

Pollution Control Policies, Carbon leakage and Border Tax Adjustment
A General Equilibrium Analysis

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Abstract

Carbon tariffs (border-tax adjustments) are gaining popularity among politicians as a means to protect the competitiveness of domestic firms after implementing a stringent environmental policy. Abstracting from potential infringements to WTO regulations, this paper uses a computable general equilibrium model to examine the competitiveness effects of implementing a border tax adjustment along with a domestic pollution control policy. Simulation results suggest that imposing a carbon tariff on GHG-intensive imports could reduce competitiveness concerns. The tariff raises the import price as much as the domestic price in energy-intensive industries and mitigates change in relative prices that are partially responsible for the carbon leakage. However, the border tax adjustment also increases the price level and introduces additional distortions in the economy that harms consumer welfare. Ultimately, the additional loss in welfare should be weighted against the improvement in sectoral equity that stems from the reduced loss of competitiveness.

1. Introduction

In recent years, there has been a growing consensus on the fact that climate change is a reality and may lead to substantial repercussions, such as the flooding of many coastal cities, if it is not addressed. Most scientists agree upon the root cause of climate change, that is the accumulation of greenhouse gases (GHGs) created by human activity (IPCC, 2007). Most jurisdictions share this viewpoint, which has led the United Nations (UN) to develop the Kyoto Protocol in 1997 to reduce global GHGs. This climate agreement came into effect in 2005 and separated countries in two different categories: Annex-B countries have ratified the protocol thereby agreeing to reduce their level of emissions by 2010¹, and the non-Annex B nations have signed the protocol without any obligation².

A peculiar feature of the Kyoto protocol is its recent suggestion to use market-based instruments (MBI) to achieve the emissions reduction target in the most cost-effective manner. However, the major drawback from MBI is that sectoral costs are unequally distributed. As a result, the carbon-intensive industries bear most of the weight caused by such a policy. Many alternatives were researched to reduce the negative impacts on the energy-intensive firms³: the output-based allocation of permits (OBA) and the use of performance standards are two examples of these. Even though those measures were seen to be more equitable among different industries, they come with a significant loss in efficiency (Bernard et al. 2007; Dissou, 2006; Fischer and Fox 2007).

Pollution abatement comes at a substantial cost to carbon-intensive industries. Whether they pay a carbon tax, buy an emission permit, or pay an indirect fee to meet a performance standard, the fees will be significant enough to have the desired effect on total domestic emissions. Consequently, it becomes more costly to produce the same

¹ The first commitment period runs from 2008-2012, which means that 2010 is the median year.

² The United States were originally part of the countries that wanted to reduce their emissions and agreed to a target in the 1997 negotiations. However, they have not ratified the protocol nor have they committed themselves to reaching those targets. Consequently, they are neither considered an Annex B nor a non-Annex B country.

³ I use carbon-intensive and energy-intensive industries interchangeably because firms that normally use a significant amount of energy in the production process are usually the most carbon intensive.

output as before, and firms in Annex B countries see a loss of competitiveness in energy-intensive industries compared to firms in non-Annex B countries.

This loss of competitiveness has two dimensions. First, in global markets, exports from Annex B countries become less competitive compared to goods produced in non-Annex B countries. For example, if Canada uses MBIs to curb its emissions, its exports to the United States will become less attractive relative to China's. This price distortion could, in principle, be remedied by applying an export subsidy to Canada's carbon-intensive exports. Second, goods produced from Annex B countries will feel a loss of competitiveness domestically compared to imports originating from non-Annex B countries. A potential solution to this distortion would be the implementation of a border tax adjustment.

Without trade measures, this competitiveness issue can give firms incentives to relocate to non-Annex B countries in order to produce carbon-intensive goods. This form of carbon leakage is commonly referred to as the terms-of-trade effect. It occurs when certain countries implement emissions-curbing policies but the reductions are offset by increases in other countries. There has been a large debate on the size of the leakage rate. Some studies find it to be small, while others find a significant rate (see for example Babiker 2005, Burniaux and Oliveira-Martins 2000, Di Maria and van der Werf, 2008, Hourcade and Shukla, 2001, Kolstad et al. 2000, and Pezzey 1992 among others).

Regardless of the current evidence on carbon leakage, the actual growth rate of GHG emissions in developing countries is impressive. For example, in China, GHG emissions have on average grown by twelve percent in the last seven years, which amounted to a 120 percent growth since the beginning of the decade. In 2007, its share in global GHG emission is 21.2 percent (Rubin and Tal, 2008). A recent study by the University of California at Berkeley even estimates that the annual growth rate of China's emissions will be between 11 and 13 percent for the upcoming future (Auffhammer and Carson, 2008). This is a significant increase relative to developed countries that are planning either to stabilize or reduce their GHG emissions. Indeed, non-OECD countries have now surpassed the OECD countries in their yearly amount of emissions, and are now producing 20 percent more (Rubin and Tal, 2008). This radical

shift in the location of production of GHG-intensive goods suggests that the competitiveness impact of environmental stringency is a matter of concern. Taking into consideration that 90% of the growth in emissions in the last decade comes from developing economies, it is easy to see that the Annex B efforts to reduce GHG emissions may be dwarfed by the increase coming from non-Annex B countries (Rubin and Tal, 2008).

These diverging trends in emissions in the two groups of countries may be linked partly to input price distortions caused by the different environmental policies. As non-Annex B countries do not have stringent environmental policies, their firms do not incur increase in their production costs as do those located in Annex B countries.⁴ Because of this inequality, certain jurisdictions who are part of the Annex B countries may wish to apply a border tax adjustment or carbon tariff to “level the playing field” (Rubin and Tal, 2008). This carbon tariff will only be applied on goods who produce GHG during the production process and who come from countries that do not have a price on carbon. Conversely, goods that emit GHG during consumption will not suffer this tariff because they will be taxed upon consumption such as domestically produced GHG emitting products.

The European Union (EU) was the first to propose such a tariff and is now considering making the purchase of permits on the emissions trading scheme (ETS) mandatory for imported goods. The amount of permits would be based on the amount of emissions released in the production process. This would have the effect of putting a cap on the level of emissions released in the atmosphere to satisfy the demand-side of the EU population (Spiegel Online, 2008).

There have been a few propositions for Canada in the recent months (Rubin and Tal, 2008 and Courchene and Allan, 2008). For example, Rubin and Tal (2008) propose to implement a carbon tariff on carbon-intensive imports coming from non-participating countries. On the other hand, Courchene and Allan (2008) propose to implement a downstream carbon tax on all domestically consumed products and imports from all countries. They suggest that all countries should adopt the same strategy. This would

⁴ This is assuming that they do not consume a substantial amount of Annex B countries GHG-intensive goods as intermediate inputs.

put a price on carbon consumed within a country (destination basis) and not carbon that is produced within a country. These proposals have been taken seriously and are part of parliamentary debates.⁵

The United States congress proposed a climate change bill called the Lieberman-Warner, named after the two senators who put this idea forward. It consists of a cap-and-trade system with a steadily declining number of permits. The original bill proposed to impose tariffs on energy-intensive imports from the likes of China, had the country not changed its environmental policies by 2020. This deadline was later brought down to a less feasible 2014 (The Economist, 2008). Finally, the bill has been rejected at the senate level (Climate Intel, 2008). This demonstrates clearly that a similar bill could be undertaken by the United States in the upcoming future

To date, there have been very few scholarly articles on the incidence of carbon tariffs⁶. The objective of this paper is to analyze the aggregated and sectoral effects of a carbon tariff in the Canadian context. To do so, we will use a static multi-sectoral computable general equilibrium (CGE) model of the Canadian economy, similar to Dissou (2005). The purpose of this study is to see if it would be beneficial for Canada to impose a carbon tariff on carbon-intensive imports.

The rest of the paper is structured as follows. Section 2 is a comprehensive survey of the literature that relates to the subject. Section 3 presents the model, while section 4 provides the data and calibration. In section 5, we present the simulation results and conclude in section 6.

2. Literature review

Over the years, the evidence between climate change and the global level of GHG emissions has been getting stronger. There has been a substantial amount of literature devoted to reducing the level of GHG emissions efficiently. Since the benefits of abating GHG emissions are shared by all nations, it can be viewed as a global public

⁵ Papers by Rubin and Tal (2008), and Courchene and Allan (2008) were discussed in a Canadian Senate debate on April 2nd, 2008. Also, the federal Liberal leader has proposed a carbon tariff.

⁶ Fischer and Fox (2008) studied many alternatives such as border-tax adjustments to reduce carbon leakage using a partial equilibrium analysis.

good, which is non-excludable and non-rival. Consequently, some countries will have an incentive to free-ride (see for example Golombek et al., 1995; Barrett 1990, 1994; Carraro and Siniscalco, 1993).

Because a climate agreement is unlikely to have full participation, some countries have incentives to apply laxer environmental policies. Barrett (1994) argues that to remain competitive it may be optimal for governments to set marginal abatement costs (MAC) lower than marginal environmental costs (MEC). In practice, this can be observed when governments set lower environmental taxes (or none) to attract investment. In the situation where direct subsidies are ruled out, this may be seen as an optimal way of providing an indirect subsidy (Kennedy, 1994). Governments thus underbid each other to remain competitive. In the end, as Hoel (2000) points out, total emissions would be higher than the Paretian optimal level for the whole group of countries.

Barrett (1997) argues that trade sanctions must be allowed as a credible threat in international environmental agreements to ensure a Pareto-efficient outcome. Otherwise, a less than full participation will lead to a Pareto-inefficiency.

2.1 Comparative advantage

A divergence in environmental policies adopted within various countries creates a distortion with respect to the production costs of producing certain goods. As a result, if carbon-intensive firms in environmentally stringent countries are not sufficiently compensated, their production may move abroad to a less regulated country (Bernard et al. 2007). This is a phenomenon commonly known as the pollution haven hypothesis. Thus, countries with lower levels of environmental regulation have a comparative advantage in the production of pollution-intensive goods (see for example Shrybman, 1990; Perroni and Wigle, 1994; Dessus and Bussolo, 1998, for surveys). Several empirical studies suggest that developing countries specialize in dirty industries (see for example Hettige et al., 1992; Lee and Roland-Holst, 1997; Copeland and Taylor, 1995; Gale, 1995). Also, an increase in trade liberalization will increase the pollution-intensiveness of less stringent countries (Yang, 2001). Eventually, the question of

competitiveness must be addressed because it is one of the main reasons why politicians are reluctant to implement environmental policies.

2.2 Carbon leakage

A desirable principle of environmental policies is to achieve their objectives in the most efficient and equitable manner. In the case of climate change, efficiency can be seen as attaining a domestic target at the lowest cost, and equity could be defined as achieving the objective without large sectoral losses in competitiveness. However, if there is a significant amount of carbon leakage, it detracts from the efficiency in reducing global emissions. Thus, even if a policy effectively reduces domestic carbon emissions to a given target, it would not be efficient if the leakage rate were of a hundred percent. Such a policy would have no effect on global emissions.

Carbon leakage is most commonly divided into two effects: the price-induced effect and the terms-of-trade effect. The price-induced effect refers to an increase in fossil fuel consumption in Non-Annex B countries following a decrease in the world price of fossil fuels triggered by the reduction in demand from Annex B countries (Di Maria and Van der Werf, 2008)⁷. The terms-of-trade effect, on the other hand, deals with prices of energy-intensive tradable goods. As the production costs of GHG intensive goods become larger in a country that implements some environmental policies, the production of the good will decrease and the level of imports coming from countries with no environmental policy will increase. This is the most important type of carbon leakage for the purpose of this paper since it arises following a reduction in the domestic competitiveness level.

The total leakage rate may be defined as the ratio of increased emissions in non participating countries that were induced by a change in environmental policy in participating countries over the reduction in the countries that have adopted a climate policy (Sjim et al., 2004). By using a similar definition, most studies find a leakage rate of 2 to 41 percent (Di Maria and van der Werf, 2008). However, studies by Pezzey (1992), Babiker (2005) and Kolstad et al. (2000) find that the carbon leakage effect is stronger. Babiker (2005) even finds a leakage rate of 130 percent in one of his

⁷ The price-induced effect may also be known as the energy-market effect.

scenarios. If this proves to be true, enforcing the Kyoto Protocol would only imply costs with no benefits. Others like, Felder and Rutherford (1993), and Jacoby et al. (1997) find less alarming carbon leakage estimates.

Besides, Kuik and Gerlagh (2003) believe that it is crucial for studies to include the tariff reductions projected in the Uruguay round from 1995 to 2005. They suggest that a reduction in trade barriers will in fact increase the ease at which firms will be able to move to pollution havens following an environmental policy. Thus, they believe that previous studies, who treat the tariff level as fixed to the year of their data, underestimate the leakage rate under the Kyoto Protocol.

On the other hand, Di Maria and van der Werf (2008), Gerlagh and Kuik (2007), Sue Wing (2006), and Barker et al. (2007) find that the leakage rate should be lower if we include induced technological effects. Following the adoption of a climate policy there is a change in relative prices, which first creates carbon leakage through a terms-of-trade effect but at the same time, it creates a greater incentive to innovate. This ends up counterbalancing the previous effect, to some extent, by creating an induced technological effect.

The variability in the estimates of carbon leakage rates is caused by a difference in the assumptions used in the model. Some of these relate to how technology is modeled, the market structure of firms, the degree of trade liberalization, and the supply and substitution elasticities used.

2.3 Optimal tax structure

In theory, Hoel (1996) attempts to determine the optimal carbon tax structure. To do so, he takes the approach of maximizing a given country's welfare by using total domestic consumption as the most welfare enhancing variable and total global emissions as a welfare deteriorating argument. He finds that the optimal scenario is to apply a uniform domestic carbon tax mixed with a carbon tariff and an export subsidy on energy-intensive goods. This would ensure that firms do not lose a significant amount of competitiveness after the imposition of the new carbon mitigation policy. Considering the potential possibility that carbon tariffs may not be feasible, he also looks at the case where tariffs and subsidies are prohibited. In this case, he finds that

the domestic carbon tax rate must be differentiated among sectors. By doing so, a lower carbon tax rate is applied to the tradable energy-intensive sector to reduce the negative competitiveness effect.

Krutilla (1991) obtains the same type of conclusion in which when trade measures are unavailable, the optimal tax will be distorted away from the Pigouvian level because of the terms-of-trade effect associated with the tax. For more theoretical papers that look for solutions on how to reduce GHG emissions while mitigating carbon leakage, see Bohm (1993), Golombek et al. (1995), and Hoel (1994).

Some authors, such as Olewiler and Mintz (2008), challenge Hoel (1996) and Krutilla's (1991) conclusions and argue that emissions must be priced evenly across industries. In practice, applying a lower carbon tax on energy-intensive tradable goods lowers their financial burden such as in the case of output-based allocation (OBA) or grandfathering of permits. In those cases, the goal is to mitigate the negative competitiveness effect that is mostly suffered by tradable energy-intensive goods. Nonetheless, Hoel (2000) argues that the tariff method is superior to the differentiation of taxes.

2.4 Second-best setting

Another problem with imposing an environmental tax is that there are prior distortionary taxes, such as a labour income tax (second-best setting). A general equilibrium framework is the most appropriate way to analyze the potential impacts of GHG emissions control since the true cost of an environmental tax is affected by prior distortions in the tax system. In the absence of previous distortionary taxes (first-best setting) and with no carbon leakage, many economists suggest setting the tax rate at the Pigouvian level, where MAC equals MEC. However, in the presence of prior tax distortions the deadweight loss created by adding another distortionary tax will be amplified by the tax-interaction effect (for more on this effect see for example Goulder, 2002; and Bernard et al. 2007). More explicitly, Kallbekken (2007) finds that prior distortionary taxes can increase the cost of new taxes by 30 percent.

To counter this effect, if an environmental policy generates a considerable amount of revenue, it may reduce the deadweight loss by using this revenue to

decrease prior distortionary taxes. This is known as the revenue-recycling effect. As Parry and Williams III (1999) point out, the advantage of using emissions taxes and other revenue-raising instruments is the capacity of using this revenue to reduce other distortionary taxes.

In the past, the weak form of the double dividend hypothesis was most often assumed to hold. This is when it is considered less costly for an economy to recycle revenue by reducing previous distortionary taxes instead of recycling that money through lump-sum transfers. However, as Babiker et al. (2003) point out, in an economy with multiple distortions a weak double dividend may not occur. They believe that this may be the case in a number of European countries. Thus, to know which policy is best for a given country, it is important to evaluate whether it is most optimal to recycle revenue through lump-sum transfers or through a reduction in previous factor taxes.

There has been a significant amount of literature on whether the strong form of the double-dividend hypothesis exists. The first dividend is if the environmental quality improves following a new policy. The second dividend is if the environmental taxes improve the level of economic efficiency by reducing other distortionary taxes with the extra revenue. The strong form of the second dividend would be appealing to have because in this case the level of the environmental benefit would not be important, so long as it were positive. Parry et al. (1999) conclude that if the revenue generated by a carbon tax is used to reduce other distortionary taxes, it can substantially increase welfare as long as environmental benefits are positive. This would generally happen if we replace a highly distorting tax by a less distorting tax. One can evaluate this by assessing whether the revenue-recycling effect dominates the tax-interaction effect. Generally, the double-dividend literature model has two taxable commodities (a dirty one and a clean one), and leisure which is thought of as clean and nontaxable (Bernard and al., 2007). In theory and through empirical analysis, most studies do not find the strong form of the double dividend to hold (see for example Goulder, 1995; Babiker et al., 2003; Bovenberg and Goulder, 2002). However, Bento and Jacobsen (2007) find that if you assume a fixed factor in the production of the dirty good and allow for Ricardian rents, an environmental policy that reduces labour income taxes may produce

a double dividend. They find that the presence of a strong double dividend for an environmental tax rate up to eleven percent.

In most scenarios, whether the revenues are recycled through lump-sum transfers or through cuts in the marginal rates of distortionary taxes, the optimal environmental tax rate will lie below the first-best or Pigouvian rate. More explicitly, Bovenberg and Goulder (1996) find that the optimal carbon tax rates are 6 to 12 percent below marginal environmental damages.

2.5 Instruments to achieve emission targets

A number of Computable General Equilibrium (CGE) models have been designed to evaluate different environmental policies and investigate the potential adverse effects on competitiveness. CGE models have gained a significant amount of respect in the literature because they not only look at the aggregate effects of a policy, but can also depict the sectoral effects. In general, market-based instruments (MBI) are the preferred instruments by economists because they achieve a target at the lowest cost, which is achieved by letting the market equalize MAC between various firms. However as Hoel (1996) points out, in the presence of carbon leakage, it would not be optimal to equalize MAC between industries. When using MBI, Goulder et al. (1999) and Parry et al. (1999) find that carbon-intensive firms suffer a significant loss in competitiveness. Carbon-intensive industries argue that without subsidies, a policy of emissions prices will compromise their capability to compete with countries that do not have a price on emissions (Bernard et al. 2007).

In light of this argument, many recent studies tried to find a way to address the carbon-intensive goods competitiveness issues (see for example Bernard et al. 2007; Dissou 2005, 2006; Fischer 2001; Fischer and Fox 2007; Smith et al. 2002; and Goulder, 2001 among others). A few of these authors look at how we could modify emissions trading to make it more equitable. Bernard et al. (2007) provide a comprehensive overview of the various ways in which output-based rebating can be administered. They explain that all these techniques have the same goal, which is to administer a price on pollution and to provide a subsidy to production. This subsidy is not fixed, but rather in proportion with the output level of the firm.

Fischer and Fox (2007) find that the indirect subsidies created by output-based allocation (OBA) are superior to grandfathering at reducing tax interactions. If the OBA is based on historical emissions it better supports larger polluters but end up being more costly. On the other hand, they attest that if OBA is based on value-added, it will have a similar effect as revenue recycling through auctioning.

Goulder (2001) looks at distributing 10 percent of the initial permits through OBA to affected industries based on historical emissions. He finds that the increase in equity comes at a small efficiency cost.

This hypothesis is refuted by Smith et al. 2002 who argue that if we consider the real costs of adopting a carbon trading scheme, it would be difficult to recycle revenue and compensate affected firms. In addition, Dissou (2006) observes firm heterogeneity in a dynamic CGE model and found that OBA of permits came at a significant efficiency cost. Thus, there is a need to look at other less conventional policy instruments.

Dissou (2005) looks at implementing performance standards that mandate a reduction in the emissions intensity of various firms to lower the domestic carbon footprint. He finds that this may be efficient, more equitable, and not too costly to implement if we assume that the government has sufficient information on firms MAC curves, which may be considered a strong and unrealistic assumption. Another strong criticism of using the performance standard system is the lack of incentive to firms to continuously innovate after they have attained the specific requirements.

The biggest problem of most strategies considered in the past is that they are either very costly, or they reduce carbon-intensive industries competitiveness significantly. One should note that all these studies have only used domestic instruments or, in the context of Kyoto, instruments that applied to Annex B countries. The literature is currently lacking numerical studies that analyze the impact of a domestic environmental policy in conjunction with a trade measure. This has been the preferred strategy of many theoreticians but it has not yet been analyzed in a CGE setting.

2.6 Border tax adjustment and international trade agreements

To date, the border tax adjustment alternative has not yet been analyzed numerically in a general equilibrium setting in the literature.⁸ Two reasons may explain this situation. First, in the Kyoto Protocol, there is a clause prohibiting signatory countries of imposing trade sanctions on other countries that are part of the agreement. This may be a problem until the Protocol's expiration in 2012. However, if this clause inhibits jurisdictions from implementing the most efficient and equitable outcome, it is imperative that it should be revised in the post-Kyoto agreement. A second reason is that people fear that it will not be accepted under WTO legislation. Under the GATT, Fischer et al. (2003) argue that taxes could be levied on pollution embodied in imports such as domestic goods; however, governments cannot tax emissions arising in the production process⁹. Bernard et al. (2007) argue that nondiscrimination requirements of the WTO may prohibit jurisdictions from taxing imports that have not paid a price on their emissions. In this respect, Hoel (2000) believes that tax differentiation would also be prohibited under the WTO. He argues that a country could counter this by applying a lower uniform domestic carbon tax mixed with performance standards on the industries that would have a higher tax rate under the differentiation process. Thus, there may be a way to make trade measures approved under the WTO.

Rubin and Tal (2008), Courchene and Allan (2008), Pauwelyn (2007), Charnovitz (2007), and Neumayer (2004) give recommendations on how to adopt carbon tariffs for them to be feasible under WTO legislation. Rubin and Tal (2008) argue that countries without a price on carbon are giving an unfair subsidy to their energy-intensive trade sectors, so a countervailing tariff should be imposed on those imports to correct this implicit subsidy. Courchene and Allan (2008) believe that the carbon tax rate must be harmonized on what is consumed in a country. They therefore suggest imposing a carbon tax on goods that were produced and consumed domestically as well as imported goods. This is similar to what is proposed by Hoel (1996) because in this way, exports are not taxed and do not need a subsidy to remain competitive abroad.

⁸ Fischer and Fox (2008) has only researched this idea in a partial equilibrium setting.

⁹ The GATT (General Agreement on Tariffs and Trade) was a treaty that started in 1947, then in the 1990s the World Trade Organization (WTO) took over the functions of the GATT.

In this paper, we will assume that adopting a carbon tariff will be feasible under all legislation. Also, we will build a model explaining what the potential impacts to various firms and households will be under a carbon tax/tariff policy.

3. Model Specification

The static multi-sector computable general equilibrium (CGE) model we use follows closely what was built in Dissou (2005). Some modifications include the way that the industries are aggregated in the social accounting matrix (SAM), and the choice of closure rules. All input-output and emissions table are from 2004. In the model, Canada is divided into 15 industries: (1) Agriculture; (2) Oil and gas; (3) Coal; (4) Other mining; (5) Power generation; (6) Gas pipelines; (7) Pulp and paper; (8) Paper manufacturing and printing; (9) Other manufacturing; (10) Refined petroleum; (11) Chemical; (12) Cement and non-metallic; (13) Metal and machinery; (14) Transport industries; (15) Services. Most industries only produce a single commodity. The oil and gas industry and the petrol refineries industries produce two (Crude oil and natural gas) and four (Gasoline, diesel, liquid petroleum products, and other refined petroleum products) commodities respectively, which makes for 19 commodities. The goal of this paper is to analyze the aggregate and sectoral impacts resulting from different policy shocks to the Canadian economy. The following paragraphs will give a general description of the model.

3.1 Production

The technology is characterized by constant returns to scale (CRS). Output in each economic sector is obtained by a constant elasticity of substitution (CES) function of intermediate inputs and a composite of value-added and energy. Value-added is a Cobb-Douglas (C-D) aggregate of labour and the composite of capital and energy. The composite of capital and energy is a CES function of capital and total energy.¹⁰ The latter is CES composite of electricity, and the index of fossil energy, which is in turn a CES composite of coal, natural gas and refined petroleum. Aggregate carbon dioxide

¹⁰ For a clearer picture of the links in the production process refer to appendix 2.

(CO₂) emissions can be depicted as the sum of emissions emanating from the use of various fossil fuels, which are proportional to their quantities used.¹¹

$$\text{TOTEM} = e(\text{coal}) \times Q(\text{coal}) + e(\text{natural gas}) \times Q(\text{natural gas}) + e(\text{gasoline}) \times Q(\text{gasoline}) + e(\text{diesel}) \times Q(\text{diesel}) + e(\text{liq_petr}) \times Q(\text{liq_petr}) + e(\text{oth_refined}) \times Q(\text{oth_refined}) \quad (1)$$

Where TOTEM is total emissions, $e(\text{coal})$ is the emission intensity of coal and $Q(\text{coal})$ is the total quantity consumed of coal. This specification assumes that emissions are proportional to fuel use and that there is no end of pipe technology to reduce the level of emissions¹² (Parry and Williams III, 1999). To reduce the level of GHG emissions there is the possibility to substitute from a more emitting fossil fuel to a less GHG emitting fossil fuel. Also, there is the possibility to substitute from energy to capital. Finally, labour and physical capital are seen as mobile across all industries within the Canadian economy¹³.

Firms take prices as given because of the assumption that we are in a scenario of perfect competition. By maximizing their profit functions, we obtain the optimal levels of labour, capital, intermediate products demanded by the firm to attain the output level where marginal cost is equal to output price. Finally, a fixed share of the profits is distributed to the shareholders (the representative consumer in this model) and the remainder is kept as retained earnings.

3.2 Households

Households are represented by a representative consumer who maximizes his utility by determining the amount of leisure and the index of consumption. His preferences are characterized by a linear expenditure system (LES) utility function. His main sources of income are labour income, distributed profits, government transfers, and net transfers from abroad. From his total income he pays a certain amount as direct taxes to the government. Then, a proportion of his disposable income is saved and the

¹¹ For the purpose of this paper I will use carbon dioxide as the only GHG.

¹² An end of pipe technology may be defined as a way to treat and filter pollution before it is discharged into the environment. This is a way of reducing wastes without changing the process by which the waste was created.

¹³ For a table depicting the percentage of industrial emissions per industry see appendix 3.

rest is consumed. The index of consumption is a CES function of all goods and energy. In the utility maximization process, the level of labour supply and the level of consumption is determined in the first stage given income and the price of the index of consumption. In later stages, the level of various consumption goods is determined through cost minimization.

3.3 Government

In this model, we assume that there is only one government and that its expenditures are fixed in real terms. Even though it is not maximizing any type of welfare function, the government's decisions concerning the source of revenue and expenses may have a significant effect on the economy. Its main sources of revenue are indirect taxes, enterprise taxes, direct taxes on income (personal and corporate), and taxes on imports. In addition to its fixed expenditures (in real terms) the other government expenses are paying the interest on debt and giving transfers to households. We assume in the model that government saving, that is the difference between its revenue and its outlays, is fixed. We use the level of transfers to households as the adjusting variable to ensure that this closure rule holds.

3.4 Relations with the rest of the world

Following the assumption that Canada is a small open economy, it cannot affect the world prices of its exports and imports. In this model, demand and supply of various goods are distinguished by origin and destination. Domestic firms treat domestic consumption and exports as imperfect substitutes, which follows a constant elasticity of transformation (CET) function. They maximize their revenue function taking the price of domestically consumed and exports as given and subject to a CET function. Thus, export demand depends on the world price of exported goods relative to the price level of domestic goods using the same currency. The same type of imperfect substitution lies between imports and domestic goods, which is commonly referred to as the Armington assumption (Armington, 1969). Through cost minimization, we determine the optimal level of both imports and domestically consumed goods. This is subject to the constraint that we treat both goods as imperfect substitutes and that they follow an

Armington CES function. Thus, if the domestic price of a certain commodity goes up, domestic demand will necessarily fall relative to import demand.

3.5 Equilibrium conditions and closure rules

The model is set so that the endogenously determined prices clear all markets. First, there will be an equilibrium in the domestic goods market, which means that the total supply of a commodity is equal to its demand. This will solve the prices of the domestic goods. Second, there will be an equilibrium in the labour market, which will determine the wage rate and the employment level. Third, there will be a balance of payments equilibrium to prevent a “free-lunch” scenario from being possible.¹⁴

We set aggregate investments equal to aggregate savings as a closure condition. Aggregate investment is therefore treated as savings-driven. This specification is referred to as neoclassical closure in the general equilibrium literature and is very common in static models.

A feature of CGE models is that it can only determine relative prices. In this model we will treat the nominal exchange rate as the numeraire. Price changes should be seen as relative to the numeraire. Explicitly, the real exchange rate may be seen as the relative price of goods that are traded to goods that are not traded. If the real exchange rate change is positive it means that there is a depreciation of the domestic currency. As mentioned earlier, government transfers will be used as the adjusting variable.

3.6 Carbon dioxide emissions and carbon taxes

The rationale of having the government add a carbon tax is to put a price on carbon to give an incentive to substitute away to less carbon-intensive goods. This tax could be implemented upstream or downstream; however, as Dissou (2005) points out, upstream is preferable because it is much less costly to implement. We favour a carbon tax versus tradeable emission permits because the level of the penalty is known ex-ante. This will be very beneficial in the implementation of the carbon tariff; otherwise it

¹⁴ Free-lunch could be a scenario where a country continuously gets capital inflows from abroad in exchange for nothing.

may be very hard to implement an appropriate tariff that will not be dismantled by the WTO.

The carbon tax rate will be uniform and will be a dollar value per ton of carbon dioxide. Every GHG emitting good will have an emissions intensity (e.g. $e(\text{coal})$) which will represent the amount of carbon dioxide in tons released per unit of the good used. By multiplying this to the carbon tax rate, we then get the specific tax in dollars (e.g. $ts(\text{coal})$) per unit of the good. Consequently, goods that emit the most carbon will suffer the highest per-unit tax. Firms and households will then take this new gross price into account to determine their demand for the good. Mathematically, firms will still maximize profits but will now be subject to an additional cost represented by the last summation in equation 2.

$$\text{Max}_{X_{ij}} \pi_j = P_j f(x_{ij}) - \sum_i w_i x_{ij} - \sum_i ts_i x_{ij} \quad (2)$$

In equation 2, P_j represents the price of the good sold and $f(x_{ij})$ the amount of goods produced with respect to the production function. Thus, in equation 2 the first term is total revenue, the second term is related to the normal costs of all the inputs of production, and the third term is used to represent the additional costs brought forth by the specific per-unit carbon tax. If we take the first-order condition it gives us

$$P_j \cdot f'(x_{ij}) = w_i + ts_i \quad (3)$$

instead of

$$P_j \cdot f'(x_{ij}) = w_i \quad (4)$$

Thus, for this equality to keep on holding, firms will need to reduce the consumption level of its dirty goods so as to increase the level of $f'(x_{ij})$. The demand for dirty goods will then fall relative to the cleaner substitute. The revenue raised from these carbon taxes will then be recycled back to individuals in a lump-sum fashion.

3.7 Carbon tariff

Following the imposition of a domestic carbon tax, the domestic carbon-intensive firms will experience a loss of competitiveness vis-a-vis foreign firms that operate in countries with no constraining environmental policies. A carbon tax is easy to administer nationally because it is possible to control the price of polluting intermediate inputs through the production process. It is harder to control for imported goods. The carbon tariffs would not be imposed on the imported goods whose use generates carbon dioxide emissions. These goods are already subject to the carbon tax as their domestic counterpart. Instead, the carbon tariffs would be imposed on imported goods whose use does not generate carbon dioxide emissions (like steel), but whose production is energy intensive.

There are multiple ways to determine the level at which the specific tariff should be set. First, the carbon tariff would depend on the emission intensity of the imported good. This would require information on the technology of producing the good in the originating country. For example, Rubin and Tal (2008) argue that China emits almost twice more than Canada in producing the same good. Thus, in this case it would give a comparative advantage to the more efficient country to produce the energy-intensive goods.

Second, there is the option to look at how much a specific good such as domestic steel pays in total carbon taxes per unit produced. This amount may then be applied to imports, assuming that they produce goods as efficiently as the more stringent country. This would rarely be the case, but it may be seen as an easier alternative to implement. Here, even though the same per unit tax would be applied to domestically produced and imports, it does not mean that relative prices will remain the same. If we assume that the initial domestic price to import price ratio is greater than one then by applying the same per unit tax on the numerator and denominator will have the effect to bring the relative price ratio down and closer to one. This would then favour domestic goods versus imported goods, and vice-versa if the ratio was initially smaller than one.

In this paper, the focus is mostly set on the loss of competitiveness of a country following the imposition of a domestic environmental policy. The third option would thus be to impose a tariff rate that corrects for the competitive disadvantage of domestic energy-intensive industries vis-a-vis their foreign peers created by the unilateral environmental tax. In other words, the tariff would be imposed so as to keep the ratio of imports to domestic sales constant to its value prior to the imposition of the environmental tax. This will have for effect to keep the same relative price ratio as the business as usual (BAU) scenario to remove any additional comparative advantage due to environmental stringency from happening. Again, the import carbon tax revenue will be recycled the same way as the domestic carbon tax to compensate the local citizens for the imported goods price increase. One issue that may arise with this technique is that not all commodities aggregated into the 19 commodities have the same emission intensity as all others in the same sub-group. This would mean that the commodity specific carbon tariff rate applied may be too high for some commodities and too low for others.

4. Data calibration and numerical simulation

To calibrate the model, we have selected a 2004 dataset from Statistics Canada. The specific input-output table appears not only to be the most recent, but also the most comprehensive dataset available which could then be transformed into a social accounting matrix (SAM). This SAM is aggregated into fifteen industries and nineteen commodities, as mentioned above. The industries were consolidated using a dataset that initially included 109 industries. Appendix 1 shows the methodology used for the aggregation. Note that there is a clear distinction between commodities and industries in the SAM. The industries of oil and gas and refined petroleum were separated into two (crude oil and natural gas) and four (gasoline, diesel, liquid petroleum products, and other refined petroleum products) commodities respectively. As for the other industries, we assume that they only produce one commodity. The SAM also features the other economic agents and provides a snapshot of their relationships for the year 2004. For each economic agent, there is a row that shows all of its income sources and a column that depicts all of its expenditures. As in all other SAM, we have ensured that the sum

of every agent's column is its equal to the sum of its respective row to avoid lost money in the economy.

Considering that the goal of this model is to reduce greenhouse gases, we not only need a SAM which records the monetary flows, but we also need a table that illustrates the level of carbon dioxide emissions by fossil fuel and by industry in the same given year.

When we calibrate the model to reproduce the observed equilibrium in the reference year, this equilibrium satisfies the model assumptions. In this respect, CGE calibration procedure is used to determine the initial equilibrium values of some parameters. This calibration is achieved by using observed data such as the figures found in the SAM, the first-order conditions (FOCs), and the equilibrium conditions discussed above, along with some behavioural parameters, such as elasticities. The elasticities used in this model can be found in appendices 4 to 6.

The reader may refer to Yang (2001) for a similar model with information regarding the key equations. We solve the model numerically using GAMS with the CONOPT solver.¹⁵

5. Simulation results

We run two simulations in order to analyze the different aggregate and sectoral effects of two different policies. First, we analyze the effect of solely imposing a carbon tax on the Canadian economy. Then, we look at the scenario of adopting a carbon tax mixed with a carbon tariff on energy-intensive imported goods. In these two schemes, the additional revenue raised by the government is entirely recycled back to households through lump-sum transfers. Both scenarios will have the same \$40 per ton carbon tax¹⁶. The difference lies with the carbon tariff, which will have the effect of increasing the import price of carbon-intensive goods by the same percentage as the increase in price of the domestically produced equivalent.

¹⁵ Information on the GAMS software package may be obtained at www.gams.com

¹⁶ In addition, we ran a scenario with a \$25 per ton carbon tax which only yielded a difference in the magnitude of the percentage deviations from BAU. Also, the \$40 per ton carbon tax is based on 2004 dollars. This number was arbitrarily chosen but resembles Olewiler and Mintz (2008) proposition.

The normal transmission mechanisms expected after the imposition of a domestic carbon tax are presented in appendix 7. Adding a carbon tariff induces firms and households to substitute a domestic carbon-intensive good for a similar imported good, as the latter's relative price has now fallen. With the tariff, market participants will now be forced to pay for the carbon embodied in all goods consumed, resulting in a clearer substitution towards less carbon-intensive goods.¹⁷

In both simulations, domestic carbon dioxide emissions are endogenous. By looking at the various levels, we may determine whether there is a significant difference in the emission reduction capabilities between the policies. One must keep in mind that the percentage reduction in national emissions ignores how the emission level changed in the rest of the world. Thus, if imposing a carbon tariff manages to reduce carbon leakage while reducing domestic emissions by the same level, it may prove to be more successful at reducing global GHG emissions. Even though carbon leakage is not modeled in this paper, it is expected that imposing a carbon tariff would decrease its occurrence.

The results of the first simulation will be discussed in detail with an analysis of the various transmission mechanisms involved. Then, there will be a short analysis of the aggregate and sectoral effects of adding a carbon tariff. Finally, the reasons underlying these differences shall be discussed.

5.1 Impact of a \$40/ton carbon tax without carbon tariff

Table 1 reports the aggregate results of a national carbon tax and recycling the revenue through lump-sum transfers to households. The figures in the table represent the percentage deviation from the reference case, unless specified otherwise. The analysis will first identify the salient points of the aggregate effects, and then it will identify the main sectoral channels through which these aggregate results are obtained.

¹⁷ We expect to attain a similar conclusion as if we modeled Canada as a closed economy with a domestic carbon tax seeing that all carbon-intensive goods will see a price increase no matter what is their country of production.

Table 1: Aggregate effects of a \$40 per ton of carbon tax when used by itself or with a carbon tariff.

(Unless otherwise mentioned figures are percentage deviations from the BAU scenario)

	Without tariff	With tariff	Difference between with a tariff and without
GDP at market price	-0.91	-1.15	-0.24
GDP at factor cost	-0.64	-0.86	-0.22
%change real total consumption	-0.64	-0.87	-0.23
% change in real total investment	-2.66	-3.23	-0.57
% change in real total net exports	0.07	0.15	0.08
total real imports	-2.43	-4.19	-1.76
total real exports	-2.16	-3.73	-1.57
real exchange rate	0.24	0.29	0.05
consumption price index (with permits)	0.87	1.07	0.20
consumption price index (w/o permits)	-0.20	0.00	0.20
domestic good price index	-0.24	-0.29	-0.05
rental rate of capital	-3.19	-3.72	-0.53
nominal wage rate	-0.79	-1.26	-0.46
gross real wage rate cpi	-1.65	-2.30	-0.65
household labour supply	-1.04	-1.39	-0.35
household labour income	-1.82	-2.63	-0.80
household capital income	-3.19	-3.72	-0.53
household disposable income	-0.09	-0.32	-0.23
household real consumption	-0.64	-0.87	-0.23
equivalent variation in % of non labour income	0.17	0.22	0.05
equivalent variation in % of GDP at market price	0.03	0.03	0.01
price of carbon permit	40.00	40.00	0
% reduction in industrial emissions	-29.17	-29.37	-0.21
% reduction in household emissions	-12.46	-12.49	-0.03
% reduction in total emissions	-26.27	-26.45	-0.18

In the BAU scenario, GHG emissions were considered a free good with no cost. Adding a \$40 per ton tax to this scenario has for effect of adding a direct per-unit price to emissions. Using a tax instead of an emissions cap allows firms to know the price they will have to pay on carbon emissions ex-ante. What is uncertain ex-ante for a tax though is the level of reduction in CO₂ emissions. In this case, this happens to be a reduction of 26.27% in total domestic emissions compared to the reference case. The consumption price index rises by 0.87% when we consider the carbon tax, however we should note that it declines by 0.2% if we ignore the value of the carbon tax. In aggregate real GDP (Gross Domestic Product) at market prices and at factor cost

decline by, respectively, 0.91 and 0.64%. The nominal wage rate and the rental rate of capital decline by 0.79 and 3.19% correspondingly. Even though, household's real consumption falls by 0.64%, equivalent variation (EV) in percentage of non-labour income and in percentage of BAU GDP at market price rise by 0.17% and 0.03%. This rise in welfare is due in part to the fall in labour supply of 1.04%, which means that households now consume more leisure. Secondly, households receive a lump-sum transfer at the expense of firms, which increases their welfare.¹⁸

The reduction in labour supply may be explained by the fall of 1.65% of the gross real wage rate, stemming from the rise in consumer price index. Since the stock of capital is fixed, the changes in the labour market are the sole contributor to changes in GDP at factor cost. GDP at market price can be decomposed into two effects: the substitution effect (SE) and the income effect (IE). The changes in GDP at factor cost represent the IE side of GDP at market price¹⁹. On the other hand, the SE is based on changes in the composition of final demand caused by the changes in relative prices. Thus, the SE looks at the distortion created by the carbon tax on commodities and the IE looks at the change in prices of commodities relative to the wage rate. In percentage terms, the SE is the difference between the percentage change of GDP at market price and GDP at factor cost, which would be of 0.27% in this case.

The problem with a policy such as this one is that you cannot base conclusions on the aggregate effects. If some industries are severely affected by such a policy they may have enough political pressure to prevent governments from adopting such a policy even though it is found to be slightly welfare enhancing. It is thus imperative that we look if there are some substantial sectoral effects that are unapparent in the small aggregate effects. For example, output falls by 61.5, 15.6 and 12.4 % in, respectively, 'Coal', 'Refined petroleum' and 'Chemical' industry. This fall is slightly offset by the small rise in output of the 'Other manufacturing' and 'Agriculture' industry by, respectively, 1.4 and 0.14%. In general, even though we aggregated all industries into

¹⁸ Both firms and households are affected by the carbon tax and the carbon tariff, however only the households get to touch the revenue that gets recycled back.

¹⁹ This is the only determinant of the income effect because capital inflows are treated as exogenous in the closure rules.

15 subgroups, it may be easier to regroup them into only three groups for further analysis. The first group is the fossil fuel producers who are directly hit by the carbon tax. The second group consists of the carbon-intensive industries that are hit indirectly by the carbon tax by a rise in their production costs. The last group is composed of the remaining industries. These industries will enjoy a rise in demand because of the substitution effect of consumers. However, all of the industries will see a loss in demand because of the income effect due to lower household income.

The first effect that must be observed after the imposition of a carbon tax is to look at the percentage change in the price of the energy goods. Coal being the largest GHG emitter sees a rise of its consumption price of 221.5%. All other fossil fuel products experience a rise in their consumption price between 20.5 and 42.5%. Linked to this price increase was a decrease in its consumption and output levels. As the consumption price of 'Power Generation's' only rises by 5.3% we can see a substitution happening towards it coming from fossil fuel users. This can be observed by the very small decrease in consumption and output levels relative to that of fossil fuels.

As the price of these commodities rise, domestic demand as well as output falls. Coal reduces its output by 61.5% and uses 61.3% less labour to produce that lower level. It is important to note that even though the consumption price in the coal sector has increased substantially (221.5%), it does not benefit the firms because they see a large rise in their costs due to the carbon tax. The same applies to all other fossil fuel producer which means that the producer prices fall.

The next step in looking at the transmission mechanism is to look at how the increase in the price of energy goods affects the costs of downstream energy-intensive industries. To counter this cost increase, carbon-intensive firms raise their selling price and thus their output falls. For example, 'Chemical', 'Pulp and paper', 'Metal and machinery', and 'Transport' see their output fall by 12.4, 6.6, 4.9, and 4% respectively.

In less energy-intensive industries, output either remains relatively stable or increases slightly. In this simulation, only 'Other manufacturing' and 'Agriculture' rise by 1.4 and 0.14% accordingly. These are modest increases because the positive impact of

the SE has been weakened by the negative impact on household income. The mix of a falling wage rate and labour supply, with a rise in CPI causes the household purchasing power to be diminished. It explains why the increase in output in these sectors was so small. However, its rise has been possible because of a reallocation of primary factors and an increase in employment and capital stock at the expense of other industries.

The change in relative prices due to the carbon tax also has an impact on the trade structure of goods. Most fossil fuel products see a larger fall in domestic sales compared to exports²⁰. The reason for this is because exports of fossil fuel products are not subject to the carbon tax for their emissions are not released within Canada.²¹ Producers then get to sell their products for a higher price abroad than domestically.

Imports of fossil fuel products face the same tax on emissions released than locally produced fossil fuels. Thus, the only difference in producer price that happens after the imposition of the tax is that the local producer of fossil fuel has a slight increase in intermediate input costs due to the use of fossil fuel and other carbon-intensive goods in the production process. However, energy-intensive industries experience a significant increase in their production cost. They incur a loss in competitiveness with respect to their foreign peers. Their domestic sales fall considerably, while competing imports fall less. An example of this would be an 8.97% drop in domestic sales versus a 1.34% drop in imports in the chemical industry. This is due to the 4.10% increase in domestic price versus a constant import price. Other industries also demonstrate a higher fall in domestic sales compared to imports. For example domestic sales fell by 4.37% and imports fell by 0.34% for 'Pulp and paper', 1.77% and 0.54% for 'cement and non metals', and 3.70% and 1.29% for 'Metal and machinery'.

In less energy-intensive industries, the shift is ambiguous. Some of them see the opposite effect happening because of a fall of their production cost due to the cheaper value-added. In aggregate, total real imports and total real exports fall by 2.43 and

²⁰ Gasoline and diesel however see a larger fall in exports than domestic sales.

²¹ This must not be confused with an export rebate. If a country sets a carbon tax on carbon released within its borders then fossil fuel products exported will naturally not be subject to this tax.

2.16% following a \$40 tax that is recycled through lump-sum transfers. Finally, total CO₂ emissions fall by 26.27%, which is mostly due to a 29.17% reduction in industrial emissions.

5.2 Impact of adding a carbon tariff to the previous \$40 per ton national carbon tax

In this second simulation, we add a carbon tariff on imports of commodities of energy-intensive industries. These are: 'Pulp and paper', 'Chemical', 'Cement and non-metal', and 'Metal and machinery'²². The tariff rate is determined endogenously to keep the ratio of imports to domestic sales constant to its value in the reference case. All four commodities will thus face a different tariff rate because their production costs and demand have changed in different ways. The tariff rate allows us to ensure that imports do not get an unfair comparative advantage after implementing a domestic carbon tax. As for the carbon tax, the carbon tariffs received by the government will be recycled to the households in a lump-sum fashion.

Following the imposition of the tariff, the percentage increase of the import price is the same as the percentage increase of the domestic good price. Endogenously, the carbon tariff rates were found to be 3.3%, 7.2%, 0.6%, and 2.1% for 'Pulp and paper', 'Chemical', 'Cement and non metals', and 'Metal and machinery' respectively. These tariff rates are intuitively appealing because the commodities that saw a higher rise in their domestic price, in the case of a carbon tax without a carbon tariff, are the ones that will have the highest tariff rate. As prices of both domestic and imported energy-intensive goods have in fact increased, consumers have an incentive to substitute to less carbon-intensive goods. However, they no longer have an incentive to substitute away from domestically produced goods in favour of imported goods. This substitution was earlier referred to as the terms-of-trade effect or carbon leakage. The increase in domestic good prices of these goods is now higher than in the previous scenario because firms can now transfer their increase in production costs to consumers without fear of losing out to imported goods. The domestic price increases by up to 3.04% more than in the previous scenario. This was the case for the 'Chemical' commodity, where

²² For the commodity specific results of these four commodities refer to appendix 8.

domestic sales even rose by 2.07%. As for the 'Pulp and paper', 'Cement and non-metal', and 'Metal and machinery' commodities we see a slight fall in domestic sales, where the highest decline is of 0.45%. In all four commodities, the import demand falls following the addition of the carbon tariff. In both of the case of 'Pulp and paper' and 'Metal machinery' the increase in domestic price received more than compensates for the fall in domestic sales at increasing their revenue level. For example, 'Metal and machinery' sees an additional fall of domestic sales of 0.11%, which is compensated by an increase of 0.86% in the domestic good price. The 'cement non metal' industry may not have had a large enough divergence in the domestic sales and imports sales to justify the application of a carbon tariff. Therefore, for competitiveness concerns it may be revised that this commodity should not have had a tariff applied to its imports²³.

The overall aggregate effects are comparable to only imposing a carbon tax on the Canadian economy. We are once again adding an extra distortionary tax on the economy, which is recycled in a lump-sum fashion. Therefore, it is easy to think that most of the aggregate effects will, to some extent, be worse than in the previous scenario for the deadweight loss shall be greater. Most of the aggregate changes are less than 0.8% different than before except the change in real imports and real exports. The additional decrease in real imports of 1.76% can be explained by the carbon tariff. Then to maintain a balance of payments equilibrium real exports had to fall by 1.57% considering the small appreciation of 0.05% of the real exchange rate. Additionally, the labour supply has once again fallen because through the rise in the consumption price index and the fall in the nominal wage rate, people have less of an incentive to sacrifice leisure for consumption goods. Thus, household real consumption as well as real total consumption has fallen by an additional 0.23%. In the end, the reduction in total emissions seems to be greater by 0.18% and the rise in EV is of 0.05% as a percentage of non labour income and of 0.01% as a percentage of GDP at market price. Note again here that the increase in equivalent variation stems mainly from the increase in leisure as aggregate real consumption falls with the imposition of the tariff.

²³ A small fact that we must note is with a balance of payments condition, it is not feasible to reduce the level of imports without sacrificing a certain reduction in exports as well.

On the one hand, we have an improvement in terms of competitiveness or carbon leakage, and on the second hand, aggregate real consumption declines. The natural next step would be to weigh the gain obtained in terms of competitiveness with the loss in GDP.

6. Concluding remarks

Market-based instruments have often been referred to as the preferred instrument by many economists because of its capacity in equalizing marginal abatement costs. However, it has often been criticized by certain industries of putting a disproportionate burden on them. The biggest argument against any type of instrument has been the worry that such a measure would have a negative impact on employment. This paper has used a static computable general equilibrium with 15 industries that produce 19 commodities in total to evaluate the effectiveness of a carbon tariff at minimizing these competitiveness concerns. The carbon tariff is administered on four carbon-intensive tradeable commodities in a second-best setting.

Our simulation results indicate that it is possible to reduce the competitiveness concerns of the carbon-intensive industries with only a small cost in terms of reduction in GDP and real consumption. This happens because the carbon tariff inhibits the ability of economic agents to simply substitute to imported carbon-intensive goods to avoid paying a carbon penalty. However, considering that the carbon tariff is recycled in a lump-sum fashion actually increases the level of distortions present in the economy, which increases the level of the deadweight loss. A further extension would be to evaluate the same policy whilst recycling revenue by reducing factor income taxes. This would give another picture on the aggregate effects of another policy option. Conversely, the purpose of this paper was to evaluate the effectiveness of imposing a carbon tariff on protecting the competitiveness level of domestic carbon-intensive firms. Our results suggest that the carbon tariff was in fact effective at reducing the harm inflicted on domestic firms. Households, also enjoy a larger level of welfare under the tariff system because of the higher level of leisure time, the larger lump-sum transfer, and the lower level of emissions.

It is important to note that having a tariff level set on an aggregated commodity may not be the most effective solution. Some sub-commodities may face too high or too low of a tariff. In the end, more information on commodity-specific emission intensities may arise, which will allow the tariff level to be set on non-aggregated commodities, which will be more successful at being efficient. Also, if other countries adopt an environmental policy, this will reduce the need for a carbon tariff allowing carbon emissions to be reduced the most effectively at the source.²⁴ A carbon tariff should only be seen as a temporary solution or a credible threat to encourage other jurisdictions to adopt the same sort of policies. A possible extension would be to aggregate countries into ones that will participate in an environmental policy and ones that are likely to do nothing. The participating countries would not face a carbon tariff between each other but would apply a carbon tariff on non-participating imports. This could once again look at the capacity of using a carbon tariff at protecting the competitiveness of participating countries and to reduce the amount of carbon leakage.

²⁴ Note that once another country adopts an environmental policy equivalent to the domestic one it will no longer face a carbon tariff.

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Appendices

Appendix 1: Description of industry aggregation

Participants of the 2004 Canadian Economy

Industries (109)

- Agriculture (4)²⁵
- Crude oil (2)²⁶
- Coal (1)²⁷
- Other mining (3)²⁸
- Power Generation (1)²⁹
- Gas pipelines (1)³⁰
- Pulp and paper (2)³¹
- Paper manufacturing and printing (1)³²
- Refined petroleum (4)³³
- Chemical (7)³⁴
- Cement and non-metallic (2)³⁵
- Metal and machinery (3)³⁶
- Other manufacturing (29)³⁷

²⁵ This category includes four sectors: crop and animal production; forestry and logging; fishing, hunting and trapping; support activities for agriculture and forestry.

²⁶ This category includes two sectors: crude oil minerals; natural gas, excluding liquified.

²⁷ This category includes one sector: coal mining

²⁸ This category includes three sectors: metal ore mining; non-metallic mineral mining and quarrying; support activities for mining and oil and gas extraction.

²⁹ This category includes one sector: Electric power generation, transmission and distribution.

³⁰ This category includes one sector: Natural gas distribution, water, sewage and other systems.

³¹ This category includes two sectors: pulp, paper and paperboard mills; converted paper product manufacturing.

³² This category includes one sector: Printing and related support activities

³³ This category includes four sectors: motor gasoline; diesel and fuel oil, aviation fuel; liquid petroleum gases; other refined petroleum

³⁴ This category includes seven sectors: basic chemical manuf.; resin, synthetic rubber, and artificial and synthetic fibers and filaments manuf.; pesticides, fertilizer, and other agricultural chemical manuf.; pharmaceutical and medicine manuf.; miscellaneous chemical product manuf.; plastic product manuf.; rubber product manuf.

³⁵ This category includes two sectors: cement and concrete manufacturing; miscellaneous non-metallic mineral product manuf.

³⁶ This category includes three sectors: primary metal manuf.; fabricated metal product manuf.; machinery manuf.

³⁷ This category includes twenty-nine sectors: animal food manufacturing; sugar and confectionary product manufacturing; fruit and vegetable preserving and specialty food; dairy product manufacturing; meat product manuf.; seafood product preparation and packaging; miscellaneous food; soft drink and ice; breweries; wineries; distilleries; tobacco manuf.; textile and textile product mills; clothing manuf.; leather and allied product manuf.; wood product manuf.; computer and peripheral equipment manuf.; electric product manuf.; household appliance manuf.; electrical equipment and component manuf.; motor vehicle manuf.; motor vehicle body and trailer manuf.; motor vehicle parts manuf.; aerospace product and parts manuf.; railroad rolling stock manuf.; ship and boat building; other transportation equipment manuf.; furniture and related product manuf.; miscellaneous manuf.

Industries (continued)

Transport (8)³⁸

Services (41)³⁹

Factors (2)

Labour

Capital

Institutions (4)

Households

Firms

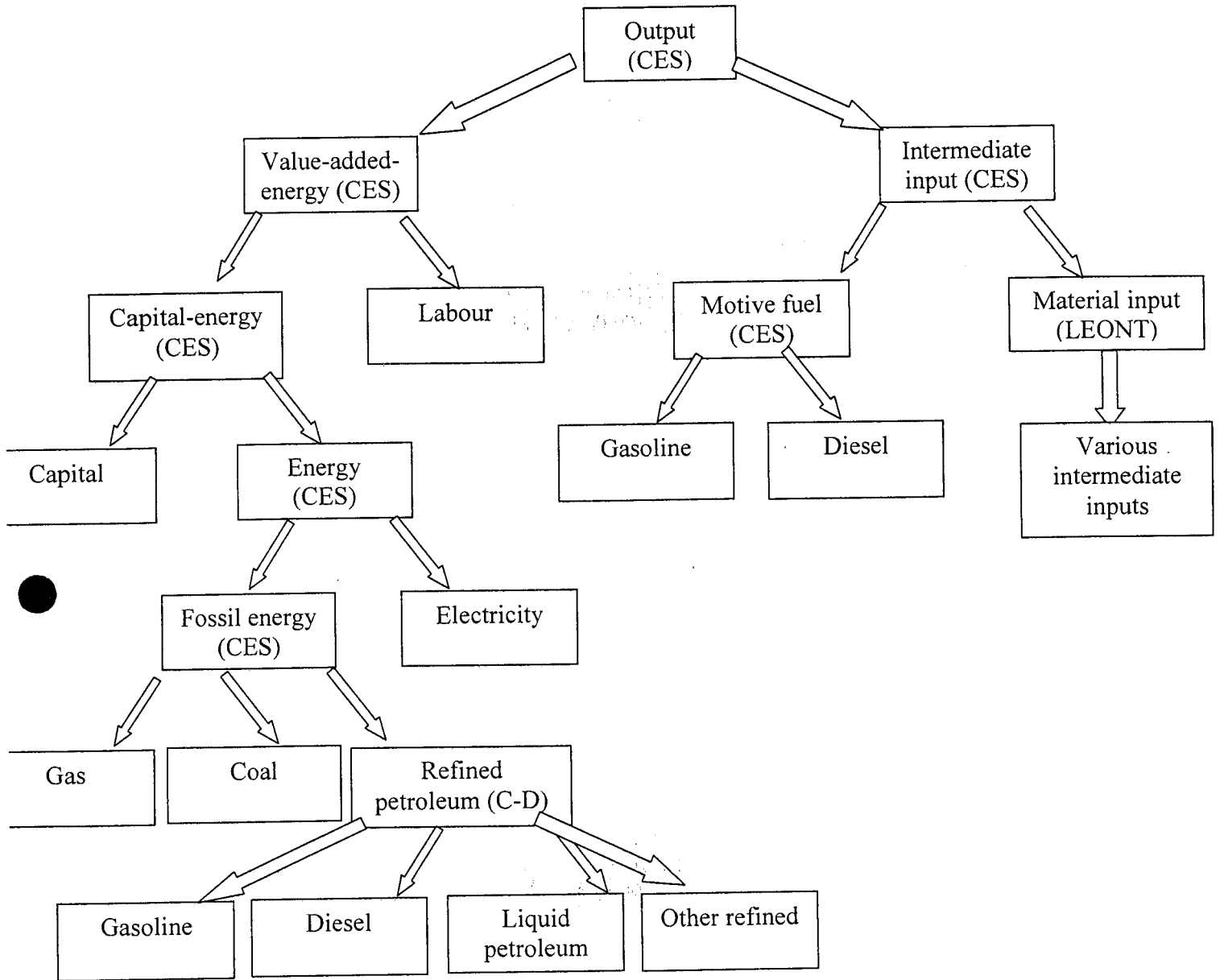
Government

Rest of the world

³⁸ This category includes eight sectors: air transportation, rail transp.; water transp.; truck transp.; truck transp.; transit and ground passenger transp.; pipeline transp.; scenic and sightseeing transp. and support activities for transp.; postal service and couriers and messengers.

³⁹ This category includes forty-one sectors: Residential building; non-residential building and engineering construction; repair construction; other activities of the construction industry; wholesale trade; retail trade; motion picture and sound recording industries; radio and television broadcasting; pay TV, specialty TV and program distribution and telecommunications; publishing industries, information services and data processing services; monetary authorities and depository credit; insurance carriers; lessors of real estate; owner-occupied dwellings; rental and leasing services and lessors of non-financial intangible assets (except copyright works); other finance, insurance and real estate and management of companies and enterprises; advertising and related services; legal, accounting and architectural, engineering and related services; computer systems design and other professional, scientific and technical services; administrative and support services; waste management and remediation services; educational services (except universities); health care services (except hospitals) and social assistance; arts, entertainment and recreation; accommodation and food services; repair and maintenance; grant-making, civic, and professional and similar organizations; personal and laundry services and private households; religious organizations; non-profit welfare org.; non-profit sports and recreation clubs; other non-profit institutions serving households; non-profit education institutions; hospitals; government residential care facilities; universities; government education services; other municipal government services; other provincial and territorial government services; other federal government services.

Appendix 2: Structure of firm's technology



C-D : Cobb-Douglas function

CES : Constant elasticity of substitution function

LEONT. : Leontieff function

Appendix 3: Sectoral distributions of GHG emissions in Canada in 2004

Industries	Shares in total industrial emissions (%)
AGRICULT	3.0%
OIL_GAS	16.2%
COAL	0.2%
OTH_MINING	1.3%
POWER_GEN	24.8%
GAS_PIPEL	1.9%
PULP_PAPER	2.1%
PAP_MAN_PRINT	0.1%
OTHER_MAN	2.2%
REFINED_PETR	5.8%
CHEMICAL	3.8%
CEM_NON_MET	3.5%
METAL_MACH	5.6%
TRANSPORT	10.1%
SERVICES	19.2%
TOTAL	100.0%

Appendix 4: Elasticities with respect to exports and imports of commodities

	CET (Exports/ domestic)	Armington (Imports, domestic)
	SIGX1	SIGM1
AGRICULT	2	2
CRUDE_OIL	4	4
NAT_GAS	4	4
COAL	4	4
OTH_MINING	4	4
POWER_GEN	2	2
GAS_PIPEL	2	2
PULP_PAPER	2	2
PAP_MAN_PRINT	2	2
GASOLINE	4	4
DIESEL	4	4
LIQ_PETR	4	4
OTH_REFINED	4	4
CHEMICAL	2	2
CEM_NON_MET	2	2
METAL_MACH	2	2
OTHER_MAN	2	2
TRANSPORT	2	2
SERVICES	2	2

Appendix 5: Elasticities of production per industry

	SIG_VA_INT	SIG_KE_L	SIG_CAP_EN	SIG_ELEC_FOSS	SIG_FOSSIL
AGRICULT	0.7	1	0.35	1.08	1.17
OIL_GAS	0.4	1	1.45	0.7	0.38
COAL	0.7	1	0.63	0.78	0.38
OTH_MINING	0.7	1	0.64	0.83	0.43
POWER_GEN	0.5	1	0.66	0.5	0.9
GAS_PIPEL	0.5	0.65	0.94	0.75	2.46
PULP_PAPER	0.4	1	0.23	0.78	1.07
PAP_MAN_PRINT	0.4	1	0.23	0.78	1.07
REFINED_PETR	0.9	1	1.29	0.76	2.5
CHEMICAL	0.4	1	1.26	0.93	0.73
CEM_NON_MET	0.4	1	0.38	0.7	1.55
METAL_MACH	0.4	1	0.37	0.86	1.2
OTHER_MAN	0.4	1	0.37	1.05	0.88
TRANSPORT	0.4	1	0.5	0.49	2.52
SERVICES	0.4	1	0.6	1.03	1.93

SIG_VA_INT: Elasticity of subs. of value-added-energy and intermediate inputs
 SIG_KE_L: Elasticity of subs. of capital-energy and labour
 SIG_CAP_EN: Elasticity of subs of total capital and energy
 SIG_ELEC_FOSS: Elasticity of subs. of electricity and fossil energy
 SIG_FOSSIL: Elasticity of substitution among fossil energy

Appendix 6: Elasticities of production per industry (cont'd)

	SIG_NON_MOTIV	SIG_MAT_MOTIV	SIG_MOTIV	SIGT
AGRICULT	1	0.34	1	0.75
OIL_GAS	1	0.34	1	0.75
COAL	1	0.78	1	0.75
OTH_MINING	1	0.65	1	0.75
POWER_GEN	1	0.3	1	0.75
GAS_PIPEL	1	0.3	1	0.75
PULP_PAPER	1	0.64	1	0.75
PAP_MAN_PRINT	1	0.64	1	0.75
REFINED_PETR	1	0.3	1	0.75
CHEMICAL	1	0.37	1	0.75
CEM_NON_MET	1	0.72	1	0.75
METAL_MACH	1	0.36	1	0.75
OTHER_MAN	1	0.42	1	0.75
TRANSPORT	1	0.83	1	0.75
SERVICES	1	0.41	1	0.75

SIG_NON_MOTIV: Elasticity of subs. among non-motive refined petroleum products

SIG_MAT_MOTIV: Elasticity of subs. between material inputs and motive fuels

SIG_MOTIV: Elasticity of subs. among motive fuels

SIGT: CET multi-product elasticity

Appendix 7: Explanation of transmission mechanism following a carbon tax

Figure taken from Barker et al. 2007

T. Barker et al. / Energy Policy 35 (2007) 6281–6292

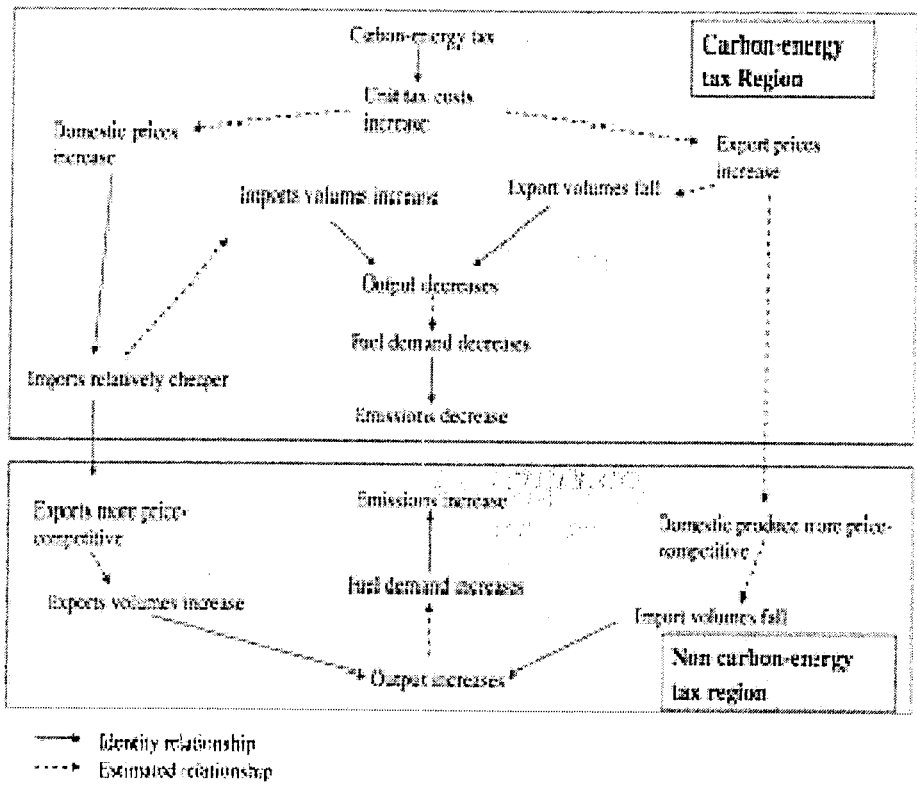


Fig. 1. How carbon leakage would occur in E3ME

Appendix 8: Specific results to the four commodities that had a carbon tariff applied

(All these figures are percentage deviations from the reference case. If there is no number it is because it has not changed)

	cons	tot_sup	exports	d_sales	imports	tot_dem	dinv	dint	cons_pr	dom_pr	imp_pr
Tax											
pulp_paper	-2.76	-6.61	-8.23	-4.37	-0.34	-3.09	-4.44	-3.12	1.39	2.08	
chemical	-3.38	-12.38	-16.01	-8.97	-1.34	-4.90	-4.85	-5.13	1.83	4.10	
sem_non_met	-1.35	-2.03	-2.96	-1.77	-0.58	-1.38	-3.52	-1.37	0.42	0.61	
metal_mach	-1.47	-4.94	-6.04	-3.70	-1.29	-2.29	-3.59	-2.08	0.51	1.24	
Tax + Tariff											
pulp_paper	-5.63	-8.27	-10.79	-4.81	-4.81	-4.86	-6.73	-4.75	3.30	3.30	3.30
chemical	-10.67	-12.67	-18.90	-6.90	-6.90	-6.96	-10.08	-6.36	7.14	7.14	7.14
sem_non_met	-1.84	-2.48	-3.42	-2.22	-2.22	-2.17	-4.25	-2.19	0.62	0.62	0.62
metal_mach	-3.97	-5.87	-7.72	-3.81	-3.81	-3.82	-5.64	-3.45	2.10	2.10	2.10
Difference											
pulp_paper	-2.88	-1.66	-2.56	-0.44	-4.47	-1.77	-2.30	-1.63	1.90	1.21	3.30
chemical	-7.29	-0.29	-2.89	2.07	-5.56	-2.07	-5.24	-1.22	5.31	3.04	7.14
sem_non_met	-0.49	-0.45	-0.46	-0.45	-1.65	-0.79	-0.73	-0.82	0.19	0.01	0.62
metal_mach	-2.50	-0.93	-1.68	-0.11	-2.52	-1.53	-2.05	-1.38	1.59	0.86	2.10

Cons:	Consumption
Tot_sup:	Total Supply
Exports:	Total exports
D_sales:	Domestic sales
Imports:	Total Imports
Tot_dem:	Total demand
Dinv:	Total demand for investment purposes
Dint:	Total demand for intermediate inputs
Cona_pr:	Consumption price
Dom_pr:	Domestic price
Imp_pr:	Import price