive), and multiplied by two different units of marketable output (2, tonnes per year and dollars). We should also notice that the numbers of parameters for the conventional and environmentally sensitive approaches are different.[12]

The first set of constraints [4] requires that the translog specification of the production technology be no smaller than 0, which means that the value of the estimated input distance function be equal to or higher than 1 at every observed input-output combinations, ensuring these combinations to be feasible or identified as observations

[12] More information about the parameters is presented in the Appendix 2.

within the technology frontier. By definition, the value of the distance function measures the maximum proportion by which all inputs can be proportionally reduced without any change in the output vector. Therefore, the second set of constraints [5] is needed to ensure that the input distance function is non-decreasing in inputs. On the other hand, the constraints in [6] require that the input distance function be non-increasing in desirable outputs while the fourth set of constraints [7] requires that the function be a non-decreasing function of undesirable outputs. Constraint sets [5] - [7] impose the monotonicity condition into the problem. Thus, the constraints in [6] and [7] together form the essential asymmetry between desirable and undesirable outputs in the production technology characterization; that is, the desirable outputs can be freely disposable but pollutant abatement is costly, since a reduction on the pollutant outputs requires the use of inputs for abatement, other outputs remaining the same. The constraint sets [8] - [11] ensure the linear homogeneity in inputs of the function and constrains in [12] and [13] impose the parameter symmetry conditions for the translog functional form. The remaining sets of constraints [14] – [17] impose constant returns to scale on the estimated input distance function.

Because we solve the linear programming problems with and without undesirable outputs, and for two different time periods, the numbers of constraints are different accordingly. Here we take the longer time period (1971-2012) as an example: the parameter estimation for the input distance function with pollutant outputs for each province in a time period of 42 years is carried out by minimizing the sum of deviations from 1 subject to constraints. There are 42 (for 42 year) feasibility constrains; 294 (for 7 types of inputs and outputs and for 42 years) monotonicity constrains related to inputs (168), desirable outputs (42) and pollutant outputs (84); 9 linear homogeneity conditions; 8 translog symmetric restrictions; 9 constant returns to scale conditions. While the linear homogeneity, translog symmetry and constant returns to scale restrictions are equality restrictions that can be applied directly on the parameters, there are 336 weak inequality restrictions.

After we get the parameter estimates, we can insert them into the input distance function [2] and use the panel data sets we have to compute the translog value. By definition, the reciprocal of ψ, the value of the input distance function, provides the standard input-based Farrell (1957) measurement of technical efficiency (TE) as shown in [18]. Since we have the feasible constrains in the parameter estimation problem, ψ is equal to or greater than 1. Thus, the value of TE should be no greater than 1. The closer the value of TE is to 1, the more efficient the observed input-output vector is.

$$\mathrm{TE}_x(u, x, t) = \frac{1}{\psi(u, x, t)} \qquad [18]$$

Based on technical efficiency, we can calculate another analysis figure, i.e. the rate of change in TE (EC). In our calculation, this is done by computing the logarithm of TE (the last year) over TE (the first year), then diving by the number of years. A relatively large value of rate of change in TE gives the indication that technical efficiency has improved.

Another productivity measurement, technical change (TC) can be computed based on the input distance function by differentiating the value with respect to time as shown in equation [19]. In terms of input-conversation, technical change is defined as the rate at which inputs can be proportionally reduced over time without a change in output levels. The larger the value of technical change is, the faster speed the industry shows to produce the same amount of outputs.

$$\mathrm{TC}_x(u, x, t) = \frac{\partial \psi(u, x, t)}{\partial t} \qquad [19]$$

The Malmquist index of productivity growth (Caves et al. 1982) is adopted in this paper to show the performance of the industry. The Malmquist index of productivity growth based on input can be decomposed into technical efficiency (TE) and technical change (TC) components (Fuentes et al. 2001). The calculation of the growth rate in the Malmquist productivity growth index from time period t to time period t+1 was carried out as equation [20]:

$$\ln M(x^{t+1}, x^t, u^{t+1}, u^t) = \{\ln\psi(u^t, x^t, t) - \ln\psi(u^{t+1}, x^{t+1}, t+1)\} + \frac{\{TC_x(u^{t+1}, x^{t+1}, t+1) + TC_x(u^t, x^t, t)\}}{2} \quad [20]$$

The first term relates to the rate of improvement in technical efficiency between period t and t+1. The second term averages the technical change for period t and t+1, thus obtaining the estimated rate of technical change over that period.[13]

The way that an environmentally sensitive approach credits the producers for reduction of pollutant output leads to the significant differences in productivity performance estimation between conventional and environmentally sensitive methods while the former does not account for any efforts in pollutant abatement. The specification of the technology treats desirable and undesirable outputs symmetrically, in which case the desirable output can be freely disposal, but the pollutant outputs are costly, since the reduction on the pollutant outputs requires the use of inputs for abatement, other outputs remaining the same. The input-based estimates of technical efficiency, technical change and the Malmquist index reflect that asymmetry. The technical change measure, for example, can be computed by differentiating the value of the input distance function with respect to time trend variable $\left(TC_x(u, x, t) = \frac{\partial\psi(u,x,t)}{\partial t}\right)$. Since the input distance function is non-decreasing in desirable output and non-increasing in pollutant outputs, the measure of technical change is non-decreasing in desirable output and non-increasing in pollutant outputs. That is, the technical efficiency estimates credit the producers for the production of more desirable output and less undesirable outputs. Similarly, since the technical efficiency is equal to the reciprocal of the input distance function $\left(TE_x(u, x, t) = \frac{1}{\psi(u,x,t)}\right)$, it credits the producers for reduction in pollutant outputs in the same sense of the input distant function. Moreover, the Malmquist productivity growth measure is composed of technical efficiency and technical change, thus it also treats desirable and undesirable

[13] See Fuentes et al. (2001) and Grifell-Tatje and Lovell (1995) for more on the links between the Malmquist TFP growth index and the productivity measures used here.

outputs asymmetrically by crediting the producers for the production of more desirable output and less undesirable outputs.

5. Data

In this paper we used a panel data set covering the period from 1971 to 2012 for British Columbia, Ontario and Quebec. The data set includes marketable output and two effluent outputs, and four inputs, namely labor, capital, energy and materials. Appendix 1 shows the data sources. Output and input data are reported in Table 1.

Table 1. Changes in inputs, desirable and undesirable output rates (1971-2012)

variable	1971 value	2012 value	mean 1971-2012 value	Average annual growth 1971-2012(%)
Labor (10^3)				
BC	18.33	7.99	16.14	-1.38
Ontario	43.87	19.55	36.70	-1.35
Quebec	42.13	17.36	35.54	-1.43
Capital (10^6 1992$)				
BC	5.04	1.52	4.35	-1.70
Ontario	3.08	1.74	3.84	-1.06
Quebec	3.54	2.51	5.16	-0.71
Energy (10^3 TJ)				
BC	69.04	58.79	83.89	-0.36
Ontario	65.71	38.19	72.67	-1.02
Quebec	115.11	70.00	120.09	-0.96
Material (10^6 1992$)				
BC	1.73	2.63	2.62	1.27
Ontario	3.12	4.11	3.86	0.78
Quebec	3.03	4.50	4.16	1.18
Pulp and paper output (10^6 t/year)				
BC	4.58	6.09	6.69	0.81
Ontario	4.53	2.50	4.77	-1.09
Quebec	7.21	6.65	8.82	-0.19
BOD (10^3 t/year)				
BC	207.28	11.36	100.10	-2.31
Ontario	326.49	4.20	115.12	-2.41
Quebec	500.67	5.09	229.62	-2.41
TSS (10^3 t/year)				
BC	172.28	27.78	75.49	-2.05
Ontario	131.80	5.53	36.87	-2.34
Quebec	212.25	12.29	95.26	-2.30

6. Results and Discussion

The data were used to estimate the parameters of the translog function [2]. Based on the estimation result, technical efficiency, technical change and productivity growth estimates were generated using the formulae in equations [18], [19] and [20]. Our data cover the period from 1971 to 2012 and we use quantity to measure all output variables. However, to make comparisons with Hailu (2003), we also consider the period from 1971 to 1993 and the real dollars measurement for marketable output. Also, instead of pooling data for all regions, we analyze them individually (i.e. province by province), because we think it more sensible to look at these regions with different pulp and paper industry circumstances case by case. Since we look at the problem in terms of two approaches (conventional and environmentally sensitive), two time periods (longer: 1971-2012 and shorter: 1971-1993), and two ways to measure the marketable output (tonnes per year and real dollars), the results are discussed and compared with each other and with Hailu's below respectively. Results from both conventional and environmentally sensitive approaches for period from 1971 to 1993 using tonnes per year to measure the marketable output are first presented, followed by the results from the same ways of analysis, but for longer period from 1971 to 2012. Then results for longer period and shorter period, in both conventional and environmentally sensitive approaches using real dollars to measure the marketable output, are discussed together for the sake of simplicity. Table 10 in Appendix 2 provides an example of parameter estimation.

6.1 Results from conventional and environmentally sensitive approach, using tonnes per year, 1971-1993

The results are summarized in Tables 2 and 3. The conventional average estimates of technical efficiency (TE) do not indicate much difference among the three regions (0.972, 0.987 and 0.977 for BC, Ontario and Quebec respectively) and the all region average is 0.979. The efficiency levels in 1971 were very close to those in 1993 for all three regions, thus figures for the change of technical efficiency over time (EC) were very small for three regions, resulting in an all-region estimate of 0.001% between 1970 and 1993. The average technical change was negative for BC (-0.390%) and Ontario (-0.963%), and positive for Quebec (0.209%). Since the productivity growth (PRR) can be decomposed into technical efficiency and technical change components, and the changes in technical efficiency over the period were quite small here, the estimates of productivity improvement depend mainly on technical changes. In that sense, only Quebec enjoyed positive growth (0.209%) due to its positive technical changes and the other two regions got -0.390% (BC) and -0.959% (Ontario), close to those of technical changes during 1971 and 1993.

Table 2. Regional pulp and paper industry efficiency, technical change and total factor productivity estimates (1971-1993) (tonnes per year)

Productivity criteria	Conventional	Environmentally sensitive
Technical Efficiency (TE)		
BC	0.972	0.954
Ontario	0.987	0.962
Quebec	0.977	0.984
All Regions	0.979	0.967
Rate of Change in TE (EC, %)		
BC	-0.00002	-0.010
Ontario	0.004	-0.450
Quebec	0.00004	0.000003
All Regions	0.001	-0.153
Technical Change (TC, %)		
BC	-0.390	4.466
Ontario	-0.963	0.541
Quebec	0.209	1.337
All Regions	-0.381	2.115
TFP Growth Rate (PRR, %)		
BC	-0.390	4.456
Ontario	-0.959	0.091
Quebec	0.209	1.327
All Regions	-0.380	1.958

Table 3. Technical efficiency estimates for regional pulp and paper industries (1971-1993) (tonnes per year) (two methods)

	Conventional			Environmentally sensitive		
	BC	Ontario	Quebec	BC	Ontario	Quebec
1971	1.000	0.999	1.000	1.000	1.000	1.000
1972	0.965	1.000	1.000	0.873	1.000	1.000
1973	0.979	1.000	0.988	1.000	1.000	1.000
1974	0.968	0.974	0.931	0.940	0.962	0.920
1975	1.000	1.000	1.000	1.000	1.000	1.000
1976	0.989	0.965	0.976	0.979	0.936	0.999
1977	0.995	0.976	0.994	1.000	0.907	1.000
1978	0.998	0.983	1.000	1.000	0.936	0.975
1979	0.975	0.986	1.000	0.946	0.936	1.000
1980	0.958	0.981	0.991	0.938	0.938	0.971
1981	0.916	0.963	0.980	0.942	0.964	0.954
1982	0.925	0.994	1.000	0.868	1.000	1.000
1983	0.963	1.000	1.000	0.986	0.987	1.000
1984	1.000	1.000	1.000	1.000	1.000	1.000
1985	0.991	0.985	0.942	0.978	0.965	0.980
1986	1.000	0.989	0.933	1.000	0.970	1.000
1987	0.993	1.000	0.909	0.960	1.000	0.954
1988	1.000	1.000	0.912	1.000	0.899	0.933
1989	0.923	0.961	0.945	0.629	1.000	0.970
1990	0.894	0.970	0.986	0.910	0.978	1.000
1991	0.934	1.000	1.000	0.984	0.974	1.000
1992	0.996	0.985	0.988	1.000	0.872	0.979
1993	1.000	1.000	1.000	0.998	0.906	1.000
Average	**0.972**	**0.987**	**0.977**	**0.954**	**0.962**	**0.984**

Although the technical efficiency estimates did not see much difference (0.954 for BC, 0.962 for Ontario and 0.984 for Quebec), there is a significant increase in productivity growth estimates when the input distance function and the productivity measures are re-estimated in environmentally sensitive ways for all three regions. The productivity growth estimates were all positive for the three regions after incorporating the two water pollutants of BOD and TSS. British Columbia had the highest level of average productivity growth (4.456%), while Ontario and Quebec had an average score of 0.091% and 1.327% respectively from 1971 to 1993. These significant changes in productivity growth are a result of the differences in technical change estimates obtained from the conventional and the environmentally sensitive analysis. The technical change estimates for Ontario and Quebec were 0.541% and 1.337%.

6.2 Results from conventional and environmentally sensitive approach, using tonnes per year, 1971-2012

When we extend the time period to the more recent year 2012, we can observe variations in these estimates. Both conventional and environmentally sensitive approaches indicate the presence of significant differences in technical efficiency among the three regions. For example, the environmentally sensitive efficiency levels are lowest in Ontario, which has an average score of 0.910 for the period from 1971 to 2012. The efficiency level in that province was 1 in 1971 but exhibited a negative overall trend through the period covered in the study (0.946 in 2012). Quebec has the highest average efficiency level (0.970), followed by British Columbia with average efficiency scores of 0.933. The estimation results are summarized in Table 4.

From Table 4 we can see that there is a significant improvement in productivity performance when we change from conventional approach to environmentally sensitive approach, which is consistent with what we would expect. The average growth rate in the degree of technical efficiency (EC), was negative, yet in small value, for all three regions in both conventional and environmentally sensitive approaches. British Columbia achieved the highest productivity growth estimates, which were 1.750% for conventional method and 5.151% for method including the pollutant outputs. Ontario and Quebec presented similar results. They both had a negative conventional productivity growth, -0.305% for Ontario and -0.113% for Quebec, and the estimates increased to 0.996% and 1.517% respectively after switching to environmentally sensitive method. Since the productivity growth (PRR) is determined by adding up the rate of improvement in technical efficiency (EC) and the average technical change (TC) ($\ln M(x^{t+1}, x^t, u^{t+1}, u^t) = \{\ln\psi(u^t, x^t, t) -$

$\ln\psi(u^{t+1}, x^{t+1}, t+1)\} + \frac{\{TC_x(u^{t+1},x^{t+1},t+1)+TC_x(u^t,x^t,t)\}}{2}$), and EC estimates were negative yet small, the productivity growth (PRR) estimates were close to, yet a little smaller than average technical changes estimates as shown in Table 4. Also, we can observe that compared with shorter period (Table 2), the longer period productivity performance estimates have higher scores both in conventional and environmentally sensitive approaches, which means that the pulp and paper industry has made bigger performance improvement at the latter part of the period covered in the study due to technology improvement.

Table 4. Regional pulp and paper industry efficiency, technical change and total factor productivity estimates (1971-2012) (tonnes per year)

Productivity criteria	Conventional	Environmentally sensitive
Technical Efficiency (TE)		
BC	0.927	0.933
Ontario	0.874	0.910
Quebec	0.972	0.970
All Regions	0.924	0.938
Rate of Change in TE (EC, %)		
BC	-0.075	-0.138
Ontario	-0.835	-0.136
Quebec	-0.119	-0.260
All Regions	-0.343	0.178
Technical Change (TC, %)		
BC	1.825	5.289
Ontario	0.530	1.132
Quebec	0.006	1.777
All Regions	0.787	2.733
TFP Growth Rate (PRR, %)		
BC	1.750	5.151
Ontario	-0.305	0.996
Quebec	-0.113	1.517
All Regions	0.444	2.555

6.3 Results from conventional and environmentally sensitive approaches, using real dollars (1992), 1971- 1993 and 1971-2012

Table 5. Regional pulp and paper industry efficiency, technical change and total factor productivity estimates (1971-1993) (real dollars, 1992)

Productivity criteria	Conventional	Environmentally sensitive
Technical Efficiency (TE)		
BC	0.999	0.999
Ontario	0.991	0.989
Quebec	0.996	0.998
All Regions	0.995	0.995
Rate of Change in TE (EC, %)		
BC	0.000006	-0.000001
Ontario	-0.00001	0.000009
Quebec	0.00004	0.000271
All Regions	0.00001	0.000009
Technical Change (TC, %)		
BC	0.266	0.419
Ontario	-0.547	0.098
Quebec	0.575	0.949
All Regions	0.098	0.489
TFP Growth Rate (PRR, %)		
BC	0.266	0.419
Ontario	-0.547	0.098
Quebec	0.575	0.949
All Regions	0.098	0.489

For convenience, we pool the discussion of results for longer period and shorter period from both conventional and environmentally sensitive approaches using real dollars (1992) together. From Table 5 and 6, it is not hard for us to find the similar patterns of variations as we can find in Table 2 and 4. That is, taking the pollutant outputs into account would give better productivity performance than ignoring the undesirable outputs, and that productivity growth (PRR) would be similar in values with technical changes, given that the impact of growth rates in technical efficiency over time on the productivity is small, such that it is mainly determined by technical changes.

Table 6. Regional pulp and paper industry efficiency, technical change and total factor productivity estimates (1971-2012) (real dollars, 1992)

Productivity criteria	Conventional	Environmentally sensitive
Technical Efficiency (TE)		
BC	0.998	0.997
Ontario	0.993	0.990
Quebec	0.996	0.996
All Regions	0.996	0.994
Rate of Change in TE (EC, %)		
BC	0.026	0.036
Ontario	-0.0002	0.037
Quebec	0.00002	-0.002
All Regions	0.009	0.024
Technical Change (TC, %)		
BC	0.098	0.226
Ontario	0.011	0.058
Quebec	0.317	0.315
All Regions	0.142	0.200
TFP Growth Rate (PRR, %)		
BC	0.124	0.262
Ontario	0.011	0.095
Quebec	0.317	0.313
All Regions	0.151	0.223

However, if we compare Table 5 and 6 with Table 2 and 4, it is very clearly shown that productivity performance estimates by both conventional and environmentally sensitive approach dropped much in values when switching the marketable output measurement from tonnes per year to real dollars (1992). This shows that the productivity performance is sensitive to the measurement of output. Table 7 listed the values of marketable output measured by tonnes per year and real dollars (1992) for three provinces. Though small in values, for example, the environmentally sensitive productivity growth estimates (PRR) covering the period from 1971 to 2012 were

0.262%, 0.095% and 0.313% for British Columbia, Ontario and Quebec respectively, our results were positive and revealed improving productivity performance while in Hailu (2003)'s study, these numbers were negative for most regions even after considering both desirable and undesirable outputs.

Table 7. Marketable output in different measurements

	Real Dollars (1992)			Tonnes per year		
	BC	Ontario	Quebec	BC	Ontario	Quebec
1971	3,113,467	5,475,613	5,608,709	4,580,057	4,529,723	7,209,809
1972	3,594,231	5,872,223	5,985,625	4,931,041	4,552,901	6,827,033
1973	4,147,157	6,181,860	6,030,280	5,891,648	4,612,834	7,199,552
1974	4,296,294	6,396,716	6,622,063	5,883,362	4,647,618	7,209,809
1975	3,337,994	4,906,043	5,407,096	5,849,563	4,488,332	7,286,313
1976	4,096,042	5,426,900	5,840,002	5,812,990	4,472,710	7,655,875
1977	3,729,786	5,730,517	5,987,819	5,820,655	4,692,075	7,778,515
1978	4,040,074	6,024,479	6,693,449	6,030,530	4,837,345	8,095,700
1979	4,199,813	6,378,048	6,707,005	6,094,040	4,955,605	8,094,605
1980	4,429,518	6,553,871	6,639,626	6,241,500	5,124,600	8,020,145
1981	3,554,876	6,067,507	6,284,985	6,245,515	5,207,820	8,045,330
1982	3,174,897	5,500,249	5,818,548	6,185,290	4,913,265	7,834,360
1983	3,532,696	6,245,118	6,270,622	6,736,075	5,188,475	8,240,240
1984	3,497,153	6,507,365	6,520,403	7,109,105	5,414,775	8,465,445
1985	3,771,251	6,622,329	6,642,074	7,020,410	5,358,200	8,159,210
1986	4,184,935	6,882,541	7,007,612	7,474,835	5,571,725	8,638,090
1987	4,782,055	6,977,582	7,004,827	7,575,575	5,910,810	8,744,670
1988	5,041,098	6,958,124	7,148,365	8,062,850	5,379,370	9,002,725
1989	4,929,055	6,947,999	6,747,438	5,408,570	5,961,910	9,112,955
1990	4,259,489	6,595,752	6,546,806	7,839,105	5,504,200	9,216,250
1991	3,863,868	6,333,000	6,583,792	8,167,240	5,248,335	9,412,985
1992	3,863,785	6,775,900	6,530,728	8,025,620	5,123,505	9,214,060
1993	4,043,948	6,786,189	7,188,578	7,750,775	5,398,980	9,473,575
1994	4,836,791	6,975,836	7,579,513	8,138,040	4,273,889	9,694,765
1995	5,008,966	6,677,820	7,715,933	8,367,990	6,142,220	10,263,435
1996	4,455,302	7,136,144	7,616,063	6,781,273	5,645,715	9,875,083
1997	4,520,940	7,282,281	8,022,638	6,781,273	4,568,464	9,849,180
1998	3,780,989	6,906,774	7,995,139	5,861,545	4,376,406	9,751,436
1999	4,770,353	7,166,490	8,343,301	6,451,375	4,661,973	9,666,527
2000	5,187,126	7,849,837	8,376,254	6,540,828	4,715,731	10,791,837

2001	4,340,779	7,703,501	8,312,222	6,155,443	4,399,838	9,945,785
2002	4,005,185	8,431,695	8,555,370	6,240,667	4,490,079	10,610,157
2003	4,352,751	8,443,152	8,239,055	7,673,016	5,876,496	10,683,026
2004	4,553,741	8,783,537	8,262,348	7,842,157	5,854,952	10,943,060
2005	4,211,958	8,449,425	8,442,671	7,546,731	5,470,659	10,791,564
2006	4,194,340	7,548,279	8,019,544	7,671,718	4,395,874	10,415,608
2007	4,378,959	7,093,887	7,649,949	7,543,900	3,870,095	9,839,683
2008	3,936,715	6,490,533	7,275,099	6,673,270	3,778,730	9,117,949
2009	3,059,641	5,861,460	6,345,758	5,813,529	2,606,004	7,407,954
2010	3,567,748	5,581,167	6,432,452	5,951,845	2,753,109	7,953,968
2011	3,750,363	5,795,981	6,163,700	6,111,906	2,901,351	7,435,061
2012	3,397,346	5,598,081	5,986,716	6,093,041	2,502,121	6,654,709
Average	**4,090,321**	**6,664,805**	**6,979,766**	**6,689,902**	**4,770,924**	**8,824,477**

As for the levels of technical efficiency, these methods revealed high scores. All the technical efficiency estimates were around 0.990, and they were quite stable throughout the covered period in our study, resulting in the values of EC to be insignificant (an average of 0.024% including the pollutant outputs and 0.009% excluding them for the period 1971-2012).

7. Summary and Conclusion

Canada is one of the world leaders in the production of pulp and paper products. The Canadian pulp and paper industry has been of some importance in the country's economy and contributed 0.42% of GDP to the whole economy and provided over 60 thousand jobs in 2016. However, the environmental effects, especially the wastewater from pulp and paper mills that destroyed the aquatic habitat had become the major concerns of the government and society. To tackle this problem, the Pulp and Paper Effluent Regulations (PPER) were first introduced in 1971 and amended in 1992, 2004 and 2008. Through the PPER, limits were set on the amount of total disposal of TSS and BOD and other effluents that displayed acute lethality to fish for pulp and paper mills and off-site facilities to comply with. To meet these regulations, the pulp and paper industry has been making great efforts and invested heavily to install pollutant abatement system and equipment. Great improvement has been recognized since the enforcement of the Regulations.

When analyzing the productivity performance in Canadian pulp and paper industry, the traditional approach only considered the desirable output, ignoring the pollutant outputs; and that failed to credit the producers for pollutant abatement because it did not account for the reduction in those undesirable outputs as a positive result of pollutant abatement, thus underestimating the productivity performance in the pulp and paper industry. The environmentally sensitive approach incorporated the water pollutant BOD and TSS and managed to provide an accurate indication of changes in the performance of the industry. The input distance function was estimated using the panel data for the period from 1971 to 2012, and quantities of four inputs (i.e. labor, capital, energy, material) and three outputs (desirable output and undesirable outputs of BOD and TSS) were considered.

According to our results, Quebec and Ontario have similar productivity performance, while British Columbia has better productivity performance than the two other regions. For example, the best productivity performance estimates for three regions in our study appeared when we use tonnes per year to measure the desirable output for period from 1971 to 2012 (Table 4), with BC having the highest productivity growth rate (5.151%), followed by Ontario (1.517%) and Quebec (0.996%). This is expected, since the pulp and paper industries in Quebec and Ontario have similar size and structure while British Columbia is different in size and structure from the other two regions. Regardless of longer or shorter time period, tonnes per year or real dollars, the technical efficiency estimates switching from conventional to environmentally sensitive approaches did not show much differences for BC, Ontario and Quebec individually. Also, even that the technical efficiency estimates were quite different for different regions, for each single region, the figures did not change much over the time period. The lack of much variations can be expected because the technical efficiency estimates are based on comparison of individual regions against its own frontier or the technology for a given period. Moreover, although the pollutant abatement levels have changes in all regions over time, they are improving at similar speed in terms of the pollutant abatement activities, thus we cannot expect much differences in technical efficiency estimates. The situation in Hailu (2003) was very different. In Hailu's estimation, for both the conventional and environmentally sensitive approaches indicated that there were substantial differences in the degree of technical efficiency among the regional pulp and paper industry. Still, when compared to Hailu (2003), our results yield higher values of technical efficiency estimates, with most of the results being over 0.950, while in Hailu (2003), they were barely over 0.90.

As for productivity growth and technical change, it is obvious that the environmentally sensitive approach indicates a much better productivity performance than the conventional approach, regardless of the length of the time period or what measurement we choose to count the marketable output. When compared to Hailu (2003)'s results, which showed the same conclusion as ours that the environmentally sensitive approach credits the producers for the pollutant abatement activities, thus is more favorable than conventional way to analyze the productivity performance in Canadian pulp and paper industry, our results give a much more convincing indication, especially when we use tonnes per year instead of real dollars to measure desirable output, the changes between two methods are large for three regions. The intuition behind the differences in the results between the two methods reported in both our and Hailu (2003)'s paper is that the productivity measurement is based on the input that could have been saved if desirable and undesirable outputs were to be held constant. So inputs used for the purpose of pollution abatement activities are recognized by the input-based environmentally sensitive measure as inputs that could have been saved if there were no pollution abatement activities. If the industry had been using increasing percentage of inputs for pollution abatement activities, the input-based environmentally sensitive approach recognizes that an increasing percentage of input saving could have been achieved if there were no pollution abatement activities. In that sense, the producers are credited accordingly for their investment in pollution abatement when input-based environmentally sensitive approach is used. On the other hand, the conventional input-based measurement fails to incorporate reduction in undesirable outputs, thus cannot recognize the input that is used for pollution abatement and credit the producers, therefore ended with a poorer productivity performance.

However, when we also use real dollars (1992) to measure desirable output, productivity performance by both conventional and environmentally sensitive approaches became relatively poor, if not as poor as Hailu (2003)'s, which had negative results for most regions even after taking into account both desirable and undesirable outputs. This shows that the productivity performance is sensitive in the measurement of output.

Another reason for the big difference between our results and Hailu's can be that instead of considering all regions as a whole and estimating the parameters for once, we separate them and estimate respectively. We think that analyzing the productivity performance of provinces separately is more sensible considering the different situations across regions.

From all results, we can see that the productivity growth estimates have close values to the technical change estimates. This is because the Malmquist productivity growth measure can be decomposed into technical efficiency and technical change components, and the changes in technical efficiency over the period were relatively small for all three regions, the technical changes estimates would then mainly determine the values of productivity growth. This is not true in Hailu (2003), because in his study, rate of change on technical efficiency (EC) was estimated to be more significant than ours, thus played a more important role in deciding the productivity growth rate (PRR). Besides, unlike our estimation of technical changes (TC) which were mostly positive numbers, Hailu (2003)'s technical change estimates had negative results for all regions (an all-region average of -0.21%)when excluding pollutant outputs and had negative result for BC (-0.02%) when including pollutant outputs. Given those rate of change in technical efficiency (EC) estimates and technical change (TC) estimates, it is no wonder that Hailu (2003) got negative total factor production growth rate estimates (PRR), with an all-region average of -0.85% for conventional method and -0.26% for recognizing the industries' water pollutant outputs.

To conclude, through our analysis, for any industry like the Canadian pulp and paper industry that has made much investment in pollutant abatement, the incorporation of pollutant outputs in the analysis of productivity performance is required. This confirms conclusion drawn in Hailu (2003) with more convincing results.

8. References

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Appendix 1

Effluent output data were cited from Hailu and Veeman with their permission for the years 1971-1981 and Environment Canada by special request for the years 1982-2012. Data for all other variables were from Statistics Canada. Table 2 lists the variables and their specific sources.

Table 8. Data Sources (1971-1982)

Output	CANSIM Table 301-0001 CANSIM Table 301-0003 CANSIM Table 301-0006
Capital	CANSIM Table 029-0005 CANSIM Table 029-0034 CANSIM Table 031-0002
Labor	CANSIM Table 301-0002
Energy	CANSIM Table 128-0002 CANSIM Table 128-0009 Consumption of purchased fuel and electricity by the manufacturing, mining, logging, and electric power industries, Statistics Canada, Catalogue 57-208 Consumption of purchased fuel and electricity, Statistics Canada, Catalogue 57-506 Electric power generation, transmission, and distribution, Statistics Canada, Catalogue 57-202
Material	CANSIM Table 301-0002
Industry price index	CANSIM Table 329-0038
Implicit GDP deflator	CANSIM Table 379-0025

Table 9. Data Sources (1982-2012)

Capital	CANSIM Table 031-0002 CANSIM Table 031-0005
Energy	CANSIM Table 128-0002 CANSIM Table 128-0016 CANSIM Table 329-0013 CANSIM Table 329-0050 CANSIM Table 329-0073
Price index	CANSIM Table 329-0075
All others	CANSIM Table 301-0001 CANSIM Table 301-0003 CANSIM Table 301-0006

Appendix 2

As shown in Methodology, the parameter estimation for the input distance function for each province was carried out by minimizing the sum of deviations of the translog form of the input distance function from 0, subject to monotonicity, homogeneity and symmetry conditions. The linear programming programs were written in a program called SAS and the process were repeated for 24 times to get 24 different sets of parameter estimates in terms of three regions, including pollutant outputs or not, and using real dollars or tonnes per year to measure the marketable output. Here, the results of input distance function parameter estimation for British Columbia, Ontario and Quebec covering the period from 1971 to 2012, using tonnes per year to measure the marketable output are presented in Table 10 as an example.

Table 10. Input distance function parameter estimates for model incorporating pollutant outputs for three provinces (tonnes per year, 1971-2012)

BC		Ontario		Quebec	
α0	-2.227	α0	2.572	α0	-8.673
α1	-2.435	α1	-0.370	α1	-3.665

α2	0.710	α2	2.394	α2	2.244
α3	3.311	α3	-0.006	α3	-0.878
α4	-0.586	α4	-1.018	α4	3.299
β1	1.550	β1	-2.233	β1	-0.667
β2	-2.242	β2	0.224	β2	-1.328
β3	-0.308	β3	1.009	β3	0.995
α11	-1.824	α11	-0.330	α11	0.066
α12	-0.089	α12	0.609	α12	0.557
α13	1.887	α13	-0.001	α13	-1.213
α14	0.025	α14	-0.278	α14	0.589
α22	0.025	α22	-0.337	α22	-0.294
α23	-0.061	α23	0.001	α23	-0.367
α24	0.125	α24	-0.273	α24	0.104
α33	-1.740	α33	0.000	α33	1.444
α34	-0.086	α34	0.000	α34	0.137
α44	-0.063	α44	0.550	α44	-0.830
β11	-0.569	β11	-0.005	β11	0.098
β12	0.298	β12	-0.027	β12	-0.043
β13	0.271	β13	0.032	β13	-0.055
β22	-0.252	β22	-0.010	β22	-0.024
β23	-0.047	β23	0.037	β23	0.067
β33	-0.224	β33	-0.069	β33	-0.011
γ11	0.453	γ11	-0.466	γ11	-0.077
γ12	-0.579	γ12	-0.015	γ12	-0.102
γ13	0.126	γ13	0.482	γ13	0.179
γ21	-0.533	γ21	0.117	γ21	-0.303
γ22	0.580	γ22	-0.064	γ22	0.463
γ23	-0.047	γ23	-0.053	γ23	-0.161
γ31	-0.120	γ31	-0.001	γ31	0.491
γ32	0.120	γ32	0.000	γ32	-0.713
γ33	0.000	γ33	0.001	γ33	0.222
γ41	0.200	γ41	0.350	γ41	-0.111
γ42	-0.121	γ42	0.079	γ42	0.352
γ43	-0.079	γ43	-0.429	γ43	-0.241
αt	-0.116	αt	0.095	αt	-0.097
αtt	-0.004	αtt	-0.001	αtt	0.001
α1t	-0.041	α1t	0.015	α1t	-0.007
α2t	0.001	α2t	0.019	α2t	0.011
α3t	0.043	α3t	0.000	α3t	-0.025
α4t	-0.003	α4t	-0.033	α4t	0.021
β1t	0.040	β1t	0.002	β1t	-0.008
β2t	-0.016	β2t	-0.003	β2t	0.001
β3t	-0.024	β3t	0.001	β3t	0.007