# Three essays on environmental economics:

# Subsidies, Free Riding, and Public Shaming

**Edward Dylan Morgan**

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Department of Economics

Faculty of Social Sciences

University of Ottawa

# Abstract


**Chapter 1: When Environmental Subsidies Backfire: The Case of Black Liquor and the Alternative Fuel Mixture Tax Credit:**

In 2005, the US government introduced the Alternative Fuel Mixture Tax Credit (AFMTC), which paid fifty cents/gallon for alternative fuel that was mixed and burned with traditional fuel. The American chemical pulp industry, which has traditionally burned 'Black Liquor', a residue of the pulping process, was able to make large claims on this subsidy in 2009 by mixing diesel fuel into a process where it was not required. This scenario exhibits two main downfalls of environmental subsidies: (i) the majority of the subsidy is paid to free-riders, and (ii) there are strong incentives towards overproduction and increased pollution.

In this paper, the value of the AFMTC per tonne of chemical pulp is computed and used in a simulation using the Global Forest Products Model (Buongiorno, 2001) to calculate the effects of the AFMTC on the American and Canadian chemical pulp industries. The simulation suggests that the total amount paid to the American chemical pulp industry was US$7.63 billion, that American chemical pulp production rose by 2.5 million tonnes from the baseline, and Canadian production and exports to the US fell by 285,000 and 255,000 tonnes respectively, costing Canadian chemical pulp producers US$132 million in lost production. Using Canadian chemical pulp production and pollutant release data, production/release averages were developed. These averages suggest that the increase in American chemical pulp production led to significant increase in releases of greenhouse gases, hydrogen sulfide, sulfur oxides, nitrogen oxides and particulate matter.

**Chapter 2: The Alternative Fuel Mixture Tax Credit and the Pulp and Paper Green Transformation Program: A Policy Comparison:**

In 2009, chemical pulp mills in the US and Canada were able to take advantage of two subsidy programs that paid mills fifty cents for every gallon of 'Black Liquor' burned during the pulping process. Black Liquor is a residue product from the production of chemical pulp, and is traditionally used as a fuel in further pulp production. These subsidies were the Alternative Fuel Mixture Tax Credit (AFMTC) in the US and the Pulp and Paper Green Transformation Program (PPGTP) in Canada. Even though the AFMTC was a subsidy that applied to many industries, and the PPGTP was only available to chemical pulp mills, in the context of the chemical pulp industry only, the subsidies were almost identical: Both paid mills the same amount for undertaking the same activity, and mills were able to claim the subsidies for roughly the same amount of time. The key difference between the two programs was stipulations on how the money was to be spent. In the US, the AFMTC was a refundable tax credit, and simply another source of revenue for a recipient mill. In Canada, a recipient of PPGTP funds was required to spend the money on some form of capital investment that would increase energy efficiency or lower pollution emissions from the mill.

In this paper, we develop a theoretical model with a representative chemical pulp mill in order to compare the effects that these two subsidies would have on the mill's production of pulp (and in turn its production and use of black liquor), and its decision in whether to invest in a one-time capital improvement that would increase energy efficiency at the mill. The results from this model show that the PPGTP was a more effective policy than the

AFMTC, in that it encouraged increased investment in energy efficiency, whereas the AFMTC did not. However, the PPGTP provides incentives to increase production, similar to the AFMTC, in two out of three possible outcomes. Even though the PPGTP is shown to be more effective than the AFMTC, it still exhibits several properties inherent in a second-best policy - because the subsidy is tied to production, it encouraged increased production, and may not have allocated funding in an efficient manner.

**Chapter 3: Naming, Shaming, and Abatement: Do Published 'Top Emitter' Lists Provide Incentive for Increasing Pollution Prevention Activities?**

Several works have measured the effects that publically disclosed pollutant release information has on the firms and facilities reporting the information. Most of these studies quantify the negative response that the information garners with the media, through some measure of media coverage, and measure the negative impact that this attention has on the firm; for example, by showing a negative effect on the respective company's publically traded stock performance. Subsequent studies have then shown how these negative impacts from publicity cause firms to report lower emissions levels in following years. What is currently missing from this body of literature, however, is an examination of the step in between the firm receiving negative press and reporting lower emissions, namely, increased pollution abatement efforts on behalf of the publically labeled facility.

In this paper, we attempt to gain a better understanding of this relationship by examining Canadian self-reported facility level data on pollution prevention activities from the National Pollutant Release Inventory. Two consistent samples of data are used to empirically test the effects that 'Top Ten' emitter lists, published by Environment Canada in the late 1990's, had on the number of pollution prevention activities undertaken by facilities in the following year. The results from this work were inconclusive: Between these two samples, there was a noticeable decrease in the amount of pollution prevention activities reported in years after the cessation of the Top Ten publications. Under certain model specifications, a facility that was labeled as a Top Ten emitter is estimated to have 20% more pollution prevention activities undertaken compared to a facility that was not so labeled. It was also shown that a firm that reported new pollution abatement activities also had a significant reduction in releases. This finding, along with the decreasing trend in reported activities, raises a significant policy issue, as measures that clearly reduce reported emissions are being reported with less frequency in Canada.

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# General Introduction

This thesis explores three different questions in environmental economics. The first two chapters examine two similar fuel-use and investment subsidy programs that were enacted in the United States (US) and Canada in 2009; the Alternative Fuel Mixture Tax Credit (AFMTC) in the US and the Pulp and Paper Green Transformation Program (PPGTP) in Canada. These policies had significant impacts on the pulp and paper industries of both countries. The first chapter focuses exclusively on the AFMTC and uses a simulation to quantify the impact that this subsidy had on increased production in the US pulp and paper industry, and in turn, how this increased production affected the same industry in Canada. The second chapter uses a theoretical model of a pulp mill to compare and contrast the different incentives towards increased production and investment in energy efficiency provided by both the AFMTC and the PPGTP. The third chapter uses Canadian facility level data to examine the effect of being publically labeled as a 'Top Emitter' on a facility's pollution abatement effort in the following year.

Chapter 1, titled, When Environmental Subsidies Backfire: The Case of Black Liquor and the Alternative Fuel Mixture Tax Credit, provides a case study for how a well-intentioned environmental subsidy can provide incentives to decision agents that cause behavior that is not consistent with, or, in some cases completely contrary to, the initial goal of the policy maker. In the case of the AFMTC, a subsidy was paid to business operators for the use of fuel mixtures that included a specified alternative fuel and a traditional fossil fuel. US pulp and paper mills were able to make claims on this subsidy for burning wood pulp residue, black liquor, which is a practice that has taken place since the 1930s. This lead to a substantial amount of money being given to this industry – some early sources claimed that pulp mills made more money during 2009 by collecting on the subsidy than they did making pulp. Also, since black liquor production is directly tied to pulp production, a subsidy that was originally meant to foster the use of alternative fuels compensated pulp mills for producing pulp.

This chapter calculates the amount that pulp mills received from the AFMTC per unit of pulp produced, and uses this figure in a simulation of the forestry products sector, using the Global Forest Products Model (Buogiorno. 2003), to quantify the increased production of US chemical wood pulp due the incentives brought on by the AFMTC. We also use this simulation to estimate the total amount paid to the industry, and how the increased production affected the Canadian chemical pulp industry. Finally, using plant level production and emissions data, we calculate the amount of increased air pollution resulting from US chemical pulp mills increasing production in order to maximize revenue from the AFTMC.

Chapter 2, titled, The Alternative Fuel Mixture Tax Credit and the Pulp and Paper Green Transformation Program: A Policy Comparison, uses a theoretical model of a single pulp mill to compare and contrast how four policy scenarios affect incentives for production and the decision of whether or not to invest in a one-time upgrade to the mill’s energy efficiency. This chapter examines two very similar real-world policies, the AFMTC and the PPGTP, with a no-policy scenario and a proposed alternative scenario that addresses potential market failures directly through a combination of a tax on fossil fuel use and a subsidy for investment in energy efficiency.

The PPGTP was introduced in Canada as a response to the AFMTC in the US. These subsidies were identical in all ways but one: Recipient mills of the PPGTP had to use the funds towards an approved investment in the mill's energy efficiency, whereas the AFMTC simply paid mills with no criteria on how the money was to be spent. This work shows that the PPGTP was a superior policy in terms of enticing the mill to invest, but that it is still inefficient in two ways. The first is that, like the AFTMC, it too encourages the mill to produce more than it otherwise would have. Second, as the amount received is directly related to pulp production, it is likely that more was paid out to mills than was necessary in order to encourage investment, as compared to a policy that would have paid the mill a direct investment subsidy.

Chapter 3, titled, Naming, Shaming, and Abatement: Do Published 'Top Emitter' Lists Provide Incentive for Increasing Pollution Prevention Activities?, empirically examines the relationship between public 'shaming' lists of top polluters and a facility's willingness to undertake pollution prevention activities. This chapter uses Canadian facility level data on pollutant emissions that is publically available from Canada's National Pollutant Release Inventory (NPRI) program. During the 1990s, the NPRI published Top Ten lists of emitters for each substance that was reported to the program, and in 1997, the NPRI started collecting information on pollution prevention activities. This gives a three year window where this relationship can be examined.

Most of the previous work on publically available emissions data and bad press from the media and their effects on facilities have so far only examined these relationships in terms of a firm's emissions after the information is published or cited (Hamilton, 1995; Konar and Cohen, 1997; Khanna, Quino and Bojilova, 1998; De Marchi and Hamilton, 2006;

Camp, Forthcoming). This leaves out a key explanatory factor in this relationship, namely, how exactly the facility lowers their emissions in the face of bad press. This is especially relevant for policy makers: Most regulators would agree that lowered emissions are a positive outcome, but possibly not at the expense of production. The work for this chapter is the first to include some measure of abatement effort into this relationship. While the link between increased abatement effort and lowered emissions was able to be shown, the link between being published as a top emitter and increased abatement effort was not conclusive. Also, this work highlights a decreasing trend in the reported number of pollution abatement activities from facilities in the examined sample between 1998 and 2003, which may be of some concern to environmental regulators.

# Chapter 1.When Environmental Subsidies Backfire: The Case of Black Liquor and the Alternative Fuel Mixture Tax Credit[1]

## Introduction

One effective way to reduce environmentally harmful behavior is through the use of taxes. Several researchers have shown that a Pigovian tax, or a direct tax on environmentally harmful emissions, unambiguously reduces pollution emissions from producing firms (e.g. Baumol & Oates, 1988; Conrad & Wang, 1993; Mestleman, 1982). This result holds over a wide range of model assumptions and settings. A tax on a good with environmentally harmful effects, paid by the final consumer, could have similar effects. Examples include the Gas-Guzzler taxes introduced on vehicles with low gas mileage in the United States (U.S. Environmental Protection Agency, 2009), or the five-cent-per-bag tax levied on plastic grocery bags in several municipalities across Canada (City of Toronto: Solid Waste Management, 2010).

Not only does a tax reduce the taxed behavior, and thus the negative environmental consequences that arise from it, but it also introduces a new revenue source for the governing body imposing the tax. If the goal of the tax is to alter an agent's behavior to reduce harm to the environment, then it may seem logical to apply the tax revenues to subsidize environmentally friendly alternative behaviors, with the goal of further reducing harm to the environment. In this way, the environmental tax in question could have a doubled environmental benefit. Following directly from the examples above, a subsidy could be funded by a Gas-Guzzler tax, such as Canada's EcoAuto rebate program, which subsidized

[1] Tables and figures for Chapter 1 are located in Appendix A

the purchase of fuel efficient vehicles (Transport Canada, 2010). Similarly, there is the possibility of using the revenue generated from a plastic bag tax to subsidize the production or purchase of reusable cloth grocery bags.

However, there are several pitfalls faced by policy makers attempting to enact an environmental subsidy. In particular, there are three potential pitfalls of the subsidy approach. First, subsidies generally cost more than their face value, as they usually have to be financed directly by distortionary taxation if it is not paired with a corresponding environmental tax, or if the subsidy costs more than expected. Second, most subsidies are captured by free riders – firms or individuals that were going to undertake the subsidized activity anyway. Third, subsidies that reward agents in proportion to the desired activity (e.g. abatement of emissions or consumption of an alternative fuel) can have the perverse effect of actually increasing output within a sector, thus increasing overall pollution, contrary to the policymakers' intention.

An example of an environmental subsidy that exhibits all three of the above mentioned pitfalls is the Alternative Fuel Mixture Tax Credit (AFMTC). The AFMTC subsidy was a tax credit implemented by the US government in 2005 to encourage firms to substitute alternative and renewable fuels for traditional fossil fuels (U.S. Congress, 2005). In 2008, the legislation was amended to include more industries, and in late 2008 and most of 2009 the US pulp and paper industry's chemical pulp mills started making large claims on this subsidy for burning black liquor, a wood-based by-product of the kraft pulping process (Hayes, 2009; Wilson, 2009). Estimates of the subsidy paid to pulp producers were as high as $300 USD per tonne of pulp produced (Hueston, Old, & Masters, 2009). Some journalists even speculated that several companies would actually make more money collecting on the AFMTC than they would from producing and selling pulp and paper (Hayes 2009; Ivry &

Donville). The AFMTC expired near the end of 2009, and because the industry did not start making claims on the credit until late 2008 and early 2009, the credit's effect on the chemical pulp industry was short lived. However, the industry was able to claim the subsidy for effectively one year's worth of pulp production.

Global chemical pulp production is dominated by production in Canada, the US, and the Nordic countries (Sweden, Finland, and Norway), which together made up 70% of the 113.6 million tonnes of chemical pulp produced globally in 2007. The US is by far the largest producer of chemical pulp – with 2007 production of almost 50 million tonnes, or 43% of global production. The US consumes most of its production domestically, and imports a very small amount (less than one percent of consumption) net of exports. In 2007, Canada and the Nordic Countries produced 11.6 million tonnes and 17.7 million tonnes of chemical pulp respectively. Net of imports, Canada exports 68% of its production, while the Nordic Countries export 28%. Canada and the three Nordic nations supply most of the chemical pulp produced for export (RISI, 2008). This information is summarized in Table 1.1. Although it is not shown in the table, it is worth noting that other significant exporters of chemical pulp include countries in Eastern Europe and South America (RISI, 2008). While Canada and the Nordic countries are the largest exporters of chemical pulp, the US is by far the largest producer, and so a policy that generously subsidizes US pulp producers could have significant impacts on other major producers such as Canada.

Figures 1.1, 1.2, and 1.3 show trends over time for production, consumption, and production capacity of chemical pulp from the three major producers discussed above from 1991 to 2007. Figure 1.1 shows that US chemical pulp has decreased by 12% between 1997 and 2003. Canada has also experienced a 14% from 2004 to 2007, following a sustained slow increase in production since 1991. Figure 1.3 shows that the Nordic countries have a sustained a 38% increase in chemical pulp production between 1991 and 2007 (RISI, 2008). These figures show that, with one exception in Canada, for the last two decades pulp production in the US has been decreasing while production in the next largest suppliers has been increasing. A large subsidy such as the AFMTC could temporarily reverse or at least significantly slow this overall trend.

Black liquor has long been used as a significant fuel in the pulping process and thus, claiming subsidies for using this fuel involves a large amount of free riding. Moreover, Canadian pulp and paper companies claimed that the subsidy resulted in an increase in American pulp production, leading to an oversupply on world markets (Communications, Energy and Paperworkers Union of Canada, 2009). Washington ambassadors from several countries claimed that the “credits are encouraging U.S. companies to overproduce in a depressed market”, and that “any adverse effects caused by [this] could be subject to remedies in the [World Trade Organization]” (CBC News, 2009). An example of this includes Domtar, a company with mills in Canada and the US, allegedly cancelling orders at its Canadian plants in order to shift production to the US and maximize its credits under the AFMTC (Communications, Energy and Paperworkers Union of Canada, 2009). Similarly, Boise, a paper producing division of the Packaging Corporation of America, reportedly lowered its price of newsprint from $565 USD per tonne to $430 USD per tonne (Communications, Energy and Paperworkers Union of Canada, 2009). This alleged oversupply could have consequently depressed prices, causing reduction in output and layoffs in Canada and elsewhere. Not surprisingly, there has been pressure by the Canadian sector to replicate this subsidy in Canada, to which the Canadian government responded by instituting its own version of a black liquor subsidy, The Pulp and

Paper Green Transformation Program[2].

The purpose of the research presented here is to examine in more detail the effects brought about by the US pulp and paper industry responding to the AFMTC. In particular, this paper addresses three main questions, namely:

1) What is the amount of 'free riding' done by the US pulp and paper industry? In other words, how much of the subsidy collected by the US pulp and paper industry was due to burned black liquor fuel that would have been burned anyway, with or without the subsidy?
2) Has the subsidy increased pulp and paper production in the US compared to what could have been expected in the absence of the subsidy and how has this affected the Canadian pulp and paper industry?
3) What are the environmental impacts of the US pulp and paper industry's reaction to the subsidy?

This paper begins by giving an overview of environmental subsidies as discussed in the economic literature, focusing on two of their main downfalls – that a large portion of the subsidy is paid to free-riders, and that the subsidy gives incentives for firms to overproduce. The AFMTC is then discussed with an examination of how a per-gallon fuel use subsidy in actuality turns into a per-tonne of pulp production subsidy for the US chemical pulp industry. This calculated subsidy is then used in order to run two Global Forest Product Model (GFPM) (Buonjiorno et. al. 2003) simulations, one as a base scenario, and one as subsidy

[2] The Green Transformation Program was Canada's response to the AFMTC. It was a 16 cent-per-liter tax credit paid to qualifying Canadian chemical pulp mills during 2009. Each mill submitted the amount of black liquor burned during the year in order to accumulate credits. Each company then was given five years to claim them, on the condition that the money is spent on pollution prevention technology or energy efficient capital (Natural Resources Canada, 2009).

scenario, where the subsidy is simulated by a one-year decrease in the manufacturing cost of chemical pulp in the US. The production values generated in the GFPM simulations are then used to calculate an estimate for the total amount paid out to the industry under the AFMTC, as well as how much was given for free-riding activity and how much was given due to overproduction. Finally, to measure the environmental impact of the chemical pulp industry's reaction to the AFMTC, emissions to pulp production ratios are developed for 5 substances (nitrogen oxides, sulphur oxides, hydrogen sulphide, suspended particulate matter, and greenhouse gases, expressed in carbon dioxide equivalent) using derived plant level production data and reported emissions data for 17 Canadian chemical pulp mills.

GFPM simulations show that the US pulp and paper industry received approximately $7.6 billion (USD), over 90% of which was paid for burning black liquor that would have been burned regardless. This $7.6 billion represents 3.1% of the entire $244 billion US budgeted for the entire SAFETEA-LU legislation. This subsidy is estimated to have caused an increase in American chemical pulp production of 3.4 million tonnes, and caused the US to become a net exporter instead of a net importer of this commodity in 2009. This corresponded with an estimated decrease of 387 thousand tonnes of chemical pulp production in Canada, a loss of $187 million in production value. Finally, it is estimated that this increase in US production led to the increase in the release of several pollutants that are associated with the production of chemical pulp, such as sulphur dioxide and hydrogen sulphide.

## Literature Review: The Economics of Environmental Subsidies

Much of the past literature on environmental subsidies has focused on emissions reduction subsidies (e.g. Ballard & Madema, 1993; Baumol & Oates, 1975; Conrad & Wang, 1993; Mestelman, 1982; O'Hagan, 1984; Polinsky, 1979). Emission reduction subsidies generally pay pollution emitters, usually the producers, a per unit subsidy for every unit of pollutant emissions reduced below a certain threshold level. One might expect that a per-unit subsidy would incite the exact same response from polluters as a per unit emissions tax. This is because every unit of emissions that the firm discharges into the environment costs the firm money in the form of a forgone subsidy. Thus, it can be assumed that a subsidy and a tax on emissions of the same magnitude would have exactly the same marginal effects on a given profit maximizing firm. However, the literature demonstrates that the opposite is in fact the case. Under most circumstances and assumptions, a subsidy of this sort will, at worst, actually increase total emissions from the industry, and at best, lower emissions, albeit not as effectively as a tax.

Baumol and Oates (1975) show that in a competitive setting over the long-run, the overall industry-wide effects for a tax and a subsidy on emissions are in fact very different. For instance, when a subsidy of this kind is decomposed, it actually turns out to be the same as a large lump-sum payment (the subsidy rate multiplied by the baseline level of emissions) coupled with an emissions tax (the forgone subsidy for every unit of pollutants emitted). According to Baumol and Oates, the emission tax component of the subsidy affects the firm by increasing the marginal cost faced by the firm. This in turn causes the firm to internalize the cost of pollution that it imposes on society. As a result, each firm produces less and pollutes less. However, the lump-sum payment component of the subsidy actually lowers the average cost faced by each firm, which entices firms to enter the market who were originally not profitably able to do so. It has been argued that if the amount of potential entrants is small, then the lump-sum payment component of the subsidy has a less significant effect (O'Hagan, 1984). However, under a perfectly competitive setting with no barriers to entry, the long term result is an industry where each firm produces and pollutes less, but that has more firms producing and polluting overall (Baumol & Oates).

Baumol and Oates (1975) also examined the single industry case where emissions were not tied directly to production, but were instead a function of both output and pollution abatement capital. In this setting, the tax lowered both production and emissions, whereas the subsidy raised production and had an inconclusive effect on emissions. Whether emissions rose or fell with the introduction of a subsidy in this setting was dependent on the parameters set in the model. With this analysis, Baumol and Oates showed that a subsidy that is meant to reduce pollution might actually have the perverse effect of increasing pollutant emissions overall in the long run.

Baumol and Oates' (1975) general theme was examined from several different angles in the literature by different economists. Assuming a single industry partial equilibrium setting, Conrad and Wang (1993) explored the effects of a subsidy versus a tax on three different competitive settings: perfect competition, oligopoly, and a dominant firm with a competitive fringe. Regardless of the setting, the results were the same as in Baumol and Oates and showed that total industry emissions increased with the subsidy, even though emissions per firm decreased in each setting.

Another issue raised in the literature in regards to subsidies is the fact that an emissions reduction subsidy causes each firm to produce at a level of production that does not minimize total average cost, which is inefficient. Polinsky (1979) argued that because the lump-sum payment aspect of the subsidy shifts a given firm's average cost curve down, while the emissions tax aspect of the subsidy shifts the marginal cost curve up, the point at where the shifted curves cross is not the lowest point on the new average cost curve. While this does lower production for the firm, it is no longer producing at a cost minimizing point. Overall, Polinsky demonstrates that this then leads to two economic inefficiencies brought on by the emissions reduction subsidy, namely, the increased industry wide pollutant emissions, as well as inefficient production at the firm level.

When the problem was examined from the perspective of a general equilibrium setting, the results for the effects of a subsidy were different than those previously found (Mestleman, 1982). With a simple two-industry model, it was shown that the common results found in partial equilibrium settings were not necessarily replicated under a general equilibrium setting. In general equilibrium, the effect of an emissions tax is exactly the same as in partial equilibrium, but the subsidy goes from raising total emissions to actually lowering them, albeit the reduction is only 40% of the reduction under the tax (Mestleman). The researcher attributes this difference to prices responding to constrained resources, whereas in a partial equilibrium setting, the only price that changes is the final price of the good produced by the taxed or subsidized industry (Mestleman). This work shows that the subsidy does not increase emissions in a general equilibrium setting, even though it does not reduce them as much as a tax. This suggests that in a situation where a tax on emissions is politically infeasible, a subsidy may represent a good potential second-best option.

In order to compare their effects on total social welfare, Ballard and Medema (1993) applied emissions tax and subsidy schemes to a 19 sector computable general equilibrium model based on the US economy. Similar to Mestleman's (1982) findings, the subsidy lowered emissions, albeit not as much as the tax. The main argument against a subsidy in

Ballard and Medema's (1993) analysis was the effect on total social welfare. In this model, the subsidy needed to be paid for by raising distortionary labour taxes, while the revenue raised from the emission tax could be used to lower them (Ballard & Madema). This added distortion, coupled with the fact that the subsidy was less effective at lowering overall emissions, caused the welfare gain from the tax to be three times higher than under the subsidy.

A more recent body of literature examines the free-riding aspect of environmental subsidies. In a public economics context, free-riding refers to agents using a public good even though they did not contribute to it. In an environmental economics context, free-riders refer to those who take advantage of a subsidy for doing an activity that they would have done regardless. There are many studies which focus on consumer rebates for environmentally friendly purchases, home retrofit credits, and demand-side management subsidies that suggest free-riders make up a substantial and significant portion of those that collect these subsidies (Joskow & Marron, 1992; Train & Atherton, 1995; Malm, 1996; Grosche & Vance, 2009; Chandri, Gulati & Kandlikar, 2010). These free-riders greatly increase the cost of implementing the subsidy, as only those who changed their behavior because of the subsidy can be considered in the total of its benefits.

Several works have focused on demand side management subsidies used by electric utilities in the US. Joskow and Marron (1992) claim that when utility companies do cost-benefit analyses on these kinds of programs, they fail to take into account the effect of free-riders, and suggests that the true cost of a "negawatt", a megawatt not consumed due to subsidy incentives, could cost as much as 50% more than originally projected. Train & Atherton (1995) examined the difference between stated preferences and revealed preferences of several hundred participants in a rebate/low interest loan program used by the

Southern California Edison Company in order to encourage consumers to purchase high efficiency appliances. Based on their econometric model from stated preference data obtained through surveying, they estimate that 36% of the high-efficiency refrigerators and 66% of the high efficiency air conditioners purchased under this particular program would have been purchased anyway, and hence represent free-riding on the subsidy. Finally, Malm (1996) argued that in order to get a more accurate measure of free-riding, the differences between various consumer groups needs to be taken into account. Malm (1996) divides electricity consumers based on two dimensions: high-and-low energy use and high-and-low energy efficiency, for a total of four consumer clusters. Without targeting those specific consumer groups that are least likely to invest in energy efficiency, Malm's (1996) conclusions suggest that free-riding activity could make up as much as 89% of total received subsidy payments.

Using data from 2530 German households, Grosche and Vance (2009) developed willingness-to-pay calculations for 16 various energy saving home retrofit options that had available financial support programs from the German government over the past decade. These willingness-to-pay figures were derived from energy cost savings from each project and were compared to estimated costs incurred. If the calculated willingness-to-pay was greater than the estimated cost, then the observed retrofit was deemed to be a free rider. One key assumption made by Grosche and Vance is the addition of an estimated 'hidden cost' that represents costs not observed by the researchers that may bias the results. Changing the magnitude of these hidden costs changes the percentage of those free-riding, but in their final conclusions, Grosche and Vance estimate that 50% of the households undergoing a subsidized home retrofit had a willingness to pay over the cost of the project, and likely would have undergone the retrofit regardless of a subsidy.

Chandra, Gulati and Kandlikar (2010) discussed free-riding in the context of Canadian provincial and federal rebate incentives to purchase hybrid electric vehicles (HEVs). By using vehicle purchase data from the years 2000 to 2006, a baseline was developed for trends in vehicle purchases leading up to several provincial subsidies. Based on their findings, during time periods where rebates were available, only 26% of HEVs purchased were purchased because of the availability of a rebate. The rest would have been purchased regardless. Another key problem with HEV rebates is that even of the 26% of purchases that were swayed by a rebate, most of those simply displaced the purchase of other small and fuel efficient vehicles, which makes any achieved reduction in gasoline consumption minimal (Chandra, Gulati & Kandlikar).

## The Alternative Fuel Mixture Tax Credit (AFMTC)

In 2005, under the Bush Administration, the United States Government passed the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) into law. The main purpose of the SAFETEA-LU was as a highway bill that guaranteed $244.1 billion for highway building and repairs, highway safety and public transportation (U.S. Congress, 2005). It was only near the end of the bill that a provision for alternative and renewable fuels was included. This provision stipulated that if a taxpayer blended a taxable fuel, such as gasoline, diesel, or kerosene, with a designated renewable or alternative fuel, such as liquefied natural gas, hydrogen, or ethanol, "for sale or use in a trade or business", then they would be eligible for a credit of 50 cents for every gallon of alternative fuel used (U.S. Congress, 2005). As SAFETEA-LU was a transportation bill, it is reasonable to assume that the primary targets of the AFMTC subsidy were entities associated with transportation, such as trucking companies, train operators, taxi fleets, and so on. However, despite these assumed intentions of the lawmakers, this was not explicitly expressed in the legislation.

Black liquor was able to qualify as an alternative fuel under the AFMTC because of two key parts of the legislation. First, one of the definitions of an alternative fuel is “liquid hydrocarbons derived from biomass” (U.S. Congress, 2005, p. 805). As black liquor is mostly made up of wood residues, such as wood lignin and hemicellulose fibers, it meets the definition of an alternative fuel. Second, the legislation applies to anyone “producing any alternative fuel mixture for sale or *use in a business* of the taxpayer” (U.S. Congress, 2005, p. 805, italics added for emphasis). This clause opened up the AFMTC to just about any business entity, including chemical pulp mills.

In order for this environmental subsidy to have had its intended effect of reducing the use of traditional fossil fuels, there are two key assumptions that the SAFETEA-LU legislation would have needed to articulate. The first unwritten assumption made by the legislation is that the subsidy will encourage and stimulate the use of renewable and alternative fuels *where they might not have been used previously*. The second unwritten assumption is that each unit of renewable or alternative fuel used will offset a unit of traditional fossil fuel from being used. These simple and straightforward assumptions were not explicitly stipulated in the legislation, allowing the American chemical pulp mills to collect on the subsidy without meeting either of these assumed criteria. The first assumption is not met because burning black liquor for its heat content in a recovery boiler is not a new activity encouraged by the AFMTC; this practice has been used by chemical pulp mills since the 1930s with the development of the recovery boiler (Biermann, 1996). The second assumption is not met because burning black liquor is not done in the place of burning traditional fossil fuel. In fact, several media sources have claimed that US chemical pulp mills were required to mix diesel fuel with their black liquor in order to meet the AFMTC requirements, even though the pulping process does not normally require it (Hayes, 2009; Wilson, 2009).

## Pulp Mills under the AFMTC

There are three main issues at play in how the American pulp and paper industry reacted to the AFMTC. First, there is a substantial amount of free riding, as most of the renewable fuel, black liquor, would have been burned if the AFMTC were not in place. Therefore, the subsidy was collected without a change in behavior on behalf of the recipients of the credit. Second, the subsidy helped sustain a higher level of pulp production than there otherwise would have been. This higher than expected production could have come from each mill increasing production as they responded to the monetary incentive of the subsidy, but it is more likely that, similar to the model discussed by Baumol and Oates (1975), the increase was due to mills continuing to produce that would have otherwise shut down or stayed offline without the subsidy. This type of reaction was explicitly stated in a petition to the United States Senate, which claimed that the “Alternative Fuel Mixture Tax Credit has allowed Alabama River Pulp to operate at full capacity” (Affiliates of the Alabama River Pulp Company, 2009). Data on American chemical pulp production may not show a noticeable increase that coincides with the AFMTC. Rather, it is likely that the credit sustained a higher level of production than would have otherwise been observed through a recessionary period by allowing mills to continue producing profitably. Finally, there are the environmental effects of the American pulp and paper industry responding to the AFMTC.

These include higher than expected production, which, in the short run, causes higher than expected pollutant emissions.

**Previous Work on Calculating the AFMTC Subsidy.**

In early 2009, J.P. Morgan's North American Equity Research group released a small analysis report entitled "Black Liquor Gold" (Hueston, Olds, & Masters, 2009). The report examined quarterly statements from two American pulp and paper companies, Verso Paper and International Paper, and compared their stated production capacity to their disclosures of credits received under the AFMTC. With this information, a credit of $294 United States Dollars (USD) per short ton of pulp was estimated, or, $323 USD per metric tonne[3]. The authors themselves, however, state that their calculation method is very "back of the envelope" and that they were forced to make an "educated best estimate as to the amount of integrated pulp capacity at each mill" (Hueston, Olds, & Masters). These estimates were then applied to the estimated production capacity of several other American pulp and paper companies. The resulting potential estimated payments were startlingly high. For example, the estimated quarterly credits for International Paper and Domtar were $936 million and $229 million USD, respectively, which translates into $3.7 and $0.9 billion USD annually for these two companies alone.

By the first quarter of 2010, the annual reports of the public American pulp and paper companies that received payments under the AFMTC were made available. A web-based blogger and activist who publishes "The Dead Tree Edition" searched through these reports

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[3] The different spelling of ton/tonne is intentional in order to distinguish between an American short ton and a metric tonne. The referenced report used short ton measurements whereas this research uses metric tonne measurements. The conversion factor is 1.1023 tons/tonne.

and summarized the AFMTC payments each company collected in 2009 (Tree, 2010). These figures were independently verified by myself[4] and are provided in Table 1.2.

The numbers reported in each company's annual financial statements were significantly lower in The Dead Tree Edition publication than the estimates published by J.P. Morgan in early 2009. For example, the 2 billion and 0.5 billion USD reported by International Paper and Domtar are just over half of the J.P. Morgan estimates of $3.7 billion and $0.9 billion for these two companies. This result is not surprising, since the J.P. Morgan figures were based on one quarter only and assumed production levels. However, as discussed in the introduction of this paper, the claim that the AFMTC made the difference between a net profit and a net loss for several companies is substantiated. In particular, of the 21 companies examined by the Dead Tree Edition, only 10 had net profits that were greater than their AFMTC payments and hence would have still been profitable without the AFMTC. The rest either would have suffered a loss without these subsidy payments, and some still suffered a loss regardless (Tree, 2010). As a consequence, the industry as a whole (or at least the publicly traded companies) would have suffered a loss of over one billion US dollars if not for the AFMTC payments.

### Assumptions and Calculations for the Production Subsidy

The following section provides a 'bottom-up' estimation methodology for calculating the AFMTC credit in terms of dollars per tonne of pulp. According to Biermann (1996), for every one tonne of pulp extracted from wood, there is about seven tonnes of black liquor left over as residue. At this stage of the pulping process, the black liquor has a solid content

[4] The amount of money received under the AFMTC by each company listed in Table 1.2 was verified by searching through each company's publicly available financial statements.

concentration of 15%. This percentage varies slightly depending on the type of wood used in the pulping process, but for the purposes of this calculation, a 15% concentration was assumed.

Before it can be used as a fuel, the black liquor must be condensed and concentrated, by evaporating off the water, to 65-80% solid content (Biermann, 1996). Most chemical pulping operations concentrate their black liquor to 65% solid content before burning it in a recovery boiler (Biermann). Since the renewable fuel subsidy received is directly proportional to the volume of renewable fuel burned, a profit maximizing firm would likely choose to burn its black liquor residues at the lowest solid content concentration possible, thus maximizing the volume of fuel, and in turn maximizing the subsidy received. Therefore, for the purposes of this research a concentration rate of 65% solid content was assumed.

Based on this information, 1.62 tonnes of usable black liquor fuel, at a 65% solid concentration, is produced per tonne of pulp, i.e.

$$\left(\frac{7BL_{15}}{1Q}\right)\left(\frac{0.15SC}{1BL_{15}}\right)\left(\frac{1BL_{65}}{0.65SC}\right)=\frac{1.62BL_{65}}{1Q} \tag{1.1}$$

where Q is pulp production, $BL_{15\%}$ is non-concentrated black liquor at 15% solid content, $BL_{65\%}$ is concentrated black liquor at 65% solid content, and SC is tonnes of solid content.

The conversion from tonnes to gallons of black liquor is calculated as follows. According to Gullischsen & Fogelholm (1999), black liquor density can be approximated by simple linear and quadratic relationships with solid content concentration and temperature in the following two equations:

$$p_{25} = 997 + 649\,X \tag{1.2}$$

$$\frac{p}{p_{25}} = 1.008 - 0.237\left(\frac{T}{1000}\right) - 1.94\left(\frac{T}{1000}\right)^2 \tag{1.3}$$

where T is the temperature of the black liquor in degrees Celsius, $p_{25}$ is the density of black liquor in kilograms per cubic meter at a temperature of 25 degrees Celsius, X is the percent solid concentration of the black liquor, and *p* is the density of black liquor at the given temperature. Combining these two equations gives

$$p = \left(1.008 - 0.237\left(\frac{T}{1000}\right) - 1.94\left(\frac{T}{1000}\right)^2\right) \bullet \left(997 + 649X\right) \qquad (1.4)$$

Black liquor quickly loses viscosity as it is concentrated, and in order to be effectively used as a fuel it is commonly kept at a temperature of 115 degrees Celsius (Biermann, 1996). Therefore, substituting X = 0.65 (solid concentration) and T = 115 into the equation yields a density of concentrated black liquor of 1355.13 kilograms per cubic meter. This figure can be converted into gallons per tonne in the following way;

$$\frac{1}{\left(\frac{1355.13kg}{m^3}\right) \bullet \left(\frac{m^3}{264.17gallons}\right) \bullet \left(\frac{Tonne}{1000kg}\right)} = \frac{194.94gallons}{Tonne} \qquad (1.5)$$

Therefore, 1 tonne of concentrated black liquor that is ready to be burned in a recovery boiler has a volume of 194.94 gallons. At a subsidy rate of $0.50 USD per gallon, every 1 tonne of concentrated black liquor burned earns the firm a subsidy of $97.47 USD. Given the earlier calculations of 1.62 tonnes of concentrated black liquor produced for every 1 tonne of pulp produced, this subsidy corresponds to $157.90 USD for every 1 tonne of pulp produced. The GFPM assumes an average cost of production of chemical pulp in the US $255. This suggests that the AFMTC subsidy is very significant, representing 62% of average production costs.

## Global Forest Products Model (GFPM)

### Model Framework

In order to estimate the effects of this subsidy empirically, a simulation was run using the GFPM. A full and detailed description of this model is available in Buongiorno et al. (2003)[5]. A brief description of the model, focusing on the aspects most relevant to this work, is presented below[6].

The GFPM is a recursive dynamic, computable partial equilibrium model that simulates demand and supply relationships for 14 forest and wood products for 180 nations. The model is partial in the sense that it focuses on the forest sector, while taking the evolution of the rest of the economy as given. GDP growth has an effect on demand and supply of forest products, but changes in forest product markets do not have an effect on GDP growth.

The 14 forest products are as follows: fuelwood, industrial roundwood, other industrial roundwood, sawnwood, veneer sheet/plywood, particleboard, fiberboard, mechanical wood pulp, chemical wood pulp, other fiber pulp, wastepaper, newsprint, printing and writing paper, other paper and paperboard. In the GFPM, these 14 products are grouped as primary, intermediate and end products. Figure 1.4 shows the relationships between these products. Both mechanical pulp and chemical pulp are labeled as intermediate products in the GFPM, as they are used as inputs in the production of the three paper

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[5] The most recent version of the GFPM is available on-line at
< http://forestandwildlifeecology.wisc.edu/facstaff/Buongiorno/book/GFPM.htm>

[6] With the exception of the two equations for manufacturing cost, all of the equations in this section come directly from the GFPM. For a more detailed description, see Buongiorno et al. (2003).

products, newsprint, printing and writing paper, and other paper. Even though pulp is an intermediate product, the GFPM allows for it to be imported and exported between countries.

In country *i*, $D_{ik}$ represents the quantity demanded for end product *k* in a given year. Demand follows a constant price elasticity specification

$$D_{ik} = D_{ik}^{*}\left(\frac{P_{ik}}{P_{ik,-1}}\right)^{\sigma_{ik}} \tag{1.6}$$

where $P_{ik}$ and $P_{ik,-1}$ are current and last year's prices, $\sigma_{ik}$ is the price elasticity of demand, and $D_{ik}^{*}$ is a scale factor based on previous year's demand. The latter is defined as

$$D_{ik}^{*} = D_{ik,-1}(1+\alpha_k g_i) \tag{1.7}$$

where $\alpha$ is the elasticity of demand with respect to GDP (a measure of income elasticity) and $g$ is the assumed growth rate of GDP. In this way, demand is price responsive but also shifts due to changes in GDP.

In the GFPM, forest products are generally sorted into two broad categories – primary products, such as industrial roundwood, are governed by a supply function that is based on price. Manufactured products encompass both intermediate products, such as chemical wood pulp, and final products, such as writing paper. Primary or intermediate products are transformed into intermediate or final products at a manufacturing cost. The price of intermediate and final products is calculated in order to clear the markets and maximize benefits (price minus costs).

Supply of primary product *k* in country *i* is denoted $S_{ik}$ and follows a constant price elasticity specification

$$S_{ik} = S_{ik}^{*}\left(\frac{P_{ik}}{P_{ik,-1}}\right)^{\lambda_{ik}} \tag{1.8}$$

where $P_{ik}$ and $P_{ik,-1}$ are the same as for the demand and $\lambda$ is the price elasticity of supply. $S_{ik}^*$ is a scale factor based on the previous year's supply. In particular,

$$S_{ik}^* = S_{ik,-1}(1+\beta_{ik}) \tag{1.9}$$

where $\beta$ is a parameter for exogenous shifts in supply.

Manufactured output[7] of intermediate and end products is denoted $Y_{ik}$ (country $i$ and product $k$) and is produced at an increasing marginal cost of $m_{ik}$.. This marginal cost includes all manufacturing costs that are endogenous to the model, such as labour, energy and capital. Year-to-year change in marginal cost is responsive to year-to-year changes in output, and also follows an underlying exogenous rate of change; i.e.

$$m_{ik} = m_{ik}^* \left(\frac{Y_{ik}}{Y_{ik,-1}}\right)^{s_{ik}} \tag{1.10}$$

where $m_{ik}^*$ is the manufacturing cost at last year's output, and $s_{ik}$ is the elasticity of manufacturing cost with respect to year-to-year change in output. $m_{ik}^*$ is determined by the previous year's manufacturing cost times the exogenous rate of change, $g_{m_{ik}}$, as follows:

$$m_{ik}^* = m_{ik,-1}(1+g_{m_{ik}}) \tag{1.11}$$

The export of good $k$ from country $i$ to country $j$ (trade) is denoted T and is transported at unit cost $c_{ijk}$. Trade is subject to inertia, which is captured by upper and lower bounds $T_{ijk}^U$ and $T_{ijk}^L$; i.e.

$$T_{ijk}^L \le T_{ijk} \le T_{ijk}^U \tag{1.12}$$

[7] In the most recent version of the GFPM, the equations that model a marginal manufacturing cost that increases as output increases replaced a set of equations that modeled a manufacturing capacity constraint. For more information, please see Buongiorno et al. (2009).

The bounds are based on the previous period's trade numbers, and shift exogenously based on GDP growth, as follows

$$T_{ijk}^{U} = T_{ijk,-1}(1+\alpha_{ijk} g_i + \varepsilon_{ijk}) \qquad (1.13)$$

$$T_{ijk}^{L} = T_{ijk,-1}(1+\alpha_{ijk} g_i - \varepsilon_{ijk}) \qquad (1.14)$$

where $\alpha_{ijk}$ is the elasticity of exports and imports with respect to GDP, g is the exogenous GDP growth rate, and $\varepsilon$ is the exogenous trend inertia parameter. The bounds in trade can be thought of as an Armington assumption for the differentiation of products between countries. Different tree species produce pulps that are more suited for particular paper products as compared to others, and as such countries with different species makeups of their forests would supply pulps for particular products. Having bounds within which trade numbers can fluctuate partially models the fact that there would be differences in chemical pulp from different countries.

For country *i* and good *k*, market clearing requires that

$$\sum_{j \neq i} T_{jik} + S_{ik} + Y_{ik} = D_{ik} + \sum_{n} a_{ikn} Y_{in} + \sum_{j \neq i} T_{ijk} \qquad (1.15)$$

where $a_{ikn}$ represents the input requirements of good *k* in the manufacturing of good *n* and other variables are described above.

The model solves a static global equilibrium for the forest products sector in the base year of the simulation. This solution is then projected forward to the next year using the exogenous assumptions about GDP growth ($g_i$), supply shifts ( $\beta_{ik}$ ), and trade inertia ( $\varepsilon_{ijk}$ ) described above. The model employs a dual approach whereby equilibrium corresponds with the maximization of total surplus, across goods and countries, in the forest products sector. Total surplus is given by

$$\max\ Z = \sum_i \sum_k \int_0^{D_{ik}} P_{ik}(D_{ik})dD_{ik} - \sum_i \sum_k \int_0^{S_{ik}} P_{ik}(S_{ik})dS_{ik} - \sum_i \sum_k Y_{ik} m_{ik} - \sum_i \sum_j \sum_k c_{ijk} T_{ijk} \tag{1.16}$$

This approach entails that all markets are perfectly competitive. Prices ($P_{ik}$), quantities ($D_{ik}$, $S_{ik}$, $Y_{ik}$), and trade ($T_{ijk}$) adjust endogenously to achieve equilibrium (maximize total surplus) in the 14 forest products markets in each period. In this way, the GFPM simulates global forest product markets as a series of static equilibria. Table 1.3 lists the parameters, exogenous input values, and endogenous variables in the model.

### Calibration and Scenarios

The base year of the model is calibrated to 2007 data on production, imports and exports, in both quantity and value (quantity multiplied by price), for the 14 forest products and 180 countries. The data are taken from FAOSTAT (2010). In order to incorporate the effects of the global recession in 2008 and 2009, the assumed exogenous GDP growth rates ($g_i$) supplied in the GFPM in 2007 were updated and replaced with observed yearly GDP growth rates for each country from 2007 to 2010. These growth rates, summarized in Table 1.4, were obtained from the International Monetary Fund's World Economic Outlook Database (International Monetary Fund, 2011). The baseline scenario of the model then projects forward seven years, to 2014, based on the values of the calibrated and exogenous parameters (see Table 1.3). This scenario assumes the AFMTC was not implemented.

The AFMTC scenario involves a one-time shock to the unit production cost, *m*, for US chemical pulp, in 2009, the third year of the simulation. All other parameter values are the same as the baseline. The shock to the US production cost reflects the estimated $158 subsidy per tonne of pulp under the AFMTC (see Section IV). The base (calibrated) value for 2009 is $257 per tonne, yielding a net value (after the AFMTC) of $99 (257-158). In 2010, the value of m for US chemical pulp reverts to the baseline.

## Simulation Results

This section presents the results of the baseline and AFMTC scenarios for prices, production, imports and exports, and production value for chemical pulp, in the United States, Canada, and the rest of the world (ROW).

### Prices.

For prices, the subsidy had a large, one-period impact in 2009 in the US, and then the price reverted to the baseline scenario as soon as the subsidy was removed. The subsidy did not affect the price of pulp in Canada, or the world price. The one year decrease in the projected price of pulp in the US was 155 dollars per ton, which is not significantly different from the 158 dollar per ton subsidy. Figure 1.5 shows the projected prices in the US and Canada, and the World price, respectively.

### Production.

The effects on production, as predicted by the GFPM, are much more long lasting than the effects on price. Because of the global recession in 2009, the baseline scenario shows a steep decrease in global and US chemical pulp production from 2008 to 2009. In the absence of the AFMTC, the GFPM results predict that there would have been decreases in US and world production of 1 million tonnes and 2.4 million tonnes, respectively. The introduction of the AFMTC, however, allowed for the US to significantly increase production, which substantially lessened the decrease in world supply. This result strongly supports the possibility that the AFMTC allowed mills to produce when they otherwise would have went offline during a time of decreased demand. In the US, the model predicts an increase of chemical pulp production of over 3.4 million tonnes over and above the baseline in 2009, an increase of almost 8%. During the same period, global chemical pulp production had a simulated increase of 1.9 million tonnes. This result suggests that 56% of the increase in US production showed up as increased global chemical pulp supply, and the remaining 44% displaced the production from other nations, such as Canada, whose simulated production decreased by 387 thousand tons compared to the projected base scenario, a decrease of 3%. Figure 1.6 shows projected global chemical pulp production, for both the base scenario and the subsidy scenario. Figures 1.7, 1.8 and 1.9 show the same in Canada, the US and the Rest of the World. Unlike the changes in prices, the changes in production carry through the entire simulation, rather than only affecting one year. As described in the modeling framework section above, this persistence in the difference in production, and the slow convergence back to baseline levels, is due to inertias built into the GFPM.

Figures 1.10, 1.11 and 1.12 show the percentage distribution, or share of the market, of simulated total global production for Canada, the US, and the rest of the world, respectively. These figures show that the increased production in the US in 2009 accounts for a 2% increase in the country's share of the world market, and that this increase comes at the expense of other countries, such as Canada. The US and rest of the world market share figures (1.11 and 1.12) show a slow convergence back to baseline figures over time, while Canada's simulated market share does not. Instead, Canada's simulated market share continues to stay 0.4% lower than baseline figures. In either scenario, Canada's share of the market is characterized by a strong upward trend, and even though Canada's market share does not catch up to baseline figures, by 2012, two years after the expiration of the subsidy, Canada's share of the market returns to where it would have been in 2009 of the subsidy scenario. This result suggests that the subsidy in the US set growth in Canada back by two or three years.

**Exports and Imports.**

According to the GFPM simulations, the main reason for the drop in Canadian production is from lost exports. Compared to the base scenario, the addition of the AFMTC caused American chemical pulp mills to export 916 thousand tonnes more pulp into the world market than they would have without the subsidy, which was enough to change the US from a net importer of chemical pulp to a net exporter. This in turn displaced Canadian pulp exports, as they declined by 350 thousand tons, which accounts for over 90% of the 387 thousand tons of lost production in Canada. Countries in Europe also experienced significant decreases in net exports, with a decrease of 490 thousand tonnes. As well, similar to the results in production, Canadian exports take two years to return to the 2009 levels observed in the base simulation. Figure 1.13 shows the simulated values for net chemical pulp exports for both the US and Canada, in both the base scenario and the subsidy scenario.

**Production Value and Total Subsidy Payments.**

Finally, the effect of the US subsidy on the simulated value of Canada's chemical pulp is very similar to the simulation results for Canada's production. This is because the model did not predict a change in the domestic price of Canadian chemical pulp; it only predicted a change in the amount of production. The US in the subsidy scenario had a predicted drop in price that was almost equal to the amount of the subsidy. Even with the predicted increase in production, the decrease in price was enough to lower US production value by almost 5.6 billion US dollars, as compared to the base scenario. This decrease in production value, though, was more than made up for by subsidy payouts of 7.6 billion US dollars, which is very similar to Tree's (2010) estimate of 8.03 – 8.53 billion US dollars. When the value of the subsidy is included, the US chemical pulp producers experience a one year jump in production value of just over two billion US dollars over and above the production value in the base scenario. Figure 1.14 and Figure 1.15 show simulated Canadian and American production values, for both the base and subsidy scenarios.

**Free Riding and Excess Production.**

As discussed in the literature section of this paper, there are two main ways that an environmental subsidy can backfire: free-riding and incentives towards overproduction. The American chemical pulp industry's response to the AFMTC exhibits both of these aspects, as burning black liquor is not a new activity encouraged by the subsidy, and the GFPM results show a clear increase in production over the baseline scenario. Since the AFMTC credit in reality works out to be a subsidy per unit of pulp, as shown above, it is straightforward to split the total amount paid to chemical pulp mills under the AFMTC into that which was paid for free-riding (existing black liquor), and that which was paid for overproduction (new black liquor). The GFPM simulations showed that US chemical pulp production in 2009 was 47.9 million tonnes under the subsidy simulation and 44.4 million tonnes in the base scenario. The total subsidy paid for free riding is then the subsidy rate of 158 dollars per tonne times the predicted base line scenario production. This production, and its corresponding black liquor use, represents the production that would have happened with or without a subsidy like the AFMTC. The difference between the base and the subsidy scenario, 3.5 million tonnes, multiplied by the subsidy rate, represents the amount of subsidy paid which reflects overproduction, as this is the pulp that was produced over and above what would have been expected without the AFMTC. Multiplying these amounts by the subsidy rate gives approximately 7.02 billion USD paid for free-riding and approximately 541 million USD paid for the stimulation of overproduction. This gives percentages of 92.8% and 7.2% paid for free riding and overproduction respectively. None of the subsidy paid to pulp mills reflected reduction of fossil fuels, which was the original intent of the legislation.

## Sensitivity Analysis

Sensitivity analysis was performed on two variables in the GFPM model – the elasticity of manufacturing cost with respect to output, $s$, and the trade inertia parameter, $\varepsilon$. In both cases, the parameters were doubled for all countries and products. Increasing the elasticity of manufacturing cost causes manufacturing cost to change more as production changes year to year. It would be expected that increasing this parameter would increase the inertia in the model, as increasing manufacturing costs slow the rate of change in production. Increasing the trade bound parameters would allow for exports and imports to change more year to year, which would cause the effects on Canadian exports to increase as the US subsidy increases US exports. Table 1.5 shows three GFPM simulations – the model with the standard assumptions as discussed above, and the models with doubled trade bounds and doubled elasticity of manufacturing. Each model is run with the same black liquor subsidy. Production and net exports are shown for Canada and the US for the three models.

As shown in Table 1.5, doubling the trade bounds actually lessened the effects of the AFMTC on Canadian production, even though it allowed US production to increase by 24 thousand tonnes more than under the standard assumptions. Doubling the elasticity of manufacturing cost did not affect the export numbers for either country, but seemed to have increased the inertia in the model, as the Canadian production grows more slowly after the subsidy as compared to the standard assumption model. This result suggests that the inertia in production numbers after the cancellation of the subsidy is due to the way the GFPM models changes in manufacturing costs. Whether this is a plausible result or simply due to the structure of the model remains unclear at this point. It should be noted that these changes in parameters had very little effect on the overall results from the model simulations. The effects of the AFMTC on Canadian production were very similar – within 0.2% of the standard assumptions. Also, the result of the US switching from a small net importer to a small net exporter holds under all three settings.

## Environmental Impacts

There are two main environmental concerns that are brought about by the AFMTC's effects on the American pulp and paper industry. The first is the increased production, which results in an increase in the emission of environmentally harmful substances, including sulphur dioxide, nitrogen oxides, hydrogen sulphide, suspended particulate matter, and greenhouse gases (Environment Canada - Air, 2010). In the absence of changes in mitigating technologies, it is assumed that a short run spike in pulp production would lead to a short term increase in the release of those substances associated with the production of chemical pulp. The second issue of concern is the increase in diesel fuel use in order to qualify for the subsidy, for example, from firms switching from natural gas to diesel, as diesel fumes have higher concentrations of environmentally harmful substances than black liquor. With the introduction of the AFMTC, several chemical pulp mills have reportedly added diesel in their black liquor fuel (Hayes, 2009; Wilson, 2009). This section uses Canadian data[8] on emissions and output to quantify the first effect. Unfortunately, sufficient data to quantify the second effect does not exist. Therefore, the estimate obtained represents a lower bound on the total environmental effect.

In order to assess the environmental impacts of the pulp industry's response to the AFMTC, emissions/tonne of pulp produced were calculated for five substances of concern using data for 17 Canadian chemical pulp mills supplied by Natural Resources Canada's Pulp and Paper Green Transformation Program and Environment Canada's National Pollutant Release Inventory (Environment Canada – Pollution and Waste, 2010). The substances examined were Nitrous Oxides, Sulfur Dioxide, Total Suspended Particulate Matter, Hydrogen Sulfide, and Greenhouse Gases (expressed as Carbon Dioxide Equivalent). It should be noted that this analysis omits effects on pollutant discharges to water from pulp mills. As the AFMTC was part of a transportation bill, and the subsidy was paid in order to displace fossil fuel use, it is assumed that the primary motivator behind the policy was to reduce air emissions for burning these fuels, and as such, this paper will focus exclusively on air emissions.

[8] Canadian data was used because the Pulp and Paper Green Transformation Program's payments were tracked at the mill level, which was a good fit for the facility level data collected by the National Pollutant Release Inventory. Also, no other source of data for production at the mill level was readily available.

Of the 38 participants in Canada's Pulp and Paper Green Transformation Program, 17 mills also reported emissions data to Canada's National Pollutant Release Inventory (NPRI) and Greenhouse Gas Emissions Reporting Program (GHGERP), and self-identified as North American Industry Classification Code (NAICS) 322112 – Chemical Pulp Mills. Using the same methodology that was used to calculate the industry's response to the AFMTC, estimated production values were calculated from each mill's obtained black liquor credits earned under the Green Transformation Program. The following gives the process:

$$\frac{TC_i}{c} * \frac{1.35513\ kg}{L} * \frac{0.001 Tonnes}{kg} = BL_{65\% i} \tag{1.17}$$

where $TC_i$ is the total amount of credits paid to mill *i* under Canada's Pulp and Paper Green Transformation Program, and *c* is the credit rate of 16 cents per liter of black liquor burned. The resulting number for liters of black liquor was then converted to tonnes by multiplying by the density of black liquor at the assumed concentration of 65% solid content. $BL_{65\%\, i}$ is the resulting amount of black liquor burned by mill *i* in 2009. Given the previous assumptions expressed when discussing the reaction to the AFMTC, tonnes of black liquor correspond to tonnes of pulp produced by:

$$\frac{BL_{65\% i}}{1.62} = Q_i \tag{1.18}$$

where $Q_i$ is the derived production for mill *i* in 2009.

These derived production values were then compared to pollutant release data corresponding to each mill as reported to Environment Canada's NPRI and GHGERP. Ratios of emissions-per-tonne-of-pulp-produced were then calculated for the five pollutant indicators for each pulp mill. These ratios were then averaged across mills, weighted by pulp production. These emissions averages were then multiplied by the simulated increase in chemical pulp production in 2009[9], as calculated in the GFPM simulations, in order to estimate the magnitude of additional air pollutants released due to the chemical pulp industry's response to the AFMTC. These averages, as well as the predicted increase in pollutant emissions in the US, relative to the baseline, are presented in Table 1.6. As discussed above, the increase in American chemical pulp production was partially offset by decreases in production in Canada and the rest of the world. Because of this offset, some of these estimated emissions are not necessarily increases, but rather displacements from one part of the world to another. For this reason, the overall net worldwide change in releases is presented in Table 1.6 as well.

There are two main assumptions that are needed for this analysis to hold. The first is that in the short run, firms would not be able to respond to a subsidy such as the AFMTC with new environmental technologies or major capital investments. A short term spike in production would use the same existing technology already available to the firm, and thus average releases per tonne of production would not significantly change over the year that the subsidy was in place. The second assumption is that pulp and paper production methods, environmental technologies, and the mix of mill types do not differ significantly between the US and Canadian pulp and paper industries. Under these assumptions, the Canadian pollution to production ratios can be applied to the change in US pulp production.

[9] While the GFPM simulations suggest that there was a sustained increase in US production over the baseline scenario due to the AFMTC, for simplicity we will only calculate the additional emissions for 2009, the year that mills made claims on the subsidy.

## Conclusions

This research has addressed the three main questions raised regarding the US pulp and paper industry's response to the AFMTC. Based on the Global Forest Products Model (Buongiorno et al. 2003) the subsidy would be expected to support a higher level of production in the US pulp and paper industry, leading to a decrease in prices for chemical pulp. This increase in production resulted in an increase in the release of several key air pollutants. Finally, a very large portion, over 90%, of the payouts to chemical pulp producers was for burning black liquor that would have already been burned anyway, while the remaining portion stimulated additional production of pulp. None of the subsidy paid to the US pulp and paper industry resulted in a reduction in fossil fuel consumption. Indeed, there is reason to believe that the program resulted in an increase in fossil fuel consumption, as mills are reported to have added diesel to their black liquor in order to qualify for the subsidy.

The increase in production shown in the GFPM simulations supports several of the previously discussed claims made by the media and other sources in both Canada and US (Wilson, 2009; CEP Union of Canada). This increase is likely to have come from mills staying online and running at full capacity, when they more likely would have run at a reduced capacity or even temporally suspended operations.

The effects of this higher production are especially worrisome for Canadian pulp and paper producers. The GFPM show a substantial decrease in the production value of Canadian chemical pulp production during the year of the subsidy. Even more worrisome is the continued divergence in Canadian pulp production from the base scenario. It seems to be the case that not only did Canada's pulp production fall during the year of the subsidy, but growth in this industry is also hampered for every year projected after the subsidy expires. The AFMTC may not have “ushered in the end of the Canadian pulp and paper industry” (Communications, Energy and Paperworkers Union of Canada, 2009), but the industry may feel the effects of this subsidy for years to come.

Unfortunately, data for the AFMTC was not readily available from the US government, and calculations such as how much of the total AFMTC program was paid out to pulp mills are not possible at this time. However, the estimated total payments to pulp mills under the AFMTC represented a significant (3.1%) portion of the entire $244.1 billion (US) SAFETEA-LU highway legislation.

The increased production of chemical pulp also resulted in an increase in pollutant emissions. The mechanism behind this increase in pollutant emissions is not exactly as described in the literature on environmental subsidies (Baumol & Oates, 1975). Pulp mills receiving payment from the AFMTC were not paid to lower their emissions, but the end result of unintentionally encouraging overproduction is the same as expressed in the literature. The subsidy was meant to lower the use of, and hence the emissions from, traditional fossil fuel use, but had the perverse effect of actually increasing pollutant emissions. Also similar to the literature, the AFMTC allowed several firms to produce profitably when they would not otherwise have been able to do so.

A significant consequence of the AFMTC which was not discussed in this paper was the introduction of the Pulp and Paper Green Transportation Program in Canada. This program paid mills in Canada in a very similar way to the AFMTC. As such, the results from this work may be tempered somewhat by the addition of the PPGTP, and a logical next step in this analysis would be to simultaneously simulate the AFMTC and PPGTP and examine how much of the detrimental effects for Canada from the AFMTC were mitigated by the PPGTP.

# Chapter 2. The Alternative Fuel Mixture Tax Credit and the Pulp and Paper Green Transformation Program: A Policy Comparison[10]

## Introduction

Much of the economic literature on environmental policy has focused on market based mechanisms, such as taxes and tradable permits, and command and control regulations. More recently, attention has also been focused on environmental subsidies. Environmental subsidies generally fall into two categories; the Pigouvian subsidy, which pays a decision agent to reduce an environmentally unfriendly behavior (Ballard & Medema, 1993; Baumol & Oates, 1975; Mestleman, 1982; O'Hagan, 1984), and a purchase incentive or adoption subsidy, which ideally encourage the purchase of more environmentally friendly products or technology (Chandri, Gulati & Kandlikar, 2010; Grosche & Vance, 2009; Joskow & Marron, 1992; Malm, 1996; Train & Atherton, 1995). While subsidies prove to be used more often by policy makers compared to taxes or tradable permits, the economic literature on subsidies suggests that there are some areas of concern with their use. The two main problems with environmental subsidies are that they can provide unintended incentives that are not in line with, or even completely contradictory to, the original intentions of the policy makers (Baumol & Oates, 1975), and that a significant portion of the subsidy is usually claimed by free-riders, or agents who collect the subsidy even though they would have undertaken the desired behavior even if the subsidy were not in place (Chandri, Gulati & Kandlikar, 2010).

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[10] Tables and figures for Chapter 2 are located in Appendix B

Two examples of subsidies that exhibit these issues are the 'black liquor' subsidies that occurred in the United States and Canada in late 2008 and 2009 respectively. Namely, these are the Alternative Fuel Mixture Tax Credit (AFMTC) in the United States (US Congress, 2005) and the Pulp and Paper Green Transformation Program (PPGTP) in Canada (Natural Resources Canada, 2009, 2012). Both of these subsidies paid chemical pulp mills for producing and burning black liquor, although with different stipulations on how the subsidy was to be used. Black liquor is the name given to a waste product from the chemical pulping process that is mostly made up of wood residues. Burning black liquor as a fuel in the pulp production process has been in practice since the 1930s (Biermann, 1996). Every unit of chemical pulp produced produces a fixed amount of black liquor residue. This black liquor is then concentrated, mixed with additional fuel, such as natural gas or diesel, and then put back into the production process to be burned to heat the next batch of wood pulp(Biermann, 1996). The issue with subsidizing the burning of black liquor is that it can be argued that it is not an alternative fuel that needs additional incentives or subsides to be used, as burning it is a practice that has long been in use.

The AMFTC and the PPGTP subsidies are discussed in detail later in this paper. However, a brief overview is included here. The purpose of the AFMTC was to encourage the use of alternative and renewable fuels in the place of traditional fossil fuels. The AFMTC was not intended solely for chemical pulp mills. Any business that sold or used a qualifying fuel mixture could claim the credit. While it is not stated anywhere in the legislation, it is likely that the AFMTC's primary target was the transportation industry, as it was passed as part of a transportation bill. As well, the fact that the AFMTC paid for fuel mixtures implies that the intent of the program was to displace the use of traditional fossil fuels in applications that already used them. Obvious examples include any business that sells fuel and transportation companies such as municipal transit authorities, chartered bus companies and taxi fleets. However, the credit was available to any entity that used a fuel mixture as part of its business. Because the black liquor output is directly related to chemical pulp production, when claimed by chemical pulp mills in the United States, the AFMTC actually became a credit that subsidized the production of chemical wood pulp. This in turn gave the mills in the United States an incentive towards over-production and allowed some mills to remain operational when it may have been economically optimal to cease operations and temporarily shut down (Affiliates of the Alabama River Pulp Company, 2009). Arguably, all of the payments made to pulp mills under the AFMTC represent free-riding on a subsidy. The AFMTC also exhibits some of the properties of subsidies discussed by Baumol and Oates (1975), such as encouraging mills to increase their production and fuel use, which is contrary to the assumed intention behind the policy.

In Canada, the PPGTP was specifically only for chemical pulp mills that produced black liquor. While never specifically stated, it is a fair assumption that this program was implemented as a direct response to the AFMTC in the United States. When United States mills started making claims on the AFMTC in late 2008, the reaction from Canadian industry and lobby groups was substantial (CBC News, 2009; Communications, Energy and Paperworkers Union of Canada, 2009; Wilson, 2009). Both the United States and Canada are major producers and users of chemical pulp, and many groups in Canada argued that the AFMTC provided an unfair advantage to United States producers at the expense of Canadian producers. (Communications, Energy and Paperworkers Union of Canada, 2009) The next year in June 2009, the Canadian government announced the PPGTP, which paid Canadian pulp mills approximately the same amount as United States pulp mills under the AFMTC. The only difference was that the PPGTP required that recipient mills use the funds for investments in the purchase and installation of energy efficiency technology and equipment.

Even though there were stipulations on how the money was to be spent, the fact that the payments were tied to production, as under the AFMTC, means that the program would have provided similar production incentives as the AFMTC, such as increased pulp production. However, the fact that the credits are constrained to be spent on investment reduces this incentive as compared to the AFMTC. While the PPGTP will be shown to add incentive for a mill to undertake investment in energy efficiency, it does so in a less than optimal way. Because the PPGTP simultaneously encourages increased production as well as increased investment, the mill moves away from the most cost-effective production level at increased marginal cost. For a mill deciding to participate in the program, the payment must be large enough not only to entice investment, but also to cover this increased cost. As well, due to the all-or-nothing nature of the PPGTP program funding, under certain conditions the program pays for the entire cost of the investment undertaken by the mill, whereas a more direct investment subsidy could potentially entice the mill to invest at less cost for the regulator. Despite its second-best nature, however, the PPGTP proves to be a more effective program when compared to the AFMTC: The PPGTP does provide incentive to invest in energy efficiency, while the AFMTC does not, and while it does encourage over production of pulp like the AFMTC, the incentive is less.

The AFMTC and PPGTP do not neatly fit into any one area of economic literature on environmental subsidies. They do, however, exhibit properties from three main areas, which will be discussed in the literature review of this paper. I will then describe the AFMTC and PPGTP in more detail, highlighting specifically the similarities and differences between them. I then present a theoretical model of a pulp mill to show the effects that each policy would have on the recipients of the credits. The effects of both policies are compared to each other and to a proposed policy alternative that is composed of an environmental tax on fossil fuel and an investment subsidy that is directly tied to investment, rather than to production. The model shows, depending on the assumptions placed on the firm, that the AFMTC and PPGTP have similar effects on a typical pulp mill's production, and that, while the PPGTP does offer a clear incentive for the mill to invest in energy efficiency, it does so with some added economic inefficiencies that would not have occurred under a policy with similar intent but different structure.

## Literature Review

The literature reviewed for this research covers three main topics in environmental subsidies; per unit Pigouvian pollution abatement subsidies, free-riding on environmental subsidies, and the uptake of environmentally friendly technology with subsidies. The AFMTC and PPGTP policies cannot be categorized completely by any one of these topics, but instead exhibit certain properties of each. Therefore, I present research from each of these areas and demonstrate what characteristics from these subsidies are in line with the AFMTC and the PPGTP.

### Pigouvian Subsidies

A significant amount of past work on environmental subsidies focuses on the Pigouvian subsidy (e.g., Ballard & Madema, 1993; Baumol & Oates, 1975; Conrad & Wang, 1993; Mestelman, 1982; O'Hagan, 1984; Polinsky, 1979). In brief, a Pigouvian subsidy pays a firm a set amount for every unit of emissions abated below a baseline amount. This is in contrast to a Pigouvian tax, which charges a firm for every unit of pollutant emissions that it releases into the environment.

According to Baumol and Oates (1975), a Pigouvian subsidy can be decomposed into two parts - a lump-sum payment and a per unit tax on emissions. The lump-sum payment is the total amount of pollution abatement subsidy that a firm could receive if it abated fully and did not release any pollutants into the environment. This is equal to the baseline level of emissions times the subsidy rate. The per unit tax represents the amount of the lump sum payment that the firm gives up by choosing to emit any positive amount of pollutants. The 'tax' portion of the subsidy has the exact same effect on the firm as a Pigouvian tax of the same amount (Baumol & Oates, 1975; Polinsky, 1979). Baumol and Oates (1975) describe how each firm will abate to the point where the marginal cost of abatement is equal to the per-unit value of the subsidy. Unfortunately, in the long run, when firms are free to enter and exit the market, Baumol and Oates show that the 'lump sum' portion of the subsidy actually acts as an alternative revenue source that allows a firm to enter the industry when it otherwise would not have been able to do so profitably. O'Hagan's (1984) work demonstrates that the effect from potential entrants can be very small if there are other barriers to entry into the market. However, in a competitive market with few barriers to entry, the lowered emissions from the 'tax' portion of the subsidy are outweighed by new entrants, and total emissions from the industry actually increase, contrary to the intent of the subsidy (Baumol & Oates).

The subsidy's overall effect of increasing emissions in the subsidized industry does not occur in a general equilibrium setting (Ballard & Madema, 1993; Mestleman, 1982). In a general equilibrium setting prices adjust to lessen some of the firm entry incentives as discussed in a partial equilibrium setting (Mestleman). This causes the subsidy to lower emissions overall, but not nearly as effectively as a tax, suggesting that a subsidy may be a second best alternative to a tax (Mestleman). Ballard and Madema, however, argue that the subsidy must be paid for by raising other distortionary taxes elsewhere, such as labour taxes. When this increased tax is taken into account, Ballard and Medema show that a Pigouvian subsidy only provides one third of the welfare increase as compared to a similar Pigovian tax.

The AFMTC and the PPGTP are not pure Pigouvian subsidies because they did not pay the mills to reduce emissions but to use alternative fuel sources. However, they do have similar unintended effects on a recipient's production incentives. As the model in this paper will demonstrate, the AFMTC and PPGTP provided a recipient mill with the incentive to produce more pulp than it otherwise would have in order to maximize revenue gained from the subsidy. This is similar to the finding by Baumol and Oates (1975) that a Pigouvian subsidy would lead to an overall increase in emissions from the subsidized sector, and was shown to be the case for US pulp mills receiving AFMTC payments (Morgan and Shiell, 2011) . All else being equal, as a recipient mill produces more pulp it consequently increases pollution emissions. The AMFTC and the PPGTP also represent another revenue source for a pulp mill, which could potentially allow it to profitably stay operable when it would otherwise shut down and cease production. One example of this is evident from the petition of a pulp mill in Alabama to the United States government asking to maintain the AFMTC after its scheduled expiration, as this subsidy was the only thing that allowed the mill to stay profitable (Affiliates of the Alabama River Pulp Company, 2009) Table 2.1 also shows that payments from the AFMTC made the difference between a profit and a loss for eight out of 21 United States forestry companies. Therefore, much like a Pigouvian subsidy, the AFMTC and to some extent the PPGTP were subsidies that were intended to have certain environmental impacts, but in reality acted to support and maintain unprofitable operations and increase emissions.

### Free-riding with Subsidies

Another issue around environmental subsidies is free-riding. Most literature on this activity is focused on subsidies that are meant to encourage the adoption of some kind of environmentally friendly behavior or product (e.g., Chandri, Gulati & Kandlikar, 2010; Grosche & Vance, 2009; Joskow & Marron, 1992; Malm, 1996; Train & Atherton, 1995). Examples include consumer-oriented subsidies on energy efficient appliances (Joskow & Marron; Malm; Train & Atherton) and fuel-efficient vehicles (Chandra, Gulati & Kandlikar).

Research has found that the biggest issue with these types of subsidies is that there is no way for the regulator to determine who made the purchase or undertook the subsidized activity because of the added incentive, as opposed to those that would have done it anyway but now get to collect a subsidy (e.g., Joskow & Marron). Many studies on these type of subsidies have confirmed that a significant portion, and in most cases almost all, of the subsidy recipients fall in the category of free-riders (e.g., Malm). The fact that most recipients are free-riders leads to these types of policies being very expensive for the benefit that they provide. For example, Joskow and Marron calculated that the true cost of a "negawatt", or a megawatt of electricity that is not consumed due to a government incentive, actually costs 50% more than standard estimates would suggest once free-riders are taken into account. In most cases, the success of subsidy programs of this type is measured by the total amount that was paid. However, a true measure of a program's effectiveness would take into account an estimate of the number of free-riders. Examining the program in this way would compare the environmental benefits from those recipients who are not free-riders only, against the total cost of the program.

In some cases, it can be shown that subsidies of this type are very expensive, and provide very little benefit relative to their cost. Chandra, Gulati and Kandlikar, for example, calculated free-riding of Canadian rebate incentives for the purchase of hybrid electric vehicles. Their work shows that of the rebate recipients, only 26% were swayed by the rebate, and even then, most of these purchases simply displaced other already small and fuel efficient vehicles. Once both of these effects were accounted for, the overall reduction in gasoline consumption was very minimal.

While the AMFTC and the PPGTP are not consumer oriented green subsidies like those referenced above, they do exhibit similar levels of free-riding behavior. The AFMTC, which was intended to encourage the use of alternative fuels, ended up paying for the use of black liquor that would have been burned regardless. According to Morgan and Shiell (2011), over 90% of the money received by United States mills under the AFMTC was from burning the baseline amount of black liquor that would have been burned whether the credit was in place or not. The rest was paid for black liquor that was produced over and above what would have otherwise been produced. While this does technically represent an increased use of alternative fuels as would be desired under an environmental subsidy, it is not as a replacement of traditional fuel. In fact, the stimulation of this extra black liquor production actually led to an increase in traditional fuel use as well, since black liquor must be mixed with a traditional fuel prior to burning (Biermann,  1996).

The PPGTP subsidy was intended to increase investment in cleaner and more efficient technology, but it similarly suffered from free-riding as well. As the model in this paper will show, a pulp mill that already had an incentive to undertake investment in this area in order to reduce cost would have simply replaced their own investment spending for PPGTP credits. Also, because the funding amount is tied to production, there is the possibility that some mills received more funding than was necessary to entice them to invest.

### Uncertainties of Investment and Investment Subsidies

According to Jaffe and Stavins (1994[b]), there are three steps that are required to get pollution abatement technology into general use by decision agents: (a) Invention or developing the new technology, (b) innovation or finding ways to apply it into current modes of operation, and (c) uptake or actually purchasing and installing the technology, which is also called technology diffusion. Each of these steps has several market failures that prevent the optimum amount from being achieved (Stoneman, 1983). For this research, the third step is relevant when examining the AFMTC and the PPGTP subsidies since the PPGTP paid mills to purchase and install energy efficiency technology and equipment (Natural Resources Canada, 2009).

A key concept in literature on investment is the theory of real option value, as reviewed by Dixit and Pindyck (1994). This theory likens a firm with an opportunity to make an investment to a financial investor who holds a financial call option - the right, but not the obligation to undertake the investment. In financial markets, this type of option has tangible market value, and so it follows that the firm with an investment opportunity would also place a value on this option to invest. The three main criteria that need to be in place in order for there to be a tangible option value are irreversibility of the investment, uncertainty about the future, and the ability to delay and invest later when more information is available. If these criteria hold, then the investment has a significant option value over and above its actual monetary value that is not accounted for in a traditional net present value analysis of the investment, which the firm gives up upon making the investment (Dixit and Pindyck, 1994).

In the context of investment in environmentally friendly technology, there are several possible sources of irreversibility and uncertainty that would potentially give a firm an incentive to delay making an investment in increasing energy efficiency. One of these sources is technological lock-in. Arthur (1994) shows how self-reinforcing mechanisms and path dependence can cause simple random chance early on to be the deciding factor for one type of technology to dominate other viable technologies. In the context of several different types of new competing technologies, there would certainly be uncertainty early on about which technology will be the one that ends up dominating in the future. A firm that invests early in a technology type that later turns out to be not the type that dominates may find itself at a disadvantage compared to those firms that choose 'correctly'. These disadvantages might include lack of specialized expertise in the type of technology that was not widely adopted, making maintenance or improvement difficult or costly (Arthur, 1994). This type of uncertainty would give a firm an incentive to wait and see which type of technology is the one that is widely adopted, and then decide accordingly. However, if each firm faces the same uncertainty, then all firms will delay and the uncertainty will not be resolved.

From the standpoint of the regulator, some have pointed out the danger in imposing a regulation or incentive too early that would 'pick a winner' of the various technologies (Kverndokk, Rosendahl, & Rutherford, 2004). With technological lock in, picking the wrong technology may have lasting effects, as switching after the fact may prove to be too costly. However, as pointed out by Pindyck (2000, 2002), irreversibilities and uncertainties in the form of environmental damages would impose an option value for investing, or, looked at another way, a negative option value on delaying the investment. For a regulator that is trying to mitigate environmental damages that are external to the costs of the regulated firm, it may be optimal to entice firms early on to adopt new environmentally friendly technologies, even at the risk of 'locking-in' one type over another, as the uncertainties and irreversibilities about the environmental damages associated with delayed investment may outweigh uncertainties about which technology will come to dominate. In the face of irreversible environmental damages, the regulator may wish to resolve the uncertainty to do with technology lock-in early, even at the expense of possibly locking in a technology that is less efficient.

Past works have attempted to explain what has been called an "energy paradox" (Hassett and Metcalf, 1999, Jaffe and Stavins, 1994[a]), the observation that there is a very high hurdle rate for investments in energy efficiency. There are many reasons why an energy paradox could exist. Market failures such as incomplete information and positive spillovers, as well as non-market failures such as exceedingly high rates of discount, can all contribute towards explaining this observation (Jaffe and Stavins, 1994[a]). One other possible explanation could be an option value that the investing firm places on the cost of investment, over and above the actual monetary cost, representing the benefit of delaying investment. This option value could arise from uncertainties faced by the firm that are not shared with a regulator.

Another potential reason for underinvestment, especially for a newer technology, is "Learning by Doing" (Johansen, 1965). Positive spill-overs from adopting a new technology, such as lowered cost for future adopters or improved network effects are external to the early adopting firm. By not taking this into account, the firm will underinvest relative to the social optimum level of investment. In the context of environmentally friendly or abatement technology, this positive externality is in addition to the negative externality of pollutant releases, which only adds to the external cost from underinvestment (Johansen, 1965).

It has been argued that with the improvement of technology, total abatement cost can be minimized by delaying investment into the future when abatement technology will become cheaper (Wigley, Richels and Edmonds, 1996). However, this finding only applies to a model that assumes that technology improvements are exogenous, and that abatement becomes cheaper in the future without any further input or effort. If technology improvement is endogenous and happens through “Learning by Doing”, then investment in the present is what will encourage future improvements and lower costs in the future (Schneider and Goulder, 1997). The main implications of waiting are that emissions will not be lowered in the present, which may not be optimal when compared to the potential cost savings of delayed investment, and that this improvement over time may be brought about by “Learning by Doing”. When thought about in terms of an option value placed on delaying an investment, the positive externality of Learning by Doing can give a firm incentive to wait for others to invest first, and then take advantage of the increased knowledge and lowered cost of undergoing their own investment. In this way, firms will attempt to free-ride on the learning and experience of early adopters, which leads to underinvestment. Both of these issues are strong arguments in favour of subsidized investment in the present.

While both an investment subsidy and emissions tax on their own will encourage the uptake of technology, in the event that both positive and negative externalities exist, only a combination of the two policies will lead to the most economically efficient outcome (Johansen, 1965). If only one policy is to be enacted, Jaffe and Stavins (1994[b]) suggest that adoption subsidies have a greater effect on technology adoption than an energy tax. However, other work suggests that in the case where there are many different paths that technology development could take, a tax would be preferable and that subsidies should not be used in order to avoid choosing the 'wrong' type of technology to subsidize, especially if there is irreversibility in development (Kverndokk, Rosendahl, & Rutherford, 2004). Finally, Kverndokk and Rosendahl (2007) suggest that if there are two market failures, one from pollution and one from underinvestment, then an optimal policy would be a mix of both an emissions tax and an investment subsidy in tandem – using only one of these instruments will not fully fix both market failures.

This body of literature is most relevant when examining the PPGTP. The PPGTP was implemented in order to encourage investment in the uptake of efficient technology. It should be compared to an optimal policy mix for this objective, such as that suggested by Kverndokk and Rosendahl (2007). This would allow for a measure of the PPGTP's effectiveness versus the best-case scenario.

## Description of the AMFTC and PPGTP

### The AMFTC Subsidy

The AFMTC was introduced as a small part of a $244 billion highway and transportation investment bill entitled the Safe, Accessible, Flexible Transportation Equity Act – a Legacy for Users (SAFTEA-LU) (U.S. Congress, 2005). The main purpose of the SAFTEA-LU legislation was to provide funding for investments in public transportation and highway safety, construction, and maintenance. The AFMTC provision allowed for users of an alternative fuel mixed with a traditional fossil fuel to collect a refundable tax credit of 50 cents per gallon for alternative fuel used. As the AFMTC was passed as part of a highway bill, it is reasonable to assume that the credit was intended for businesses and other entities operating in the transportation sector, in order to provide a financial incentive to adopt alternative fuels that would partially displace the use of traditional fossil fuels.

American chemical pulp mills were able to qualify for the AFMTC due to the very broad definitions within the legislation. Some examples of alternative fuels as defined by SAFETEA-LU include liquefied natural gas, liquid hydrogen, liquid fuel derived from coal, and liquid hydrocarbons derived from biomass (U.S. Congress, 2005, p. 805). Black liquor is mostly made up of wood residues, such as lignin and hemicellulose fibers, and hence is included under the AFMTC's alternative fuel definition of liquid hydrocarbons derived from biomass. The legislation also allowed anyone "producing any alternative fuel mixture for sale or use in a business of the taxpayer" (U.S. Congress, 2005, p. 805) to qualify for the subsidy. Pulp mills were able to take advantage of the AFMTC as black liquor is not just a byproduct of the pulping process but is also processed and burned as an input to the pulping process (Biermann, 1996). These two aspects of the AFMTC allowed for chemical pulp mills to qualify for the credit, even though they were likely not one of its intended recipients.

While the total amounts paid out to chemical pulp mills under this program are not publicly available, some estimates have been done. In 2009, J.P. Morgan's North

American Equity Research group released an analysis report entitled “Black Liquor Gold” (Hueston, Olds and Masters, 2009). At the time of the report’s release United States pulp mills had very recently started making claims on the AFMTC. As such, J.P. Morgan’s Research group had very little information available to use for a complete analysis. The authors of the report were only able to use quarterly statements from two companies, Verso Paper and International Paper. By comparing the stated production capacities to the amounts received under the AFMTC, a subsidy of $323 USD per metric tonne of chemical pulp was calculated. The authors of the report then applied this number to estimated production capacity for several United States pulp and paper companies, with surprisingly high results. For example, the report estimated that International Paper alone would receive $3.7 billion USD by claiming the AFMTC. In early 2010, annual financial reports from publically traded companies that collected the AFMTC started to become available. From these financial reports it was shown that the estimates done by J.P. Morgan were very high as most companies reported that amounts received under the AFMTC were just over half of those estimates performed by J.P. Morgan (Morgan & Shiell, 2011; Tree, 2010). The total amount paid to paper companies with publically available financial information, as shown in Table 2.1, was $6.5 billion USD (Tree, 2010). Using the Global Forest Products Model (Buongiorno et. al, 2003), Morgan and Shiell (2011) estimated that the total amount paid to all US paper companies totaled $7.6 billion USD.

**The PPGTP Subsidy**

The PPGTP was officially announced by the Canadian government on June 17th, 2009. This program allocated funding to Canadian pulp mills, based on their production of black liquor[11], for the purpose of achieving four main goals:

-Improved energy efficiency of Canadian pulp and paper mills

-Increased production of renewable energy at Canadian pulp and paper mills

-Improved environmental performance at Canadian pulp and paper mills

-Investments in innovation and technology that contribute to an environmental and commercially sustainable Canadian pulp and paper industry (Natural Resources Canada, 2009)

To accomplish these goals under the PPGTP, Canadian pulp mills accumulated credits at the rate of 16 cents per litre of black liquor produced during 2009. The mill could then use these credits as funding towards capital investments that would produce environmental benefits, "such as investments in energy efficiency or the production of renewable energy from biomass" (Natural Resources Canada, 2009). In order to receive and use its accumulated credits, a mill had to apply and have its investment project approved by the Department of Natural Resources. Chemical pulp mills had until the end of March 2012 to apply for, receive, and spend their earned credits. A complete list of participating mills, along with their accumulated credits, is provided in Table 2.2. The program had a total funding cap of $1 billion dollars, which

[11] It should be noted that this is a slight difference in the two programs – the AFMTC paid mills to *burn* black liquor, while the PPGTP paid mills to *produce* it. This does lead to the possibility that a Canadian mill might dispose of black liquor in ways other than burning, such as a direct discharge to water. For the purposes of this paper, we will assume that all black liquor is burned, as it does have significant fuel value.

was not reached, as total credits earned by all participating mills was just over $950 million dollars (Table 2.2).

As was mentioned in the introduction, it was never stated by the Department or the Minister of Natural Resources that the PPGTP was a response to the AMFTC; however the funding amount and timing of the PPGTP suggests that the policy was a reaction to the fact that United States pulp mills were receiving a black liquor subsidy under the AFMTC. When United States pulp mills started receiving the AFMTC subsidy in late 2008, several stakeholders in the Canadian pulp and paper industry lobbied the government to react in kind, claiming that the AFMTC gave incentive to pulp mills in the United States to increase pulp production in an already depressed market (Communications, Energy and Paperworkers Union of Canada, 2009). Also, ambassadors from several pulp producing countries threatened Washington with possible legal action seeking remedies under the World Trade Organization (CBC News, 2009). These complaints have been shown to have merit (Morgan and Shiell, 2011), as it is estimated that Canadian pulp producers lost almost $200 million USD in gross revenue due to exports being displaced by increased production in the United States that was encouraged by the AFMTC.

Furthermore, given the average exchange rate in 2009 of 1.142 CAN$/USD$ (Bank of Canada), the CAN$0.16 per litre credit translated to USD$0.52 per gallon credit, which was only 2 cents higher than the AFMTC credit. The PPGTP was announced nine months after United States pulp mills started making claims on the AFMTC, but it was retroactive in that it allowed mills to claim credits for black liquor production starting in January of the 2009 year. Because of this, Canadian mills started accumulating PPGTP credits only four months after United States mills started receiving AFMTC credits.

### Comparison of the AMFTC and the PPGTP

As described above, the AMFTC and the PPGTP are similar in that they both subsidized chemical pulp mills for black liquor production. They both paid approximately the same amount, and were offered for the same amount of time. They do, however, have a few key differences, the biggest of which is what a pulp mill was able to do with the money it received from its respective program. The AFMTC was a refundable tax credit (U.S. Congress, 2005); any credits received from this subsidy lowered the income tax payable by the receiving entity, and if the subsidy were greater than the taxes owing, the entity would receive a payment for the difference. Overall, the AFMTC was simply another revenue source for United States pulp mills that was indirectly tied to production through their production of the black liquor by-product. As shown in Table 2.1, for some United States pulp and paper companies, the payments they received under this program made the difference between a profit and a loss for the year.

The PPGTP, on the other hand, required that all funding be spent on capital expenditures such as equipment that would increase the mill's energy efficiency, reduce their pollutant releases, or increase their use of renewable biomass as fuel. As was mentioned, under the PPGTP Canadian mills accumulated credits based on their production of black liquor. This differs from the AFMTC, which required that the black liquor be burned as part of the United States mill's business operations. However, since black liquor is not a material that is typically stored for future use, unless it is disposed of in some other fashion, production and burning are equivalent and the difference is trivial. In order for a Canadian mill to receive its credits, a detailed project plan on how the funding would be spent needed to be approved by Natural Resources Canada. Some examples of investments undertaken by mills with PPGTP program funding include upgrading or replacing the mill's recovery boiler, the installation of heat capture technology, or the installation of co-generation equipment (Natural Resource Canada, 2009).

Overall, these two programs are very similar in most regards. The key difference between them, that the PPGTP requires the money be spent on investments in energy efficiency whereas the AFMTC does not, show the difference in the perceived goals of the policy makers. The AFMTC was enacted in order to encourage the adoption and use of alternative fuels, displacing traditional fossil fuels, whereas the PPGTP was enacted to encourage and help with the investment in energy efficiency by Canadian chemical pulp mills.

## The Model

The model developed in this paper represents a chemical pulp mill that maximizes the total discounted present value of a stream of profits by choosing how much pulp to produce in each period and whether or not to undertake a large-scale investment in improving the mill's energy efficiency. The pulp mill has a stock of production capital that is considered fixed for the time period examined, labeled $\bar{K}$. Each period, the mill chooses $K \epsilon [0, \overline{K}]$ – the amount of capital to employ in the production of pulp. The mill can choose to make full use of this capital, or, in the case of a period of decreased demand, the mill can run at less than full capacity and use less than the full amount. The mill faces a fixed cost that is simply the depreciation of the production capital stock, which depreciates at a rate of $\delta_k$. This assumption of fixed production capital is supported by the short time frame of the programs examined (one year) plus the fact that the year the programs were in place, 2009, was a recession year.

In each period, the pulp mill uses production capital to produce pulp through a production function:

$$Y_t = F(K_t) \tag{2.1}$$

where $t$ is the time period, $Y$ is the production of chemical pulp, $K$ is the amount of production capital used by the firm, and $F$ is the production function. $F$ is a continuous, twice differentiable function that is increasing in $K$ at a decreasing rate, and marginal product goes to infinity as $K$ approaches zero, such that:

$$F'(K_t) > 0 \tag{2.2}$$

$$F''(K_t) < 0 \tag{2.3}$$

$$\lim_{K \to 0} F'(K_t) = \infty \tag{2.4}$$

The mill faces an energy requirement function:

$$G_t = E(K_t) \tag{2.5}$$

where $G$ is the amount of energy required for production and $E$ is the energy requirement function. $E$ is a continuous, twice differentiable function that is increasing in $K$ at an increasing rate, and it is assumed that the marginal fuel requirement approaches infinity as $K$ becomes increasingly large; i.e.

$$E'(K_t) > 0 \tag{2.6}$$

$$E''(K_t) > 0 \tag{2.7}$$

$$\lim_{K \to \infty} E'(K_t) = \infty^{12} \tag{2.8}$$

The energy needed to meet the energy requirement comes from two different sources: black liquor that is concentrated and put back into the production system, and energy purchased from other outside sources, such as fossil fuels or electricity. The total amount of energy used by the mill is the sum of both of these types of energy:

$$G_t = f_t + B_t = E(K_t) \tag{2.9}$$

where B is the amount of black liquor available to the mill to use as fuel, and $f$ is the amount of energy purchased from other sources.

As black liquor is a by-product of the pulp production process, $B$ can be expressed as a linear function of production:

$$B_t = bY_t = bF(K_t) \tag{2.10}$$

where $b$ is the per unit amount of black liquor produced as a by-product of every unit of pulp produced. Previous work on this subject has estimated that $b$ is approximately 1.62 tonnes of concentrated black liquor fuel per tonne of chemical pulp produced (Morgan & Shiell, 2011).

The mill has the opportunity to invest in reducing the energy requirement for all future periods for a one-time cost of $C$. This investment benefits the mill by reducing the amount of fuel required to produce the same amount of pulp. This investment does not add to the stock of production capital – it simply makes the current stock of production capital require less energy. This investment can be undertaken in any

[12] Note that $K$ is bounded by $\overline{K}$. However, we use the assumption that $K$ can go to infinity in order to define the form that the energy requirement function takes.

period, and to represent the value of deferring this investment, the mill places an option value over and above the monetary cost of undertaking the investment. This option value, $OV$, represents all the benefits of delaying the investment until sometime in the future, as discussed in the literature section of this paper. If the option value is due to some positive spill-over from the investment of other mills, as discussed in the literature section in this paper, then the option value of investment would be endogenous to the industry. However, from the standpoint of each individual mill, it is exogenous as it is determined by the investment decisions of other mills, and as such, outside of any one mill's control. As this model is only examining one mill's reaction to the examined policies, the option value will be treated as exogenous. The investment decision is labeled as the discrete variable $I$, which has a value of 1 if the mill invests, and 0 if the mill does not.

This increase in energy efficiency is represented by a lowering of the mill's energy requirement for all possible levels of $K$ following the investment. If the investment is made, the energy requirement function equation (2.9) becomes

$$G_t' = f' + B' = E(\gamma K_t) \tag{2.9'}$$

where $\gamma$ is a parameter between 0 and 1. $B'$ and $f'$ are the amounts of fuel and black liquor used under the new efficiency level.

The AFMTC and PPGTP paid mills approximately the same amount: a set amount for each unit of black liquor produced. As black liquor production is directly correlated to pulp production, the mill indirectly received a production subsidy through its use of black liquor. The total amount received by a mill under the AFMTC is modeled as:

$$S_t = sbF(K_t) \tag{2.11}$$

where $S$ is the total subsidy received, and $s$ is the subsidy received per unit of black liquor produced and burned.

A mill receiving credits under the PPGTP would receive an amount similar to that expressed in equation (2.11) with the subsidy rate expressed as $\hat{s}$. A mill participating in the PPGTP can only spend credits on the energy efficiency investment, and any credits earned over and above this amount are not paid to the mill. A mill participating in the PPGTP receives credits as follows

$$\hat{S}_t = \min\left[\hat{s}bF(K_t), I_t \cdot C\right] \tag{2.12}$$

where $\hat{S}$ is the total amount received under the PPGTP program.

The mill sells pulp in a competitive market at a given price of $P_p$, and buys energy in a competitive market at a price of $P_f$. Each period, the mill earns a profit that is equal to total revenue from the production and sale of pulp and from subsidies received, less the cost of purchased fuel to meet the energy requirement, a Pigovian tax on fuels, the fixed cost of depreciation, and the cost of investment in energy efficiency capital (if such an investment is made). The mill's profit each period is represented by:

$$\pi_t(K_t, I_t) = P_{p,t} \cdot Y_t - (P_{f,t} + T_{f,t})f_t - \delta_k \overline{K} + S_t + \hat{S}_t - [(1-\omega)C + OV] \cdot I_t \tag{2.13}$$

where $\pi_t$ is the mill's profit in period $t$, and $T$ is a Pigouvian tax added to the price of fuels in order to internalize climate damages brought on by their use. $\omega$ represents a direct subsidy rate paid to the mill if it undertakes the energy efficiency investment.

The AFMTC and PPGTP programs were only available in the US and Canada for one year, which will be denoted period 0 in the model. Thus, $S_t = \hat{S}_t = 0$ for $t = 1,2, \ldots$ Similarly, since the PPGTP applies subsidy credits to the purchase of energy efficiency capital, we will only focus on investment choices taken in period 0. Thus, $I_0 \epsilon \{0,1\}$ and $I_t = 0$ for $t = 1,2,\ldots$ Now substituting equations (2.1), (2.5), (2.9), (2.10), (2.11) and (2.12) into (2.13) for period 0 yields

$$\pi_0(K_0, I_0) = P_{p,0} \cdot F(K_0) - (P_{f,0} + T_{f,0})[E(K_0) - bF(K_0)] - \delta_k \overline{K} + sbF(K_0) + \min[\hat{s}bF(K_0), I_0 \cdot C] - [(1-\omega)C + OV] \cdot I_0 \tag{2.14}$$

If the mill undertakes the investment ($I_0 = 1$), the profit in subsequent periods is given by

$$\pi'_t(K_t) = P_{p,t} \cdot F(K_t) - (P_{f,t} + T_{f,t})[E(\gamma K_t) - bF(K_t)] - \delta_k \overline{K} \tag{2.15}$$

while if the mill does not undertake the investment ($I_0 = 0$), the profit in subsequent periods is given by

$$\pi_t(K_t) = P_{p,t} \cdot F(K_t) - (P_{f,t} + T_{f,t})[E(K_t) - bF(K_t)] - \delta_k \overline{K}, \tag{2.16}$$

Under the PPGTP, if the mill undertakes the investment ($I_0 = 1$), the profit function is non-differentiable at the point where $\hat{s}bF(K_0) = C$, in period 0. The consequences of this non-differentiability will be discussed later. For convenience, we define gross profit in period 0, $\hat{\pi}_0$, as the profit from producing pulp without the cost associated with the investment in energy efficiency. Thus equation (2.14) becomes

$$\pi_0(K_0, I_0) = \hat{\pi}_0(K_0, I_0) - [(1-\omega)C + OV] \cdot I_0 \tag{2.14'}$$

Each period, conditional on $I_0$, the mill chooses how much of its capital stock it will employ in the production of pulp such that profit for the period is maximized,

$$\max_{K_t} \pi_t(K_t, I_t) \tag{2.17}$$

*subject to:*

$$0 \le K_t \le \overline{K}.$$

Given the assumptions placed on the production and fuel requirement functions, $\pi_t$ is a concave function. The first-order derivative is

$$\frac{\partial \pi_t}{\partial K_t} = \left[P_{p,t} + b\left(P_{f,t} + T_{f,t} + s_t + \hat{s}_t\right)\right]F'(K_t) - \left(P_{f,t} + T_{f,t}\right)E'(K_t) \tag{2.18}$$

Due to the assumption made in equation (2.4), $\lim_{K\to 0} \frac{\partial \pi_t}{\partial K_t} = \infty$, and due to the assumption made in equation (2.8), $\lim_{K\to \infty} \frac{\partial \pi_t}{\partial K_t} = -\infty$[13]. The second order derivative with respect to $K$ gives

$$\frac{\partial^2 \pi_t}{\partial K_t^2} = \left[P_{p,t} + b\left(P_{f,t} + T_{f,t} + s_t + \hat{s}_t\right)\right]F''(K_t) - \left(P_{f,t} + T_{f,t}\right)E''(K_t) \tag{2.19}$$

Due to the assumptions given in equations (2.3) and (2.7), the second derivative is negative for all possible values of $K$, which shows that $\pi_t$ is a strictly concave function. Therefore, the maximization problem (2.17) has a unique solution. A regular interior solution of (2.17) is characterized by the first-order condition $\frac{\partial \pi}{\partial K_t} = 0$. (In one scenario under the PPGTP, in period 0, the solution of (2.17) occurs at the non-differentiable point where $\hat{s}bF(K) = C$. This outcome will be discussed below.)

**Optimized Production and Investment Decisions Under 4 Policy Regimes**

There are four scenarios that will be examined, where the mill is operating…

1) without any policy in place ( $T = s = \hat{s} = \omega = 0$ ),
2) under a direct policy[14] composed of a Pigouvian tax on fuel purchases (representing the social marginal damage of fuel emissions) and a direct

[13] Not that $K$ is bounded by $\overline{K}$. However, we analyze the case where $K$ goes to infinity in order to define the functional form of the profit function.
[14] While it may be tempting to call this policy the first-best policy, the potential deadweight loss from having to finance the investment subsidy by taxation brings the term 'first-best' into question in this model. This policy will be referred to as the direct policy in this paper, as it directly deals with two market failures – a tax on the

investment subsidy (to offset the private option value) ( $T > 0, \omega > 0, s = \hat{s} = 0$),

3) while receiving AFMTC payments ($s > 0, T = \hat{s} = \omega = 0$), or,

4) while participating in the PPGTP ($\hat{s} > 0, T = s = \omega = 0$).

Each policy will be examined in terms of production levels and the mill's investment decision. For each of these policies, there is the possibility of investing in period 0, which affects profit and capital use in subsequent periods. The investment decision is only of interest in period 0, as this is the period where the AFMTC and PPGTP policies are introduced. While a mill that delays investment can choose to invest in a future period, for simplicity of the following analysis the investment decision will only be examined in period 0. For convenience, Table 2.3 shows all of the optimal values for capital use and profit for each policy, with and without investment in period 0.

***Business as Usual - No policy***

For a mill operating without any policy in place, the first order condition with respect to production capital is,

$$\left(P_{p,t} + bP_{f,t}\right)F'(K_t) \geq P_{f,t}E'(K_t) \quad and \quad \bar{K} - K_t \geq 0 \qquad (2.20)$$

$$with\ complementary\ slackness$$

which gives an optimal level of capital use labeled $K_t^*$ .

The corresponding profit in period 0 is $\pi_0^* = \hat{\pi}_0^* - I_0(C + OV)$. If the mill does not undertake the investment in energy efficiency in period 0, then profit in all

emissions from fossil fuel use and a subsidy paid for undertaking investment. In comparison, the AFMTC and PPGTP subsidies attempt to deal with one or both of these market failures indirectly; by tying funding to production.

subsequent periods will be $\pi_t^* = \hat{\pi}_t^*$ . If the mill undertakes the energy efficiency investment in period 0, then for all subsequent periods the first order condition becomes

$$\left(P_{p,t} + bP_{f,t}\right)F'(K_t) \geq P_{f,t}E'(\gamma K_t) \quad and \quad \overline{K} - K_t \geq 0 \tag{2.21}$$

which gives an optimal level of capital use labeled $K_t'^*$ and a corresponding profit labeled

$\pi_t'^* = \hat{\pi}_t'^*$.

The mill will choose to undertake the investment in energy efficiency in period 0 if the net present value of the benefits outweighs the cost. This cost is made up of two components; the actual monetary cost of the investment, $C$, and the option value of delaying, $OV$. The benefit is the lowered marginal cost of production from the lowered fuel requirement in every future period after the investment. Given that the mill will choose the optimal level of pulp production every period, the mill will invest in period 0 if

$$\hat{\pi}_0^* - (C + OV) + \sum_{t=1}^{\infty}\left(\frac{1}{1+\varphi}\right)^t \cdot \pi_t' \; > \; \sum_{t=0}^{\infty}\left(\frac{1}{1+\varphi}\right)^t \cdot \hat{\pi}_t^* \tag{2.22}$$

where $\varphi$ is the discount rate used by the mill. The left hand side shows profits in the current period minus cost of the investment, and the discounted sum of future profits with higher energy efficiency and lower cost. The right hand side shows the discounted sum of profits if the mill does not undertake the investment. Substituting for $\hat{\pi}_0^*$, $\pi_t'$, and $\hat{\pi}_t^*$ in equation (2.22) shows that the mill will choose to make the investment in energy efficiency in period 0 if

$$C + OV < \sum_{t=1}^{\infty}\left(\frac{1}{1+\varphi}\right)^{t} \cdot [P_{p,t} + bP_{f,t}] \cdot [F(K_t') - F(K_t^*)] + P_{f,t}[E(K_t^*) - E(\gamma K_t')] \tag{2.23}$$

***Direct Policy***

For a mill operating under the direct policy, and which has not undertaken the investment in energy efficiency (i.e. t=0 or t=1,2,… with no investment in energy efficiency), the first order condition with respect to production capital is,

$$\big(P_{p,t} + b(P_{f,t} + T_{f,t})\big)F'(K_t) \geq (P_{f,t} + T_{f,t})E'(K_t) \quad and \quad \bar{K} - K_t \geq 0 \tag{2.24}$$

$$with\ complementary\ slackness$$

which gives an optimal level of capital use labeled $K^{*T}$ and a corresponding period 0 profit of $\pi_0^{*T} = \hat{\pi}_0^{*T} - I_0[(1-\omega)C + OV]$.

If the mill does not undertake the investment in energy efficiency in period 0, then profit in all subsequent periods will be $\pi_t^{*T} = \hat{\pi}_t^{*T}$ . If the mill undertakes the energy efficiency investment in period 0, then for all subsequent periods the first order condition becomes

$$\big(P_{p,t} + b(P_{f,t} + T_{f,t})\big)F'(K_t) \geq (P_{f,t} + T_{f,t})E'(\gamma K_t) \quad and \quad \bar{K} - K_t \geq 0 \tag{2.25}$$

which gives an optimal level of capital use labeled $K_t'^{*}$ and a corresponding profit labeled

$\pi_t'^{T} = \hat{\pi}_t'^{T}$.

A Pigouvian tax on the purchase of fossil fuel would be implemented in all periods. Adding a tax and an investment subsidy adjusts the mill’s investment decision as follows,

$$\hat{\pi}_0^{*T} - \left((1-\omega)C + OV\right) + \sum_{t=1}^{\infty}\left(\frac{1}{1+\varphi}\right)^t \cdot \pi_t'^T \;>\; \sum_{t=0}^{\infty}\left(\frac{1}{1+\varphi}\right)^t \cdot \hat{\pi}_t^{*T} \qquad (2.26)$$

where $\hat{\pi}_t^{*T}$ is the gross profit obtained from the optimal choice of production given a Pigouvian tax on fossil fuels and no investment in energy efficiency, and $\pi_t'^T$ is profit after the investment in energy efficiency, also under the tax. $\omega$ is the subsidy rate paid to the mill if they undergo the energy efficiency investment.

As discussed above, the policy maker does not necessarily share the same uncertainties as the mill does. There are several reasons that this could be, which are discussed in the literature section of this paper, such as the policy maker's concern for irreversibility of environmental damages, or, if there is uncertainty about which technology will be adopted, and the policy maker would like to entice a decision in order to resolve the uncertainty. As such, the policy maker would choose a value of $\omega$ that would allow for the total subsidy to offset the mill's option value of investing, such that

$$\omega C = OV \qquad (2.27)$$

Using equations (2.14), (2.15), and (2.27), equation (2.26) can be re-written and solved as,

$$C < \sum_{t=1}^{\infty}\left(\frac{1}{1+\varphi}\right)^t \cdot \{\,[P_{p,t} + b(P_{f,t}+T)] \cdot [F(K_t'^T) - F(K_t^{*T})] - (P_{f,t}+T)[E(\gamma K_t'^T) - E(K_t^{*T})]\} \qquad (2.28)$$

We see on the LHS the cost of the investment, while on the RHS the benefit of a lower fuel requirement due to the investment. Under the direct policy, production choices are made in all periods in the presence of the Pigovian tax, to account for the negative externalities from the use of carbon-based fossil fuels , while the private option value, OV, is fully offset by the investment subsidy, $\omega$.

The fuel tax and investment subsidy policy is made up of two parts that can be examined separately to some degree. The investment subsidy does not affect current period production at all, and it only affects future production to the extent that it encourages the mill to make the energy efficiency investment, which will change the optimal amount of production in future periods. However, even if the mill were to make the investment under this policy, in the absence of a tax, future production levels would not be any different than if the mill had made the investment in the absence of a policy.

The fuel tax, however, does have an impact on both current and future production. Equation (2.24) shows how the tax raises both the marginal revenue and the marginal cost of the pulp mill. The increase in marginal cost is expected, as the tax increases the cost of fuel purchased by the mill. The increase in marginal revenue is due to the fact that black liquor is used in the place of additional, more costly, fossil fuel. As the total price of fossil fuel faced by the firm increases, the value that the mill places on its black liquor by-product also increases. This in turn adds an additional incentive to the production of pulp.

To determine the balance between these two contradictory effects, note that equation (2.24) implicitly defines the optimal capital choice $K^{*T}$ as a function of prices and the tax, i.e. $K^{*T} = \xi(P_p, P_f, T)$[15]. Differentiating (2.24) with respect to $T$ yields

[15] This discussion assumes an interior solution for simplicity.

$$\frac{\partial K^{*T}}{\partial T} = \frac{-P_p[F'(K^{*T})]^2}{(P_f+T)^2[E''(K^{*T})F'(K^{*T})-F''(K^{*T})E'(K^{*T})]} \quad (2.29)$$

Given the assumptions on the signs of the derivatives of *F(K)* and *E(K)* as shown in equations (2.2), (2.3), (2.6) , and (2.7), we see that $\partial K^{*T}/_{\partial T}$ is negative.

Combining equations (2.9) and (2.10) yields the demand for fuel use, which is the difference between the fuel requirement and black liquor production,

$$f_t = E(K_t) - bF(K_t) \quad (2.9'')$$

Taking the derivative of the fuel use function with respect to $T$ yields $\frac{\partial f}{\partial T} =$

$$[E'(K^{*T}) - bF'(K^{*T})]\frac{\partial K^{*T}}{\partial T} \quad (2.30)$$

Rearranging equation (2.24) and substituting into (2.30) yields

$$\frac{\partial f}{\partial T} = \left[\frac{P_p}{P_f + T_{f,t}}\right] F'(K^{*T})\frac{\partial K^{*T}}{\partial T} \quad (2.31)$$

which, given the value of $\partial K^{*T}/_{\partial T}$, is negative.

Equations (2.29) and (2.31) show how the fuel tax unambiguously lowers the optimal level of $K$ chosen by the mill, and the amount of fossil fuel used. While the overall effect of the tax is to lower production, the competing effect due to black liquor production does counter the decreasing effect somewhat, and the overall effect is not as pronounced as it would be in an industry without a by-product such as black liquor that can be used as a fuel.

The effect of the tax alone on the investment decision is ambiguous due to the complicating factor of the relationship with black liquor to production. Modifying equation (2.28) to reflect the case where $\omega = 0$ yields

$$C + OV < \sum_{t=1}^{\infty}\left(\frac{1}{1+\varphi}\right)^t \cdot \{ [P_{p,t} + b(P_{f,t} + T)] \cdot [F(K_t'^T) - F(K_t^{*T})] + (P_{f,t} + T)[E(K_t^{*T}) - E(\gamma K_t'^T)]\}\,. \tag{2.28'}$$

Also recall equation (2.23)

$$C + OV < \sum_{t=1}^{\infty}\left(\frac{1}{1+\varphi}\right)^t \cdot\ [P_{p,t} + bP_{f,t}] \cdot [F(K_t') - F(K_t^*)] + P_{f,t}[E(K_t^*) - E(\gamma K_t')] \tag{2.23}$$

which shows the condition for investment under a policy-free scenario. Comparing the right hand side of both equations shows that the fuel tax has two effects on the decision to invest. The first is that it increases the value of the terms multiplying the differences in production and energy requirement. The other is to lower production in all cases, as $K_t'^T < K_t'$ and $K_t^{*T} < K_t^*$ . Both of these effects have an ambiguous effect on the entire decision. If

$$\sum_{t=1}^{\infty}\left(\frac{1}{1+\varphi}\right)^t \cdot \{ [P_{p,t} + b(P_{f,t} + T)] \cdot [F(K_t'^T) - F(K_t^{*T})] + (P_{f,t} + T)[E(K_t^{*T}) - E(\gamma K_t'^T)]\}$$
$$> \sum_{t=1}^{\infty}\left(\frac{1}{1+\varphi}\right)^t \cdot\ [P_{p,t} + bP_{f,t}] \cdot [F(K_t') - F(K_t^*)] + P_{f,t}[E(K_t^*) - E(\gamma K_t')] \tag{2.32}$$

then the fuel tax will have a positive overall effect on the mill's willingness to invest in improving energy efficiency. However, as discussed by Schneider and Goulder (1997), the fuel tax alone may not be enough to stimulate investment in energy efficiency.

The subsidy on investment $\omega$ has a very clear positive effect on the mill's incentive to invest by simply lowering the cost of the investment by the rate of the subsidy. Compared to the PPGTP, a subsidy of this type pays the mill for every unit of investment undertaken, rather than paying the mill for every unit of black liquor burned, and indirectly, every unit of pulp produced.

***AFMTC***

A mill receiving AFMTC payments (i.e. $s > 0$), has a first order condition in period 0 with respect to production capital of

$$\big(P_{p,0} + b(P_{f,0} + s)\big)F'(K_0) \geq P_{f,0}E'(K_0) \quad and \quad \bar{K} - K_0 \geq 0 \tag{2.33}$$
$$with\ complementary\ slackness$$

which gives an optimal level of capital use labeled $K_0^{*a}$. The corresponding profit in period 0 is denoted $\pi_0^{*a} = \hat{\pi}_0^{*a} - I_0(C + OV)$.

The mill does not receive AFMTC payments after period 0. If the mill did not undertake the investment in period 0, then future periods are characterized by the first order condition expressed in equation (2.20) for the no policy scenario, and the mill produces at $K_t^*$ for a profit of $\pi_t^* = \hat{\pi}_t^*$ . If the mill did invest in period 0, then future periods are characterized by the first order condition expressed in equation (2.21), again for the no-policy scenario, and the mill produces at $K_t'^*$ for a profit of $\pi_t'^* = \hat{\pi}_t'^*$.

Adding the AFMTC to Equation (22) changes the investment decision to

$$\hat{\pi}_0^{*a} - (C + OV) + \sum_{t=1}^{\infty}\left(\frac{1}{1+\varphi}\right)^t \cdot \pi_t' \ > \ \hat{\pi}_0^{*a} + \ \sum_{t=1}^{\infty}\left(\frac{1}{1+\varphi}\right)^t \cdot \hat{\pi}_t^* \tag{2.34}$$

where $\hat{\pi}_0^{*a}$ is the optimized gross profit for the mill receiving the AFMTC subsidy. When simplified, this equation becomes identical to equation (2.23) above in the no–policy scenario. This is due to the fact that the mill receives the AFMTC subsidy regardless of whether it invests in energy efficiency or not, and the increased profits in period zero on both sides of the equation simply cancel out. This result clearly shows that the AFMTC provides no incentive to invest in energy efficiency.

Equation (2.33) implicitly defines the optimal capital choice in period 0, $K_0^{*a}$, as a function of prices and the subsidy, i.e. $K_0^{*a} = \psi(P_p, P_f, s)$. Differentiating (2.33) with respect to *s* yields

$$\frac{\partial K_0^{*a}}{\partial s} = \frac{b[F'(K_0^{*a})]^2}{P_f[E''(K_0^{*a})F'(K_0^{*a}) - F''(K_0^{*a})E'(K_0^{*a})]} \tag{2.35}$$

Given the assumptions on the signs of the derivatives of *F(K)* and *E(K)* as shown in equations (2.2), (2.3), (2.6) , and (2.7), $\partial K_0^{*a}/\partial s$ is positive.

Taking the derivative of the fuel use function, equation (2.9''), with respect to the AFMTC subsidy, *s*, yields the effect on fuel demand

$$\frac{\partial f_0}{\partial s} = [E'(K_0^{*a}) - bF'(K_0^{*a})]\frac{\partial K_0^{*a}}{\partial s} \tag{2.36}$$

Rearranging equation (2.33) and substituting into (2.36) yields

$$\frac{\partial f_0}{\partial s} = \left[\frac{P_p + bs}{P_f}\right]F'(K_0^{*a})\frac{\partial K_0^{*a}}{\partial s} \tag{2.36'}$$

which, given the value of $\partial K_0^{*a}/\partial s$ , is positive.

The positive signs of $\partial K_0^{*a}/\partial s$ and $\partial f_0/\partial s$ show that the AFMTC increases production and fossil fuel use in period 0. Changes to the mill's marginal revenue and profit functions under the AFMTC, as compared to the absence of any policy, are shown graphically in Figure 2.1 and Figure 2.2.

Figure 2.1 shows a profit maximizing mill operating in the absence of any policy. The bottom half of the graph shows the marginal revenue and marginal cost as expressed in equation (2.20), as well as the optimal production level where $K_0 = K_0^*$.

The top half shows the profit functions with and without undertaking the energy efficiency investment.

Figure 2.2 shows the effects of the AFMTC. Adding the AFMTC subsidy shifts the mill's marginal revenue curve up, which gives a higher optimal $K_0 = K_0^{*a}$. This also causes the profit curves to shift up by the amount of the subsidy paid, $s$, whether the mill invests or not. The magnitude of the shift in the profit functions is equal to the height of the subsidy curve for all values of *K.*

Comparison of equations (2.23) and (2.34) show that the AFMTC does not affect the mill's investment decision, as the mill receives AFMTC payments whether it invests or not. Even though the intent of the AFMTC was to encourage the use of alternative fuels, when claimed by chemical pulp mills, the credit had the perverse effect of actually increasing pulp production and traditional fossil fuel use, without increasing overall energy efficiency.

***PPGTP***

A mill participating in the PPGTP (i.e. $\hat{s} > 0$) faces a more complicated production decision than in the previous cases, as its marginal profit of $K$ is affected by whether it invests or not as well as the cost of its investment. In period 0, if the mill does not invest ($I = 0$), then it does not participate in the program and its first order conditions are the same as expressed in equation (2.20) for the no policy scenario. If the mill does invest ($I = 1$), it receives the subsidy rate for each unit of black liquor up until the total payment is equal to the investment cost, $\hat{s}bF(K_0) = C$, which implicitly defines a capital utilization value of $K_c$. For levels of $K$ greater than $K_c$, the mill does not receive any subsidy for the marginal unit of black liquor. This feature introduces a discontinuity in the marginal profit function (2.18) at $K_c$ in period 0 (alternatively a non-differentiability in the profit function). As a result, there are three possibilities for the solution to the profit maximization problem (2.17) in period 0 when the mill participates in the program. First, the solution may be less than $K_c$ ; i.e. $K_0^{*g} < K_c$ , where $K_0^{*g}$ represents the optimal choice. In this case, the mill receives PPGTP credits at the margin, and therefore the first-order condition which characterizes the solution is

$$\left(P_{p,0} + b(P_{f,0} + \hat{s})\right)F'(K_0) \geq P_{f,0}E'(K_0) \quad and \quad \bar{K} - K_0 \geq 0 \tag{2.37}$$

$$with\ complementary\ slackness$$

Second, $K_0^{*g} = K_c$ ; i.e. the solution lies at the kinked point of the period 0 profit function. Third, $K_0^{*g} > K_c$ . In this case, the mill does not earn PPGTP credits at the margin, and therefore the first-order condition is the same as the no-policy case in (2.20). We denote the optimized profit in the first and second cases as $\pi_0^{*g} = \hat{\pi}_0^{*g} - I_0(C + OV)$, and, of course, in the third case the optimized profit is the same as the no policy scenario $\pi_0^* = \hat{\pi}_0^* - I_0(C + OV)$ .

The mill is only able to participate in the PPGTP in period 0. If the mill did not participate and did not undertake the investment in period 0, then future periods are characterized by the first order condition expressed in equation (2.20) in the no-policy scenario, and the mill produces at $K_t^*$ for a profit of $\pi_t^* = \hat{\pi}_t^*$ . If the mill did invest in period 0, then future periods are characterized by the first order condition expressed in equation (2.21), also in the no-policy scenario, and the mill produces at $K_t'^*$ for a profit of $\pi_t'^* = \hat{\pi}_t'^*$.

Equation (2.22) can be adjusted to represent a mill participating in the PPGTP as follows,

$$\hat{\pi}_0^{*g} - (C + OV) + \sum_{t=1}^{\infty} \left(\frac{1}{1+\varphi}\right)^t \cdot \pi_t' \ > \hat{\pi}_0^* + \sum_{t=1}^{\infty} \left(\frac{1}{1+\varphi}\right)^t \cdot \hat{\pi}_t^* \tag{2.38}$$

where $\pi_0^{*g}$ is the optimized profit for a mill receiving PPGTP credits in period zero. The right hand side of the equation shows the mill refusing participation in the PPGTP and not investing. The left hand side of the equation shows the mill participating in the program. In order to receive the credits, the mill must invest, and because the credits are tied to production, the mill's optimal profit in period 0 ($\pi_0^{*g}$) changes to accommodate the added revenue source of the PPGTP credits. The benefits for the mill from participating in the program are then two-fold: the increase in profits in period zero ($\pi_0^{*g} - \pi_0^*$), and the lowered cost of production in future years. The cost is the required monetary cost plus lost option value (*C+OV*). Using equation (2.14), this condition solves to,

$$\begin{aligned} C + OV - \min[\hat{s}bF(K_0^{*g}), C] &< [P_{p,0} + bP_{f,0}] \cdot [F(K_0^{*g}) - F(K_0^*)] - P_{f,0}[E(K_0^{*g}) - E(K_0^*)] \\ &+ \sum_{t=1}^{\infty} \left(\frac{1}{1+\varphi}\right)^t \cdot \{ [P_{p,t} + bP_{f,t}] \cdot [F(K_t') - F(K_t^*)] + P_{f,t}[E(K_t^*) - E(\gamma K_t')]\} \end{aligned} \tag{2.39}$$

The above equation shows two competing incentives to invest provided by the PPGTP as compared to a mill without any policy or a mill receiving the AFMTC. The positive incentive is the subtraction of the PPGTP credits from the cost of investment on the left hand side of the equation. The negative incentive is the movement away from the optimal amount of production from $K_0^*$ to $K_0^{*g}$, which is expressed in the first two terms that are added to the right hand side of the equation. As will be shown in proposition 4, the summation of these two terms is negative.

A mill receiving payments under the PPGTP is given similar production incentives as a mill receiving payments under the AFMTC, up to the point where the total credits received are equal to the cost of investment. Up to this point, the mill faces a marginal revenue of $[P_p + b(P_p + \hat{s})]F'(K)$, the same as under the AFMTC. After this point, the mill stops receiving credits and faces a marginal revenue of $[P_p + bP_p]F'(K)$, the same as a mill without any policy. This causes the mill's marginal revenue function to have a discontinuous jump at $K_c$ , where $\hat{s}bF(K_c) = C$. This also causes the mill's profit function to have an un-differentiable 'kink' at the same point.

Assuming that the PPGTP payment is enough to cause the mill to participate in the program and invest, then there will be three possibilities for the value of $K$ that the mill will choose in order to maximize profit in period 0: (i) $K_0^{*g} < K_c$ , (ii) $K_0^{*g} = K_c$ , and (iii) $K_0^{*g} > K_c$ . These values depend on how $K_c$ compares to the optimal values of $K_0$ under the AFMTC, $K_0^{*a}$, and in the absence of any policy, $K_0^{*}$. The latter two values are relevant because the mill will have marginal effects similar to a mill under the AFTMC while receiving PPGTP credits, but these marginal effects will revert to the no policy scenario once the credit limit is reached at $K_c$ .

The situation where $K_0^{*a} < K_c$ is shown in Figure 2.3. The bottom half of Figure 2.3 shows how the PPGTP shifts out the mill's marginal revenue by the same amount as under the AFMTC. The mill faces this marginal revenue curve until $K_c$ , and then shifts down to the marginal revenue without the subsidy. $K_c$ is also the point where the subsidy curve reaches the cost of investment, *C,* and where the profit function ($\hat{\pi} + \hat{S} - C$ to the left of $K_c$ , $\hat{\pi}$ to the right of $K_c$) kinks. For values of $K_0 < K_c$ , the mill has a profit function that is identical to the profit function under the AFMTC (in Figure 2.2) with the cost of investment. For values of $K_0 > K_c$, the mill has a profit function equal to the profit function under no policy (in Figure 2.1) without the investment cost, as after this point, the mill no longer receives credits and the entire monetary cost of the investment is covered by $\hat{S}$.

The profit maximizing choice of $K_0$ can now be derived under the PPGTP when $K_0^{*a} < K_c$ as follows

**Proposition 1:** When $K_0^{*a} < K_c$, $K_0^{*g} = K_0^{*a}$.

**Proof:** For $K_0 < K_c$, the profit function under the PPGTP is the same as under the AFMTC (provided $\hat{s} = s$). It follows that a unique maximum occurs at $K_0^{*a}$. ■

In this case, the PPGTP simply mimics the AFMTC, in terms of its incentives for production in period 0. The mill receives a payment of $\hat{s}bF(K^{*a})$, which does not fully cover the cost of $C$.

The situation where $K_0^* > K_c$ is shown in Figure 2.4. As above, the profit function kinks at $K_c$, which is also the point where $\hat{S} = C$, and where marginal revenue jumps down to the marginal revenue curve without the subsidy. In this case, the mill will not benefit from marginal funds under the program, as the mill will not be able to keep any credits over and above the cost of the energy efficiency investment.

The profit maximizing choice of $K_0$ when $K_0^* > K_c$ is derived as follows.

**Proposition 2:** When $K_0^* > K_c$, $K_0^{*g} = K_0^*$.

**Proof:** For $K_0 > K_c$, the profit function under the PPGTP is the same as under no policy. It follows that a unique maximum occurs at $K_0^*$. ■

In this case, the PPGTP simply mimics the no policy scenario, in terms of its incentives for production in period 0. The mill will earn credits of $\hat{s}bF(K^*)$, but will only be able to accept a payment of $C$. As such, the mill will leave a portion of its credits unclaimed, and the entire monetary cost of the investment will be covered by the PPGTP.

The situation where $K_0^* < K_c < K_0^{*a}$ is shown in Figure 2.5. In this situation, the mill's marginal revenue curve intersects its marginal cost curve at the point of the discontinuous jump, shown in the lower half of Figure 2.5 at $K = K_c$ . The mill will benefit from additional PPGTP funds up to the point where $\hat{S} = C$, but not after. For values of $K < K_c$ , the mill faces the profit function similar to the AFMTC profit with investment cost. For values of $K > K_c$ , the mill faces the profit function similar to the no-policy profit without investment cost. Because $K_0^* < K_c < K_0^{*a}$, the left portion of the kinked profit function is positively sloped, whereas the right portion is negatively sloped.

The profit maximizing choice of $K_0$ when $K_0^* < K_c < K_0^{*a}$ then follows directly.

**Proposition 3:** When $K_0^* < K_c < K_0^{*a}$ , $K_0^{*g} = K_c$ .

**Proof:** $\hat{\pi} + \hat{S} - C$ attains a maximum (non-differentiable) at $K_c$ . ■

In this case, the total payment received will be $\hat{s}bF(K_c)$, which will exactly offset the cost of *C.* The mill still has incentive to increase production beyond the no policy level, but not to the same extent as under the AFMTC.

Equation (2.39) shows that the PPGTP affects the investment decision in two ways. The first is the rather obvious subtraction of the PPGTP funding from the cost of investment shown on the left had side of the equation. The second is the period 0 terms added to the right hand side of the equation, ($[P_{p,0} + bP_{f,0}] \cdot [F\left(K_0^{*g}\right) - F(K_0^*)] - P_{f,0}\left[E\left(K_0^{*g}\right) - E(K_0^*)\right]$) which show the difference in production induced by receipt of the PPGTP credits. In the second scenario discussed above where the mill is not able to claim all of its earned credits ($K_0^* > K_c$), this effect goes to zero, as $K_0^{*g} = K_0^*$ . For the other two scenarios, $K_0^{*g} > K_0^*$ . In this case, it is possible to show that the terms above take on a negative value.

**Proposition 4:** When $K_0^{*g} > K_0^*$ , $[P_{p,0} + bP_{f,0}] \cdot \left[F\left(K_0^{*g}\right) - F(K_0^*)\right] - P_{f,0}\left[E\left(K_0^{*g}\right) - E(K_0^*)\right] < 0$

**Proof:** By definition $\hat{\pi}_0\left(K_0^{*g}\right) < \hat{\pi}_0(K_0^*)$ when $K_0^{*g} > K_0^*$ ; i.e. the gross profit in period 0 under no policy and no investment evaluated at the optimal choice $K_0^*$ is greater than at $K_0^{*g}$. Substituting from equation (13) then gives the result ■

This result demonstrates that the PPGTP involves the standard economic inefficiency of second-best policy. By tying the investment subsidy to the unrelated activity of production, the policy induces a tradeoff whereby the mill owner chooses to increase first-period production above the baseline profit maximizing level in order to obtain the benefit of the subsidy. This loss of profitability has the perverse effect of increasing the overall cost of investment. Therefore, the subsidy needs to be greater than otherwise to have the desired effect.

Another point to note about the PPGTP is that the funding amount is entirely based on the amount produced by the mill. In a situation where each mill has a different energy efficiency investment, each with different costs and effectiveness, it may not be the case that the most economically efficient investments are the ones that are funded. It could be the case that a small mill with a possibility to greatly improve its energy efficiency may not be able to raise enough credits through its production in order to make the investment worthwhile, whereas a large mill with a less effective investment opportunity, but much higher production, and hence credits, could. Put another way, a more effective subsidy would distribute the funding to the mills that can make the greatest and most cost effective improvements in energy efficiency, but the PPGTP funding is distributed based on production level, and the two may not be the same.

In contrast to the PPGTP, a subsidy that pays the mill directly for its investment, as under the direct policy, has three key benefits:

1) The subsidy itself does not distort the mill away from the optimal level of employed capital and production. This lowers the required amount that must be paid to the mill in order to entice investment, as the subsidy does not have to cover the increased costs of production at the margin on top of the cost of the investment, as shown in the discussion on the PPGTP
2) There is the potential for less free riding compared to the PPGTP. While the total number of free riding mills on the subsidy would be the same (they would have invested regardless without any intervening policy, and hence would invest under either subsidy policy as well), but the total amount paid for free-riding activity would be less if $OV$ is small relative to $C$. Under the PPGTP, in two out of three possible scenarios, the investment made by the mill is entirely covered by the program. A subsidy that matches a set amount for every dollar spent by the mill would ensure that the mill pays at least a portion of the cost of its investment if $OV < C$. However, if $OV > C$, then the optimal $\omega > 1$, which would lead to higher payments compared to the PPGTP, which is capped at $C$.
3) The subsidy would better target mills with more effective energy efficiency investments. By uniformly lowering the cost of all the possible investment

> projects by the same rate, the more effective projects will be encouraged to be undertaken. The PPGTP, however, awards credits based on size of the mill through production. The effectiveness of a particular mill's investment may not necessarily be related to the size of the mill: It is quite reasonable to assume that an older and less energy efficient, yet smaller mill would have cheaper abatement options compared to a new state-of-the-art mill that happens to also be large. A mill with a very ineffective investment might be encouraged to invest if their production was large enough to have the PPGTP funding cover the cost, simply because they are large, whereas there may be more effective options available at a smaller mill which is not able to garner enough credits due to lower production.

One advantage offered by the PPGTP over the direct policy could be its ease of implementation. It may not be feasible to empirically measure the option value that the mill places on investment, and without a proper understanding of this valuation, it would not be possible to set the correct subsidy rate, $\omega$. Setting $\omega$ too low would not give the optimal number of energy efficiency projects undertaken, and setting $\omega$ too high would lead to too much investment and the adoption of projects that are too expensive. Also, if each mill values their ability to delay investment differently, i.e. different OV's, then each mill would have to be offered a different subsidy rate in order to make the policy cost effective. Only in the case that all mills have an $OV$ as the same percentage of $C$, can the regulator use the same $\omega$ across all mills.

## Conclusions

This paper is a first step in examining the issues with the AMFTC and the PPGTP subsidies. The theoretical model presented here provides valid insight for comparing the AFMTC and PPGTP policies. Also, the interaction of environmental policies with an industry with a by-product that can be used as part of the firm's production process has some interesting implications, as the traditional results for these policies do not necessarily apply to a firm that has competing incentives, such as a pulp mill.

The model presented in this paper shows that the AFMTC policy does not offer a pulp mill any incentive to undertake an investment in energy efficiency. Even though the AFTMC was a policy that was meant to encourage the use of alternative fuels in the place of traditional fossil fuels, when claimed by chemical pulp mills, the credits led to increased production and an increased fuel requirement faced by the mill.

In contrast to the AFTMC, the PPGTP was shown to provide incentive for a mill to undertake an investment in energy efficiency, with less incentive towards over production. However, even though the PPGTP policy was shown to provide more investment incentive than the AFMTC, the policy still exhibits failings of a second-best policy.  This is due in part to the credits earned under the program being tied to black liquor production, and hence, pulp production. This increased incentive to produce causes the mill to shift away from the optimal level of production at increasing marginal cost. As the subsidy must be spent on investment, the total payment must be large enough to not only spur investment, but also reimburse the mill for this increased production.

The work undertaken and discussed in this paper also contributes to the current body of literature by applying economic theory to two environmental programs that were implemented with the goal of lessening environmental impact. Examining these two policies after the fact provides a very interesting case study in how environmental policies can have unintended results. It should be noted that there was likely a significant amount of politics involved with both of these policies, particularly the PPGTP, which was enacted as a response to the AFMTC, and was lobbied for significantly by the Canadian pulp and paper industry. As such, these policies may not have been enacted on purely environmental reasons.

A reasonable next step for this research would be to undertake a quantitative measure of the overall effects of these two policies at both the firm and industry level. In order to complete this measure, data on mill level production, fuel use, and investment would be needed. It would also be of great interest to measure the total impact on overall energy efficiency and investment compared with the amount spent by the regulatory agencies. This would offer a comparison of the AMFTC and PPGTP's effectiveness to other policies with similar goals. Overall, the results found by the model in this paper would provide a strong analysis that could have implications on regulating bodies considering similar subsidies in the future. This, combined with a quantitative investigation, could help policy makers avoid similar unintended effects with the programs they design and implement in the future.

# Chapter 3: Naming, Shaming, and Abatement: Do Published 'Top Emitter' Lists Provide Incentive for Increasing Pollution Prevention Activities?[16]

## Introduction

This paper investigates how being labeled as a top emitter by a regulatory body shapes the decision of a firm to undertake new pollution abatement activities, and in turn, how these abatement activities affect a firm's subsequent reported emission levels. The study uses Canadian facility-level Pollutant Release and Transfer Registry data that includes information on pollutant releases, employee counts, and types of pollution abatement activities undertaken at the facility level. The data also provides for a natural experiment that can be used to evaluate Environment Canada's decision to cease naming large emitters in print on an annual basis.

Pollution Release and Transfer Registries (PRTR), such as Canada's National Pollutant Release Inventory (NPRI), or the United States Toxics Release Inventory (TRI), require the industrial facilities in these nations to report information on their polluting activities on an annual basis. The data collected by these programs, made available to the public on an annual basis in the form of large databanks, include pollutants directly released to the environment, managed disposals, and transfers for treatment and recycling of various substances deemed harmful to human health and the environment. It is argued that the main purpose behind these programs is the 'public right to know' of the environmental impact of these industrial facilities. It is assumed that if a firm is required to make its pollution information public knowledge, then community and environmental groups can use the

[16] Tables and figures for Chapter 3 are located in Appendix C

information to pressure the firm to reduce emissions where needed. As well, consumers and investors are able to become better informed of a company's environmental impact and to make more informed purchasing and investing decisions (Tientenberg, 1998). Previous research has suggested that these effects would encourage the firm to reduce its emissions without the need for costly or intrusive government regulation (Fung and O'Rourke, 2000).

One way that the NPRI tried to motivate more environmental awareness was to publish *Top Ten* lists between the years of 1993 to 1999. These lists named the top ten emitters for each pollutant as part of a comprehensive data summary that was published annually. These lists published the names of the facilities that had the largest total releases of each pollutant to air, water, land, and underground injection. In theory, these lists were published to raise awareness among the public, environmentally conscious consumers, and environmental groups about who the major emitters of pollution in Canada were at the time. If one of the main purposes of a PRTR is to raise public awareness of the environmental impacts of facilities operating in the country, then publishing a form of top emitter list seems like a simple and cost-effective way to increase the dissemination of this information. In theory, publishing a list of top emitters would encourage those firms listed to voluntarily reduce emissions without the need of costly regulation, assuming that when "large investments in reputational capital are at stake, no major firm wants to be listed as one of the dirty dozen" (Terry and Yandle, 1997).

Most past studies on the topic of how publically available environmental information causes facilities to reduce their emissions voluntarily focus on a direct relationship between negative press and reduced emissions from facilities (Hamilton (1995), Khanna, Quino, and Bojilova (1998), De Marchi and Hamilton (2006), Campa (Forthcoming)). Overall, it is assumed that negative press leads to increased abatement efforts by the firms, which in turn leads to a reduction in emissions. What is missing from this body of literature is an examination of abatement efforts undertaken by these firms. This paper attempts to address this gap in the literature by using facility level information on types of abatement activities undertaken by facilities, and to discern the relationship between bad press and abatement efforts, followed by the impact of abatement efforts on reported releases.

For the purposes of this paper, published *Top Ten* lists by the NPRI program were used as a measure of bad press. This methodology allows for the testing of the significance of bad press on a facility's abatement effort while at the same time providing a natural experiment to examine the validity of Environment Canada's decision to cease their publication.

The results show no definitive relationship between Top Ten publications and abatement effort on average. However, the results do show a significant reduction in emissions for those facilities that reported an increase in abatement effort. This result, coupled with the overall downward trend in reported pollution abatement activities, has significant environmental policy implications.

This paper begins by synthesizing the background literature relevant to the study, including empirical works using TRI and NPRI data as well as more general research on voluntary pollution abatement. This is followed by the research questions for this paper. A theoretical model provides context for the hypothesis, and the data used for this study is then described. This is followed by a description of the empirical models that will be tested, and a summary of the empirical results. The paper concludes with a discussion and policy recommendation.

## Background Literature

The literature examined falls into two broad categories: papers that explore the effect of publically released environmental information on firms and the effects of bad press on future pollutant releases; and papers that explore reasons why a firm would engage in voluntary measures to reduce pollutant emissions, in the absence of any intervening policy. Most research in the former area uses publically available data published by the US TRI. A majority of the work in the latter area revolves around firm participation in voluntary US environmental programs such as the US EPA's 33/50 program. This section provides an overview of both of these branches of literature and discusses the current gap that exists that we hope this work will partially address.

Several papers have attempted to examine whether the publication of firm or facility level environmental performance information has an effect on firms, and consequently, how firms respond to potential or actual negative publicity in subsequent reporting of this information in following years. Hamilton (1995) was one of the first to work in this area, showing that, for publically traded companies, below average stock market returns were correlated with the release of TRI data in 1989. Interestingly, Hamilton also demonstrated that this effect was exacerbated for those firms that received more media coverage on their TRI data, measured by number of times cited in major newspapers. Finally, Hamilton showed that the amount of releases was not significant, but the number of substances reported was. Lanoie, Laplante, and Roy (1998) used a government agency's own publication as a measure of bad press, and, like Hamilton (1995), attempted to correlate this to company stock market performance. In this case, the bad press took the form of companies being publically labeled by the provincial government as 'out of compliance' with environmental regulation in the province of British Columbia. While no significant relationship was found, this may be due to the small sample size (19 companies), or the fact that the labeling was in BC only.

Hamilton's work in particular was followed up by Khanna, Quino, and Bojilova (1998) and Konar and Cohen (1997), who both showed a relationship between this stock market effect and future emissions. Those firms that had the largest reduction in market value coinciding with the release of TRI data subsequently reduced their emissions (Konar and Cohen), or increased their transfers for treatment and recycling (Khanna, Quino, and Bojilva). Supporting Hamilton's finding that release amounts are not significant to a firm's emissions reduction, De Marchi and Hamilton (2006) compared the Top 40 largest emitters in the TRI to the Top 40 facilities that received the most media attention. Interestingly, media attention was shown to affect emissions reductions more significantly than the amount of releases. Finally, a forthcoming paper by Campa uses TRI data to show that negative press, proxied by distance to local newspapers, is also a significant force in the reduction of pollutant emissions.

Of particular note is a relevant working paper by Scorse and Schlenker (n.d.), which addresses the same problem as this paper, ie, the effect of being labeled as a Top Ten emitter on a firm's emissions. This paper uses TRI data from 1995 to 2001 and are able to show that once firms are no longer labeled as a Top Ten emitter, they go on to significantly increase emissions in the following three years. The authors make use of an expansion in the TRI program that coincided with the addition of several industrial sectors that were required to report. This addition replaced several Top Ten labeled emitters with new facilities, and the effect of no longer being labeled as such was able to be shown. Unfortunately, a similar expansion to the NPRI program did not happen until after the cessation of the publication of Top Ten lists, and so a similar approach was not able to be done on the Canadian NPRI data.

One common theme in this branch of literature is the absence of any sort of measure on abatement effort – conscious and possibly costly actions undertaken by the firm with the intent to reduce emissions, as opposed to lost sales leading to lower production and lower emissions. The relationship between changes in a firm's releases in subsequent years following some measure of bad press on those releases is for the most part consistent. Whether bad press is measured directly, such as by number of newspaper articles citing a company (Hamilton, 1995, De Marchi and Hamilton, 2006) or indirectly, for example by measuring distance between the facility and surrounding newspaper offices (Campa), the result is the same – facilities or companies that experience more bad press from their publically available emissions tend to report lower emissions in subsequent years. Also of particular interest is the finding by DeMarchi and Hamilton that show that the *amount* reported does not really matter, but rather it is how much attention that the facility gets in the media that drives the change. This finding suggests that the act of simply making the data available is not in and of itself enough to give incentive to reduce emissions – the information must be discussed in the media in order to have any noticeable effect. What is missing from this body of literature is an examination of the mechanism by which these emissions reductions take place. Are they indeed due to increased abatement effort from the firm in light of its bad press, or is there some other explanation? For example, could the bad press received by the firm cause lost sales, which lead to less production, and in turn less emissions? In only examining changes in reported emissions, the literature to date has identified media coverage as a trigger for future reduced emissions but it has failed to identify the driver behind decreased emissions, that is to say the method by which a facility lowers those emissions, whether that be increased abatement measures or decreased production. This is especially relevant from a policy perspective – policy makers certainly want to see reductions in emissions, but ideally not at the expense of reduced economic output.

Also relevant to this study is the literature examining participation by firms in voluntary pollution abatement activities, which gives insight into reasons why firms choose to undertake costly abatement activities in the absence of direct monetary incentive or government enforced command and control mechanism. Most of these studies examine reasons for joining the US EPA's 33/50 program, which targeted 17 pollutants for a 33% reduction in emissions by 1992 and a 50% reduction by 1995, as compared to a 1988 baseline (US EPA, 1999). Videras and Alberini (2000) showed positive publicity had a significant and positive impact on the likelihood of participating in the 33/50 program, which suggests there may be real intangible benefits for a firm who is seen as making an effort to reduce emissions. Another, perhaps less obvious benefit arises as a result of less environmental inspections from the EPA. Sam, Khanna, and Innes (2009) empirically showed that firms were more likely to participate in the 33/50 program if they were subject to more regular inspections. Interestingly, it was also shown that these inspections occurred less frequently after a firm joined the program. These works begin to explain why a firm would participate in a program like the EPA's 33/50, because "under a voluntary approach, a polluter will not participate unless his payoff is at least as high as it would be without participation, ie, the firm must perceive some gain (or at least no net loss) from participation" (Alberini and Segerson, 2002).

While there are some clear benefits to participation in a voluntary program, the impact of these types of programs on a firm's reported releases has been questioned. In two separate works, Vidovic and Khanna (2007 and 2012) show that during the time that the 33/50 program was in place there is no statistical difference in emissions reductions between firms that participated in the program versus those that did not. Any reduction in emissions from participating firms was attributed to the overall downward trend in emissions seen during that time.

Some recent work from Canada provides additional context for the finding that firms may voluntarily abate in order to decrease intervention and inspections from a governing body. These works include four papers: Antweiler and Harrison (2003); Harrison and Antwieler (2001 and 2003); and Antweiler (2003). To our knowledge, these studies are also the only use of Canadian NPRI data in an economics context. Two of these papers model regulatory threat and how it affects a firm's emissions (Antwieler, 2003, Harrison and Antwieler, 2003). Harrison and Antwieler (2003) show that pollution intensity is the most significant variable in a firm's pollution emissions reduction. Both of these papers use a measure of a firm's releases that are deemed toxic under the Canadian Environmental Protection Act as a proxy for potential future regulation.

This branch of literature contrasts with the previous body discussed in that it examines voluntary abatement from the context of benefits to the firm from doing so, either from decreased intervention and regulation, or by positive press in the media, whereas the other body of literature assumes the firm will abate in order to avoid costly bad press. This body of literature is also interesting in that its examination of voluntary programs shows there is at least a partial observation of increased abatement effort, if we assume that a firm participating in the program will abate more than it otherwise would have if it had not participated. However, this is a very indirect and imprecise measure of abatement, and, as discussed, was shown to have no significant effect on reported emissions outside of an overall decreasing trend.

As discussed, the main gap in both these bodies of literature is the lack of information on abatement effort undertaken by the examined firms. The literature examined for this paper provides a preliminary exploration of why a firm might voluntarily undertake costly abatement in the absence of direct incentives or controls, as well as the relationship between bad press on future emissions (Campa, Forthcoming, Hamilton 1995, De Marchi and Hamilton, 2006). However, an understanding of *how* a facility lowers its emissions, and the reason *why* bad press might lead to lower emissions, is absent from the current literature.

The research presented in this paper attempts to shed some light on whether or not bad press actually encourages a firm to increase its abatement efforts, and examines whether increased abatement efforts correspond with a decrease in reported emissions. The difference in approach is expressed in Figure 3.1. Figure 3.1 shows the relationship between bad press and lower reported releases, as outlined in the previous literature, labeled as line A. This paper examines the intermediate step in this relationship, namely, the firm investing in abatement, which in turn leads to reduced emissions, labeled as lines B and C. For completeness, an alternative possibility, that the bad press leads to lost sales and production, and subsequently less emissions, is presented and labeled as lines D and E.

In order to investigate the linkage between negative press and abatement efforts, this study worked from the hypothesis that the amount of negative press a firm receives regarding its reported emissions is what encourages a firm towards increased abatement (Campa, Forthcoming), rather than the magnitude of the reported emissions (De Marchi and Hamilton, 2006, Hamilton 1996). In this study, this negative press will be defined as whether or not the facility was labeled as a Top Emitter in an annual report published by the NPRI program for any one of the substances reported on. While simply appearing on the list is not a direct measure of bad press, it is a similar measure to that used by Lanoie, Laplante, and Roy (1998), who posited that lists published by a regulatory body have impacts, for example a list of facilities that they deem have a larger environmental impact than their peers. It is assumed that this published information is easily picked up by the mainstream media, leading to bad press for the facilities labeled. As will be described in more detail in the data section of this paper, the NPRI program collects information on what kinds of activities reporting facilities undertake in order to reduce their emissions. This information will be used as a direct measure of facility level abatement effort. This paper focuses on two main research questions:

1) What is the effect of being publically labeled as a Top Emitter on a facility's pollution abatement effort?
2) Does increased reported number of pollution abatement activities lead to a measurable decrease in reported pollution emissions?

## Theoretical Model

The following section provides a theoretical model of *n* firms that do not compete directly with each other in the market for the goods they produce. The firms are ranked according to emissions level and the top emitters are publically disclosed, which results in a fixed cost imposed on the firm due to negative publicity. The model goes some way to informing the effect of being publically labeled as a top emitter that will attempt to be examined empirically.

There are *n* firms, who use capital equipment in order to produce a good that is sold in a competitive market. These firms do not produce the same good, and hence are in not direct competition with each other.

Firm *n*'s profit function is

$$\pi_n = P_n F(K_n) - rK_n - gA_n - C_n \tag{3.1}$$

where revenue is the price multiplied by production and cost is the cost of using production capital (*rK*) and the cost of pollution abatement (*gA*). The production function *F* is increasing in *K* at a decreasing rate. $C_n$ represents the lost goodwill from being labeled as a large polluter, as follows,

$$C_n = C \ if \ E_n \geq E_{10} \tag{3.2}$$

$$C_n = 0 \ if \ E_n < E_{10} \tag{3.3}$$

Where *En* is the level of emissions produced by firm *n* and $E_{10}$ are the emissions produced by the firm that is ranked 10th in terms of magnitude of releases. The 10th firm is used as the basis of comparison as it is the 10 largest firms in terms of emissions that are published.

Emissions are a function of capital use and abatement, as follows;

$$E(K_n, A_n) \tag{3.4}$$

$$E_A(K_n, A_n) < 0 \tag{3.5}$$

$$E_K(K_n, A_n) > 0 \tag{3.6}$$

When examining firm *n*'s profit maximizing problem, there are two possible scenarios due to the discontinuous nature of the goodwill cost of being labeled as a large polluter.

***Scenario one:*** $\boldsymbol{E_n < E_{10}}$

Firm *n*'s emissions are lower than the emissions of the 10th ranked firm. As such, there is no negative goodwill cost faced by firm $n$, and no incentive to abate emissions. Firm *n*'s profit maximization problem yields the following FOC and optimal capital use, $K$*,

$$\frac{\partial \pi_n}{\partial K_n} = PF'(K_n) - r = 0 \;\; => \;\; F'(K_n^*) = \frac{r}{P_n} \tag{3.7}$$

which gives the following maximized profit and associated emissions

$$\pi_n^* = P_n F(K_n^*) - rK_n^* \tag{3.8}$$

$$E_n^* = E(K_n^*, 0) \tag{3.9}$$

***Scenario two:*** $\boldsymbol{E_n \geq E_{10}}$

If firm *n*'s emissions are larger than the tenth firm in the emissions ranking, then firm *n* will be publically labeled as a large emitter and will incur the additional cost to its goodwill, *C*. The firm then has two choices:

1) To not abate and simply incur the cost of *C* in the following period
2) To abate up to the point where firm *n*'s emissions are reduced such that it will no longer be publically labeled in the following period

If the firm chooses not to abate, its profit maximizing problem does not change, as *C* is a fixed cost. The maximized profit for firm *n* becomes

$$\pi_n^* = P_n F(K_n^*) - rK_n^* - C \tag{3.10}$$

and emissions are the same as in scenario one with no abatement.

If the firm chooses to abate, it will abate up to the point where emissions reductions are enough to take the firm off the published top emitters list, but no more. Firm *n*'s profit maximizing problem becomes

$$max\ \pi_n = P_n F(K_n) - rK_n - gA_n - C \tag{3.11}$$
$$s.t. E(K_n, A_n) < E_{10}$$

$$\mathcal{L}_n = P_n F(K_n) - rK_n - gA_n + \lambda_n[E(K_n, A_n) - E_{10}] \tag{3.12}$$

which yields the following two FOCs for *K* and *A*

$$\frac{\partial \mathcal{L}_n}{\partial K_n} = P_n F'(K_n) - r - \lambda_n E_K(K_n, A_n) = 0 \tag{3.13}$$

$$\frac{\partial \mathcal{L}_n}{\partial A_n} = -g + \lambda_n E_A(K_n, A_n) = 0 \tag{3.14}$$

which solve to give the optimal capital use, $K^A$, and the optimal abatement, $A^A$. This in turn gives the maximized profit

$$\frac{P_n F'(K_n) - r}{g} = \frac{E_K(K_n, A_n)}{E_A(K_n, A_n)} \;=>\; K_n^A, A_n^A \tag{3.15}$$

$$\pi_n^A = P_n F(K_n^A) - rK_n^A - gA_n^A \tag{3.16}$$

Firm *n* will abate to $E_n < E_{10}$ if maximized profit under abatement is greater than without abatement:

$$\pi_n^* < \pi_n^A \tag{3.17}$$

Or, put another way, if the benefits from abating (no goodwill cost, less cost of capital) outweigh the costs (cost of abatement, lost production)

$$P_n F(K_n^*) - rK_n^* - C < P_n F(K_n^A) - rK_n^A - gA_n^A \tag{3.18}$$

which re-arranges to,

$$P_n[F(K_n^*) - F(K_n^A)] + gA_n^A < C + r[K_n^* - K_n^A] \tag{3.19}$$

For reference, Figure 3.2 shows the three possible profit maximizing outcomes for firm *n*.

Having a negative cost associated with the NPRI Top Ten list publications raises the possibility of tournament style behavior among NPRI reporters, similar to that first modeled by Lazear and Rosen (1981). Most of the literature in this area focuses on differing rates of pay by employee rank in large organizations and various business and contract case studies, which is summarized extensively by Connolly et. al. (2013). The NPRI Top Ten lists could be viewed as a rank-ordered tournament, as the magnitude of a facility's releases do not determine if a facility will appear on the list, but rather it is the magnitude of the facility's releases compared to all other facilities that release the same substance that matters. Rosen (1986) explored the implications of heterogeneous contestants with varying ability, and hence, varying probability of winning the contest. This work is applicable to the NPRI's Top Ten publications in that different firms likely have different abatement costs. Tournament style behavior would suggest that facilities that are close to being published as a Top Emitter, for example, the 11$^{th}$ and 12$^{th}$ ranked facilities, would also have some incentive to undertake pollution prevention activities in anticipation of possibly being labeled in a future year as those who are ranked above them and who are published will attempt to lower their emissions. The nature in which the Top Ten lists were generated could confound this analysis, however. As will be discussed in more detail in the Data section of this paper, the Top Ten lists for several substances are not truly Top Ten lists. For example, some lists were cut off before the tenth facility if there were a difference of several orders of magnitude in releases between a facility and the next ranked facility. In this case, the next ranked facility's emissions would be low enough as to not entice any further abatement effort. Also, several substances do not have ten or more facilities that report them. In these cases, the published list would simply be all the facilities that reported the particular substance. In both of these cases, if $C$ varies for each rank, we could expect to see some competition among published reporters, as they try to move lower down the ranking compared to other listed facilities.

This model makes a few strong key assumptions. The first is that each firm chooses its abatement decision based on their own current ranking in the published top emitter list and the cost they are incurring from lost goodwill. The model abstracts away from any sort of tournament style behavior on the part of the firms in making their abatement decisions. Since each firm produces a different product and are not in direct competition with each other (for example, a steel plant and a pulp mill), there is no incentive to reduce emissions in order to force a competitor to incur the negative goodwill cost of being publically labeled. As discussed above though, they may be in competition with each other in the published Top Ten lists, and as such, there may be an overall measurable effect on pollution abatement effort as these firms attempt to move lower down in their ranking as compared to other published facilities. Also, we assume that a firm will only react to the negative goodwill cost upon incurring it – a firm that is not currently on the top emitters list will not abate in order to avoid getting on the list in the first place.

While this model is quite simple, it does show that, under certain conditions, in particular, high enough values of $C$, the cost of negative goodwill from publicly reported data could give a firm incentive in reducing its emissions. The current presentation of this model is also quite restrictive. For example, there are likely numerous costs involved with being publically labeled as a large emitter, such as lost sales due to environmentally conscious consumers substituting away from the firm. Also, the firm may have incentive to abate even though they will not be able to get off the Top Ten list, as there may be positive attention for a large firm that is seen to be improving. That being said, the model informs one of the testable hypothesis for this work, namely, that being publically labeled as a Top Emitter is costly enough to a firm that it will want to increase its abatement efforts. This will be examined directly, rather than indirectly through examining changes in emissions, which could change for a number of reasons, only one of which includes increased abatement effort.

## Data

The data used for this paper comes from Environment Canada's National Pollutant Release Inventory (NPRI). The NPRI is Canada's publically available pollutant release and transfer registry that collects self-reported information from over 8000 facilities. Facilities are required to report on approximately 350 substances or substance groupings of environmental concern, for which they report direct releases to the environment, as well as managed disposal activities and transfers to other facilities for recycling.

Since the first year that the NPRI was enacted in 1993, to 1999, the NPRI produced, as part of its annual summary of data, lists that put in print the names of the top emitting facilities for each substance that was on the program's list of substances. These lists were colloquially known as 'Top Ten' Lists, and will be referred to as such in this paper. The lists were not necessarily all the top ten emitters of a particular substance – some substances, for instance, had less than 10 emitters. In this case the list would simply contain all the emitters. Also, some of the choosing of the top emitters was somewhat arbitrary. If a substance had a few large emitters followed by several small emitters with releases orders of magnitude less relative to the larger facilities, then only the larger ones would be published. The published reports do not make it entirely clear what the exact threshold for determining which emissions would be too small relative to the large emitters to be published. This reduces consistency for each substance, as the threshold for being labeled as a top emitter is partially based on the context of the other releases for that substance.

The primary reason for the cessation of the publication of the Top Ten lists was due to their unpopularity with reporting facilities. This unpopularity is mostly the result of incomparability between facilities. Some examples of why simply ranking facilities in this manner may not be a comparable metric are:

1) Comparing facilities across different industries may not make for relevant comparisons – different industries have different processes and use different substances. What could be a large emission intensity for one industry could be a relatively small emission intensity in another industry.
2) Labeling large emitters simply because they are large omits context in regards to efficiency – just because a facility emits a large amount of releases does not necessarily mean it is a 'dirty' facility. For example, a large, new power plant may emit much less per MW of electricity produced compared to a smaller, older plant, even though the larger plant's total emissions are greater.
3) Labeling large emitters simply because they are large leaves out context about changes over time – a large facility that has undertaken substantial investments in pollution abatement and reduced its emissions would not have this information reflected in a simple one year ranking if its emissions were relatively large compared to other facilities. Similarly, a smaller facility could have substantially increasing emissions over time but still be small enough to not be labeled as a Top Ten emitter and not receive the associated negative attention.

Thus, in the year 2000 the NPRI ceased publishing their own *Top Ten* lists and instead left it to public groups to determine who the top emitters were, if that information was so desired.

Starting in 1997, Canadian facilities were required to report information to the NPRI on their pollution prevention activities. This reporting took the form of a series of YES/NO flags describing certain broad pollution abatement activities. The choices that a facility could choose were: (a) Material and Feedstock Substitution, (b) Product Design Reformulation, (c) Equipment or Process Modifications, (d) Spill and Leak Prevention, (e) On-Site Recovery, Re-Use, or Recycling Techniques, (f) Improved Management or Purchasing, (g) Good Operating Practice or Training, and (h) Other Pollution Prevention Activity.

For a given year, a facility could report that they had undertaken any number of these activities or none at all. A facility would fill out a Pollution Prevention report for each substance it emitted, so some activities could apply to one or several substances or, a facility wide activity could apply to all substances that the facility reported on[17]. Unfortunately, the manner in which this type of data is collected leaves something to be desired from a data analysis standpoint. The pollution prevention activities are very broad, and two facilities that report undertaking the same pollution prevention activity could in reality be undertaking very different activities. This reduces comparability across facilities. Also, the reporting of these activities is a simple yes-or-no question – and as such, there is no measure of intensity. Two facilities spending very different amounts on pollution abatement could in theory report the exact same activities to the NPRI. There is also the issue of what gets reported year to year. For example, one facility could undergo a large retrofit of its entire operation in one year and

[17] In 2002, the pollution reporting of prevention activities was expanded to include more detailed options for the reporter to choose. Choosing one of the above options would be followed up with several options that described the nature of the activity in more detail. However, because this additional detail was added to the reporting requirements several years after the discontinuation of the publication of the Top Ten lists, further detail on these additional options will not be discussed for this paper.

report that it undertook an ‘Equipment or Process Modification’ for that year only, and no activity for years preceding or following the retrofit. Another facility could undertake the same retrofit incrementally, with small changes over the years, and report an ‘Equipment or Process Modification’ several years in a row. Some of the pollution prevention options, such as ‘Equipment or Process Modification’ would likely be activities that a facility would undertake once, report once, and then not do again for some time. Other activities, such as ‘Spill and Leak Prevention’ and ‘Good Operating Practice and Training’ are activities that could easily be ongoing, and reported every year. Finally, some activities, such as ‘On-site recovery, re-use and recycling techniques’ are somewhat ambiguous in terms of what to report over time. For instance, if a facility undertakes a new recovery method, it is unclear whether they are to report this activity only in the first year they start doing it (implementing a new activity), or if they report this activity for all years in which they do the recovery (made use of the new activity).

For the purposes of this study, the NPRI data was filtered to produce a consistent and comparable sample in order to measure the effect that the published Top Ten lists had on a facility’s willingness to undertake pollution prevention activities between the years 1998 and 2003. The primary restriction this analysis is due to the timing of the introduction of required pollution prevention activity data reporting and the cessation of the production of the Top Ten lists. Pollution prevention activities were not added to the required reporting until 1997 and the NPRI ceased publishing its Top Ten lists in 1999. This allows for only a three-year window where the relationship between the two can be studied. Because a lagged relationship is being examined (the effect of being labeled as a Top Emitter last year on the current year’s abatement activity decision), the 2000 reporting year will also be included in the treatment sample. To maintain comparability, an equal number of years were included in the sample after the cessation of the Top Ten publications. For the rest of this paper, the data used from years 1998 to 2000 will be referred to as the treatment sample, and the data used from years 2001 to 2003 will be referred to as the control sample.

For the 2000 to 2003 reporting years, artificial Top Ten lists were constructed for each substance in each year. This exercise was carried out in a manner that is consistent with how the original Top Ten lists were constructed: If there were less than ten facilities reporting on a substance, then all reports were selected as a Top Ten emitter. If the first few emitters were relatively large and followed by several facilities whose releases were orders of magnitude smaller, than the list was cut off at that point, even if the largest emitters did not make up a full list of ten facilities[18].

With this time period determined (1997-2003), a list of consistent substances was developed. This list includes any substance or substance group that did not have any changes to its definition or reporting guidance for the 7 years examined. Excluded were substances that were added to or removed from the NPRI substance list during that time. This left a list of 138 consistent substances for the seven year time period. Some examples of substances that were excluded due to this process include Xylene and its isomers (amalgamated in 1999), and Acetone (removed in 1999).

This substance list was then used to develop a list of consistent facilities. A facility that reported information on at least one of the above labeled consistent substances in all four years[19] for the control sample and the treatment sample was kept, and all other facilities were removed. This process excluded any facility that started or stopped reporting in the examined

[18] The threshold for exclusion was two orders of magnitude. For example, if the 3rd ranked facility released 10 tonnes, and the 4th ranked facility released less than 0.1 tonnes, the list was cut off after the third facility.

[19] Consistency was required for four years rather than three due to the time lag in the estimated models

years. Finally, only those substance reports that were consistent for all years were kept – ie, in order to be included in the sample a substance had to be reported on by the same facility in every year of that sample.

It should be noted that some substances, such as Mercury, Lead and Cadmium, had changes to their reporting threshold levels in the years 2000 and 2002. These substances were kept in the treatment and control samples on the grounds that heavy metals such as these substances are of great environmental concern. They are also arguably better known than most other substances, and in any sort of public ranking, they would likely get more attention than most other substances. Also it is defensible to leave them in due to the nature of the screening of consistent substance reports. Changing the reporting threshold only changes who must report, not how much they would report or how they would calculate the final reported number. Since each sample is restricted to only those facilities that reported on each substance consistently for every examined year, facilities that started reporting one or more of these substances for the first time due to the threshold change would be screened out.

Finally, even though they met all the screening criteria described above, the following substances were removed from the sample due to collinearity: Hydroquinone (and its salts); Toluene-2,4-diisocynate; 4,6-Dinitro-o-cresol (and its salts); Chloroacetic acid (and its salts); Peracetic acid (and its salts); Thiourea. Over the four year period examined in each sample, these substances were each only reported consistently by one or two facilities. In all cases, the amount released did not change between 1997 and 2000 in the treatment sample, or between 2000 and 2003 in the control sample. This caused the release values to be perfectly correlated with substance dummy variables in each regression. Removing these substances solved the collinearity issue while only removing 42 observations from the final sample.

### Summary of the Data Sample

The combined sample used for testing the hypothesis includes 2,136 facilities reporting on 112 substances, for a total of 35553 substance-facility-year observations. The number of facilities reporting to the NPRI increased significantly between 1997 and 2003, due to increased reporting requirements, and as such, the percentage of facilities retained in the consistent sample decreases as year increases. Very few facilities were excluded from 1997, but by 2003, the 2136 consistent facilities represent 26% of the complete NPRI database for that year. The average number of substances reported by a given facility is 3.42, with a minimum of 1 per facility and maximum of 45. As shown in Figure 3.3, this distribution is skewed to the left, with over one third of the sample facilities only reporting on one substance, and over half of the sample only reporting on one or two. The average number of facilities that report on a given substance is 57. As shown in Figure 3.4, this distribution is similarly skewed as the facility average, with a median observation of 13 facilities per substance. The substance with the most facilities reporting on it was Sulfuric acid with 378 facilities.

Employment was similarly skewed with an average employee count of 318 and a median of 104. This distribution is shown in Figure 3.5. The range in employee count is from 2 employees to 7100 employees (Dofasco Hamilton steel facility).

Tables 3.1 and 3.2 show the percent of YES reports for each possible pollution prevention activity for the treatment sample (1998-2000) and for the control sample (2001-2003), respectively. These tables also show the percent of reports that were YES following either a YES or NO report in the previous year. Overall, these tables show several things. The first and most obvious is that, with the exception of ‘Good Operating Practice and Training’, and ‘Spill and Leak Prevention’, the number of substance reports with a YES reported for any pollution prevention activity is quite low – in some cases less than 10%. The second is the overall persistence in the reporting of most of the activities. For most of the activities, if the substance report had a given activity in the previous year, there was approximately a 50% likelihood that the same activity would be reported again in the following year. Similarly, those that did not report a particular activity were very likely to continue not reporting it in subsequent years. Finally, when comparing the control sample with the treatment sample, it is evident that there is noticeably less reporting of pollution prevention activities during the years 2001-2003 compared to 1998-2000. This also applies to the rate at which facilities continue to report YES for a given activity if the reported it in the previous year. By all measures, either by number of YES reports, or the likelihood of reporting a YES given that a YES or NO was reported a previous year, there is less reporting of pollution prevention activities in the more recent control sample compared to the earlier treatment sample.

Figure 3.6 also highlights this downward trend in reported pollution prevention activities over time. This figure compares the average number of pollution prevention activities reported across substance reports for each year, with those substance reports that were labeled as a Top Ten compared to those that were not. Figure 3.6 suggests that those substance reports that were labeled as a Top Ten do have a higher average number of pollution prevention activities reported – an observation that only applies to the period of time where Top Ten lists were published. Figure 3.6 also highlights the decreasing trend in reported number of pollution prevention activities starting in 2001. The reason for this decrease is currently unexplored, and is beyond to scope of this paper, but further research into this issue will be briefly discussed in this paper's conclusion.

A summary of the Top Ten substance reports is presented in Tables 3.3, 3.4, and 3.5, and Figure 3.7. Table 3.3 shows the number of Top Ten substance reports were observed in each industry sector, defined at the North American Industry Classification System four digit code, for the years 1997 to 1999. Four industry sectors - Basic Chemical Manufacturing, Oil and Gas Extraction, Petroleum and Coal Products Manufacturing, and Electric Power Generation, Transmission and Distribution – have over 100 substance reports that were published as Top Ten emission sources. Other notable industries with large Top Ten counts include Pulp, Paper, and Paperboard Mills, Plastic Product Manufacturing, and Motor Vehicle Manufacturing. Half of the observed industries (60 out of 111), had at least 1 Top Ten observation.

Figure 3.7 shows a distribution of facilities by the ratio of their reported substances that were labeled as Top Ten. As shown in Figure 3.7, most facilities (84%) do not have Top Ten labels for any of their substances. The remaining facilities are distributed by the percentage of their substance reports that were labeled as Top Ten, in bands of 15%. Approximately 230 facilities per year have between 1% and 60% of their substances labeled as Top Ten. Very few (10 to 15 per year) facilities fall in the range of greater than 60% to 90%. A small but significant number of facilities (44 per year) have almost all of their substances labeled as Top Ten. Most facilities do not make it onto any Top Ten lists, but there is a significant group of likely very large facilities that are repeatedly labeled.

Tables 3.4 shows that for each of the observed years, between 8% and 8.36% of the substance reports were labeled as Top Ten, and that there is very little variation in this number per year. Table 3.5 shows that most of the facilities that are labeled as Top Ten in one year are quite likely to be labeled the same the next. 80% of the Top Ten reports were also Top Ten reports in the subsequent year. Similarly, of the substance reports not labeled as Top Ten, only 1.6% would go on to be labeled as Top Ten in the following year.

## Empirical Model

As discussed in the introduction and background sections, this paper empirically examines two relationships: the effect that being published in a list of top emitters has on a facility's decision to undertake new pollution abatement measures; and the effect that these new abatement measures have on subsequent reported emissions from the facilities that undertook them. The following presents two major model specifications, one for each of these effects. Each model is tested with several different assumptions on the type of fixed effect assumed around facilities, substances, and industry sectors, and various combinations of the three.

The first model specification examines the relationship that being labeled as a top emitter has on the facility's decision to undertake new abatement activities, as follows,

$$\begin{aligned} A_{i,j,t} = \alpha + \beta_1 R_{i,j,t-1} + \beta_2 E_{j,t-1} + \gamma_1 T_{i,j,t-1} \\ + \gamma_2 P_{i,j,t-1} + \rho_j + \varphi_i + I_j + f_j + \varphi_i I_j + \varphi_i f_j + d_t \end{aligned} \tag{3.20}$$

Where $A$ is the count of new pollution prevention activities reported by facility $j$ on substance $i$ in year $t$, and $R$ is the corrected log of releases of substance $i$ by firm $j$ in the previous year. $R$ is corrected by adding one to the release number in order to include releases that are less than one tonne or zero in the log specification. $E$ is the log of employees at firm $j$ in the previous year, and is used as a proxy for facility size. As discussed in the Data Summary section, both employee count and releases of pollutants are heavily skewed to the left, with many small facilities and few very large facilities. Logging these variables is done to correct for this. Other researchers, particularly Harrison and Antwieler (2003), use emissions intensity, emissions per employee, as an explanatory variable. As this model is already attempting to control for level of emissions, and is already using employees as a proxy for size and production levels, adding emissions intensity would over-correct for both of these variables. *T* is a dummy variable to denote whether firm *j* was a top emitter of substance *i* in the previous year, and *P* is a dummy variable to denote whether or not this top emitter status was published by the NPRI program or not. *P* is 1 if *T* is also 1 and if *t* is equal to 1998, 1999 or 2000. $\rho$ is a control for province or territory. $\varphi$ is a control for substance, *I* is a control for industry sector (North American Industry Classification System; 4-Digit level of detail), and *f* is a control for facility. Further controls include interactions of these terms denoted as $\varphi I$ and $\varphi f$, which control for variation between substance/sector combinations, and substance/facility combinations, respectively. Finally, *d* is a control for variation across years.

All explanatory variables are lagged one time period. This is done on the assumption that a facility's abatement decisions in the current period are based on the situation faced by the facility in the previous period. This assumption is especially relevant for the *T* and *P* dummy variables. If the *T* and *P* variables are indeed significant, then the effect of these variables on abatement would have a time lag: A facility reports its emissions from last period, and, if they are large enough, gets labeled as a top emitter. Any pressure to abate on its level of emissions that would come from being labeled as a top emitter would come after the publication, and would factor into the facility's abatement decisions in the following period. Releases, *R*, are lagged as a control for the *T* and *P* variables: Lagging releases to match the same period as *T* will capture any pressure to increase abatement from simply being a large emitter, whether the facility is labeled as a top emitter or not. Employment is included as an attempt to control for facility size, and the effects that size could have on abatement level. Unfortunately, employment is an imperfect measure of facility size, but it is the only measure that is available within the data examined.

The dependent variable, *A*, is a score variable that measures the amount of new pollution prevention activities undertaken at the facility as compared to the previous year. This is not simply a change over time variable. As previously discussed, some activities would conceivably be done once, such as installing a new piece of equipment, whereas some activities would conceivably be done repeatedly, such as an annual workplace safety briefing. We are primarily interested in *new* abatement effort in response to negative press, so, in order to control for this, each activity (8 in total) for each facility and substance combination was compared one year to the next. If the activity was done in the current year and not in the previous year, the facility-substance observation was given a point. Activities that were repeated one year to the next were not scored. Activities that were done in the previous year and not in the current year were also not scored, under the assumption that the facility did not 'stop' doing the activity, but rather, reported introducing a new activity that going forward will continue to be used, such as new equipment installation or a product reformulation. In this fashion, every facility-substance combination for each year was given a score on the total new pollution prevention activities undertaken. This score can take a value between 0 and 8. An alternative measure of pollution was also used as the dependent variable. This measure is simply a count of the pollution prevention activities in each period, which can also take a value of between 0 and 8.

Ten models were tested with various combinations of the above specification as expressed in equation 3.20, which vary on the fixed effects assumed. Model 1 assumes only a fixed effect based on substance. Model 2 assumes that there are differences across substances and differences across industry sectors. Model 3 assumes there are differences across substances and facilities. Model 4 assumes that there is a fixed effect between substance and industry sector combinations, and model 5 assumes that there is a fixed effect between substance and facility combinations. Each one of these models is estimated with and without controlling for year by adding dummy variables for each year. The difference between models 2 and 4 and between models 3 and 5 is subtle, but significant: For example, Model 3 assumes there is a fixed effect for each substance and a separate fixed effect for each facility – the fixed effect observed for each substance will be the same across facilities, and the fixed effect observed for each facility will be the same for each of the substances that that facility reports on. Model 5, on the other hand, assumes that there is a different fixed effect for every substance and facility combination – one facility will have a different effect on a substance than all other facilities on that same substance, and there will be a separate effect for each substance within the same facility. Of all the models tested, the only true panel model is Model 5, with a fixed effect on substance/facility combinations. All other model specifications have more than one observation across controls per year. All other models are pooled regressions with the specified controls.

Each model was tested with three variations. The first variation, labeled a, does not include controls for years. As will be discussed in the next section of this paper, this was done to examine the effect that the control and treatment samples being from two different time periods has on the results. The second variation, labeled b, includes the controls for time period. The third variation, labeled c, omits the Top Ten variable in order to examine the possibility that the Top Ten variable is endogenous to the model, and correlated with the Releases variable. Removing the Top Ten variable does not significantly affect the parameter and significance of the release parameter in all models, as shown in Tables to 3.6 to 3.9, which suggests that the endogenous nature of the Top Ten variable is not a misspecification error. It should also be noted that while we were not able to exogenize the Top Ten variable, the true variable of interest, the Published variable, is exogenous, as ceasing the publication of Top Ten lists was beyond the control of the firms being labeled.

Two restricted samples were also analyzed for all five specified models. The first restricted sample only examined toxic metals (Lead, Cadmium, Mercury, Arsenic, Antimony, Cobalt, Chromium) instead of all substances. The majority of substances on the NPRI substance list are likely not familiar to the general public, and it is possible that being highlighted as a large emitter of a substance that few people are informed on would have less of an impact than a substance that is people are generally more informed on. The second restricted sample analyzes only those facilities with 50 or more employees. This restriction is done to examine the possibility that larger facilities may face more public scrutiny than smaller facilities, and as such, would face more negative press for being labeled as a top emitter as compared to a smaller facility. A larger facility also may have more resources to devote to pollution prevention, and may be more responsive to being labeled as a large emitter.

The second specification examines the effect that these new abatement activities have on releases reported by the facility in the subsequent year, for which five models were also estimated. The specification is as follows,

$$\Delta R_{i,j,t} = \alpha + \beta_1 \Delta E_{j,t} + \beta_2 A_{i,j,t} + \varphi_i + I_j + f_j + \varphi_i I_j + \varphi_i f_j \qquad (3.21)$$

Where $\Delta R$ is the change in reported releases of substance *i* by facility *j* in period *t* compared to the previous year. $\Delta E$ is the change in employee count at facility *j* in period *t* compared to the previous year, and is included as a control for change in facility production. All other variables and fixed effects are the same as described above. The five models estimated with this specification are the same as described above in regards to the fixed effects examined: Model 6 assumes that a new pollution prevention activity would have the same effect across all facilities and sectors, and only controls for substances. Models 7 and 8 both control for substances and for sector and facility respectively. Model 9 controls for fixed effect across sector and substance combinations, and Model 10 controls for fixed effects across facility and substance combinations. The distinction between Models 7 and 9 and between Models 8 and 10 is the same as discussed above between Models 2 and 4 and Models 3 and 5.

Specification one uses abatement as the dependent variable, and releases as an independent variable, while specification two shows the opposite relationship, which raises the concern of  simultaneity in the model. This is partly addressed in two ways. The first is that specification one uses releases and a variable, and specification two uses change in releases. Specification one tests to see if the size of emissions is different from Top Ten status or if that status is published. Specification two examines if a new abatement activity causes releases to increase or decrease. Also, the time lags within the model assume a sequential period-by-period relationship, rather than a simultaneous one: High releases induce abatement in the following year, and this abatement causes reduced releases in the year it is installed.

As the dependent variable in models 1 through 5 is count data, a fixed effects Poisson regression was used to estimate each. The Hausman test was used to differentiate between fixed effects and random effects. Models 6 through 10 have a continuous dependent variable, and were estimated with Ordinary Least Squares.

## Results

The results from the various model specifications, as discussed in the previous section, are included in five tables in the appendix. The results for models 1 through 5, both with and without controls for years and with and without the Top Ten variable are included in Tables 3.6, 3.7, 3.8, and 3.9, and the results for models 6 through 10 are included in Table 3.10. In all tables, values without brackets are the coefficient on the relevant variable, values in brackets are the standard errors for those coefficients, and variables in curled brackets are the associated P-values to test if the coefficient is significantly different from zero. All standard errors were corrected to take into account the effect of clustered standard errors. For models 1, 2, 3, 6, 7, and 8, errors were clustered by facility. For models 4 and 9, errors were clustered by substance-sector combinations, and for models 5 and 10, errors were clustered by facility-substance combinations.

For the full data sample as shown in Table 3.6, the results for models 1 through 5 are confounded by an obvious downwards trend overall in reported pollution prevention activities. Without controls for year, the results suggest that being a Top Ten emitter does not cause a facility to increase the number of pollution prevention activities to be reported – in fact, the coefficient on this variable was negative and significantly different from zero. Being a Top Ten Emitter and having that information published, however, was shown to be significant in the absence of the controls for years for all 5 models. On average, being published as a Top Ten emitter would cause a facility to report approximately one tenth of an additional pollution prevention activity as compared to the previous year.

The addition of year controls to these 5 models changed these results significantly. In all cases, once the year was controlled for, the coefficient for being a Top Ten emitter became small but positive. This positive effect is shown to be significant at the 5% level in model 4 and at the 10% level in models 1, 2, and 5. In all cases, the coefficient on the Published variable became negative, and only significant in model 5.

The only variables for these models that were significant in all cases and consistent across all models were the controls for the years 1998-2001. For all the models specified the value of the coefficients on year decreases in value from approximately 0.95 activities in 1998 to not significantly different from zero in 2002. This result is not one that this work was originally attempting to find, but it is certainly significant. It is quite likely that the significance of the Published variable in the models without controlling for year was due to the two-period nature of the data sample. The publication of the Top Ten lists coincided with a period of higher reporting in pollution prevention activities, and the control sample with which it was compared coincided with a period of relatively less reporting of pollution prevention activities. It is likely that the Published variable picks up most of this variation across the two periods if time is not controlled for. This finding is very similar to that of Vidovic (2007) and Khanna (2012), albeit in a different context. At first glance, Top Ten publications seem significant in increasing abatement effort, much as joining the 33/55 program is significant in causing a firm to reduce emissions. When viewed in the larger context in an overall decreasing trend, however, this statistical significance disappears.

At the present time, the reason for this observed consistent decrease in reported pollution prevention activities over time is not fully understood, and requires further study. An overall decrease in the reporting of pollution prevention activities across Canada warrants better understanding. It is certainly possible that this change is due to the cessation of the publication of Top Ten lists, but this was not able to be proven with this work.

The results for the Toxic Metals restricted sample contradict the full sample in that they show more significance for the Published variable. These results are shown in Table 3.4. For all five models, the coefficient on the Published variable is approximately twice that of the full sample. Also, adding controls for year does not make the Published variable insignificantly different from zero as in the full sample in three out of five models. In all cases, the coefficient decreases significantly when controls for time are added, but still proves to be significantly different from 0 at the 10% level of confidence in model 1, and at the 5% level of confidence for models 2 and 4. This result suggests that a Top Ten publication list has a more significant effect on substances that the general public is likely more informed about.

The results for the Large Facilities restricted sample are shown in Table 3.5. The results for this restricted sample for the Published variable were very similar to the results for the full data sample – significance is shown for the models without controls for time, but once these controls are added, this significance ceases to be shown. Interestingly, the Top Ten variable is shown to be more significant after controlling for time for the Large Facilities restricted sample than the full sample. After controlling for time, the Top Ten variable is shown to be significant at the 5% level for 4 out of the 5 models compared to only 1 in the full sample. This suggests that larger facilities may be more responsive to being a Top Emitter, whether published or not. A possible explanation is that larger facilities garner more media scrutiny, even without being publically labeled as Top Emitter.

The results for the alternative dependent variable – a simple count of activities instead of a score for new activities – are shown in Table 3.9. The results from this model specification are much more definitive than the count of new pollution prevention activities. The Top Ten variable did not prove to be significant with this dependent variable, but the

Published variable was, and remained so after the addition of the time control in all five models. Adding time controls did lower the parameter significantly however (greater than 0.55 without control for time and less than 0.2 with controls for time). This result suggests that the relationship between being a published Top Emitter and pollution abatement effort may be more complicated than a simple year to year reaction, as those facilities that were published as large emitters have on average slightly more reported pollution prevention activities. The results from the Poisson regressions are exponential, and must be transformed. The parameters for the Published variable in the 'b' models (with Top Ten as a variable, and year controls) range from 0.1305 and 0.1965, which suggests that having a Top Ten status published causes a firm to have, on average, between 14 and 21 percent more pollution prevention activities. This finding is significant to the 1% level in all model specifications using the count of total pollution prevention activities. Interestingly, the Top Ten variable proved to be insignificant, suggesting that Top Ten does not have an effect on increased abatement, but having that status published does.

The results for the effect that new reported pollution prevention activities had on changes in emissions were much more conclusive. In all the models tested with this specification, a newly reported pollution prevention activity will lead to lower emissions of between 1.15 and 1.29 tonnes. This effect was shown to be significant in all cases at the 5% level of significance. Obviously, this figure would change quite dramatically between substances; for example, a tonne of Ammonia is much different than a tonne of Mercury. All models control for substances, even though these fixed effects are not reported here.

Interestingly, the coefficient for change in Employment proved to be not significantly different from zero in all cases. Change in Employment was used as a proxy for change in production level or facility size. The fact that this variable did not provide any explanatory power suggests that Employee count is not a useful proxy for production level. As the NPRI does not contain any other information that could reasonably be used to measure production, further data sources would be required to control for this variable.

## Discussion and Conclusion

With the addition of the time control in the first model specification, statistical significance for the effect of being published as a Top Ten emitter on new pollution prevention activities was not able to be shown in the full data sample. As such, no policy recommendation can be made in regards to the cessation of the publication of the Top Ten lists in 2000 from using the New Pollution Prevention Activities dependent variable. There is certainly the possibility that this result may be due to the fact that the measure of new abatement effort is simply not accurate enough. As discussed in the data section of this paper, the way in which this data is collected has no measure for relative scale. If the publication of the Top Ten lists indeed has an effect on abatement effort, it would likely be very small, and is not able to be discerned with the current measure of abatement effort. Perhaps, with facility level data on abatement spending, which would be a continuous and much more accurate measure of abatement effort, a small but significant result could be found. However, different treatments of the data, in particular the sample restriction for only toxic metals, suggest that a Published Top Emitter list may be more effective under certain conditions, such as for substances that the public is generally assumed to me more informed of.

As discussed in the results section, using the Total Pollution Prevention Activities dependent variable showed some more interesting results. This specification suggests that facilities that have a published Top Ten status will have approximately 20% more pollution prevention activities for that substance as compared to a facility that has not been labeled as a Top Ten. The fact that the Top Ten variable was insignificant reinforces this finding, and suggests a policy recommendation for the NPRI program – in order for the publically available data to garner enough attention to affect behavior, the information must be published in an easily understood format, such as a Top Ten list. As discussed, this result may be somewhat confounded by the decreasing number of pollution abatement activities reported in the time period following the cessation of the Top Ten lists. However, this finding is significant enough that a re-examination of this publication is warranted.

Statistical significance was able to be shown for the relationship between new pollution prevention activities and decreased reported emissions. This finding on its own is not surprising. But this significance, coupled with the clear downward trend in reported pollution abatement activities over time, raises a clear policy issue for Canadian environmental regulators. Reported pollution prevention activities clearly have a negative effect on reported emissions, and as such, their decrease in reporting since the early 2000s should be of concern for policy makers. Currently, the reason for this decreasing trend is not clearly understood. At first glance it appears to be correlated with the cessation of the publication of Top Ten lists, but this has not been proven. Further research should be done on this topic to identify the main driver behind this decrease in reported pollution prevention activities.

This paper is the first to use the pollution prevention activity information to Canada's NPRI program in an environmental economics context. This work attempted to examine the relationship between bad press and releases in more detail than in previous literature by looking at two steps in between receiving bad press and subsequent reported releases – the facility increasing abatement effort which then leads to reduced emissions. Statistical significance was shown for the second relationship examined, and for the first with the count of total abatement activities. The finding that being a Top Emitter, and having that status published, causes a firm to undertake additional pollution abatement activities is in line with most other works on this area, as increased abatement would lead to decreased emissions, all else being equal. The difference offered by this paper, is an examination of the effects on abatement, rather than on emissions. It should be noted however that the measure of increased abatement effort is far from an accurate measure, and that the published Top Ten lists are not indicative of bad press all on their own. A more complete analysis of this issue would require more detailed information on abatement spending, rather than a count of abatement categories.

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# Appendices

# Appendix A: Tables and Figures for Chapter 1

Table 1.1

2007 Chemical Wood Pulp Production, Consumption, and Net Imports – Thousands of Tonnes

| Country/Region | US | Canadian | Nordic Countries | Rest of World | World |
|---|---|---|---|---|---|
| Production | 49,144 | 11,599 | 17,751 | 35,131 | 113,625 |
| Consumption | 49,181 | 3,713 | 12,694 | 48,037 | 113,625 |
| Net Imports | 37 | -7,886 | -5,057 | 12,906 | 0 |

Table 1.2

Total Credit Received Under the Alternative Fuel Mixture Tax Credit in 2009, Compared to Net Income, by Company, in Millions of US Dollars

| Company | Credits (Millions of US$) | Net Income or Loss (Millions of US$) | Income or Loss Without Credits (Millions of US$) |
|---|---|---|---|
| International Paper | 2060 | 2360 | 300 |
| Smurfit-Stone Container | 654 | 8 | -646 |
| Domtar | 498 | 310 | -188 |
| MeadWestvaco | 375 | 225 | -150 |
| Weyerhauser | 344 | -545 | -889 |
| NewPage | 304 | -308 | -612 |
| AbitibiBowater | 276 | 1553 | 1277 |
| Verso Paper | 239 | 106 | -133 |
| Temple-Inland | 218 | 206 | -12 |
| Boise | 208 | 154 | -54 |
| Rayonier | 205 | 313 | 108 |
| Kapstone Paper and Packaging | 178 | 80 | -98 |
| Packaging Corporation of Canada | 176 | 266 | 90 |
| Clearwater Paper | 171 | 182 | 11 |
| Graphic Packaging | 147 | 56 | -91 |
| SAPPI | 136 | -251 | -387 |
| Buckeye Technologies | 130 | 154 | 24 |
| P.H. Glatfelter | 108 | 123 | 15 |
| Rock-Tenn | 75 | 279 | 204 |
| Appleton Papers | 18 | 25 | 7 |
| Wausau | 14 | 21 | 7 |
| **Total for Publicly Traded Companies (Billions of $US)** | 6.534 | 5.317 | -1.217 |
| **Estimate for Private Companies (Billions of $US)** | 1.5 - 2 | **Not Available** | **Not Available** |
| **Total Payments to Pulp and Paper Companies (Billions of $US)** | 8.03 - 8.53 | **Not Applicable** | **Not Applicable** |

Source: Tree (2010)

Table 1.3

Variables and Parameters in the Global Forest Products Model

| Variables/Parameters | Description |
|---|---|
| **Exogenous Parameters** | |
| $g_i$ | GDP growth rate of country *i* |
| $g_{mik}$ | Exogenous growth rate in manufacturing cost of product *i* in country *j* |
| $\varepsilon_{ijk}$ | Trade inertia parameter for product *k* between countries *i* and *j* |
| $\beta_{ik}$ | Supply shift, primary product *k*, country *i* |
| $\sigma_{ik}$ | Price elasticity of demand, product *k*, country *i* |
| $\alpha_k$ | Elasticity of demand with respect to GDP, product *k* |
| $\alpha_{ijk}$ | Elasticity of imports or exports with respect to GDP between country *i* and country *j*, product *k* |
| $\lambda_{ik}$ | Price elasticity of supply for primary product *k*, country *i* |
| $c_{ijk}$ | Unit transport cost, product k from country *i* to country *j*. Includes tariffs. |
| $s_{ik}$ | Elastcity of manufaccturing cost with respect to output |
| **Calibrated Parameters** | |
| $m_{ik}$ | Unit manufacturing cost of intermediate or end product *k* in country *i*. |
| $\pi_{ik}$ | Shadow price of capacity of product *k* in country *i* |
| $a_{ikn}$ | Input requirement, product *k* in product *n*, country *i* |
| **Variables** | |
| $D_{ik}$ | Demand for product *k* in country *i* |
| $S_{ik}$ | Supply of primary product *k* in country *i* |
| $Y_{ik}$ | Quantity of intermediate or end product *k* manufactured in country *i* |
| $T_{ijk}$ | Amount of product k transported from country *i* to country *j* |
| $P_{ik}$ | Price of product *k* in country *i* |
| **Starting Variables** | |
| $P_{ik,-1}$ | Price of product *k* in country *i*, from the previous year |
| $D_{ik,-1}$ | Demand for product *k* in country *i*, from the previous year |
| $S_{ik,-1}$ | Supply of primary product *k* in country *i*, from the previous year |
| $T_{ijk,-1}$ | Amount of product *k* transported from country *i* to country *j* in the previous year |

Table 1.4

GDP Growth Rates (Constant Prices, Expressed in %), 2007-2014

| | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|
| US | 1.9 | 0.0 | -2.6 | 2.8 | 2.8 | 2.9 | 2.7 | 2.7 |
| Canada | 2.2 | 0.5 | -2.5 | 3.1 | 2.8 | 2.6 | 2.5 | 2.1 |
| World[1] | 5.4 | 2.9 | -0.5 | 5.0 | 4.4 | 4.5 | 4.5 | 4.6 |

(1) World: 186 countries. Individual $g_i$ values were used in the model. They are aggregated here for presentation only.

Source: International Monetary Fund (2011)

Table 1.5

Simulation Results for Sensitivity Analysis on Two Parameter – Thousands of Tonnes

| Parameter Tested | Output | Country | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|---|
| Standard Assumptions | Production | Canada | 12484 | 12643.9 | 12330.6 | 12514.2 | 12700.6 | 12978.5 | 13261.1 | 13552.6 |
| | | US | 45760.4 | 45403.7 | 47859.8 | 46532.1 | 46245.5 | 46027.9 | 45735 | 45439.1 |
| | Net Exports | Canada | 8465.9 | 8657.7 | 8492.9 | 8683.3 | 8876.8 | 9073.1 | 9272.5 | 9475.1 |
| | | US | -660.3 | -594.3 | 376.4 | 338.8 | 304.9 | 274.4 | 247 | 222.3 |
| Doubled Trade Bounds | Production | Canada | 12458 | 12616.7 | 12304 | 12487.4 | 12672.8 | 12949 | 13230.7 | 13520.9 |
| | | US | 45792.1 | 45441.2 | 47883.3 | 46557.9 | 46269.1 | 46049 | 45753.9 | 45455.8 |
| | Net Exports | Canada | 8443.1 | 8634.3 | 8469.9 | 8659.7 | 8852.3 | 9048 | 9246.7 | 9448.6 |
| | | US | -653.7 | -588.3 | 372.6 | 335.3 | 301.8 | 271.6 | 244.5 | 220.1 |
| Doubled Elasticity of Manufacturing | Production | Canada | 12509.9 | 12612.6 | 12300.7 | 12472.2 | 12664.3 | 12909.1 | 13162.4 | 13424.4 |
| | | US | 45791.2 | 45544.9 | 47968.8 | 46976 | 46789.6 | 46620.2 | 46297.3 | 45971.4 |
| | Net Exports | Canada | 8490.5 | 8617.5 | 8453.5 | 8643.2 | 8835.8 | 9031.3 | 9229.8 | 9431.6 |
| | | US | -660.3 | -594.3 | 376.4 | 338.8 | 304.9 | 274.4 | 247 | 222.3 |

Table 1.6

Environmental Effects of the AFMTC, 2009

| Substance | Average Release per Tonne of Pulp (kg) | Increased Release in the US (Tonnes) | Net Worldwide Increased Releases (Tonnes) |
|---|---|---|---|
| Nitrogen Oxides | 4.69 | 16,094 | 8,952 |
| Sulphur Dioxide | 4.66 | 15,989 | 8,893 |
| Suspended Particulate Matter | 2.78 | 9,516 | 5,293 |
| Hydrogen Sulphide | 0.0936 | 321 | 179 |
| Greenhouse Gases (Expressed as Carbon Dioxide Equivalent) | 571.61 | 1,959,875 | 1,090,115 |

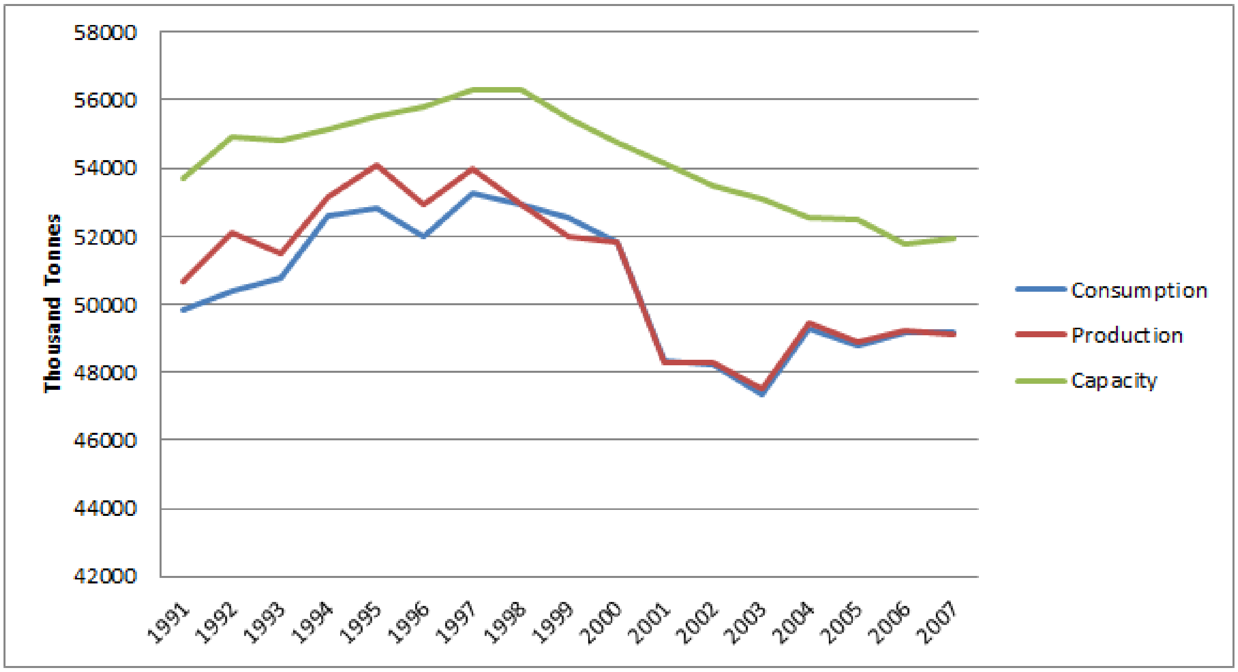


*Figure 1.1.* US Chemical Pulp Production, Capacity, and Consumption (RISI, 2008)

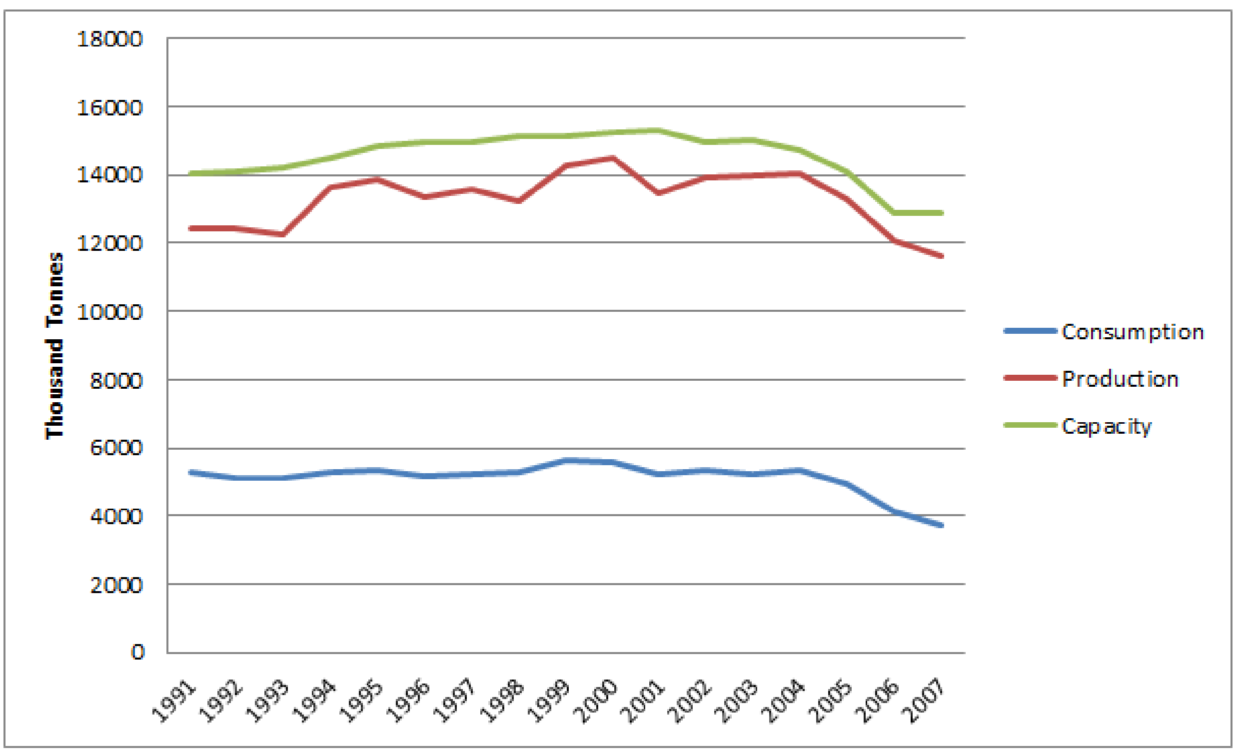


*Figure 1.2.* Canadian Chemical Pulp Production, Capacity, and Consumption (RISI, 2008)

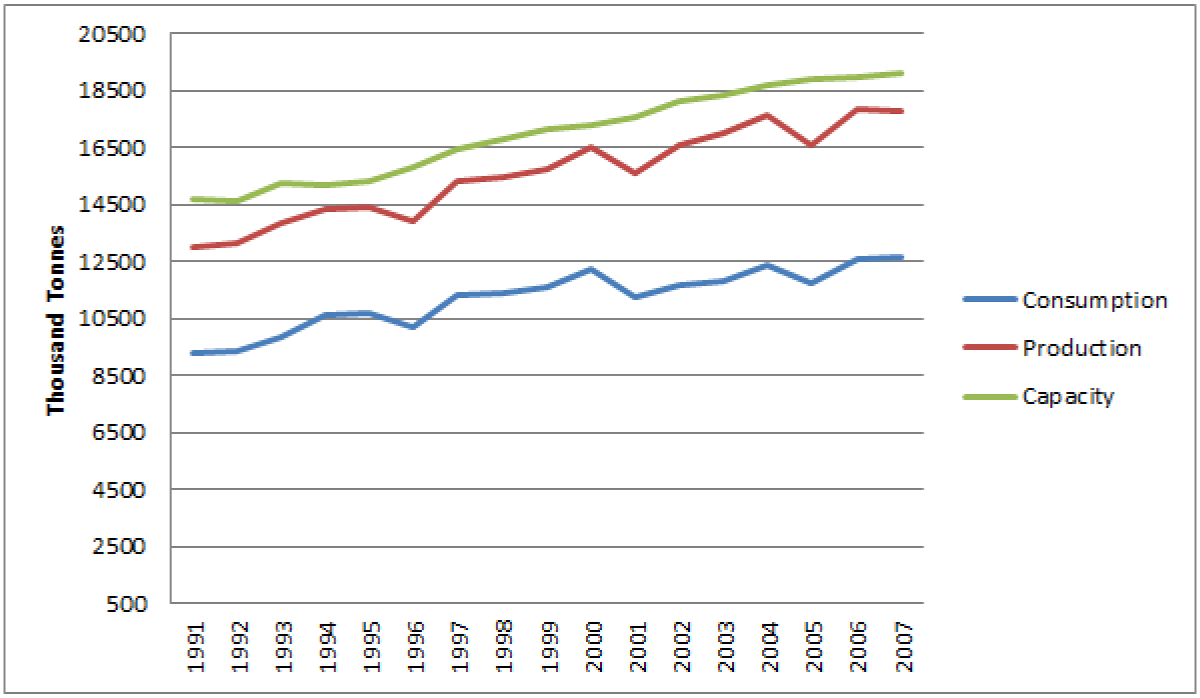


*Figure 1.3.* Nordic (Sweden, Finland, Norway) Chemical Pulp Production, Capacity, and Consumption (RISI, 2008)

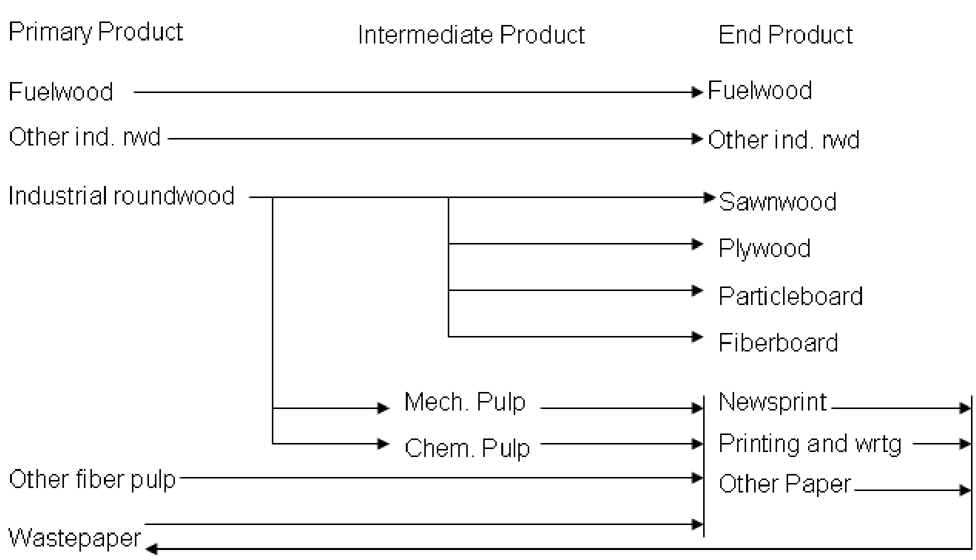


*Figure 1.4.* Product Transformation Mapping in the GFPM (Boungiorno et al., 2003)

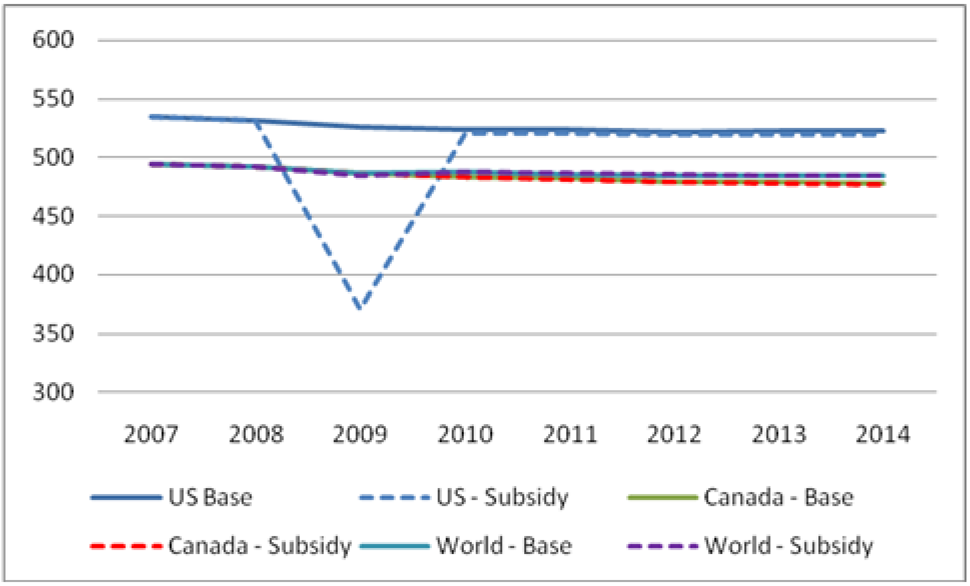


*Figure 1.5*. GFPM Results: Simulated Chemical Pulp Prices in $US/Tonne

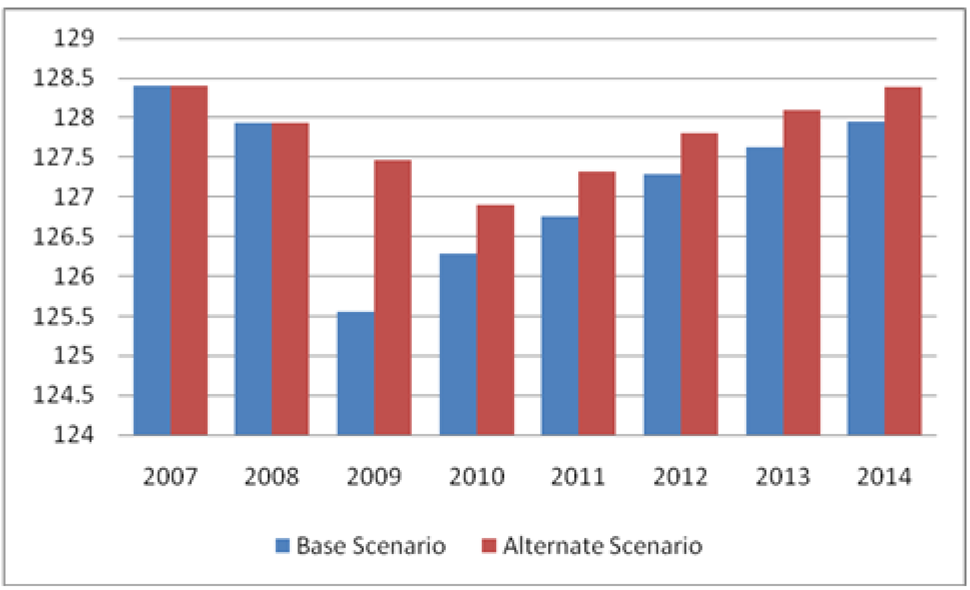


*Figure 1.6.* GFPM Results: Simulated World Production of Chemical Pulp in Millions of Tonnes

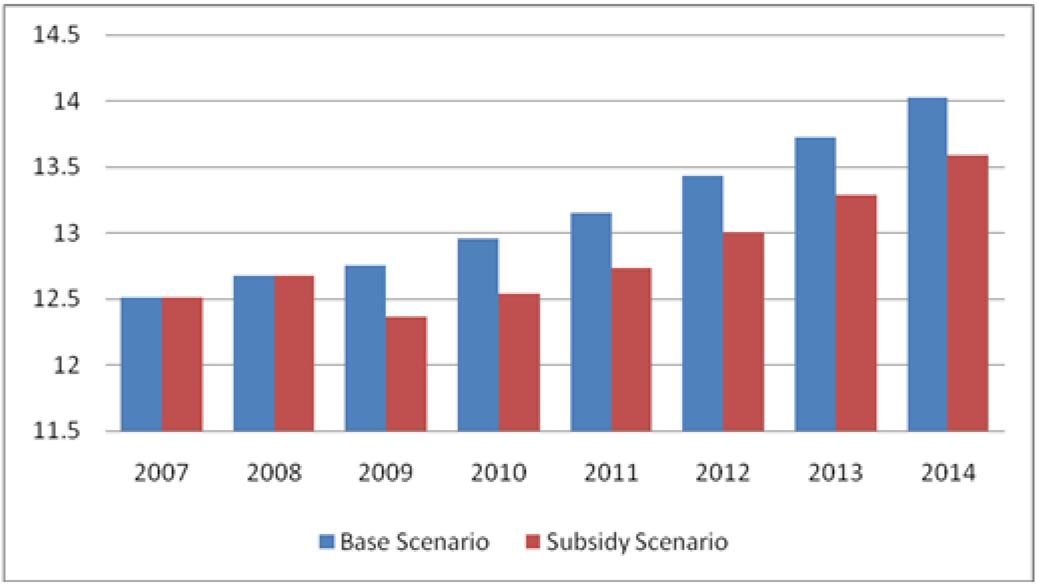


*Figure 1.7*. GFPM Results: Simulated Canadian Chemical Pulp Production in Millions of Tonnes

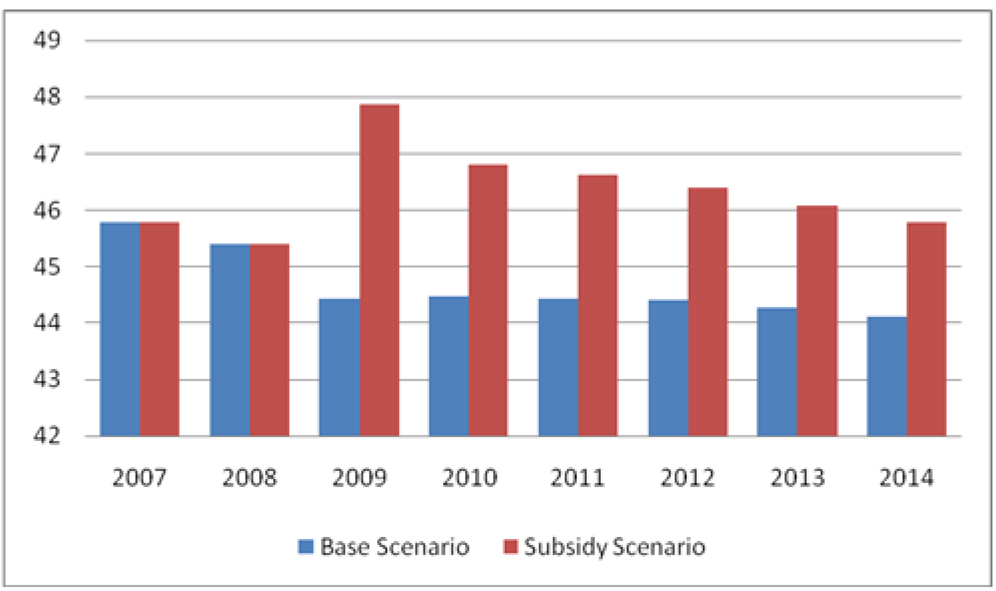


*Figure 1.8.* GFPM Results: Simulated US Chemical Pulp Production in Millions of Tonnes

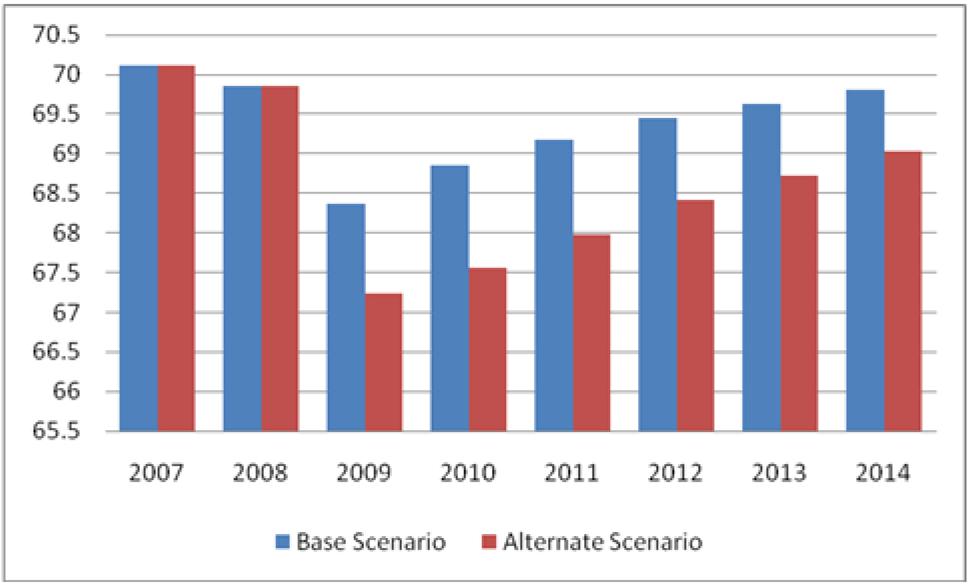


*Figure 1.9.* GFPM Results: Simulated Rest of the World Chemical Pulp Production in Millions of Tonnes

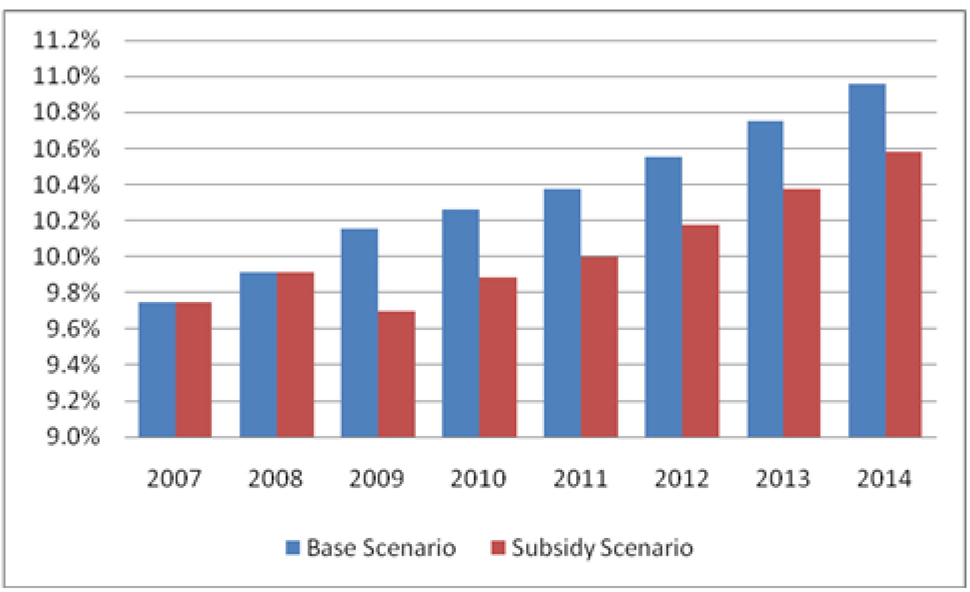


*Figure 1.10.* GFPM Results: Simulated Canadian Chemical Pulp Share of the Global Market

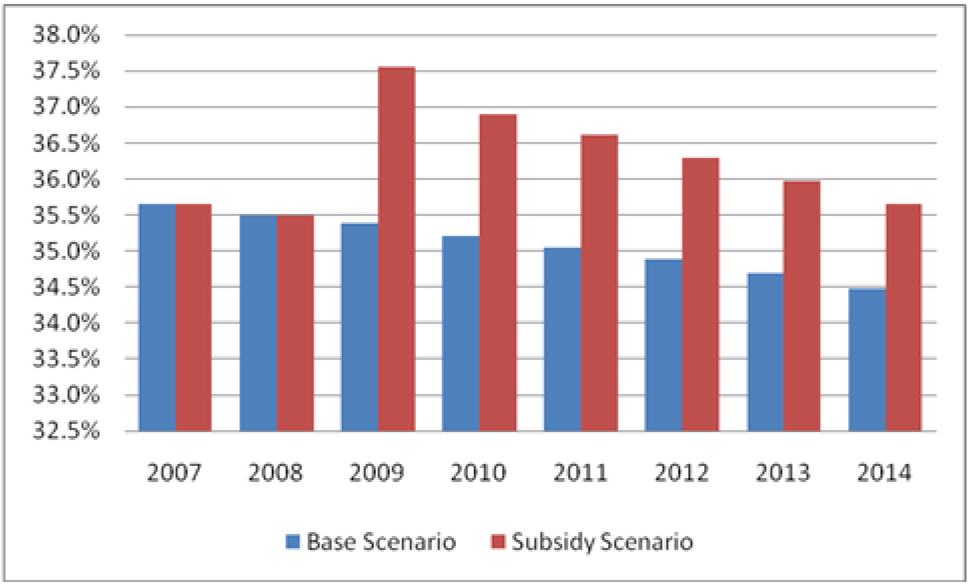


*Figure 1.11*. GFPM Results: Simulated US Chemical Pulp Share of the Global Market

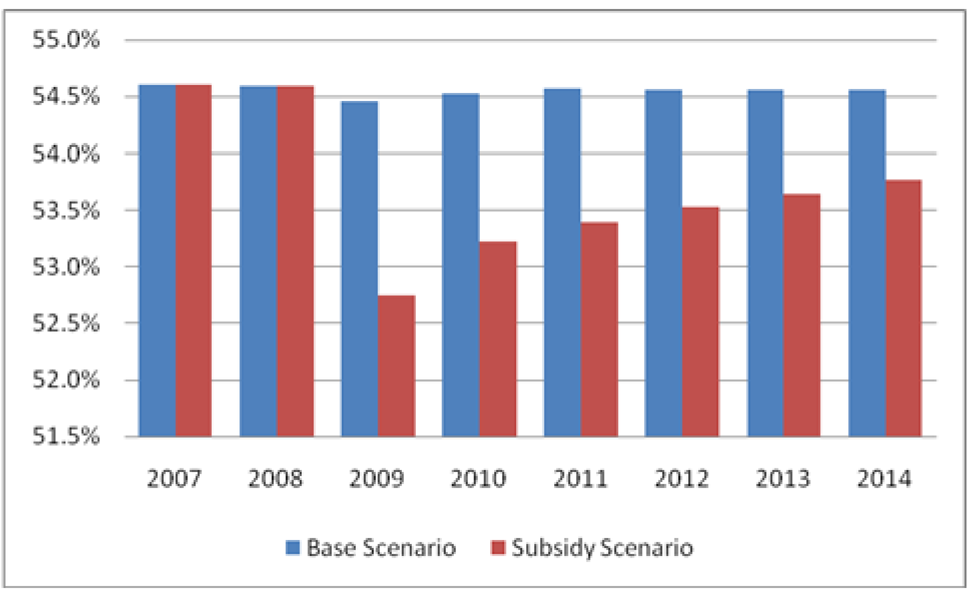


*Figure 1.12*. GFPM Results: Simulated Rest of the World Chemical Pulp Share of the Global Market

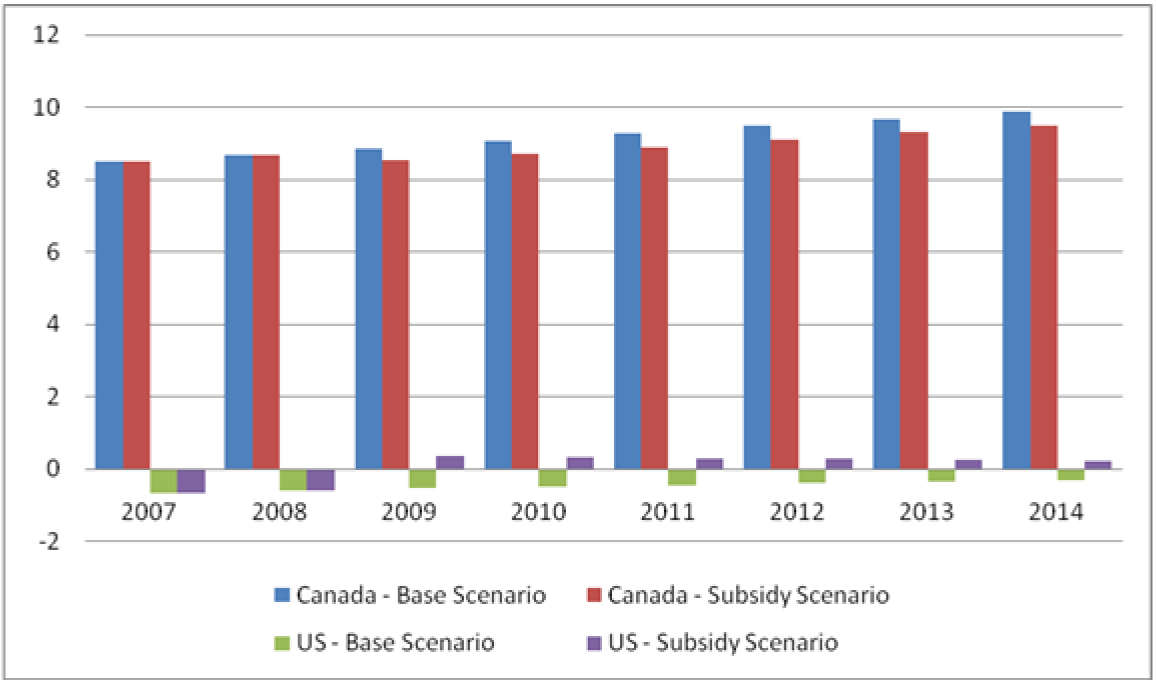


*Figure 1.13*. GFPM Results: Simulated US and Canadian Net Exports of Chemical Pulp in Millions of Tonnes

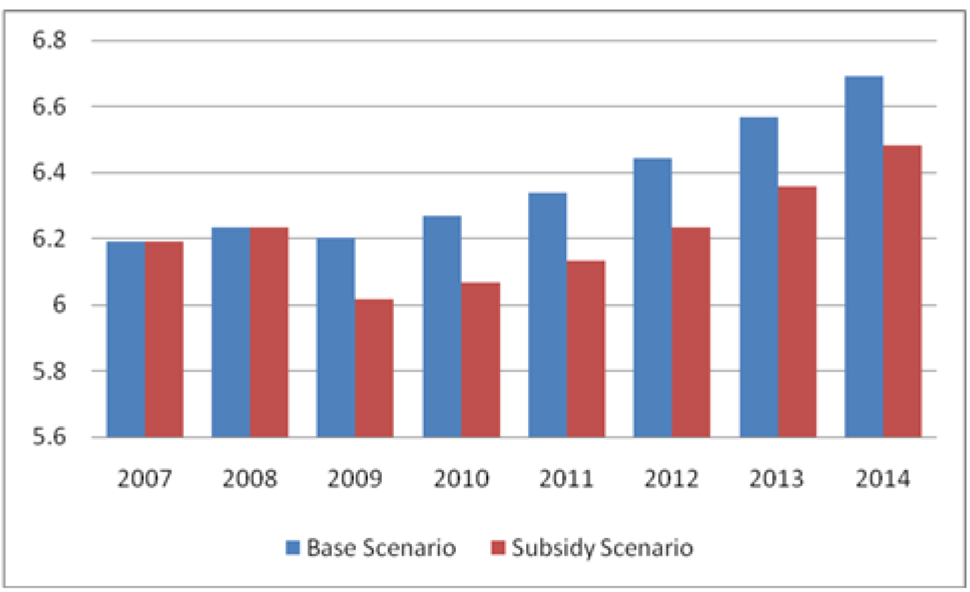


*Figure 1.14*. GFPM Results: Simulated Canadian Chemical Pulp Production Value in Billions of $US

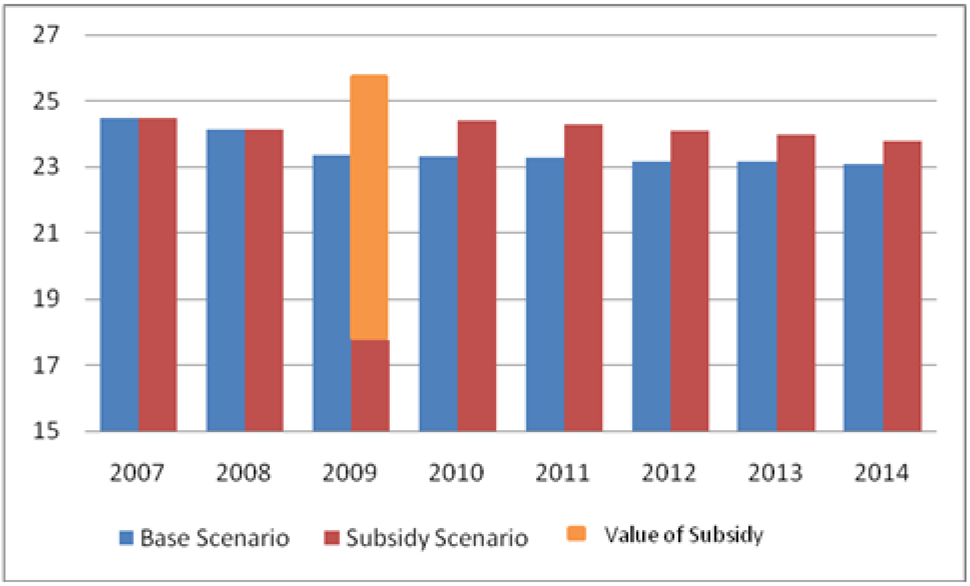


*Figure 1.15.* GFPM Results: Simulated US Chemical Pulp Production Value in Billions of $US

# Appendix B: Tables and Figure for Chapter 2

Table 2.1

Total Credit Received Under the Alternative Fuel Mixture Tax Credit in 2009, Compared to Net Income, by Company, in Millions of US Dollars (Tree, 2010).

| Company | Credits (Millions of US$) | Net Income or Loss (Millions of US$) | Income or Loss Without Credits (Millions of US$) |
|---|---|---|---|
| International Paper | 2060 | 2360 | 300 |
| Smurfit-Stone Container | 654 | 8 | -646 |
| Domtar | 498 | 310 | -188 |
| MeadWestvaco | 375 | 225 | -150 |
| Weyerhauser | 344 | -545 | -889 |
| NewPage | 304 | -308 | -612 |
| AbitibiBowater | 276 | 1553 | 1277 |
| Verso Paper | 239 | 106 | -133 |
| Temple-Inland | 218 | 206 | -12 |
| Boise | 208 | 154 | -54 |
| Rayonier | 205 | 313 | 108 |
| Kapstone Paper and Packaging | 178 | 80 | -98 |
| Packaging Corporation of Canada | 176 | 266 | 90 |
| Clearwater Paper | 171 | 182 | 11 |
| Graphic Packaging | 147 | 56 | -91 |
| SAPPI | 136 | -251 | -387 |
| Buckeye Technologies | 130 | 154 | 24 |
| P.H. Glatfelter | 108 | 123 | 15 |
| Rock-Tenn | 75 | 279 | 204 |
| Appleton Papers | 18 | 25 | 7 |
| Wausau | 14 | 21 | 7 |
| **Total for Publicly Traded Companies (Billions of $US)** | 6.534 | 5.317 | -1.217 |
| **Estimate for Private Companies (Billions of $US)** | 1.5 - 2 | **Not Available** | **Not Available** |
| **Total Payments to Pulp and Paper Companies (Billions of $US)** | 8.03 - 8.53 | **Not Applicable** | **Not Applicable** |

Table 2.2

Pulp and Paper Green Transformation Program Credits by Company (ForestTalk.com, 2009).

| Company Name | Recipient Mills | Company Level Credits |
|---|---|---|
| Abitibi-Bowater | Fort Frances Mill (Fort Frances, ON)<br>Thunder Bay Mill (Thunder Bay, ON) | 33,213,351 |
| AlPac Forest Products Inc. | Alberta Pacific Forestries Mill (Boyle, AB) | 62,869,884 |
| AV Group | AV Cell Mill (Atholville, NB)<br>AV Nackawic Mill (Nackawic, NB) | 36,379,474 |
| Canfor Pulp Limited Partnership | Intercontinental Pulp Mill (Prince George, BC)<br>Prince George Pulp and Paper Mill (Prince George, BC)<br>Northwood Pulp Mill (Prince George, BC) | 122,243,936 |
| Cascades Inc. | Norampac Trenton Mill (Trenton, ON)<br>Norampac Cabano Mill (Cabano, QC)<br>Cascades East Angus Mill (East Angus, QC) | 6,130,127 |
| Catalyst Paper Inc. | Crofton Division Mill (Crofton, BC) | 18,049,466 |
| Daishowa-Marubeni Inc. | Peace River Pulp Division Mill (Peace River, AB)<br>Cariboo Pulp and Paper Mill* (Quesnel, BC) | 59,100,267 |
| Domtar Inc. | Domtar Kamloops Mill (Kamloops, BC)<br>Dryden Pulp Operations Mill (Dryden, ON)<br>Domtar Espanola Mill (Espanola, ON)<br>Domtar Windsor (Windsor, ON) | 143,488,505 |
| West Fraser Mills Limited | Hinton Pulp Mill (Hinton, AB)<br>Eurocan Pulp and Paper Mill (Kitimat, BC)<br>Cariboo Pulp and Paper Mill* (Quesnel, BC) | 88,423,335 |
| Fraser Papers Inc. | Fraser Papers Edmundston Mill (Edmundston, NB) - (Now Twin Rivers Pulp)<br>Fraser Papers Thurso Mill (Thurso, QC) | 33,094,432 |
| Howe Sound Pulp & Paper | Howe Sound Pulp & Paper Mill (Port Mellon, BC) | 45,493,164 |
| Irving Pulp & Paper | Irving Pulp & Paper Mill (Saint John, NB) | 33,401,247 |
| Kruger Inc. | Kruger Wayagamack Mill (Trois-Rivières, QC) | 6,905,533 |
| Meadow Lake | Meadow Lake Mill (Meadow Lake, SK) | 2,610,046 |
| Mercer Celgar | Zellstoff Celgar Mill (Castlegar, BC) | 57,769,363 |
| Nanaimo Forest Products | Harmac Pacific Pulp Operations Mill (Nanaimo, BC) | 26,892,617 |
| Neucel Specialty Cellulose Ltd. | Neucel Specialty Cellulose Mill (Port Alice, BC) | 6,457,455 |
| Northern Pulp Nova Scotia Corp. | Northern Pulp Nova Scotia Mill (Pictou, NS) | 28,138,334 |
| SFK Pulp | SFK Pâte – Usine de Saint -Félicien (Saint-Félicien, QC) | 20,940,707 |
| Smurfit-Stone Container Corp. | Smurfit Stone Mill (La Tuque, QC) | 29,630,672 |
| Tembec Inc. | Tembec Chetwynd Pulp Division Mill (Chetwynd, BC)<br>Tembec Skookumchuck Pulp Division Mill (Cranbrook, BC)<br>Tembec specialty Cellulose Division Mill (Témiscaming, QC) | 24,235,166 |
| Terrace Bay Pulp Inc. | Terrace Bay Pulp Inc. Mill (Terrace Bay, ON) | 19,183,535 |
| Tolko Industries Ltd. | Tolko Manitoba Kraft Papers Mill (The Pas, MB) | 13,357,389 |
| Weyerhaeuser Canada Inc. | Weyerhaeuser Grande Prairie Operations Mill (Grande Prairie, AB) | 32,375,594 |
| **Total Credits** | | **950,383,599** |

Table 2.3

Profit and Capital Use, Under All Possible Policy Scenarios

| | | Invest in Period 0 | Do Not Invest in Period 0 |
|---|---|---|---|
| No Policy | Period 0 | Capital: $K^*$<br>Profit: $\hat{\pi}^* - (C + OV)$ | Capital: $K^*$<br>Profit: $\hat{\pi}^*$ |
| | Subsequent periods | Capital: $K'^*$<br>Profit: $\hat{\pi}'^*$ | Capital: $K^*$<br>Profit: $\hat{\pi}^*$ |
| Direct Policy | Period 0 | Capital: $K^{*T}$<br>Profit: $\hat{\pi}^{*T} - ((1 - \omega)C + OV)$ | Capital: $K^{*T}$<br>Profit: $\hat{\pi}^{*T}$ |
| | Subsequent periods | Capital: $K'^{*T}$<br>Profit: $\hat{\pi}'^{*T}$ | Capital: $K^{*T}$<br>Profit: $\hat{\pi}^{*T}$ |
| AFMTC | Period 0 | Capital: $K^{*a}$<br>Profit: $\hat{\pi}^{*a} - (C + OV)$ | Capital: $K^{*a}$<br>Profit: $\hat{\pi}^{*a}$ |
| | Subsequent periods | Capital: $K'^*$<br>Profit: $\pi'^* = \hat{\pi}'^*$ | Capital: $K^*$<br>Profit: $\hat{\pi}^*$ |
| PPGTP | Period 0 | Capital: $K^{*g}$<br>Profit: $\hat{\pi}^{*g} - (C + OV)$ | Capital: $K^*$<br>Profit: $\hat{\pi}^*$ |
| | Subsequent periods | Capital: $K'^*$<br>Profit: $\hat{\pi}'^*$ | Capital: $K^*$<br>Profit: $\hat{\pi}^*$ |

Table 2.4

List of Variables and Functions

| | |
|---|---|
| **Parameters** | |
| $b$ | Black liquor production coefficient |
| $s$ | Subsidy rate under the AFMTC |
| $\hat{s}$ | Subsidy rate under the PPGTP |
| $T$ | Tax on fuel |
| $P_{f,t}$ | Price of fossil fuel in period t |
| $P_{p,t}$ | Price of pulp in period t |
| $OV$ | Option value of delayed investment for the mill |
| $\bar{K}$ | Amount of production capital owned by the mill |
| $C$ | Cost of the one-time investment in energy efficiency |
| $\delta_k$ | Rate of depreciation of the produciton capital stock |
| $\varphi$ | Rate of time preference used by the mill |
| $\gamma$ | Energy efficiency parameter |
| $\omega$ | Subsidy rate paid to the mill under the tax and subsidy policy |
| **Variables** | |
| $Y_t$ | Pulp production in period t |
| $K_t$ | Production capital employed in period t |
| $f$ | Fossil fuel purchased and used by the mill |
| $B$ | Black liquor produced by the mill |
| $\hat{S}$ | Total subsidy received under the PPGTP |
| $S$ | Total subsidy received under the AFMTC |
| $I$ | Binomial investment variable |
| $\pi_t$ | Profit of the mill in period t |
| $\hat{\pi}_t$ | Gross profit of the mill in period t, not including investment |
| $\pi'_t$ | Profit of the mill in period t, if the investment was undertaken in a previous period |
| **Functions** | |
| $E(K)$ | Energy requirement function |
| $E(K)$ | Energy requirement function |

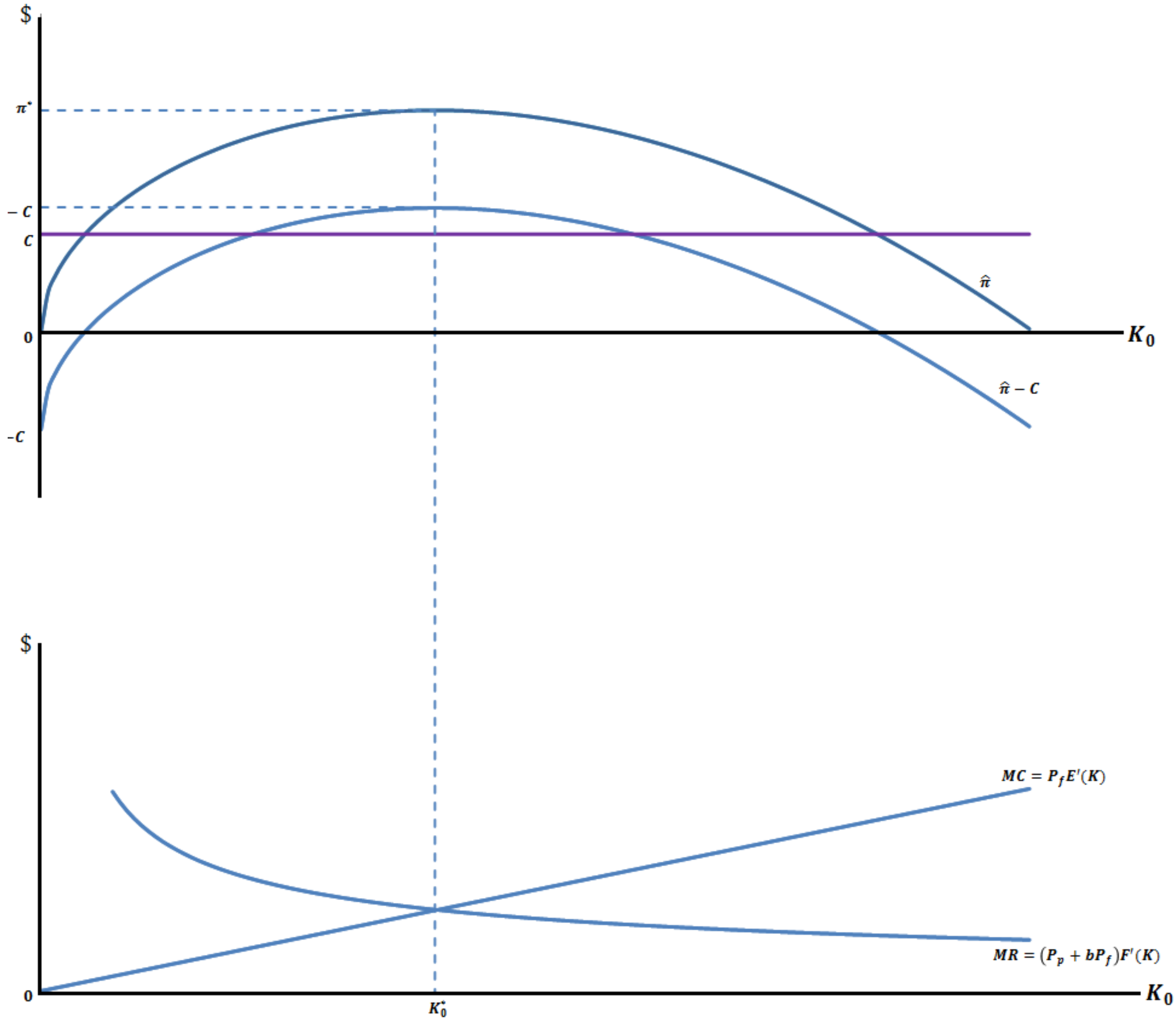


*Figure 2.1*. Pulp mill profit, marginal cost and marginal revenue – no policy

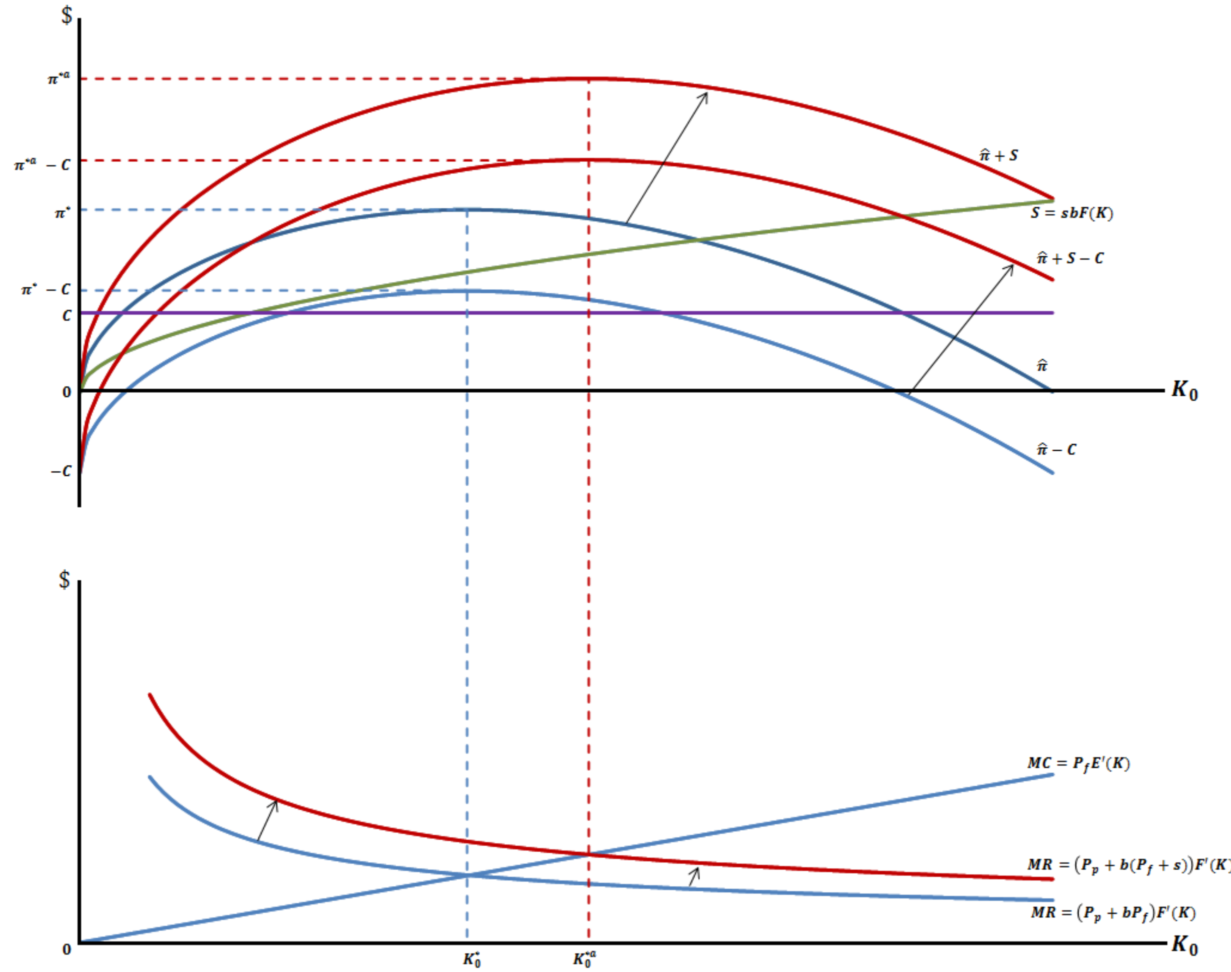


*Figure 2.2*. Pulp mill profit, subsidy payment, marginal cost and marginal revenue – no policy and AFMTC

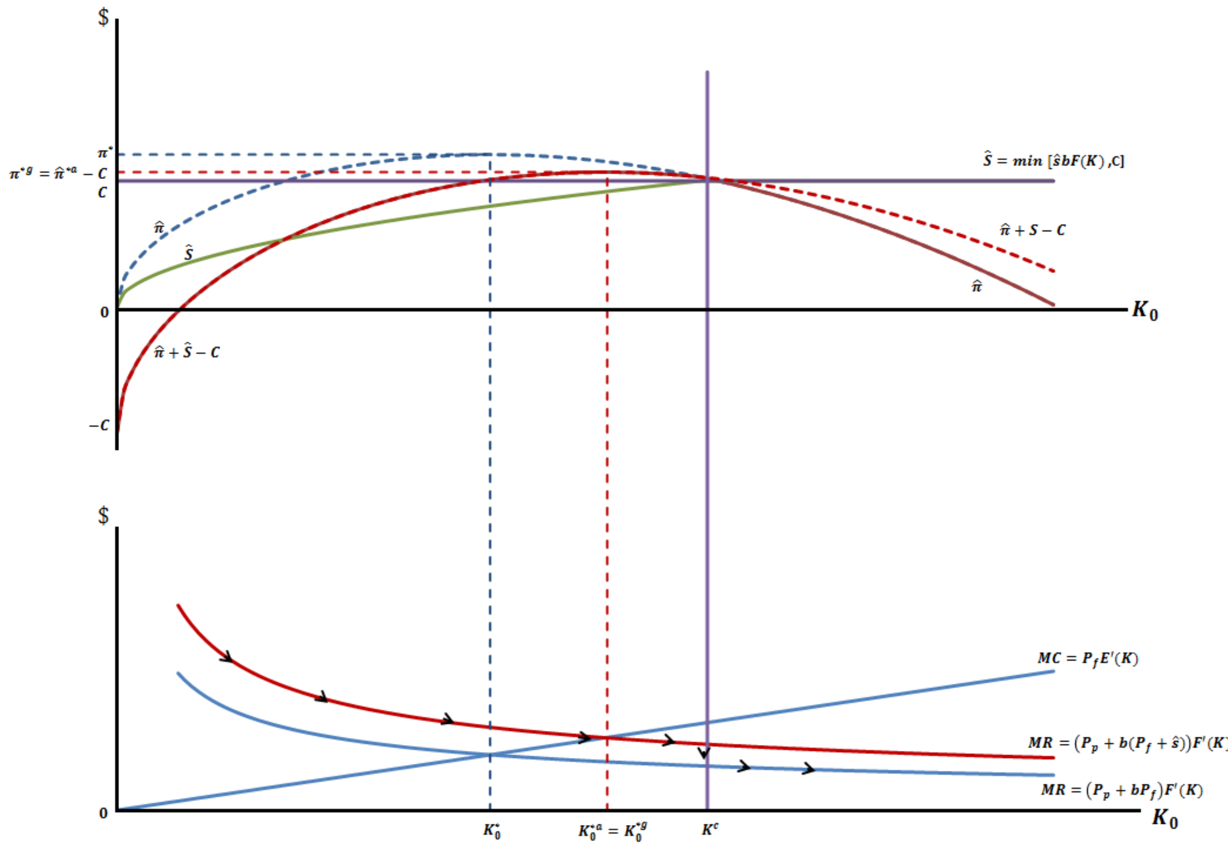


*Figure 2.3*. Pulp mill profit, subsidy payment, marginal cost and marginal revenue – PPGTP with $K_c > K_0^{*a}$

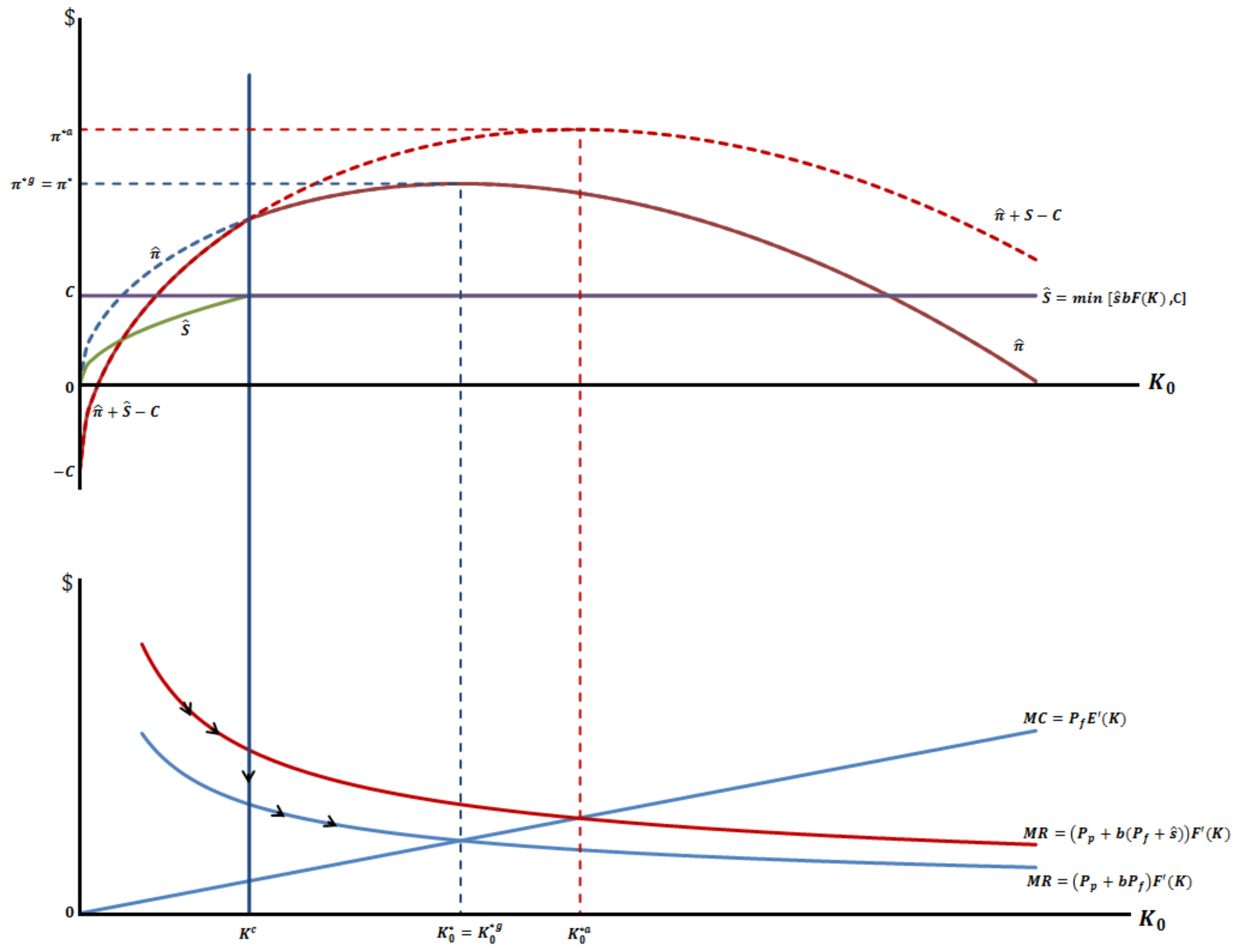


*Figure 2.4.* Pulp mill profit, subsidy payment, marginal cost and marginal revenue – PPGTP with $K_c < K_0^*$

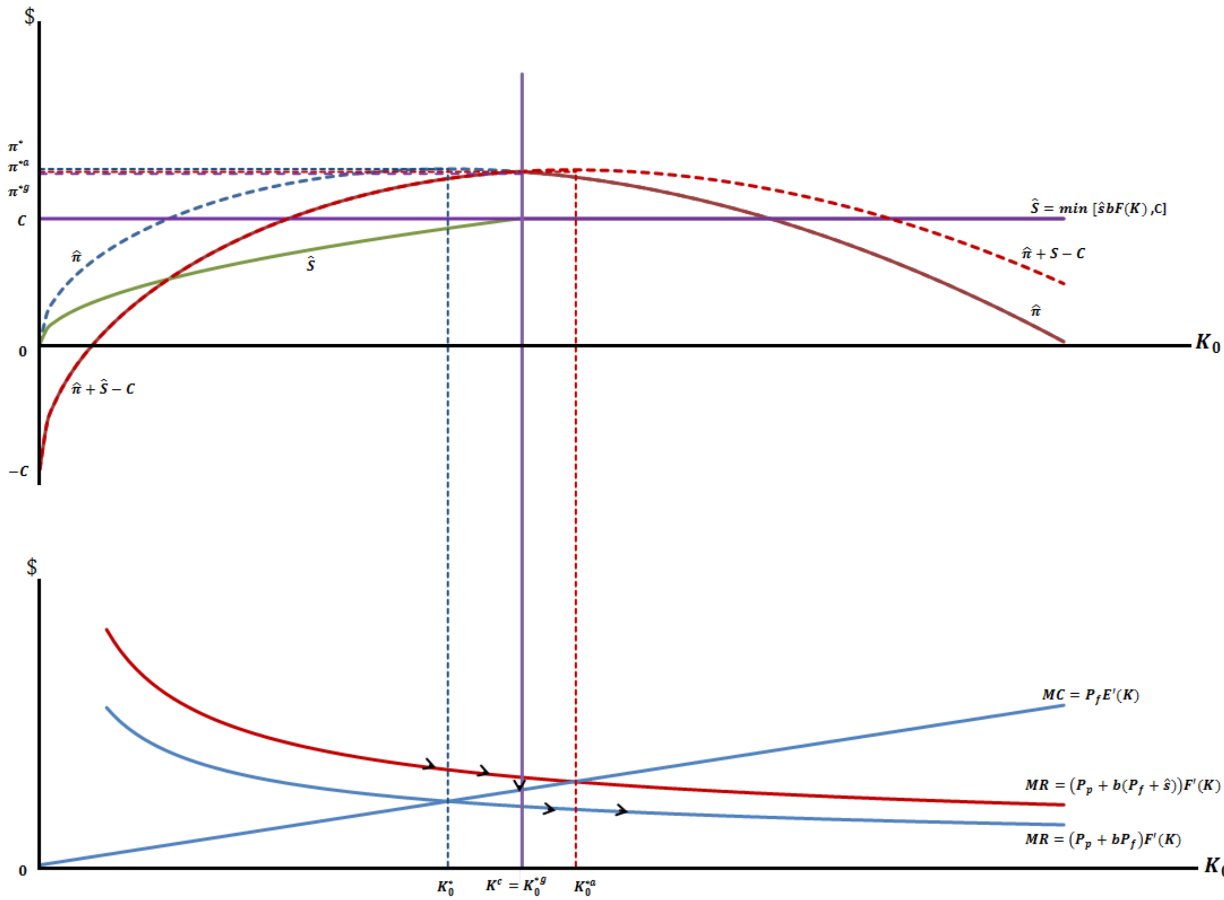


*Figure 2.5*. Pulp mill profit, subsidy payment, marginal cost and marginal revenue – PPGTP with $K_0^* < K_c < K_0^{*a}$

# Appendix C: Tables and Figures for Chapter 3

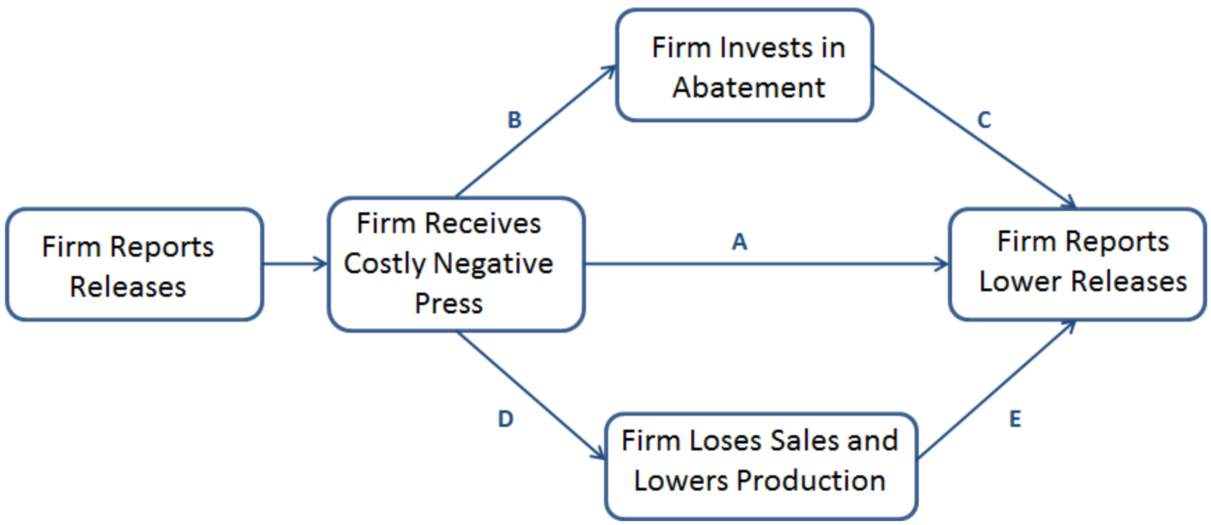


*Figure 3.1*. Possible relationships between publically available data and reducing emissions

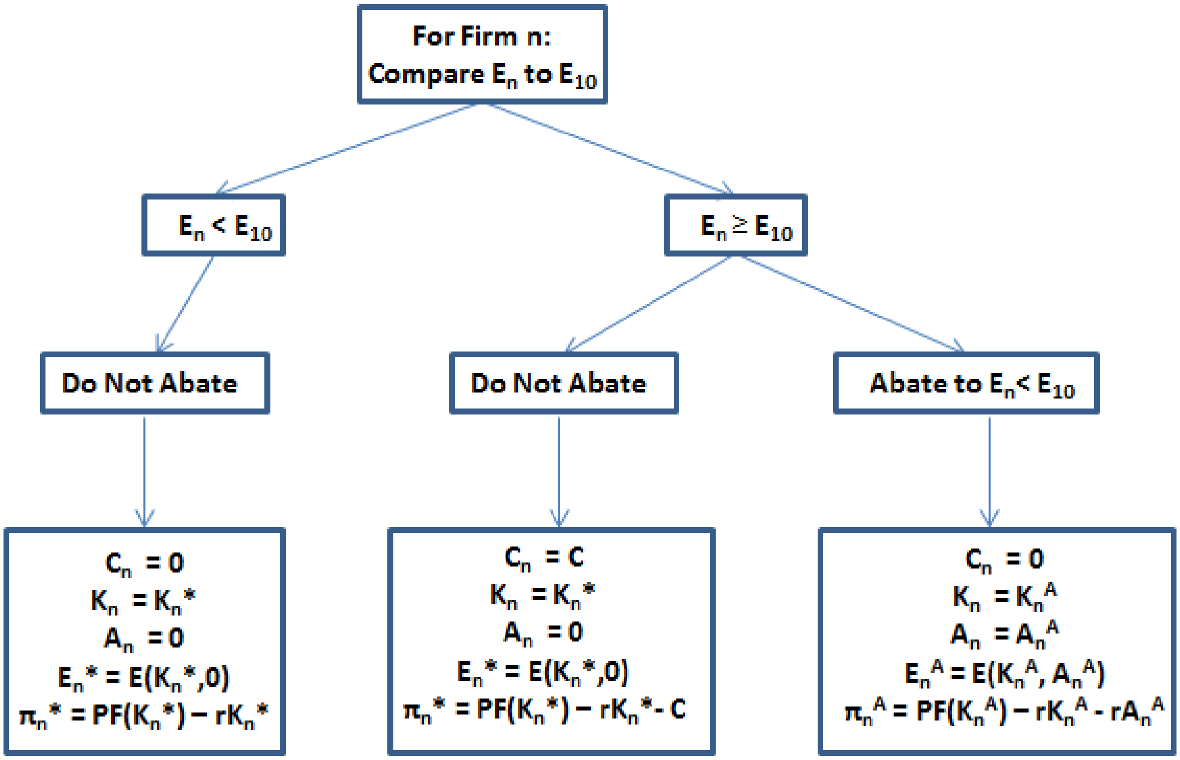


*Figure 3.2.* Decision tree for Firm *n* abatement

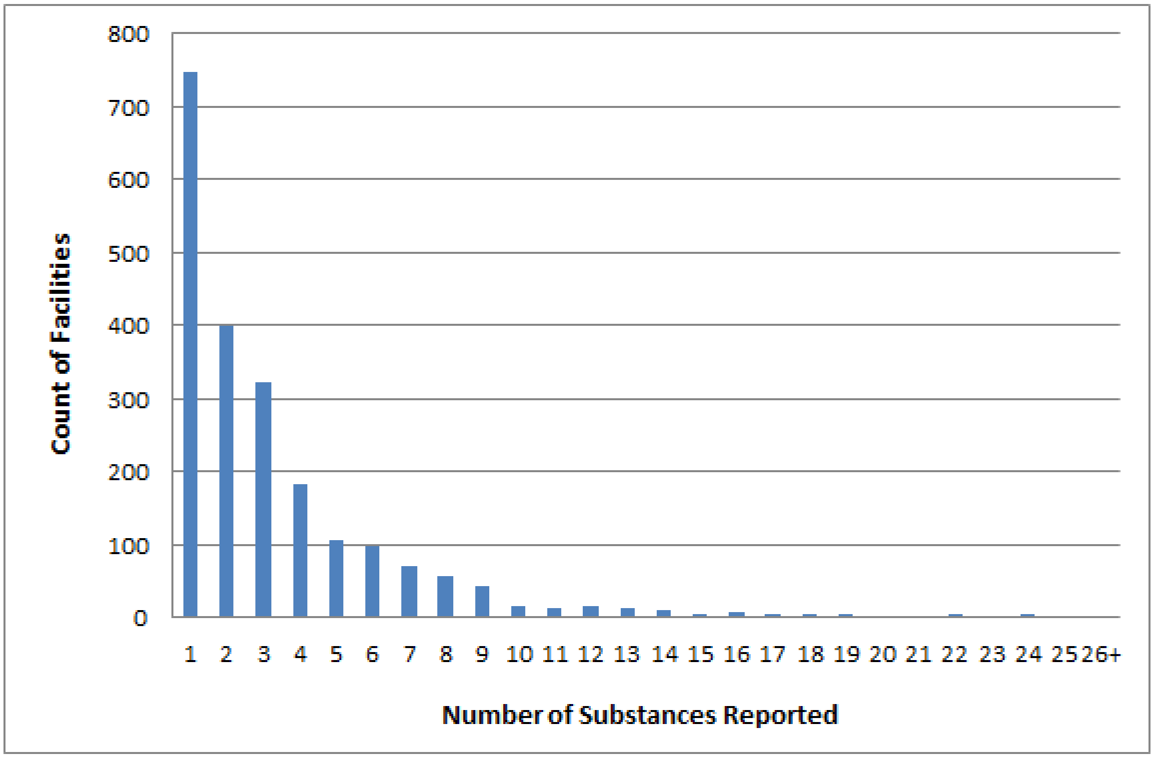


*Figure 3.3*. Distribution of Number of Substances Reported by Facilities in the Examined Sample

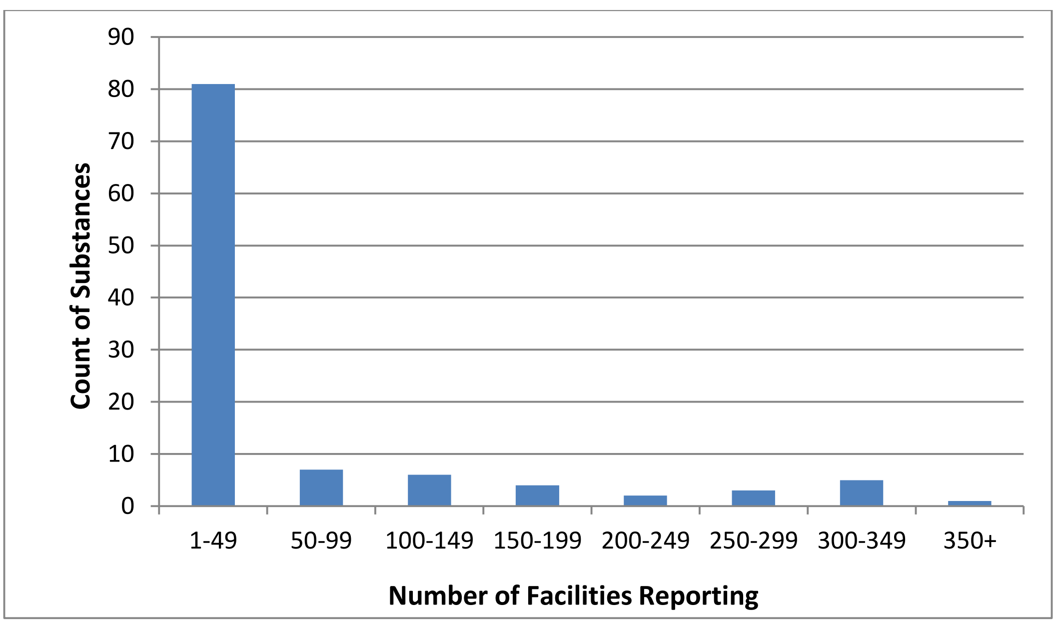


*Figure 3.4*. Distribution of Number of Facilities Reporting on Each Substance in the Examined Sample

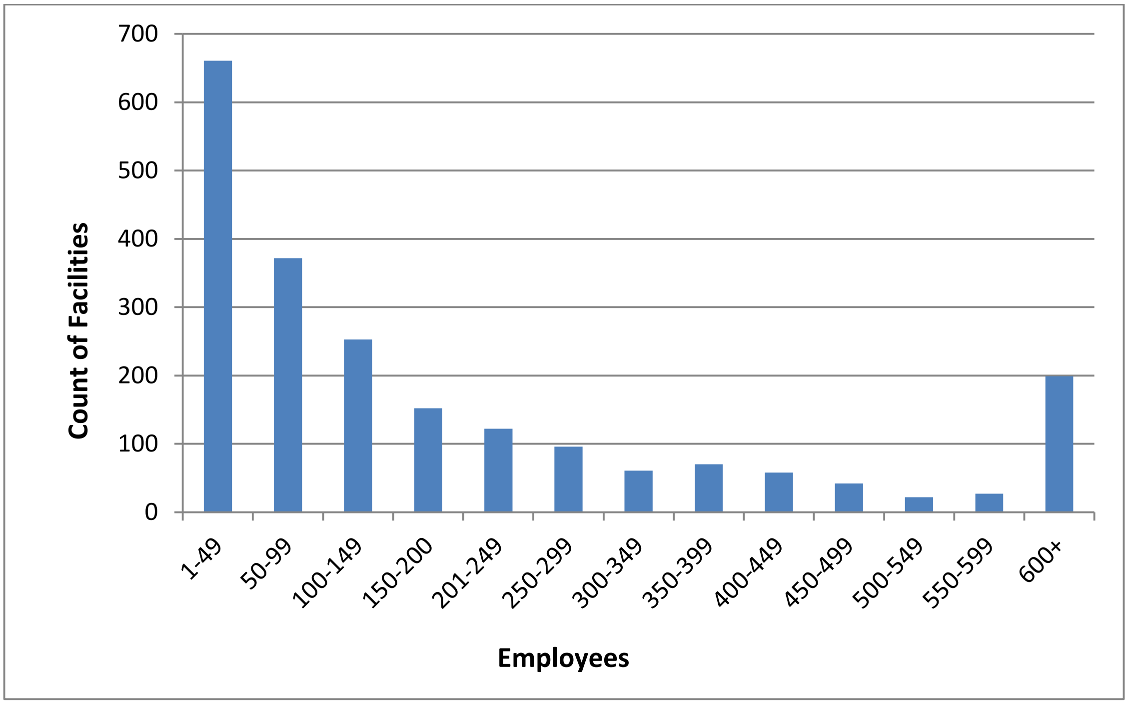


*Figure 3.5.* Distribution of Facility Employment in the Examined Sample

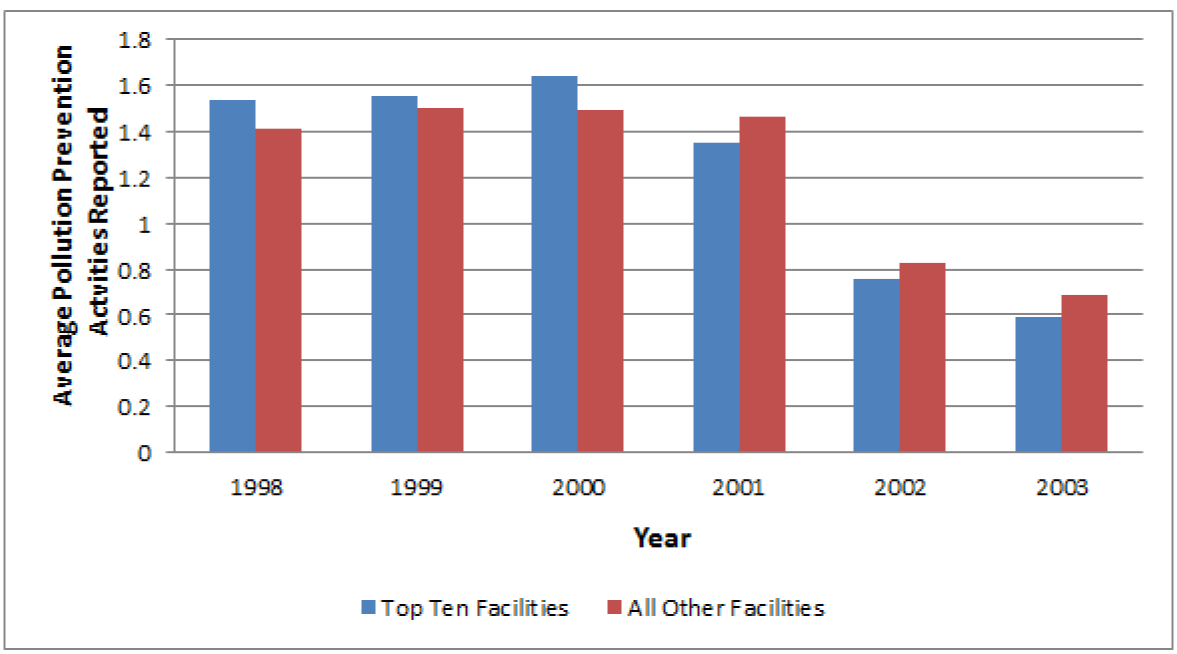


*Figure 3.6.* Average Number of Pollution Prevention Activities Reported, by Year

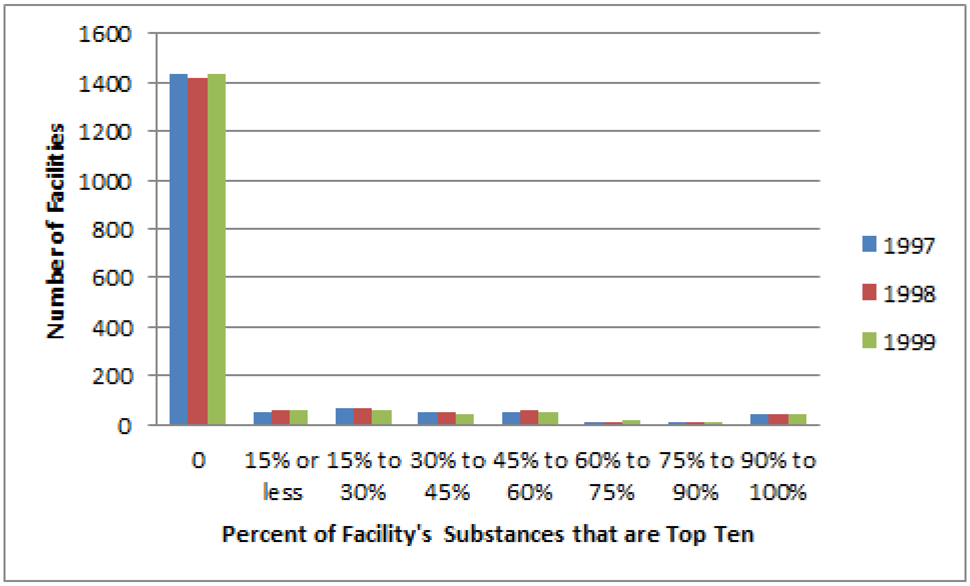


*Figure 3.7.* Count of Facilities by Percent of Facility's Substance Reports labeled as Top Ten

Table 3.1

Summary of 'YES' reports for eight pollution prevention activities reported to the NPRI between 1998 and 2000 – Treatment Sample

| Pollution Prevention Activity | % Yes | % Yes - if Yes in Previous Year | % Yes - if No in Previous Year |
|---|---|---|---|
| Material or Feedstock Substitution | 4.37 | 51.48 | 2.22 |
| Product Design Reformulation | 5.79 | 54.27 | 2.90 |
| Equipement or Process Modification | 16.65 | 56.53 | 8.56 |
| Spill and Leak Prevention | 29.95 | 74.41 | 12.40 |
| On-Site Recovery, Re-Use, or Recycling Techniques | 18.86 | 71.40 | 7.58 |
| Improved Management or Purchasing | 11.39 | 62.40 | 4.82 |
| Good Operating Practice or Training | 55.44 | 84.53 | 24.27 |
| Other Pollution Prevention Activity | 5.46 | 51.73 | 2.45 |

Table 3.2

Summary of 'YES' reports for eight pollution prevention activities reported to the NPRI between 2001 and 2003 – Control Sample

| Pollution Prevention Activity | % Yes | % Yes - if Yes in Previous Year | % Yes - if No in Previous Year |
|---|---|---|---|
| Material or Feedstock Substitution | 2.71 | 40.69 | 1.41 |
| Product Design Reformulation | 3.76 | 49.13 | 1.55 |
| Equipement or Process Modification | 9.06 | 43.18 | 4.24 |
| Spill and Leak Prevention | 19.04 | 56.84 | 6.05 |
| On-Site Recovery, Re-Use, or Recycling Techniques | 10.47 | 52.01 | 3.13 |
| Improved Management or Purchasing | 4.87 | 44.19 | 1.58 |
| Good Operating Practice or Training | 43.58 | 71.63 | 13.27 |
| Other Pollution Prevention Activity | 5.09 | 50.98 | 2.83 |

Table 3.3
Summary of Top Ten Observations by Industry – 1997 to 1999

| NAICS | Industry | Count |
|---|---|---|
| 3251 | Basic Chemical Manufacturing | 122 |
| 2111 | Oil and Gas Extraction | 120 |
| 3241 | Petroleum and Coal Product Manufacturing | 116 |
| 2211 | Electric Power Generation, Transmission and Distribution | 113 |
| 3221 | Pulp, Paper and Paperboard Mills | 91 |
| 3261 | Plastic Product Manufacturing | 87 |
| 3361 | Motor Vehicle Manufacturing | 87 |
| 3311 | Iron and Steel Mills and Ferro-Alloy Manufacturing | 81 |
| 3314 | Non-Ferrous Metal (except Aluminum) Production and Processing | 61 |
| 2122 | Metal Ore Mining | 53 |
| 3252 | Resin, Synthetic Rubber, and Artificial and Synthetic Fibres and Filaments Manufacturing | 35 |
| 3255 | Paint, Coating and Adhesive Manufacturing | 30 |
| 3315 | Foundries | 29 |
| 3399 | Other Miscellaneous Manufacturing | 28 |
| 3259 | Other Chemical Product Manufacturing | 28 |
| 3212 | Veneer, Plywood and Engineered Wood Product Manufacturing | 27 |
| 3253 | Pesticide, Fertilizer and Other Agricultural Chemical Manufacturing | 26 |
| 3313 | Alumina and Aluminum Production and Processing | 25 |
| 3231 | Printing and Related Support Activities | 18 |
| 3329 | Other Fabricated Metal Product Manufacturing | 18 |
| 2213 | Water, Sewage and Other Systems | 16 |
| 3133 | Textile and Fabric Finishing and Fabric Coating | 15 |
| 5622 | Waste Treatment and Disposal | 14 |
| 3222 | Converted Paper Product Manufacturing | 14 |
| 3312 | Steel Product Manufacturing from Purchased Steel | 11 |
| 3363 | Motor Vehicle Parts Manufacturing | 10 |
| 3279 | Other Non-Metallic Mineral Product Manufacturing | 10 |

**Note: Industries with less than 10 observations not shown*

Table 3.4

Number of Substance Reports Labeled as Top Ten

| Year | 1997 | 1998 | 1999 |
|---|---|---|---|
| Top Ten | 471 | 475 | 456 |
| Non-Top Ten | 5679 | 5679 | 5679 |
| % Top Ten | 8.29 | 8.36 | 8.03 |

Table 3.5

Percent of Substance Reports Labeled as Top Ten, Contingent on Previous Year's Top Ten Status

| % Top Ten | % Top Ten if Top Ten in Previous Year | % Top Ten if Not Top Ten in Previous Year |
|---|---|---|
| 8.33 | 80.76 | 1.60 |

Table 3.6

Regression Results for New Abatement Activities due to Top Ten Publications – Full data sample

| Model | 1a | 1b | 1c | 2a | 2b | 2c | 3a | 3b | 3c | 4a | 4b | 4c | 5a | 5b | 5c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Observations | 35553 | 35553 | 35553 | 35553 | 35553 | | 30804 | 30804 | 30804 | 34111 | 34111 | 34111 | 25041 | 25041 | 25041 |
| Releases | 0.008602 | 0.0039547 | 0.0107721 | 0.0382748 | 0.0327155 | 0.0397663 | 0.0621158 | 0.0554258 | 0.0612364 | 0.0396733 | 0.0298211 | 0.0395229 | 0.0575096 | 0.0043265 | 0.0135687 |
| | (0.0136015) | (0.136181) | (0.0131291) | (0.131978) | (0.0131299) | (0.0128356) | (0.0128063) | (0.123848) | (0.0122729) | (0.0128733) | (0.0123138) | (0.012012) | (0.028229) | (0.0286574) | (0.028046) |
| | {0.527} | {0.772} | {0.82} | {0.004} | {0.013} | {0.002} | {0.000} | {0} | {0.000) | {0.002} | {0.015} | {0.001} | {0.042} | {0.88} | {0.63} |
| Employment | -0.0203583 | -0.0211415 | -0.0210138 | 0.0087119 | 0.0083488 | 0.0087926 | -0.2523657 | -0.2252985 | -0.2252767 | 0.0116416 | 0.0134837 | 0.0139724 | -0.2482262 | -0.2151741 | -0.2147223 |
| | (0.0174293) | (0.0173568) | (0.0173564) | (0.0208788) | (0.0207359) | (0.0207225) | (0.0899281) | (0.0837004) | (0.083686) | (0.013054) | (0.0127528) | (0.0127051) | (0.0495245) | (0.0477053) | (0.0476513) |
| | {0.243} | {0.223} | {0.226} | {0.676} | {0.687} | {0.671} | {0.005} | {0.007} | {0.007} | {0.372} | {0.290} | {0.271} | {0.000} | {0.000} | {0.000} |
| Top Ten | -0.2106455 | 0.1490617 | | -0.2322251 | 0.14211711 | | -0.270148 | 0.1152892 | | -0.2199939 | 0.1683541 | | -0.2679751 | 0.1477844 | |
| | (0.0802359) | (0.0776547) | | (0.0809878) | (0.0779015) | | (0.0834796) | (0.0794678) | | (0.0740547) | (0.0731627) | | (0.0828467) | (0.0839822) | |
| | {0.009} | {0.055} | | {0.004} | {0.070} | | {0.001} | {0.147} | | {0.003} | {0.021} | | {0.001} | {0.078} | |
| Published | 0.54572 | -0.0686381 | 0.0551769 | 0.5500718 | -0.0754061 | 0.0388312 | 0.5196359 | -0.1401916 | -0.0556435 | 0.5323062 | -0.0993107 | 0.0246419 | 0.4920573 | -0.2251637 | -0.152904 |
| | (0.1063169) | (0.1045931) | (0.0701935) | (0.1059744) | (0.1048827) | (0.0697402) | (0.1112661) | (0.1075784) | (0.0669684) | (0.0874343) | (0.0872962) | (0.0611529) | (0.0785337) | (0.0831126) | (0.071031) |
| | {0.000} | {0.512} | {0.432} | {0.000} | {0.472} | {0.578} | {0.000} | {0.193} | {0.406} | {0.000} | {0.255} | 0.687 | {0.000} | {0.007} | {0.031} |
| Substance Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | No | No | No | No | No | No |
| Industry Fixed Effects | No | No | No | Yes | Yes | Yes | No | No | No | Yes | Yes | Yes | No | No | No |
| Province Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes | No | No | No | No | No | No | No | No | No |
| Facility Fixed Effects | No | No | No | No | No | No | Yes | Yes | Yes | No | No | No | No | No | No |
| Substance/Industry Fixed Effects | No | No | No | No | No | No | No | No | No | Yes | Yes | Yes | No | No | No |
| Substance/Facility Fixed Effects | No | No | No | No | No | No | No | No | No | No | No | No | Yes | Yes | Yes |
| Year Fixed Effects | No | Yes | Yes | No | Yes | Yes | No | Yes | Yes | No | Yes | Yes | No | Yes | Yes |

Table 3.7
Regression Results for New Abatement Activities due to Top Ten Publications – Toxic Metals Only (Lead, Cadmium, Mercury, Arsenic, Antimony, Cobalt, Chromium)

| Model | 1a | 1b | 1c | 2a | 2b | 2c | 3a | 3b | 3c | 4a | 4b | 4c | 5a | 5b | 5c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Observations | 3039 | 3039 | 3039 | 3039 | 3039 | 3039 | 2139 | 2139 | 2139 | 2901 | 2901 | | 1980 | 1980 | 1980 |
| Releases | -0.0464945 | -0.0595001 | -0.0859069 | -0.0565779 | -0.0667822 | -0.0830291 | 0.0428265 | 0.0143836 | 0.0145802 | -0.0859174 | -0.0993675 | -0.1096042 | -0.0642242 | -0.099601 | -0.0515321 |
| | (0.0803843) | (0.0823059) | (0.0732883) | (0.0714245) | (0.0719019) | (0.0630158) | (0.082795) | (0.0813797) | (0.0793132) | (0.0761266) | (0.072909) | (0.0710905) | (0.1633658) | (0.1545399) | (0.146967) |
| | {0.563} | {0.470} | {0.241} | {0.428} | {0.353} | {0.188} | {0.605} | {0.860} | {0.854} | {0.259} | {0.173} | {0.123} | {0.694} | {0.519} | {0.726} |
| Employment | 0.0055457 | 0.0011139 | -0.0010904 | 0.0492252 | 0.0356265 | 0.032932 | -0.2073539 | -0.2901764 | -0.2899123 | 0.0618191 | 0.0508604 | 0.0497933 | -0.211971 | -0.2910964 | -0.2878701 |
| | (0.0321321) | (0.0323359) | (0.0324436) | (0.0441035) | (0.0444124) | (0.0444586) | (0.1698156) | (0.1702272) | (0.1702353) | (0.0407592) | (0.0425962) | (0.0425301) | (0.136823) | (0.1348243) | (0.1346914) |
| | {0.863} | {0.973} | {0.973} | {0.264} | {0422} | {0.459} | {0.222} | {0.088} | {0.089} | {0.129} | {0.232} | {0.242} | {0.121} | {0.031} | {0.033} |
| Top Ten | -0.6160318 | -0.3311952 | | -0.53263511 | -0.2150681 | | -0.3072403 | 0.134041 | | -0.4551729 | -1259077 | | 0.028164 | 0.3719314 | |
| | (0.323754) | (0.3164279) | | (0.3121409) | (0.3005946) | | (0.2931537) | (0.2866856) | | (0.2548207) | (0.2478388) | | (0.3743044) | (0.3733685) | |
| | {0.057} | {0.295} | | {0.088} | {0.474} | | {0.295} | {0.963} | | {0.074} | {0.611} | | {0.940} | {0.319} | |
| Published | 1.193881 | 0.653143 | 0.3791159 | 1.307368 | 0.7434379 | 0.5731575 | 1.148699 | 0.5428652 | 0.5520254 | 1.380176 | 0.8032318 | 0.7123068 | 1.133086 | 0.45106 | 0.6237251 |
| | (0.3472977) | (0.3477195) | (0.1763737) | (0.341487) | (0.3384397) | (0.2059631) | (0.3348142) | (0.3319998) | (0.2239076) | (0.2667089) | (0.2824562) | (0.2247734) | (0.3312233) | (0.3492487) | (0.3064728) |
| | {0.001} | {0.060} | {0.032} | {0.000} | {0.028} | {0.005} | {0.001} | {0.102} | {0.014} | {0.000} | {0.004} | {0.002} | {0.001} | {0.197} | {0.042} |
| Substance Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | No | No | No | No | No | No |
| Industry Fixed Effects | No | No | No | Yes | Yes | Yes | No | No | No | Yes | Yes | Yes | No | No | No |
| Province Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes | No | No | No | No | No | No | No | No | No |
| Facility Fixed Effects | No | No | No | No | No | No | Yes | Yes | Yes | No | No | No | No | No | No |
| Substance/Industry Fixed Effects | No | No | No | No | No | No | No | No | No | Yes | Yes | Yes | No | No | No |
| Substance/Facility Fixed Effects | No | No | No | No | No | No | No | No | No | No | No | No | Yes | Yes | Yes |
| Year Fixed Effects | No | Yes | Yes | No | Yes | Yes | No | Yes | Yes | No | Yes | Yes | No | Yes | Yes |

Table 3.8
Regression Results for New Abatement Activities due to Top Ten Publications – Large Facilities Only (50 or more Employees)

| Model | 1a | 1b | 1c | 2a | 2b | 2c | 3a | 3b | 3c | 4a | 4b | 4c | 5a | 5b | 5c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Observations | 26733 | 26733 | 26733 | 26733 | 26733 | 26733 | 23191 | 23191 | 23191 | 25430 | 25430 | 25430 | 18335 | 18335 | 18335 |
| Releases | 0.0117902 | 0.0081437 | 0.0179958 | 0.0416622 | 0.0368498 | 0.0470497 | 0.0619048 | 0.0547617 | 0.0629963 | 0.0432667 | 0.0332848 | 0.0462908 | 0.058562 | -0.0043807 | 0.0128722 |
| | (0.0156966) | (0.0155605) | (0.147673) | (0.0154931) | (0.0153503) | (0.0148055) | (0.0145287) | (0.0141157) | (0.0139231) | (0.0154187) | (0.0149798) | (0.0146818) | (0.0322008) | (0.0322332) | (0.0317028) |
| | {0.453} | {0.601} | {0.223} | {0.007} | {0.016} | {0.001} | {0.000} | {0} | {0.000} | {0.005} | {0.026} | {0.002} | {0.69} | {0.892} | {0.685} |
| Employment | -0.023595 | -0.0263166 | -0.0261606 | 0.0159035 | 0.010823 | 0.0112928 | -0.2795972 | -0.2285945 | -0.2297661 | 0.0149113 | 0.0100565 | 0.0105733 | -0.2718979 | -0.2107925 | -0.2119015 |
| | (0.0267135) | (0.0265702) | (0.0266181) | (0.0319992) | (0.0317036) | (0.0317309) | (0.191566) | (0.01283548) | (0.1281731) | (0.0181412) | (0.0178638) | (0.0178014) | (0.0654847) | (0.062913) | (0.0630164) |
| | {0.377} | {0.322} | {0.326} | {0.619} | {0.733} | {0.722} | {0.045} | {0.075} | {0.073} | {0.411} | {0.573} | {0.553} | {0.000} | {0.001} | {0.001} |
| Top Ten | -0.1856015 | 0.1854436 | | -0.2043375 | 0.1768746 | | -0.235254 | 0.1442522 | | -0.2019619 | 0.1925165 | | -0.198555 | 0.2381755 | |
| | (0.0848666) | (0.0810466) | | (0.0856028) | (0.0806304) | | (0.0889204) | (0.0824426) | | (0.0752826) | (0.0746438) | | (0.091585) | (0.0928865) | |
| | {0.029} | {0.022} | | {0.017} | {0.028} | | {0.008} | {0.080} | | {0.007} | {0.010} | | {0.030} | {0.010} | |
| Published | 0.5251186 | -0.1139604 | 0.0363641 | 0.5277557 | -0.1108616 | 0.028276 | 0.5165905 | -0.1454351 | -0.041731 | 0.5345625 | -0.1063553 | 0.0312633 | 0.4932009 | -0.235262 | -0.1181757 |
| | (0.1086524) | (0.1048892) | (0.0708761) | (0.1081896) | (0.1040469) | (0.0695469) | (0.1138417) | (0.1076411) | (0.0684868) | (0.0878172) | (0.0878271) | (0.0630504) | (0.081815) | (0.087447) | (0.0744136) |
| | {0.000} | {0.277} | {0.608} | {0.000} | {0.287} | {0.684} | {0.000} | {0.177} | {0.542} | {0.000} | {0.226} | {0.620} | {0.000} | {0.007} | {0.112} |
| Substance Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | No | No | No | No | No | No |
| Industry Fixed Effects | No | No | No | Yes | Yes | Yes | No | No | No | Yes | Yes | Yes | No | No | No |
| Province Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes | No | No | No | No | No | No | No | No | No |
| Facility Fixed Effects | No | No | No | No | No | No | Yes | Yes | Yes | No | No | No | No | No | No |
| Substance/Industry Fixed Effects | No | No | No | No | No | No | No | No | No | Yes | Yes | Yes | No | No | No |
| Substance/Facility Fixed Effects | No | No | No | No | No | No | No | No | No | No | No | No | Yes | Yes | Yes |
| Year Fixed Effects | No | Yes | Yes | No | Yes | Yes | No | Yes | Yes | No | Yes | Yes | No | Yes | Yes |

Table 3.9
Regression Results for Count of Abatement Activities due to Top Ten Publications

| Model | 1a | 1b | 1c | 2a | 2b | 2c | 3a | 3b | 3c | 4a | 4b | 4c | 5a | 5b | 5c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Observations | 35553 | 35553 | 35553 | 35553 | 35553 | 35553 | 33249 | 33249 | 33249 | 35011 | 35011 | 35011 | 30843 | 30843 | 30843 |
| Releases | -0.0406705 | -0.0437792 | -0.0433037 | -0.0066507 | -0.0101829 | -0.0103747 | 0.0381053 | 0.0349449 | 0.0333502 | -0.0151102 | -0.0218649 | -0.0201566 | 0.053883 | -0.0313425 | -0.0342898 |
| | (0.0118525) | (0.0117983) | (0.0115275) | (0.0108539) | (0.0106904) | (0.0106147) | (0.0070388) | (0.006709) | (0.0070453) | -0.0131748 | (0.0126508) | (0.0117925) | (0.0159768) | (0.01689) | (0.0165796) |
| | {0.001} | {0.000} | {0.000} | {0.540} | {0.341} | {0.328} | {0.000} | {0.000} | {0.000} | {0.251} | {0.084} | {0.087} | {0.736} | {0.063} | {0.039} |
| Employment | -0.0137666 | -0.013228 | -0.0132167 | 0.0327109 | 0.0336746 | 0.0336629 | -0.0181184 | 0.0198788 | 0.0198319 | 0.0392224 | 0.0420173 | 0.0420843 | -0.0184221 | 0.0205257 | 0.0203718 |
| | (0.0203293) | (0.0201739) | (0.0201857) | (0.0308712) | (0.0304308) | (0.0304413) | (0.0373837) | (0.0272877) | (0.0272695) | (0.010837) | (0.0106618) | (0.0106844) | (0.0134378) | (0.0105303) | (0.0105281) |
| | {0.498 } | {0.512} | {0.513} | {0.289} | {0.268} | {0.269} | {0.628} | 0.466 | 0.467 | {0.000} | {0.000} | {0.000} | {0.170} | {0.051} | {0.053} |
| Top Ten | -0.1848 | 0.0101381 | | -0.209062 | -0.0036983 | | -0.2291525 | -0.0306172 | | -0.1797488 | 0.0291456 | | -0.2603812 | -0.0472753 | |
| | (0.0544318) | (0.0534063) | | (0.047428) | (0.0459895) | | (0.0432702) | (0.0395736) | | (0.0446898) | (0.0433448) | | (0.0383268) | (0.0361742) | |
| | {0.001} | {0.849} | | {0.000} | {0.936} | | {0.000} | {0.439} | | {0.000} | {0.501} | | {0.000} | {0.191} | |
| Published | 0.5520358 | 0.1912304 | 0.1995836 | 0.5563868 | 0.1838581 | 0.1808984 | 0.5171442 | 0.1408321 | 0.1186032 | 0.5657071 | 0.1964956 | 0.2177557 | 0.5376989 | 0.1304698 | 0.1083633 |
| | (0.0606639) | (0.0593308) | (0.0625675) | (0.0585597) | (0.0569482) | (0.0540268) | (0.0564422) | (0.051205) | (0.0329438) | (0.0431866) | (0.0435591) | (0.0394782) | (0.0351851) | (0.0357755 ) | (0.0302631) |
| | {0.000} | {0.001} | {0.001} | {0.000} | {0.001} | {0.001} | {0.000} | {0.006} | {0.000} | {0.000} | {0.000} | {0.000} | {0.000} | {0.000} | {0.000} |
| Substance Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | No | No | No | No | No | No |
| Industry Fixed Effects | No | No | No | Yes | Yes | Yes | No | No | No | Yes | Yes | Yes | No | No | No |
| Province Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes | No | No | No | No | No | No | No | No | No |
| Facility Fixed Effects | No | No | No | No | No | No | Yes | Yes | Yes | No | No | No | No | No | No |
| Substance/Industry Fixed Effects | No | No | No | No | No | No | No | No | No | Yes | Yes | Yes | No | No | No |
| Substance/Facility Fixed Effects | No | No | No | No | No | No | No | No | No | No | No | No | Yes | Yes | Yes |
| Year Fixed Effects | No | Yes | Yes | No | Yes | Yes | No | Yes | Yes | No | Yes | Yes | No | Yes | Yes |

Table 3.10

Regression Results for Change in Releases due to New Abatement Activities

| Model | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|
| Observations | 35553 | 35553 | 35553 | 35553 | 35553 |
| New Pollution Prevention Activities | -1.224995 | -1.15426 | -1.224995 | -1.291248 | -1.291248 |
| | (0.4874763) | (0.4719058) | (0.4874763) | (0.4450252) | (0.4602284) |
| | {0.012} | {0.015} | {0.012} | {0.004} | {0.005} |
| Change in Employment | 2.89E-06 | 3.05E-06 | 2.89E-06 | 2.77E-06 | 2.77E-06 |
| | (5.54E-06) | (5.60E-06) | (5.54E-06) | (4.32E-06) | (4.58E-06) |
| | {0.602} | {0.586} | {0.602} | {0.522} | {0.546} |
| Substance Fixed Effects | Yes | Yes | Yes | No | No |
| Industry Fixed Effects | No | Yes | No | No | No |
| Province Fixed Effects | No | No | No | No | No |
| Facility Fixed Effects | No | No | Yes | No | No |
| Substance/Industry Fixed Effects | No | No | No | Yes | No |
| Substance/Facility Fixed Effects | No | No | No | No | Yes |
| Year Fixed Effects | No | No | No | No | No |