

Pollution Emissions in the Pulp and Paper Industry: A Statistical Decomposition Analysis

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Abstract: This research paper aims to explain the relative changes in the total emission of Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS) and Greenhouse Gases (GHG) in the pulp and paper sector in Canada over an 8-year period: from 2005 to 2013. In order to achieve this, a statistical decomposition technique is applied that entails measuring changes in total industry output; emission intensity; industry composition, and mill closures. Consistent with our expectation, the total emission levels for all three pollutants decreased in 2013 compared to their levels in 2005, and a primary driving-force behind this has been the substantial decrease in output of the industry, particularly newsprint, in the aforementioned time period.

1. Introduction

Pulp and paper is one of Canada's largest manufacturing industries measured in terms of employment, value added, and net exports. In 2013, the industry provided employment to approximately 64,000 people, contributing around \$9 billion to the domestic real GDP (constant 2007 dollars) (Natural Resources Canada, 2013). The industry is also notably dispersed geographically, with 67 mills in Quebec, 34 in Ontario, 28 in British Columbia, and 33 in the Atlantic and Prairie Provinces—with a total of 162 mills operating in Canada in the year 2000 (Hailu and Veeman, 2000). This number however dropped to 156 in 2005, before falling further to 85 mills in 2013 (as reported by FPAC data). Subsequently, this had a substantial effect on changing the composition of the industry. Nonetheless, in terms of contribution to merchandise trade balance, the pulp and paper sector has continually outperformed all other industries. This may be credited to a large extent to its success in improving productivity and maintaining its competitiveness in the face of increasing capacity expansion in many other countries such as India, Brazil and the United States.

In terms of manufacturing, the pulp and paper sector is a highly resource-intensive industry that requires vast quantities of energy, water and other inputs. And, as a mature industry—having been founded over 200 years ago—it has over the years adapted rapidly to technological change and innovation in order to remain competitive in the global market. In 1990, the pulp and paper mills in Canada had been estimated to be responsible for about 50% of all waste dumped into the nation's waters and also account for approximately 5.6% of the common air contaminants from known industrial sources, the same year (Murray, 1992).

However, water discharges by mills have plummeted substantially since the 1970s: discharges of TSS and BOD matter decreased by approximately 90% and 97%, respectively (Environment Canada, 2012). This improvement has largely been due to regulations and requirements under the *Pulp and Paper Effluent Regulations (PPER)* act, first published in 1971 (followed by further amendments). Additionally, according to FPAC's 2009 Sustainability Report, since 1990, the sector has reduced their absolute (total) greenhouse gas emissions by 57% and their emissions intensity by 61%. Between 1990 and 2007, its facilities reduced their reliance on fossil fuels to 15% from 30%, while increasing their use of waste-based biomass (including pulping by-products and wood residuals such as bark) to 58% from 49% of overall energy requirements. Nonetheless, these analyses did not determine the degree to which this change was a response to improvement in energy efficiency through the adoption of more efficient technology (e.g. cogeneration), or reductions in production where less efficient mills may have closed. Yet as mills closures have occurred all along the GHG emission intensity curve, the reductions in GHG emissions have been attributed partially as a result of improvements in energy efficiency (about 1/3), while the switch from fossil fuels to low emissions energy supply like electricity and biomass have been attributed for the rest (about 2/3) (CIEEDAC, 2011). Furthermore, this invokes one to rethink the assumptions regarding the economic survival of pulp and paper mills. One would assume that cleaner mills would survive because of governmental regulations on environmental emissions, however, as the results show, the environmental efficiency of mills and their economic survival do not always go hand-in-hand.

My analysis covers the period between 2005 and 2013, and expands upon the previous research into environmental emissions in the Canadian pulp and paper sector by utilizing mill-level data to directly measure the role played by four specific factors with respect to BOD and TSS emissions: the change in relative output, (or the 'scale effect'); the change in technology used in production and abatement, (the 'technique/emission intensity effect'); the change in the mix of mills comprising the industry, (or the 'composition effect'); and finally, a factor that is unique pertaining to the literature — the role played by mills closures. And, for GHG emissions two additional factors are included: the emission intensity of energy use by the mills, and the energy efficiency of the mills.

Moreover, using the mill-level data from The Forest Products Association of Canada (FPAC), I am able to aggregate and analyze the data for mills at a fairly homogenous level, in terms of analyzing mills within the same category (according to their output produced and their production process), as opposed to comparing them to mills as part of the industry as a whole.

2.0 Literature Review

The research by Adès, Bernard, and Gonzales (2012) studies the evolution of GHG emissions in the Quebec pulp and paper industry from 1990 to 2006 using estimated energy demand functions. Their research focuses on the effects of energy prices and output mix on the energy use of the Quebec pulp and paper industry, and correspondingly on its GHG emissions in the aforementioned time-frame. As the authors point out, conventional policy discussions and analyses dealing with GHG mitigation thus far had focused primarily on energy input mix—the substitution of a ‘clean’ energy source, such as hydroelectricity, for a ‘dirty’ one like heavy fuel oil. They further highlight that the role of output mix in multi-product industries had received little attention in the literature pertaining to the matter. The main explanatory variables that the authors consider in the model in analyzing the evolution of GHG emissions were not only energy prices (i.e., energy source substitution), but also the output mix (i.e. pulp, cardboard, and paper).

In their paper they use a model that estimates the parameters of a cost function that captures the cost-minimizing behavior of firms in a multi-input and multi-output framework. They find that from 1990 to 2006, GHG emissions of the Quebec pulp and paper sector fell by more than 30%, while pulp and paper production had increased in the same time period. This resulted in a significant reduction in GHG emission intensity. Further, the role of biomass use and cogeneration in this respect was found to be minor. The major explanatory factor was found to be the change in output mix. Their findings also show that the lower price of electricity had favored its use relative to fuels (natural gas, light and heavy fuel, and wood residues) and this was a contributing factor towards lower emissions. However, the authors conclude that changes in output had been a more of an impact in leading to a reduction in emissions in the province.

There are other research papers, particularly focusing on the US manufacturing industries that provide an interesting perspective on the topic. One such paper is the study by Levinson (2014). The noteworthy aspect of his research was the methodology he used and its ability to directly estimate the ‘technique effect.’ To do this, he calculates analogues to the Laspeyres and Paasche price indexes across more than 400 industries for 6 major air pollutants. He finds that from 1990 to 2008, real value of US manufacturing output grew by 35% while the local air pollutants emitted from US factories fell by 52%-69% (depending on the type of pollutant). This decrease in pollution intensity, he suggests, could have two possible causes: composition or technique effects. The former refers to the fact that

mills can produce proportionally more goods whose production process involves less pollution; while the latter refers to manufacturers adopting technologies that enable production of some goods while emitting less pollution. Yet, as Levinson points out, all the research dissecting the cleanup of manufacturing into these two components has involved careful documentation of composition changes in the manufacturing sector, with any leftover pollution reductions being attributed to technique changes. Levinson refers to several recent studies that had estimated the effect of changes in the composition of the manufacturing sector by disaggregating output changes among various industries, and projecting their separate emissions using fixed industry-specific measures of pollution intensity (see, e.g., Hettige, Lucas, and Wheeler 1992; Cole 2000, 2004; Levinson 2009; Brunel 2014).

However, as Levinson highlights, they do have a drawback: because time-varying measures of pollution intensities were not available, the prior approaches relied on emissions intensities from a single year—most often the 1987 Industrial Pollution Projection System developed by the World Bank (Hettige et al. 1995). They then used that base-year pollution intensity to predict pollution in later years and calculate the technique effect as a residual source of improvement after the scale and composition changes had been accounted for. That approach assumes that there are no interactions between scale, composition, and technique. Any such interactions between scale and technique would be thus be included in the remainder term and attributed to technique effect, thus underestimating the true value. Subsequently, most of the literature found that composition changes did not explain even half of the cleanup of manufacturing and that therefore technology changes had to explain the majority.

Levinson (2014) addresses these concerns by estimating the technique effect more directly: as changes over time in the emissions intensities of industries, holding the composition of those industries constant.

By using time-varying measures of pollution intensity and calculating the technique effect directly in two ways: once using base-year industry composition and once using final-year industry composition, Levinson provides the first direct estimate of the technique effect. The first is a pollution intensity analogue to a Laspeyres price index, and the latter is a pollution intensity analogue to a Paasche price index. By measuring technique directly, he includes all sources of reductions in emissions per dollar of output, including returns to scale and dirtiest-mill culling. Moreover, by using both base-year and final-year industry compositions, he puts bounds on the degree to which composition changes could overstate or understate the technique effect.

Levinson finds that production technique changes accounted for 90% of the overall cleanup of US manufacturing. Moreover, he finds that the vast majority of the cleanup of US manufacturing had come from falling emissions intensities within industries, rather than from changing the mix of industries in the manufacturing sector.

For this research, I adopt and expand upon Levinson's methodology by adding an additional factor to the decomposition: the role of mills closures, or 'the mill-closure effect.' And so it is necessary to elaborate further on his use of the Laspeyeres and Paasche indexes.

The Laspeyeres index creates the index of change by comparing actual 1990 (base year) emissions to what the current emissions would have been had the individual industries' emission intensities changed from 1990 but each industry's output remained as it was in 1990:

$$I_L = \frac{\sum_i z_{it} \cdot v_{i,1990}}{\sum_i z_{i,1990} \cdot v_{i,1990}}$$

Where, z_{it} is the emissions intensity for industry i at time t , and v_{it} is the value shipped from industry i at time t .

While, alternatively, the Paasche index compares actual current emissions to what the 1990 emission would have been had each industry's output in 1990 been as it is currently:

$$I_P = \frac{\sum_i z_{it} \cdot v_{i,t}}{\sum_i z_{i,1990} \cdot v_{i,t}}$$

It must also be noted that for prices, the Laspeyeres index overstates inflation, while the Paasche index understates, assuming that people adjust to changes relative to prices by consuming more of the goods whose prices grow least—however, in my adoption of this technique, I do not factor in prices or inflation per se, and I simply use industry output and emission intensity ratios (in metric tons and metric tons per unit of output during a particular year, respectively).

In the pollution context, the relative sizes of the two indexes depend on whether the manufacturing sector has shifted forward or away from industries whose pollution intensities have fallen the most. If between 1990 and 2008 the manufacturing sector produced relatively less output in industries with the fastest-falling production intensities, the Laspeyeres index would be smaller than the Paasche index, suggesting a larger technique effect and vice-versa. So, rather than holding technology fixed, Levinson holds composition of output fixed and shows how pollution per dollar of output for the aggregated manufacturing sector has changed.

However, for my analysis the Paasche index, in the case of two mills (2 and 3), is represented by the technique effect, i.e.

$$\frac{z_{22} \cdot \theta_{22} + z_{32} \cdot \theta_{32}}{z_{21} \cdot \theta_{22} + z_{31} \cdot \theta_{32}}$$

Where z_{it} refers to the emission intensity of mill i in time t , and θ_{it} represents the output share of mill i at time t .

While the Laspeyers index is represented by the composition effect, i.e.

$$\frac{z_{21} \cdot \theta_{22} + z_{31} \cdot \theta_{32}}{z_{21} \cdot \theta_{*21} + z_{31} \cdot \theta_{*31}}$$

Where again, z_{it} refers to the emission intensity of mill i in time, θ_{it} represents the output share of mill i at time t , and θ_{*it} refers to the mills that were operating both in 2005 and in 2013. These mills are considered to have ‘survived’ in 2013. The decomposition formula will be presented at length in section 5.

3.0 Data

This paper utilizes pooled annual panel data across individual pulp and paper mills in 2005 and in 2013. Two different models are estimated: one model for BOD and TSS emissions, and the other model for GHG emissions. Access to the data has been provided by: The Forest Products Association of Canada (FPAC). It is voluntarily reported by FPAC member companies, and is obtained via self-reported survey results. Each mill that is a member company provides annual data on the types of fossil fuels and biomass use, on various outputs including electricity from cogeneration, and a wealth of data on energy use, and environmental emissions. Reports for individual mills are not publicly available, however the data was provided by FPAC upon request for the purposes of this analysis. There was also

a careful emphasis on distinguishing between mills that shut down, and mills that had simply stopped reporting to FPAC or had missed/skipped reporting for a particular year (in our case, the years in concern are 2005 and 2013). This was crucial in order to accurately determine the mills that were closed in 2013.

3.1. BOD and TSS

For the analysis on BOD and TSS, data on biological oxygen demand (BOD) in tons per year, total suspended solids (TSS) in tons per year, and the value of output produced in metric tons is used. While, for the analysis on GHG, greenhouse gases (GHG) in tons of equivalent carbon dioxide ($tCO_2 e$); total output produced by the mills in metric tons; total fuel consumed by mills in TJ, and total purchased electricity in TJ were used. The mill samples for BOD and TSS emission estimates were identical, whereas the GHG sample included mills that were not included for the first estimates. This is due to inconsistencies in the data.

According to FPAC, 159 pulp and paper mills were operating in Canada in 2005. However, their database included only 107 mills. This is because either the mills did not report in that particular year, or because they were not FPAC member companies. In 2013, the data were available for 77 mills, out of the 84 mills operating that year. Furthermore, there were inconsistencies to be found in the reported data, i.e. missing data or reporting errors. Since the relative change in pollution is being measured between the two years, with 2005 being the base year and 2013 being the final year—the sample data corresponding to aforementioned factors had to be available for both years.

The fact that some of the mill had to be dropped from our sample, may lead to a slight degree of overestimation in our results. However, the data was analyzed and ‘cleaned’ to the best extent possible, with respect to including data sets for all of the variables in question (emission levels of the pollutants, energy usage, output produced) for which they were consistent and available.

3.2. GHG

The data used for the analysis of BOD and TSS differs from that used for the GHG analysis, and includes a larger data sample (80 mills accounted in our sample for 2005, as opposed to 72 for BOD and TSS). Moreover, with respect to estimating total GHG emissions, it is necessary to take into

consideration an additional product, i.e. electricity sold. For the purposes of this analysis, the quantity of electricity sold by the mills was converted to the equivalent of pulp and paper sold in metric ton. This was done by dividing the product of the quantity of electricity sold by the mills in kWh and the average price of electricity in \$CAD/kWh, by the average prices in \$CAD/ton of the pulp and paper product from each of the five categories in 2005 and in 2013. The data for the prices of electricity was obtained from the Hydro Quebec website (Hydro Quebec, 2013), where the prices of electricity for large-power industrial usage in \$CAD/kWh were used for the conversion.

3.3. Mill Categories

Although the pulp and paper manufacturing industry has achieved large efficiency gains over the years, the basics of paper - making have remained more or less unchanged during the last century. There are two major classes of pulping processes: the first is known as chemical processes, where wood chips and sawdust are cooked by using a chemical solution. This process results in the separation of cellulose fibre from the wood by dissolving the lignin that binds the fibres together, then recycling the remaining solution to recuperate the chemicals. This is achieved by burning the chemical and lignin mixture (black liquor) to produce energy (recovery boiler) with the remaining residue treated in a caustic mill.

The second class is known as mechanical processes, where wood is pulped using the mechanical energy to press the fibres between narrow-gap plates (refiner mechanical pulping). This process may vary by adding steam, pressure (thermo-mechanical pulping) and sometimes chemicals, or both (chemi-thermo-mechanical pulping). Because of the major differences in the energy requirements of the two pulping processes and the type of products that are made, it is essential to categorize the mills accordingly.

FPAC classifies the mills, as part of the data set, into five categories in accordance to their production process and output produced (many mills are multi-product mills, i.e. produce more than one type of output). This categorization allows us to compare mills within their specific categories, according to their production processes and energy consumption requirements, thus, allowing for a much more weighted analysis of mill activity. The mill categories are:

1. Category 1: Chemical Market Pulp (excluding De-inked/Recycled Pulp). This category includes all kraft - chemical market pulp mills (NAICS 322112)¹, and excludes paper products from chemical pulp.
2. Category 2: Papers from chemical pulp or mechanical pulp. These include paper grades made from chemical pulp produced onsite, as well as coated ground-wood specialties from mechanical pulp (NAICS 322121). It excludes paper from De-inked/Recycled pulp and newsprint.
3. Category 3: Mechanical Market Pulp, Newsprint, and uncoated ground-wood specialty grades and board grades from mechanical pulp. This category combines mechanical market pulp mills, newsprint and uncoated ground-wood grade mills, and a number of small specialty board manufacturers (NAICS 322111, 322122, 322130).
4. Category 4: All grades from purchased fibre (recovered paper or purchased pulp). The category includes all product grades manufactured from purchased fibre (De-inked/Recycled pulp) (NAICS 32211X, 322121, 322122, 322130). Excludes product grades from chemical and mechanical pulp made onsite.
5. Category 5: Board grades from mechanical pulp. Includes board mills manufacturing from chemical pulp on site only (NAICS322130). Excludes board from mechanical pulp.

However, there were missing data in regards to the mills classified in category 5, i.e. not only were there very few mills that were classified in this category, only one of the mills identified to be in this category had complete data regarding BOD and TSS emissions (tons per year) and the total output produced (in metric tons). Thus, there was insufficient data available to include any mills in this category. However, given that the number of mills operating in the category is very small relative to the total number of mills in all other categories, the effect of leaving out this category is expected to be very small.

¹ North American Industry Classification System.

4.0 Expectations

4.1. Expectations for BOD and TSS

The *Pulp and Paper Effluent Regulations* (PPER) was published in 1971 to oversee the discharge of harmful chemicals from pulp and paper mills and to set limits on the amounts of TSS and BOD emissions, and to prohibit the deposit of effluent deposits (Environment Canada, 2012).

In 1985, about 10% of mills were subject to the regulations, and in that year, 25% of effluent samples met regulatory requirements for toxicity tests on fish, while 68% of samples met those requirements for BOD and 60% for TSS. However, particularly since 1992 when regulations became more binding, the quality of pulp and paper effluent released directly to the environment has improved considerably— In 2012, 98.3%, 99.8% and 99.8% of effluent samples met regulatory requirements for toxicity tests on fish, BOD, and TSS, respectively (Environment Canada, 2012).

Consequently, we expect the reductions in BOD and TSS to be in the ‘tail-end’ of the spectrum. In other words, we do not expect to see significant reductions in our sample period because of the rigor and success of the regulations. It is also worth emphasizing that the regulations concerning BOD and TSS emissions are a joint effort of the federal government with provincial governments, where the provincial governments can impose their own regulations. These however cannot be more ‘lenient’ than federal provisions.

Moreover, with respect to a decline in the relative change in pollution, we expect the ‘surviving’ mills to be more efficient in terms of emitting less pollutants; we expect the weight of production to shift to the less polluting firms; and we would expect the more polluting mills to be ‘knocked out,’ i.e. shut down.

It is also important to note that the relative change in pollution is not confined to the aforementioned factors that I consider in my decomposition equation—these are four among numerous other economic factors that play a role. For instance, wood fibre being one of the primary components in the production process plays a substantial role in this regard. The wood fibre available differs among different regions due to climatic reasons, etc., and some types of wood fibres are more apt than others for the production of certain pulp and paper products. Therefore, during market downturns, we expect the poor quality fibres to close or get ‘knocked out’ of the market.

Transportation costs also play an important role. Mills are typically located closer to forests and rivers to economize on transportation costs. And again, during market downturns, we expect mills that are located further away from the market to close relative to mills that are located closer to it.

4.2. Expectations for GHG

For GHG emissions, there are currently no binding regulations for mills in Canada (although British Columbia had implemented a carbon tax in 2008, with a final scheduled effect that took place in July 2012) (Ministry of Finance, B.C, 2015). Nonetheless, a changing energy mix; greater energy efficiency, and the decline in the Canadian pulp and paper-manufacturing sub-sector has reduced energy use and GHG emissions in the forest industry. And according to a report by Natural Resources Canada (2015) the forest industry's substantial cut in fossil fuel use between 2000 and 2012 has additionally helped reduce direct emissions by 56% and total energy use by 30%.

Moreover, some of this decline can also be attributed to the contraction of the forest industry between 2005 and 2009. In recent years, Canada's pulp and paper sector has gone through substantial structural changes in global and domestic markets. In particular, the rise of electronic media has resulted in deep decline for paper-based communications products—including several products (such as newsprint) that have traditionally been critical to the Canadian pulp and paper subsector (Natural Resources Canada, 2015). In 2012, Canada's total newsprint exports fell by 16%, including losses to Canada's largest three export markets: the U.S. (-9%), India (-27%) and Brazil (-6%) (Natural Resources Canada, 2013). In fact, other than the collapse of 2009 (due to global recessionary pressures), the total annual decline in exports in 2012 (670 000 tons) tied 2007 as the largest year-over-year decline in total newsprint exports on record—approximately 520 000 tons per year, roughly the output of two mills per year (Natural Resources Canada, 2013). This has had a significant effect in changing the total industry output and correspondingly, emission levels.

Likewise, a large part of the decline was also as a result of changing energy usage and increases in the self-generation of power from waste products by the mills. The pulp and paper sector is one of the most energy-intensive sectors, consuming approximately 30% of the industrial energy used in Canada (CIEEDAC, 2011). Because energy factors-in as such a significant amount of the production

cost component (about 25%), the sector has made efforts to reduce its fuel costs by switching to renewable biomass sources (by-products of the production process) and energy efficiency improvements. And on top of that, in 2009, the Government of Canada took decisive action to improve the sustainability of pulp and paper mills by creating the \$1-billion Pulp and Paper Green Transformation Program (PPGTP), that had an impact in significantly improving the environmental performance of Canada's pulp and paper industry through a record level of investment in green technologies (Natural Resources Canada, 2012).

Additionally, the substantial drop in the price of natural gas from 22.78 ¢/m³ in July 2008 to almost half the value, 11.17¢/m³ in Jan 2012 played a substantial role in the shifting towards more natural gas use—a much more cleaner source of energy in terms of GHG emissions than other fossil fuels (Ontario Energy Board, 2015). In fact, the forest industry's reduced use of refined petroleum products and natural gas between 2000 and 2012 accounted for 95% of its reduction in direct emissions over the period of time (Natural Resources Canada, 2015). This leads one to expect the 'surviving' firms to have shifted towards using cleaner, more efficient sources of energy.

We thus expect to observe improvements in the energy efficiency of pulp and paper mills, in terms of increasing the amount of renewable energy generated by mills. This includes converting fossil fuel boilers to biomass, and installing new turbines and generators—contributing further to offsetting the production of energy from the use of GHG intensive fossil fuels. And in terms of the expectations from the decomposed factors, they would be identical to that of BOD and TSS; however, for GHG we would additionally expect the more energy efficient mills to 'survive.' While with regards to the substitution of mills from fossil fuels to other sources of energy, e.g. natural gas and biomass, we would expect mills that substitute towards more efficient sources of energy to 'survive.'

5.0 Methodology

5.1. Methodology for BOD and TSS emissions

Generally, changes in total pollution are considered to arise from three sources: the overall size of the economy ('scale'), the mix of sectors comprising the economy ('composition'), and the technologies employed in production and abatement ('technique/emission intensity'). However, I factor-in an additional component: the role-played by mill closures.

To simplify the presentation of the methodology, I'll consider a situation that involves only three mills i.e. 1, 2, and 3, and the latter two mills are surviving over the two periods. Let us start with the pollution identity:

$$p_{it} = \frac{p_{it}}{v_{it}} \cdot \frac{v_{it}}{V_t} \cdot V_t \quad (1)$$

Where, p_{it} is the emissions from mill i at time t ; v_{it} is the output of mill i at time t ; and V_t is total industry output at time t .

We can write equation (1) as:

$$p_{it} = z_{it} \cdot \theta_{it} \cdot V_t \quad (2)$$

Where, z_{it} is the emission intensity of mill i at time t ; θ_{it} is the output share of mill i at time t ; and $\sum_{t=1}^3 \theta_{it} = 1$.

The total emission of the industry is:

$$P_t = p_{1t} + p_{2t} + p_{3t} = V_t (z_{1t} \cdot \theta_{1t} + z_{2t} \cdot \theta_{2t} + z_{3t} \cdot \theta_{3t}) \quad (3)$$

$$= V_t (z_{1t} \cdot \theta_{1t} + z_{2t} \cdot \theta_{2t} + z_{3t} \cdot \theta_{3t}) \quad (4)$$

So, the relative total pollution in period 2, relative to the starting year, i.e. period 1 is:

$$\frac{P_2}{P_1} = \frac{V_2}{V_1} \cdot \frac{z_{22} \cdot \theta_{22} + z_{32} \cdot \theta_{32}}{z_{21} \cdot \theta_{22} + z_{31} \cdot \theta_{32}} \cdot \frac{z_{21} \cdot \theta_{22} + z_{31} \cdot \theta_{32}}{z_{21} \cdot \theta_{*21} + z_{31} \cdot \theta_{*31}} \cdot \frac{z_{21} \cdot \theta_{*21} + z_{31} \cdot \theta_{*31}}{z_{11} \cdot \theta_{11} + z_{21} \cdot \theta_{21} + z_{31} \cdot \theta_{31}} \quad (5)$$

(i.) (ii.) (iii.) (iv.)

Where, $\theta_{i1}^* = \theta_{i1} / (\theta_{21} + \theta_{31})$ for $i = 2, 3$ and $\sum_{t=2}^3 \theta_{it}^* = 1$.

From equation (5), $\frac{P_2}{P_1}$, the relative change of total emission between the two periods, 2005 and 2013 is thus decomposed into four multiplicative factors, where:

- i. Total industry output;
- ii. Emission intensity of the surviving mills;
- iii. Production shift among surviving mills;
- iv. Mill closure.

Therefore, the model allows us to decompose the relative change in total pollution between the two periods into:

(i.) The output, or ‘scale effect,’ which is simply the change in the total output of the industry;

(ii.) The ‘technique effect’ or emission intensity of the surviving mills, estimates the relative emission intensity of the surviving mills at the final year level, i.e. the relative efficiency gain/loss. In other words, it is keeping the output share constant and looking at the efficiency of the surviving firms, i.e. changes in emission intensities—indicating whether or not the surviving firms emit more or less per unit of output than what they had in 2005;

(iii.) ‘The composition effect,’ or the production shift among surviving mills allows us to analyze whether or not the mills that were ‘cleaner’ or more efficient in 2005, grew or shrank as a share of total output produced by the ‘survivors’. In other words, it estimates whether or not the weight of production shifts to more or less polluting firms, i.e. it looks into where, keeping emission intensities constant at the base period, production shifts towards, i.e. it looks into whether or not the shift in output favors more or less efficient mills;

(iv.) Finally, ‘mill closures’ estimate the effect of production shift on emission intensity relative to the total number of mills that were operating in 2005. This allows us to look into whether or not the more, or the less polluting mills were getting ‘knocked out’ or shut down in 2013.

5.2 Methodology for GHG emissions

For the estimation of GHG emissions, a slightly different model was employed to additionally take into account the energy substitution and energy efficiency effects. Total pollution by mill i in period t can be represented by the following:

$$p_{it} = \frac{K_1 \cdot EN_{it}^1 + K_2 \cdot EN_{it}^2 + K_3 \cdot EN_{it}^3}{EN_{it}} \cdot \frac{EN_{it}}{v_{it}} \cdot v_{it} \quad (5)$$

Where, K_s is the emission intensity of energy source s by mill i ; EN_{it}^s is the use of energy source s by plant i at period t ; and EN_{it} is the ratio of the total energy consumption of the mill i in period t , i.e. total fuel consumed in TJ and total purchased electricity in TJ.

This can also be represented as:

$$p_{it} = g_{it} \cdot ef_{it} \cdot v_{it} \quad (6)$$

Where, g_{it} is the emission intensity of mill i in period t ; while ef_{it} is the energy efficiency of the mill i in period t . It is the ratio of total energy over the total output produced by mill i in period t . While v_{it} is again, the total output produced by mills i in period t .

The total GHG emission of mill i in period t , is thus the product of emission intensity, energy efficiency, and output. In the case of 3 mills, we have:

$$P_t = g_{1t} \cdot ef_{1t} \cdot v_{1t} + g_{2t} \cdot ef_{2t} \cdot v_{2t} + g_{3t} \cdot ef_{3t} \cdot v_{3t} \quad (7)$$

$$= V_t (g_{1t} \cdot ef_{1t} \cdot \theta_{1t} + g_{2t} \cdot ef_{2t} \cdot \theta_{2t} + g_{3t} \cdot ef_{3t} \cdot \theta_{3t}) \quad (8)$$

We assume that mill-1 exists only in period-1:

$$\frac{P_2}{P_1} = \frac{V_2 (g_{22} \cdot ef_{22} \cdot \theta_{22} + g_{32} \cdot ef_{32} \cdot \theta_{32})}{V_1 (g_{11} \cdot ef_{11} \cdot \theta_{11} + g_{21} \cdot ef_{21} \cdot \theta_{21} + g_{31} \cdot ef_{31} \cdot \theta_{31})} \quad (9)$$

$$= \frac{V_2}{V_1} \cdot \frac{g_{22} \cdot ef_{22} \cdot \theta_{22} + g_{32} \cdot ef_{32} \cdot \theta_{32}}{g_{21} \cdot ef_{22} \cdot \theta_{22} + g_{31} \cdot ef_{32} \cdot \theta_{32}} \cdot \frac{g_{21} \cdot ef_{22} \cdot \theta_{22} + g_{31} \cdot ef_{32} \cdot \theta_{32}}{g_{21} \cdot ef_{21} \cdot \theta_{22} + g_{31} \cdot ef_{31} \cdot \theta_{32}} \cdot \frac{g_{21} \cdot ef_{21} \cdot \theta_{22} + g_{31} \cdot ef_{31} \cdot \theta_{32}}{g_{21} \cdot ef_{21} \cdot \theta_{21} + g_{31} \cdot ef_{31} \cdot \theta_{31}} \cdot \frac{g_{21} \cdot ef_{21} \cdot \theta_{21} + g_{31} \cdot ef_{31} \cdot \theta_{31}}{g_{11} \cdot ef_{11} \cdot \theta_{11} + g_{21} \cdot ef_{21} \cdot \theta_{21} + g_{31} \cdot ef_{31} \cdot \theta_{31}} \quad (10)$$

(i.) (ii.) (iii.) (iv.) (v.)

Where, $\theta_{i1}^* = \theta_{i1} / (\theta_{21} + \theta_{31})$ for $i = 1, 2$ and $\sum_{i=2}^3 \theta_{i1}^* = 1$.

So the relative change of total emission between two periods can be decomposed into five factors:

- i. Total industry output;
- ii. Emission intensity of energy use;
- iii. Energy efficiency;
- iv. Output share;
- v. Mill closure.

The interpretation of the decomposition effects remains the same as in the previous model, however, there are two additional factors included here. From equation (10), the additional effects are:

- (i.) The ‘emission intensity of energy use,’ estimates the emission per unit of energy. Different sources of energy sources have different emissions per unit of energy, and changing the energy mix of the energy sources changes the emission levels. Shifts away from heavy fuels to relatively less emitting energy sources, such as natural gas, would thus improve emission intensity.
- (ii.) The ‘energy efficiency effect,’ estimates the energy use per unit of output. This depends on two factors: substitution effect and technical effect. The former refers to changes in energy efficiencies because of changing the sources of energy, e.g. fossil fuels, natural gas, etc., while the latter refers to technological improvements that allow for more output using the same energy input, or producing the same output with less energy inputs.

6.0. Results

6.1. BOD

Table 1 presents the information on the relative changes in BOD emissions for each category of mills. For category 1, the number of mills operating in our sample for the base year 2005, were 19 mills. Total BOD was 14, 604 tons per year, while total output was 7, 778, 759 metric tons. The BOD intensity, which is simply the ratio of the total BOD emission in tons per year divided by the total output in metric tons, is around 0.0018. While in the final year, 2013, there were 15 mills in operation: four mills had shut down.

The relative change in total BOD for Category 1 mills in 2013 were about 89% its level in 2005. This implies that total BOD emission went down by 11% for this category. In terms of decomposing the change, total output also went down in 2013 compared to 2005 by about 17%. The relative change in the emission intensity of the surviving mills went down by only about 1.1%. Thus implying that the surviving mills were emitting less in 2013 than their pollution levels in 2005. However, in terms of the effect of production shift, the shift in output favored more polluting mills, by 7%, and, in terms of the final decomposition factor—the role played by mills closure—we notice that more efficient (less emitting) mills got knocked out, but only marginally, by less than 1%.

For category 2, there were 8 mills operating in 2005 in our sample. The total BOD emitted by the mills were 4,969 tons per year, with a total output of 2,203,356 metric tons. The BOD intensity was about 0.0022. While in 2013, there were 7 mills in our sample: one mill having shut down. The total amount of BOD emitted in 2013 was 2, 282 tons per year, while total output fell to 1, 154, 388 metric tons. The BOD intensity fell to about 0.00198.

Overall, the relative change in total BOD was about 46%, i.e. total BOD emitted in 2013 fell by 54% from 2005. The particular mill that got shut down thus had a substantial share of both, relative output and pollution amongst the other mills in the same category. The total output decreased by about 47%, while emission intensity changes of the surviving mills fell by about 4%. Production shifted towards less emitting mills by about 16%. However, the effect of the single plant closure was that the production shift increased emissions by about 8%.

Category 3 had the most number of mills in our sample. In 2005, there were 32 mills, with a total BOD of 8,763 tons per year, and a total output of 10, 180,824 metric tons. The BOD intensity was 0.0008. While in 2013, there were 21 mills surviving: 11 mills having shut down. The total BOD in 2013 was 4,057 tons per year, while output fell to 5,613,694 metric tons. The overall relative change in BOD emissions for this category was about a 54% decrease in BOD emissions. Output also decreased but to a lesser extent—by 45%. The emission intensity of the survivors increased marginally by about 1%, i.e. the survivors were emitting slightly more than their 2005 levels. And, in terms of the effect of production shift, the shift in output favored the less efficient mills by about 3%. Nonetheless, in terms of the effect of production fall due to mill closure on emission intensity relative to the total number of mills in 2005, the least efficient mills got shut down, by about 20%. This is in-line with our expectations regarding this effect.

Finally, for category 4, there were 13 mills included in our sample for 2005, with a total BOD emission of 5,352 tons per year, and a total output of 1,006,999 metric tons. And, in 2005, there were 10 mills left: 3 mills having been shut down. The relative change in total BOD was a 27% reduction in emission, while there was a 25% decrease in output in 2013 since 2005. The emission intensity changes of the surviving mills fell by 11%, so the survivors were emitting 11% less than they were in 2005. The effect of production shift was a 16% decrease, implying that production shifted more in favor of more efficient mills. With respect to the effect of plant closure on emission intensity, there was a 31% increase, implying that mills that were more efficient, i.e. were emitting less, had shut down.

The last row of Table 1 indicates the geometrically weighted mean of each of the decomposed factors. The weights across categories were calculated by multiplying BOD emissions of a mill in 2005 over the total emission of mills in that particular category over the same year. This allows us to weight each category according to their total pollution relative to the other categories in the initial year, and provides an estimate of the weighted overall relative changes.

The weighted share total for the relative change in BOD was a decrease in BOD emissions by 34% in 2013 compared to their levels in 2005, while total output fell by about 31%. The emission intensity changes of the surviving mills were about a 2.7% reduction in emission by the surviving mills in 2013. The effect of production shift was very small: about a 1.3% reduction. While the effect of mill closure on emission intensity had hardly changed (0.2%). Therefore, with respect to BOD emissions, the reduction in total emissions was mostly due to the reduction in output in 2013 than compared to 2005. The surviving mills in 2013 were in fact slightly more efficient in terms of emission intensity than in 2005, and the more efficient mills had a greater share of production in 2013, than they had in 2005. And, the mill closure effect remained more or less stagnant, implying that neither the relatively more, or the relatively less efficient, or 'dirtier' mills got 'knocked out' of the industry after 2005.

Table 1: BOD

Category	Year	Total BOD (t/year)	Total Output (metric tons)	BOD Intensity	Emission intensity of the surviving mills	Production shift among surviving mills	Mill Closure
1	2005 (19 Mills)	14,604.32	7,778,759.00	0.00187746			
	2013 (15 Mills)	13,001.71	6,464,541.00	0.00201123			
Relative change (2013/2005)		0.89026454	0.83105043		0.98945211	1.07290365	1.00910461
2	2005 (8 Mills)	4,969.00	2,203,356.00	0.00225520			
	2013 (7 Mills)	2,282.37	1,154,388.00	0.00197713			
Relative change (2013/2005)		0.45932242	0.52392260		0.96197646	0.84110811	1.08351330
3	2005 (32 Mills)	8,763.36	10,180,824.94	0.00086077			
	2013 (21 Mills)	4,057.41	5,613,694.16	0.00072277			
Relative change (2013/2005)		0.46299650	0.55139875		1.01021813	1.03431800	0.80360510
4	2005 (13 Mills)	5,352.36	1,006,999.00	0.00531516			
	2013 (10 Mills)	3,898.73	748,474.00	0.00520891			
Relative change (2013/2005)		0.72841382	0.74327184		0.88583906	0.84244877	1.31320418
Total (All Categories)	2005 (72 Mills)	33,689.05	21,169,938.94	0.00159136			
	2013 (53 Mills)	23,240.22	13,981,097.16	0.00166226			
Weighted Share Totals		0.659817337	0.685533253		0.973430415	0.986612718	1.002175052

6.2. TSS

Table 2 presents the change in total TSS in 2013 relative to 2005. The data on mill numbers and production are identical to BOD. For category 1, total TSS was 25,487 tons per year, while total output was 7,778,759 metric tons. The TSS intensity, which is simply the ratio of the total TSS emission in tons per year divided by the total output in metric tons, is around 0.00327. While in the final year, 2013, there were 15 mills in operation: four mills had shut down.

Total TSS emissions decreased by 18% relative to 2005 levels. Output also went down by a similar amount, by about 17%. The emission intensity change of the surviving mills went down by about 12.5%, implying an efficiency gain. In terms of the effect of a production shift, the shift in output favored the less efficient mills by 8%. And with respect to the effect of the role played by mills closures, there was an increase by about 4.25%, thus implying that more efficient than average mills got shut down.

For category 2, there were 8 mills operating in 2005, with total TSS emissions of 7,656 tons per year and a total output of 2,203,356 metric tons. The TSS intensity for 2005 was 0.00347512. And in 2013, only one mill shut down, thus leaving the sample with 7 mills for 2013. The total amount of TSS emitted was 2,423 tons per year, while total output was 1,154,388 metric tons. The TSS intensity was 0.0021.

The relative change in total TSS emissions was thus about 68%, while total output went down by about 48%. The emission intensity changes of the surviving mills went down by 31%, indicating that the surviving mills emit less than they did in 2005. The effect of a production shift was a decrease by 11%, indicating that shift in output favored the more efficient mills, while the effect of plant closure shift on emission intensity was a 3% decrease, indicating that the ‘dirtier’ or less efficient mills got shut down.

In category 3, the total TSS emitted by the 32 mills in our sample was 20,454 tons per year, while total output was 10,180,824 metric tons. The TSS intensity for the year was 0.0021. In 2013, 11 mills were closed, and thus our sample contained, identical to the BOD data, 21 mills. The total TSS emitted by the mills were 12,315 tons per year, while the total output fell to 5,613,694 metric tons. The TSS intensity for the year was 0.0022.

The relative change in total TSS for the year was about a 40% reduction in emission relative to 2013 levels. Total output decreased by about 45% in the time period, while emission intensity changes of the surviving mills improved by about 3%. The effect of production shift saw an increase of about 16%-- thus indicating that the shift in production favored the less efficient mills. And the effect of mill closure on emission intensity was also a reduction by about 3% indicating that the 'dirtier' or less efficient mills shut down from this category.

For the final category, category 4, there were 13 mills operating in 2005, with total TSS emission of 3,798 tons per year and a total output of 1,006,999 metric tons. The TSS intensity that year was 0.0038. While in 2013, the number of mills dropped to 10: there were three shutdowns. The total TSS in 2013 emitted was 1558 tons per year, while total output produced by the 10 mills in this category was 748,474 metric tons. The TSS intensity was 0.0021.

The relative change in TSS emissions for this category was about a 59% reduction in TSS emissions in 2013, compared to 2005 levels. The emission intensity changes of the surviving mills fell by about 56%. The effect of production shift saw about a 4% decrease in the shift in output favoring the more efficient mills. However in terms of plant closure on emissions, there was about a 28% increase, implying that the less emitting mills were being shut down.

Overall, the change in the weighted share totals indicate that total TSS emission in 2013 relative to 2005 improved by about 38%, with a corresponding output decrease by 33%. In terms of the emission intensity changes of the surviving mills, there was a 16% decrease, indicating that the survivors were emitting 16% less than they were in 2005. However, in terms of the effect of production shift, there was about a 7% increase in the shift of production favoring the less efficient mills, while there was about a 2% increase in terms of the effect of plant closure on emissions, i.e. relatively more efficient or 'cleaner' mills got shut down. And so, in line with our expectations, TSS emissions fell, but this was primarily due to a drop in output. Although the emission intensity changes of the surviving mills improved, contrary to our expectations, the effect of production shift, and the mill closure effect deteriorated, but only marginally, i.e. the cleaner mills got shut down, but only slightly.

Table 2: TSS

Category	Year	Total TSS (t/year)	Total Output (metric tons)	TSS Intensity	Emission intensity of the surviving mills	Production shift among surviving mills	Mill Closure
1	2005 (19 Mills)	25,487.11	7,778,759.00	0.00327650			
	2013 (15 Mills)	20,818.45	6,464,541.00	0.00322041			
Relative change (2013/2005)		0.81682280	0.83105043		0.87523429	1.07717961	1.04252870
2	2005 (8 Mills)	7,656.93	2,203,356.00	0.00327650			
	2013 (7 Mills)	2,423.63	1,154,388.00	0.00322041			
Relative change (2013/2005)		0.31652803	0.52392260		0.69392730	0.89393495	0.97392407
3	2005 (32 Mills)	20,454.28	10,180,824.94	0.00200910			
	2013 (21 Mills)	12,315.04	5,613,694.16	0.00219375			
Relative change (2013/2005)		0.60207644	0.55139875		0.97244199	1.15649121	0.97091214
4	2005 (13 Mills)	3,798.18	1,006,999.00	0.00377178			
	2013 (10 Mills)	1,558.75	748,474.00	0.00208257			
Relative change (2013/2005)		0.41039340	0.74327184		0.44935024	0.96088280	1.27878361
Total (All Categories)	2005 (72 Mills)	57,396.50	21,169,938.94	0.00271123			
	2013 (53 Mills)	37,115.87	13,981,097.16	0.00265472			
Weighted Share Totals		0.61689553	0.67019204		0.84297707	1.06953942	1.02093905

6.3. GHG

The total GHG emission for the mills in category 1 in 2005 was 2,308,981 tons of equivalent carbon dioxide, while total output produced was 9,351,841 metric tons, with a total of 26 mills in our sample. The resulting GHG intensity was 0.2469. The number of mills falls to 17 in 2013: a drop of 9 mills. Total GHG emissions fell to 1,851,702.86 tons of equivalent carbon dioxide, while reducing total output to 7,020,946 metric tons. The GHG intensity was 0.2637—and deterioration by about 2%.

The relative change in total GHG emissions in 2013, compared to 2005 improved by about 20%, while output fell a bit further, by about 25%. However, the emission intensity of energy use worsened by about 13%. The energy efficiency also deteriorated, by about 5%. Nonetheless, the output share saw improvements by about 4%, while the mill closure reduced emissions by 7%.

In category 2, there were 7 mills in our sample for 2005. The total GHG emission of these mills were 603,935 tons of equivalent carbon dioxide, while total output produced was 2,428,130 metric tons. The GHG intensity that year was 0.2487. In 2013, there were 5 mills remaining in our sample: 2 mills had shut down. Total GHG fell to 274,351 tons of equivalent carbon dioxide, and output to 928,536 metric tons. The GHG intensity in 2013 deteriorated by about 4% to 0.29547.

The total relative change in GHG emissions for this category entailed a 55% reduction in total GHG emissions, while output dropped by a larger magnitude, by about 62%. The emission intensity of energy use improved by about 13%, while the energy efficiency deteriorated by around 14%. The output share improved by only 1%. Mill closures, on the other hand, worsened, deteriorating by about 20% in 2013.

For the mills in category 3, there were a total of 32 mills in our sample for 2005, with a total GHG emission of 603,935 tons of equivalent carbon dioxide. The total output produced by mills in this category that same year was 9,862,989 metric tons. And, the GHG intensity was 0.2120. However, in 2013, the number of mills in our sample dropped to 19: 13 mills had shut down from this category. Yet the GHG intensity improved, falling by about 13%.

The total relative change for mills in this category was a substantial drop in total GHG emissions, falling by about 66% in 2013, relative to 2005 levels. The total output also fell substantially,

however, by a lesser magnitude: by about 44%. The emission intensity saw a noticeable improvement, by about 30%, while energy efficiency deteriorated by about 5%. Output also failed to improve, but to a minimal extent, by about 1.4%. Mill closures, however, contributed to an improvement by about 18%.

For category 4, our sample included 15 mills in 2005, with a total GHG emission of 487, 819 tons of equivalent carbon dioxide. The total output produced this year was 1, 068, 069 metric tons, while the GHG intensity was 0.4567. And, in 2013, the number of mills dropped to 12: 3 mills having shut down. The total levels of GHG emissions fell to 340, 417 tons of equivalent carbon dioxide, while total output fell to 836, 534 tons. The GHG intensity, however, improved to 0.4069.

The total relative change in GHG emissions in 2013 compared to 2005, in terms of weighted share totals, therefore improved by about 46%. Total output fell but to a lesser extent, falling by about 38%. The emission intensity saw an improvement by about 10%, while energy efficiency deteriorated by 2.7%. Nevertheless, both output, and mill closures contributed to improving emissions by a marginal 1% and about 7%, respectively.

Therefore, again, consistent with our expectations, we notice a reduction in total absolute GHG emission in 2013 compared to 2005, however, this can be attributed mostly to the fall in output over the period. And, again, in-line with our expectation, we observe mills adopting cleaner sources of energy than in 2005. The emission intensity deteriorates by only slightly, by 2.7% indicating that the mills operating in 2013 did not make more efficient use of their energy, although they did adopt cleaner sources of fuel. And, the values for the changes in output and mill closure, shows that the dirtier mills got shut down in 2013, relative to 2005. Thus, the most impact on the relative levels of emission was due to production decrease, followed by the use of cleaner energy and the closure of more 'dirty' mills. Energy efficiency improvements and production shift across surviving mills had limited effects.

Table 3: GHG

Category	Year	Total GHG (t CO ₂ e)	Total Output (metric tons)	GHG Intensity	Emission intensity of energy use	Energy Efficiency	Output Share	Mill Closure
1	2005 (26 Mills)	2,308,981.86	9,351,841.78	0.24690130				
	2013 (17 Mills)	1,851,702.98	7,020,946.65	0.26373979				
Relative change (2013/2005)		0.80195649	0.75075550		1.13323211	1.05233417	0.96059569	0.93247909
2	2005 (7 Mills)	603,935.98	2,428,130.37	0.24872469				
	2013 (5 Mills)	274,351.97	928,536.68	0.29546702				
Relative change (2013/2005)		0.45427327	0.38240808		0.87121642	1.13777612	0.99450649	1.20503491
3	2005 (32 Mills)	2,091,117.65	9,862,989.82	0.21201661				
	2013 (19 Mills)	715,404.21	5,512,684.56	0.12977420				
Relative change (2013/2005)		0.34211571	0.55892632		0.702833235	1.045518349	1.010419874	0.824389848
4	2005 (15 Mills)	487,819.37	1,068,069.38	0.45673004				
	2013 (12 Mills)	340,417.92	836,534.00	0.40693854				
Relative change (2013/2005)		0.69783601	0.78322065		0.91921379	0.74752709	1.15557192	1.12209287
Total (All Categories)	2005 (80 Mills)	5,491,854.85	22,711,031.35	0.24181442				
	2013 (53 Mills)	3,181,877.08	14,298,701.89	0.22252909				
Weighted Share Totals		0.537980373	0.625346525		0.900928275	1.027103995	0.999283026	0.930363244

7.0 Conclusion

In this paper I analyze the relative changes in the total BOD, TSS and GHG emissions in the pulp and paper sector in Canada from 2005 to 2013. In order to achieve this, a statistical decomposition technique is applied that entails measuring changes in total output; emission intensity; production shift across mills; and mill closures. Consistent with our expectation, the total emission levels for all three pollutants decreased in 2013 compared to their levels in 2005. The relative improvements in BOD and TSS levels were by about 34% and 38%, respectively. While for GHG emissions, the relative improvement was by about 46%. The major driving force behind these reductions has been the decrease in output that in turn, has been a result of substantial number of mill closures over the sample period—from 156 mills operating in 2005 to 84 in 2013, while the emission intensity; shift in output among surviving mills; and mill closures had much smaller effects. Subsequently, the evolution of the industry that is mostly determined by economic factors leading to production shift and mill closures, does not necessarily lead to better performance with respect to pollution emission. Other factors such as localisation, wood supply, transportation, and energy costs play important roles in determining the surviving mills.

References

- Julie, A; Bernard, J-T and González, P. *Energy Use and GHG Emissions in the Quebec Pulp and Paper Industry. 1990–2006*. Canadian Public Policy Volume 38, Number 1, March/mars 2012 pp. 71-90 | 10.1353/cpp.2012.0003
- Brunel, C. 2014. *Pollution offshoring and emission reductions in EU and US manufacturing*. Unpublished manuscript, Social Science Research Network. Retrieved from <http://ssrn.com/abstract=2447679>
- CIEEDAC. *A Review of Energy Consumption and Related Data Canadian Manufacturing Industries: 1990, 1995, 2009*. Accessed at 29 November 2015 at http://cieedac.sfu.ca/media/publications/Pulp%20Paper%20Analysis%202010%20_2009%20data_%20Final.pdf
- Cole, M.A. 2000. *Air pollution and “dirty” industries: How and why does the composition of manufacturing output change with economic development?* Environmental and Resource Economics 17:109–23.
- FPAC Sustainable Report: 2009. Accessed 29 November 2015 at http://www.fpac.ca/publications/Sustainability_Report_2009-e.pdf

- Hailu, A. and Veeman, T.S, 2000. *Environmentally Sensitive Productivity Analysis of the Canadian Pulp and Paper Industry, 1959-1994: An Input Distance Function Approach*. Journal of Environmental Economics and Management, Elsevier, vol. 40(3), pages 251-274.
- Hailu, A. and Veeman, T.S. 2000. *Output scale, technical change, and productivity in the Canadian pulp and paper industry*. Canadian Journal of Forest Research 30:7, 1041-1050.
- Hettige, H, Lucas, R.E.B and Wheeler, D. 1992. *The toxic intensity of industrial production: Global patterns, trends, and trade policy*. American Economic Review Papers and Proceedings 82, no. 2:478–81
- Hydro Quebec. 2013. *Comparison of electricity prices of major North American cities*. Retrieved from: http://www.hydroquebec.com/publications/en/docs/comparaison-electricity-prices/comp_2013_en.pdf
- Levinson, A. 2008. *Technology, international trade, and pollution from US manufacturing*. National Center for Environmental Economics. Working Paper # 08-02
- Levinson, A. 2009. *Technology, international trade, and pollution from US manufacturing*. American Economic Review 99, no. 5:2177–92
- Levinson, A. 2014. *A Direct Estimate of the Technique Effect: Changes in the Pollution Intensity of US Manufacturing, 1990–2008*. JAERE, volume 2, number 1. Retrieved from <http://dx.doi.org/10.1086/680039>

Ministry of Finance, British Columbia. n.d. *Carbon Tax*. Accessed 29 November 2015 at

http://www.fin.gov.bc.ca/tbs/tp/climate/carbon_tax.htm

Murray, W.1992. *Pulp and Paper: The Reduction of Toxic Effluents*. Retrieved from

<http://publications.gc.ca/Collection-R/LoPBdP/BP/bp292-e.htm>

Natural Resources Canada. n.d. *Forest Industry Carbon Emissions*. Accessed 29 November 2015 at

<http://www.nrcan.gc.ca/forests/industry/changes/16590>

Natural Resource Canada. n.d. *Overview of Canada's Forest Industry*. Accessed 28 November 2015 at

<http://www.nrcan.gc.ca/forests/industry/overview/13311>

Natural Resources Canada. September 2012. *Pulp and Paper Green Transformation Program: Report*

on Results. <http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/34045.pdf>

Natural Resources Canada. n.d. *Statistical Data*. Accessed 29 November 2015 at

<https://cfs.nrcan.gc.ca/statsprofile>

Natural Resource Canada. February 2013. *Selective Cuttings*. Retrieved from

<http://cfs.nrcan.gc.ca/selective-cuttings/14>

Ontario Energy Board. n.d. *Natural Gas Rates — Historical*. Accessed 28 November 2015 at

<http://www.ontarioenergyboard.ca/OEB/Consumers/Natural+Gas/Natural+Gas+Rates/Natural+Gas+Rates++Historical>