

GHG POLICY EFFECTIVENESS IN AN UNHARMONIZED WORLD

A Thesis Submitted to the College of

Graduate Studies and Research

in Partial Fulfillment of the Requirements

for the Degree of Doctor of Philosophy

in the Department of Bioresource Policy, Business & Economics

University of Saskatchewan

Saskatoon

By

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Abstract

Lubieniechi, Simona, Ph.D. University of Saskatchewan, Saskatoon, December 2011.

GHG Policy Effectiveness in an Unharmonized World

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There is a convergence of scientific opinions about the necessity of a more focused global intervention to reduce greenhouse gas emissions. Despite international agreements, the lack of a comprehensive global agreement has led to a mixture of policies across countries, complicating domestic policy making. For Canada, policy design became particularly complex when the United States failed to ratify the Kyoto Protocol.

This dissertation explores various domestic emission policies in the context of international trade and heterogeneous policies. Using micro-economic models of vertical markets, a Muth model (Muth, 1964), and a social planner's problem, the dissertation analyzes the impact of carbon tax, cap and trade and emissions intensity policies in various scenarios.

The findings of this thesis illustrate that while cap and trade may be effective in a hypothetical world of single sector within in a closed economy, it is far less effective than a carbon tax in the real world presence of downstream emissions, input substitution, international trade, or firm relocation. Given the administrative complexity, cap and trade systems are designed to be enforced only in the upstream of an industry even though downstream consumers are responsible for a large share of emissions. When inputs and final outputs are traded with countries that do not have a similar policy in place, a cap and trade instrument is harmful for the domestic industry, while dirty foreign firms increase output to the detriment of the domestic industry and the global environment. While this can be remedied by border tax adjustments (BTAs) accompanying the cap and trade instrument, BTA's are not allowed in the World Trade Organization (WTO). Distributed carbon taxes can avoid this dilemma.

Moreover, when emission permits are distributed for free, firms have additional incentives to sell the permits and relocate to countries with less stringent environmental regulations. Emission intensity policies reduce the incentive for industrial flight, and as such can be a more efficient emission trading instrument.

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Acknowledgements

I would like to thank the following people for their support in the successful completion of this thesis.

I would like to express my sincere gratitude to my supervisor Dr. Richard Gray for his insightful feedback, guidance, mentorship and for the unfaltering moral support throughout this thesis. I would also like to thank my advisory committee, Dr. Joel Bruneau, Dr. Ken Belcher and Prof. Ken Rosaasen. I thank them for their flexibility, encouragement and advice. Moreover, I would like to thank Dr. Murray Fulton for his input and advice during the initial stages of my research. Special thanks are extended to Dr. Alfons Weersink for agreeing to be the external examiner for my thesis and for his valuable comments and suggestions.

I am also grateful for the financial support provided by the University of Saskatchewan, College of Graduate Studies and Research, Department of Bioresource Policy, Business and Economics and BIOCAP. My sincere gratitude goes to Dr. Stuart Smyth for his unfaltering support and understanding.

I also wish to thank the faculty, staff and graduate students in the Department of Bioresource Policy, Business and Economics for creating an enjoyable and friendly atmosphere.

I would like to thank my friends Geta, Simona, Crina, Heather, Laura, Daniela, Delia and Dimitris for their friendship and always being next to me.

Heartfelt thanks go to Horea, my partner in laughter and thought, for believing in me and helping me uncover my strength and smile through hard times; for his continuous encouragement, endless patience and support throughout the last years of this process.

Finally, I would like to thank my parents, Veronica (Maria) and Adrian, my brother, Cristi, my sister in law, Ady, my niece, Andra, and my grandmother, Nori for their love, encouragement and moral support in my academic pursuits.

This thesis is dedicated to my late mother Veronica (Maria), my first guide and mentor, who always inspired me to want to achieve more in life. Dear mother, with my deepest love, I dedicate this research to you; it is a promise that I should make my life worth living.

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List of Abbreviations

2 SLS – Two Stage Least Squares
AFP – France-Press Agency
BAU – Business-as-Usual
BCA – Border Carbon Adjustments
BTA – Border Tax Adjustment
CCX – Chicago Climate Exchange
CDM – Clean Development Mechanism
CER – Certified Emissions Reductions
CES – Constant Elasticity of Substitution
CO₂ – Carbon Dioxide
CO_{2e} – Carbon Dioxide Equivalent
COP – Conference of Parties
COP3 – Third Conference of Parties
EU – European Union
EU ETS – European Union Emissions Trading Scheme
EPA – Environmental Protection Agency
EPRINC – Energy Policy Research Foundation
ERU – Emissions Reduction Units
ETS – Emissions Trading Scheme
FDI – Foreign Direct Investment
GATT – General Agreement on Tariffs and Trade
GDP – Gross Domestic Product
GHG – Greenhouse Gas
GNP – Gross National Product
IET – International Emissions Trading
IPCC – Intergovernmental Panel on Climate Change
JI – Joint Implementation
LFE – Large Final Emitter
MT – Metric Tonne
Mt – Million Tonnes
NAFTA – North American Free Trade Agreement
NRTEE – National Round Table on the Environment and the Economy
OECD – Organization for Economic Co-operation and Development
R&D – Research and Development
RGGI – Regional Greenhouse Gas Initiative
ROW – Rest of the World
US – United States
UN – United Nations
UNEP – United Nations Environment Program
UNFCCC – United Nations Framework Convention on Climate Change
WCED – World Commission on Environment and Development
WMO – World Meteorological Organization
WTO – World Trade Organization

CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Mitigation of human induced climate change represents one of the most important environmental challenges faced by mankind. A growing body of scientific evidence of its adverse effects highlights the need for more focused intervention to reduce greenhouse gas (GHG) emissions. Despite the recognition of the problem, a very long period of international negotiations and the Kyoto Accord, national leaders have thus far failed to achieve a comprehensive global agreement with a common strategy to reduce emissions.

The lack of a comprehensive global agreement has led to a mixture of policies across countries. The wide range of policy instruments and emission reduction targets has further complicated the challenge of creating effective domestic policy for all governments. Possible consequences of the diverse GHG emission reduction policies include the economic and environmental consequences of industrial flight (Jenkins et al, 2002), where firms relocate from jurisdictions with strict regulations to pollution havens with lower reduction standards.

The choice of emission reduction policy instruments is therefore influenced by the relative efficiency and effects of the policies on the domestic industries. The principal emission reduction mechanisms considered by governments are the market based ones like cap and trade and carbon tax, the non-market mechanisms such as design standards, and the quasi-markets based such as emissions intensity. Considering the cap and trade example, the relatively brief international experience with this policy reveals that industrial sectors that have to comply with these policies can face competitiveness issues, such as profit and market share loss and even incentives to relocate to other jurisdictions (Neuhoff 2007, McKinsey and Ecofys 2006).

Canada has explored a wide range of emission reduction mechanisms in the last two decades. Beginning about 1990, voluntary policies and subsidies were undertaken but did not prevent the increase in the Canadian carbon emissions that came with economic growth. When the Kyoto Protocol (which Canada signed in 1997 and ratified in

2002) came into force in 2005 the Canadian government issued a comprehensive plan (Government of Canada, 2005). The plan included targets for heavy industry¹, carbon capture and storage, fuel efficiency, air quality and various subsidy programs. The mechanism selected for regulating heavy industry emissions reductions is a capped emission intensity system.

All these events took place in an environment where the United States, although a Kyoto signatory, never ratified the agreement. Given the size of the trading relationship and the near total integration of the two nations' economies through the North American Free Trade Agreement (NAFTA), many Canadian firms (including those in the auto sector) indicated that they would be unable to compete under these circumstances.

The updated version of the Canadian Project Green (2008) mentioned that, beginning in 2020, the emission intensity system will be replaced with a cap and trade system. This happened in a time when the United States was proposing, and later awaiting, the US Senate approval of a federal cap and trade system. This planned change of the Canadian carbon emission reduction policy is a tacit acknowledgement of the policy harmonization necessity.

At an international level, many of these issues and more were discussed in December 2009 at the United Nations (UN) Climate Change Conference held in Copenhagen, Denmark. The main goal of the Copenhagen Accord was to renew the Kyoto Protocol and obtain a new global agreement on mitigating climate change effects beyond the 2012 expiration of Kyoto. During the lead up to the meetings, United Nations representatives, environmental groups and various governmental and non-governmental supporters built high expectations about the outcome of the unprecedented 194-nation UN conference (UNFCCC, 2009[1]).

Much of these heightened expectations can be attributed to the timing of this conference and the perception that it represented a crucial step towards the development of a global climate change approach. The previous negotiations on countries' GHG emission reduction targets and obligations needed to be renewed. As well, the international experience accumulated prior to the Copenhagen meetings with efforts to

¹ Since 2002, the term mostly employed in governmental regulations when referring to Canadian heavy industry is Large Final Emitters (LFEs). This is the term that it is going to be used throughout this research.

reduce emissions and trade carbon, demonstrated there was a need to amend existing agreements and develop new commitments to real future emission reductions.

Despite this sense of urgency and clear sense of what issues needed to be addressed, the negotiations failed to create a binding agreement and ended up only with a vague and non-binding agreement. This again highlights the difficulty of finding a consensus on globally reducing greenhouse gas emissions.

Developed and developing country leaders were divided on who should be obligated to pay for reduced emissions. The developing countries claim that, given the emissions accumulated so far in the atmosphere, it is the developed countries' responsibility to pay for reducing not only their own emissions, but also for all the other nations' reductions efforts.

Despite the headlines suggesting the meetings were a total failure, there were limited signs of progress. One of the main achievements of Copenhagen Accord is that developing countries are going to receive financial help from industrialized nations for fighting climate change. Participant countries have also agreed that a 2 degrees Celsius increase in the global temperature should be prevented. Crucially, however, nations remain free to set their own emission reductions with no mandatory limits. It is therefore unlikely that the Copenhagen Accord will be effective in achieving this proposed target. The above developments show how difficult it is to reach an agreement on emission targets, let alone the choice of policies or how to implement them.

The Copenhagen Accord goals were carried on by the 17th session of the Conference of Parties (COP 17) to the UNFCCC, at the beginning of December 2011 in Durban, South Africa. At the end of the two weeks of difficult and extended negotiations, the 194 delegate members have agreed to negotiate a new global agreement on climate change by 2015 (UNFCCC, 2011); however, this agreement will not come into effect until 2020. The participating countries also agreed to extend the Kyoto Protocol with a second commitment period, which will start on January 1, 2013 and establishing the Green Climate Fund, which will raise \$100 millions per year aimed at helping developing countries cope with climate change adaptation issues.

A major achievement of the COP 17 is that, the US, India and China have agreed to reduce emissions as part of the new legal treaty. However, the three countries have

only voluntary emission targets reductions until 2020, or whenever the new agreement will enter into force. Canada's position at the climate change talks in Durban has shown clear intentions of withdrawing from Kyoto Protocol with the motivation that China, along with the rest of major polluting developing countries, is not equally bound by a legal treaty. Even though China and India have transpired more flexibility than expected, and ended up signing the future agreement, Canada has officially announced withdrawing from Kyoto Protocol one day after the conference has ended. While many developed countries have complained for a long time about the developing nations' lack of obligations within Kyoto, Canada becomes the first country to withdraw from the Protocol (Kennedy, 2011). The Minister of Environment has further motivated this decision through the failure of the previous liberal government to achieve the emission reductions cut that was promised when Canada ratified Kyoto. Further, he expressed his disbelief in the Kyoto Protocol's chances to represent the solution for mitigating climate change globally. However, the Minister has stated Canada's willingness to participate in a future international climate change treaty that will involve all major emitters.

Given the clear and compelling lack of a cohesive and binding international framework, this dissertation explores some economic aspects of implementing emission reductions policies at a Canadian heavy industry level in a globally unharmonized policy context.

What are the economic concepts that motivate the international choices of policy instruments? What is the impact of enforcing these policies on producers and consumers' welfare and who is going to finally bear the burden of the costs incurred? How important is the policy's point of regulation and what is its impact on the economic surplus distribution when employing a cap and trade versus a carbon tax? Which one of the policies can be considered first or second best? Under which circumstances and policies will firms have the incentive to relocate to jurisdictions with lower environmental standards? What are the lessons to be learned and considered for a successful policy design and implementation?

1.2 Objective of the Study

The main goal of this dissertation is to explore the distributional and welfare consequences of implementing alternate GHG emission reduction policies at a domestic industry level in a global context characterized by a lack of policy harmonization.

The specific objectives of this dissertation, arranged in order of increasing complexity, are:

1. To explore the equivalence of a carbon tax and a cap and trade policy in a vertical structure within a closed economy;
2. To explore the consequences of implementing a carbon tax and a cap and trade policy at a specific industry level (called point of regulation) when trade is allowed in upstream inputs;
3. To explore firms' incentives to relocate to other jurisdictions and the effect on social welfare when a cap and trade versus an emission intensity policy are enforced at a domestic level.

1.3 Methodology

The methodological approach is characterized by employing first a very simple model restricted by various constraints. For exploring the above objectives, the constraints are gradually relaxed by developing a graphical analysis, followed by a Muth model, which allows quantification of the policies investigated, and a three stage sequential game which employs numerical simulations.

To meet these objectives, this thesis uses various theoretical approaches. Regarding Objective 1, with the aim of exploring the equivalence of a carbon tax and a cap and trade policy, as well as their impacts on rents and economic surplus, the analysis is graphically performed firstly at a single firm level and then in a vertical market structure, in the very special case of a closed economy and fixed proportions production technology.

Related to Objective 2, when approximating the welfare distribution within the vertical market structure, trade is allowed. Fixed proportions assumption is relaxed and a Muth model is employed to examine the impact of foreign competition on the rent

distribution in the system when a carbon tax and a cap and trade policy are implemented at the consumer and processor level. The goal of this part of the study is to identify which of the actors involved captures the rents and who will finally bear the burden of enforcing this policy. This is shown to depend on the level where the policy is enforced. The analytical modeling is followed by numerically simulating trade between the Canadian and the global petroleum industry.

Based on this result, Objective 3 is addressed. The study continues to investigate firms' incentives to relocate production abroad which, in the current global context of various emission reduction policies implemented, will eventually lead to pollution haven phenomenon. The model, employed as a two-country, three stage sequential game, involves the analytical derivations of a social welfare maximization problem for a regulator that takes into account not only the domestic emissions but also the emissions generated by the domestic firms even after relocating abroad. Two policies are analysed: the social planner decides to implement a cap and trade policy versus emission intensity policy. Further on, a sensitivity analysis is carried out using a numerical optimization software.

1.4 Organization of the Study

The remaining chapters of the dissertation are organized as follows:

Chapter 2 explores the main greenhouse gas emission reduction policies and the environmental effects of their interactions at a global level.

Chapter 3 focuses on exploring the equivalency between a carbon tax and cap and trade policy and their distributional impacts within a closed economy with fixed proportions vertical market structure. The findings identify that, under these assumptions, compared to carbon tax, a cap and trade policy enables producers to extract rents at the level of implementation. Hence, the two policies are only quasi-equivalent. Finally, it is shown that the quasi-equivalence quickly breaks down in a vertical structure when variable proportions technologies are allowed. Little attention has been paid so far in the literature on the effects of vertical markets on the design GHG emissions policies

(Hamilton and Requate, 2004), particularly for these policies and their distributional impacts. Chapter 3 addresses this gap in the existing literature.

Chapter 4 continues this analysis and compares and contrasts the cap and trade policy with a carbon tax and, using real data from the Canadian crude oil industry, simulates introducing the policies in a variable proportions vertical structure. The chapter confirms the existence of producers' rents as a result of enforcing a cap and trade and concludes that this policy also leads to industry relocation possibility. The methodology used in this chapter builds upon the models developed by Muth (1964), Alston (1995), Wohlgenant (1993), Gray et al. (2000) and others, which focus on the distribution of research benefits within a vertical market system, in a multistage production settings for various agricultural products. The novelty that this chapter brings consists of employing the Muth model for exploring the price, quantity and distributional effects of the two GHG mitigation policies within a vertical market system with and without input substitution.

Chapter 5 takes the analysis one step further by comparing firms' incentives to relocate if emission intensity or cap and trade policy are implemented. The findings illustrate that pollution haven effect can be enhanced when implementing a cap and trade policy through the ability to sell the emission permits and relocate. In addition, an emission intensity system does create an output subsidy effect and this makes it a second best instrument to impose for achieving real emission reductions. To my current knowledge, accounting for the saleability feature of emission permits which affects firms relocation decision along with the social welfare maximization where the domestic policy maker takes into account the pollution generated by domestic firms regardless the jurisdiction in which emissions were generated, address an existing gap in the literature.

Chapter 6 summarizes the main findings and concludes the dissertation.

CHAPTER 2

ENVIRONMENTAL POLICIES AND GLOBAL GREENHOUSE GAS EMISSIONS

2.1 Domestic Policy Instruments that Deal with Pollution

2.1.1 Introduction

This chapter introduces the basic economic concepts related to negative externalities as motivation for the international choice of policy instruments designed for dealing with GHG emissions reduction. The first section of the chapter introduces the main greenhouse gas emission reductions policies and their economic and environmental impacts. Section 2.2 discusses the interactions of these policies at an international level when countries apply different degrees of stringency. Section 2.3 presents the international institutions created in the global effort of reducing carbon emissions, while Section 2.4 details the actions undertaken by the European Union, Canada and the United States.

2.1.2 Externalities

An externality is said to occur when a decision made by a person or group of persons creates uncompensated costs or benefits to other individuals and groups (Beckman and Wesseler, 2007). Externalities can be positive, when there are benefits for the third party, or negative, when there are costs incurred by the third party. For instance, a negative externality occurs when a plant or a company uses a technology that negatively impacts a third party through environmental degradation.

When introducing the concept of externalities, Field and Olewiler (2005) explain the difference between private and social costs. They define the private costs of a firm as the costs encumbered by the party that decides to produce a specific good. Meanwhile, social costs include all the costs of the action, irrespective of who experiences them. Thus, social costs include not only private costs but also any other costs. Among other costs involved could be those known as external costs (or externalities), which although they represent a cost for the society, they are not reflected in the price or costs of the

product. For example, environmental costs are a component of social costs (Field and Olewiler, 2005).

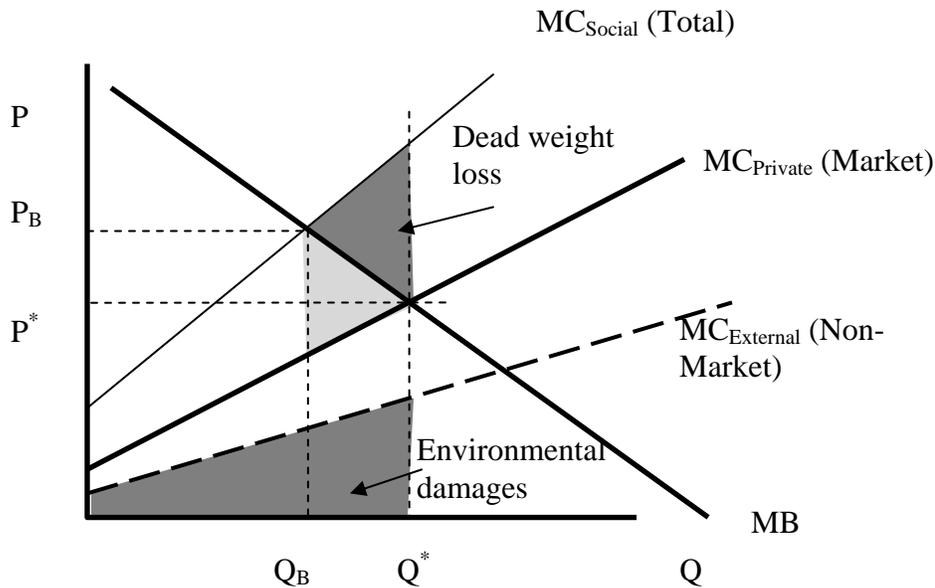


Figure 2-1.: Social and private marginal costs
 Source: Field and Olewiler, 2005

Figure 2-1 illustrates the total social marginal cost curve (sum of private marginal costs and marginal external costs), the private marginal cost curve and the external costs. When graphically adding the private and the external marginal costs, the total social costs of producing are higher than those already accounted for in the private goods market. Therefore, when firms ignore social costs, the equilibrium is at (P^*, Q^*) but when they account for them, the equilibrium shifts to (P_B, Q_B) , leading to higher prices, smaller production and reduction in consumer and producer surplus. The area under the external marginal cost curve represents the environmental damages which are reduced when the equilibrium quantity shifts from Q^* to Q_B . Social welfare is maximized at this point as the reduction in the externality more than offsets the loss in producer and consumer surplus. Thus, this market is inefficient since total net benefits are maximized at Q^B which is a different, in this case lower, level of output than Q^* .

In environmental economics externalities are one of the main forms of market failures which, as demonstrated above, occur as a result of not taking into account the negative externality effects. In this context, if the market is not efficient, market failures may be resolved through governmental intervention. Especially in the environmental area governments intervene and create policy measures for correcting market failures by internalizing externalities, enabling the price of goods and services to reflect the full social cost, including the environmental costs of the economic activity.

2.1.3 Policy Interventions and their Impacts

2.1.3.1 The main economics concepts for market regulation

Government often implements rules or restrictions, known as regulations, on firms to obtain or prevent a specific outcome. Through their coercive nature, regulations involve costs for certain groups and benefits for others. When a government intervenes in a firm's activity by imposing specific emission limits thereby regulating pollution, the government is said to be using command and control regulations (Kolstad, 2000). Command and control regulations often involve standards that are uniformly applied across firms regardless of their marginal cost of abatement, which increases the societal cost of abatement. Other drawbacks include the high cost of monitoring and the lack of incentives for firms to do more than respective standards, e.g.: technological investment (Kolstad, 2000). Given the inherent inefficiencies of standards, regulators are searching for more efficient alternatives to protect the environment, correct the externalities and stimulate firms to reduce emissions.

There are at least three commonly used alternatives to standards to get emitters to recognize social cost and reduce emissions: 1) regulate market activity through introducing a Pigouvian tax for emitters (set price of emissions to equal marginal external costs), 2) creating a new market by assigning property rights to the emitters and letting them bargain over the amount of emissions (Coase² Theorem) or 3) creating a market for pollution rights or for tradable emissions permits.

² Coase (1960) argues that establishing clear and firm property rights is a precondition to successful internalization (e.g. Pareto optimal) achieving bargaining. However, transaction costs are not accounted for in Coase's world.

Pigou, a twentieth century English economist, proposed a tax levy (from now on referred to as “Pigouvian tax”) on pollution emitters that equals the difference between marginal social cost and marginal private cost at the socially efficient level of production (Pigou, 1962). However, among the criticisms made of this tax are that the Pigouvian model ignores the reciprocal nature of the externality (Coase, 1960) and assumes that polluters pay, and also that in a world of asymmetrical information and governmental lobbying it is difficult to determine the size of the tax required to reflect the external costs.

In his essay on the theory of social cost, Coase (1960) indicated³ that in the absence of transaction costs, the assignment of property rights to either the polluter or those negatively affected by the pollution could be used to address externalities. In what has become known as the ‘Coase Theorem’, it is stated that with zero transaction costs an efficient outcome will occur through bargaining regardless of the initial property rights allocation. Coase (1960) criticized Pigou’s unilateral approach of a negative externality which arises when one actor develops a harmful action on another party. Coase states that such conflicts are reciprocal, “both parties cause the damage” (Coase, 1960 p.13) and thus, each party involved can change its behaviour to “avoid the more serious harm”. It is important to mention that in his analysis Coase assumes perfect competition⁴ conditions which imply no transaction costs. Under these assumptions, externality is self-correcting and bargaining will lead to an efficient allocation of rights (Butler and Garnett, 2003). Therefore, in the absence of transaction costs the externality is internalized through the bargaining of the actors involved (Bird, 1980). Later on, Coase (1988) himself pointed out that transaction costs are often so high that effective bargaining and efficiency of a market outcome will not be achieved with assignment of property rights. In the context of GHG emission reduction, with the assignment of property rights every polluter would have to bargain with the entire human population, including representative of future generations, making transaction costs obviously prohibitive.

³ Actually, Stigler (1966) has originated the phrase “Coase theorem” in its widely known formulation mentioned above. Coase (1988) acknowledged that the statement of the theorem is based on his earlier work “in which the same thought is found although expressed quite differently”. Coase (1960) states that, under zero transaction costs, assigning property rights is crucial to market transactions and that “the ultimate result ... is independent of the legal decision”. Coase points out (1960, 1988) that he recognizes that the assignment of property rights matters in the presence of transaction costs.

⁴ Under perfect competition there is perfect information as well and, in turn, the latter implies no transaction costs.

Furthermore, there is another solution for dealing with externalities: creating a market for pollution rights or for tradable emissions permits. Tradable emission permits can help achieve allocative efficiency, as an increase or decrease in demand and the change is evident in the price of the permits. In any case, the amount of emissions will not exceed the level determined by the number of pollution rights available.

In this context, given that many of the industries subjected to GHG emission reductions are vertically integrated (e.g. oil, coal etc.), it is appealing to explore which policy is more efficient depending on the level of implementation in the vertical structure.

When the regulator intervenes with any policy at a specific stage in an industry there are going to incur various costs (transaction costs) that can affect this specific level, but may also affect the upstream or downstream ones. Thus, important economic insights about the effects of a policy are not given only by the market of the final product but also by the other market forces (market structure, supply and demand elasticities, transaction costs etc.) from the upstream markets (McCorriston and Sheldon, 1996). At the same time, for specific industries and goods, a welfare distribution analysis carried out only at the final good level can not capture the changes in prices and welfare distribution for consumers and producers along the market chain (Sheldon, 2006). For instance, with regards to GHG emission reduction policies, while a carbon tax can be implemented at a consumer of an input or output level, a cap and trade can be implemented only in the upstream of an industry, as administratively it would not be feasible to trade permits at the final consumer level. On these grounds, Chapters 3 and 4 will be focusing mostly on a vertical industry structure.

When a government is implementing environmental policies, a vertical market structure allows identifying in more depth what determines the final price of the product or where most of the transaction costs occur. In addition, there is a high occurrence of heavily polluting vertically structured industries: oil, coal and natural gas, the automobile industry, etc. For instance, considering the case of crude oil, when implementing a cap and trade policy at a refinery level, the impact of the policy will propagate at the downstream levels: distribution, retail and final consumers. The question that arises is which level is going to be more affected? If and to what extent are the producers of crude oil influenced by the impact of this policy?

Each industry sector reacts differently when an environmental policy is implemented. In this respect, the final result is impacted by the degree of exposure to trade of the economy, industry specific characteristics, market structure and the degree of vertical integration.

2.1.3.2 Carbon tax, cap and trade and emission intensity

The current primary mechanisms globally implemented for achieving GHG emissions reductions are carbon tax, cap and trade, and emissions intensity or combinations of them. A *carbon tax* levies a fee on the carbon content of fossil fuel as a production input or consumer product. A *cap and trade* mechanism requires that the quantity of emissions is limited by an absolute cap, while the *emissions intensity* establishes a certain intensity of emissions relative to some measure of output, input or economic indicators (Ellerman and Wing, 2003).

Given their different nature, e.g. price-based versus quantity-based instrument, all the above instruments have pros and cons and have provoked disputes nationally or internationally. A carbon tax places an explicit price of CO₂ (carbon dioxide) emissions which leads to the adjustment of the quantity of emissions corresponding to the tax level. Meanwhile, a cap and trade policy sets a specific quantity of emissions and allows the price of emissions to adjust accordingly (Murray et al., 2008). In this context, whether it is better to implement a price or a quantity instrument with the aim of achieving the proposed GHG emissions target has been thoroughly discussed starting with Weitzman's (1974) seminal paper. Roberts and Spence (1976), Baumol and Oates (1988), Stavins (1997), Murray et al. (2008) and many others show that, when comparing a price versus a quantity mechanism when there is uncertainty about the costs involved may lead to different outcomes. It is expected to obtain such results for cap and trade policy, where, when emissions are capped their price will vary, while in the case of a carbon tax, the emissions price is held constant, but the quantity of emissions varies. This discussion is further developed in Section 3.2.2 of Chapter 3.

By enforcing a carbon tax, the regulator determines a price on carbon emissions and allows the market to determine the quantity of emissions to be reduced. A carbon tax

is applied on the carbon contained in goods and services consumed and produced. This means that they can be applied to all fossil fuels according to their carbon content. A higher price of goods and services reduces demand (and implicitly emissions), as consumers will reduce their consumption and try to substitute with less emission intensive goods and services. For instance, in the case of energy and power generation, a carbon tax may encourage substitution with less emission intensive alternatives, e.g. using natural gas or biofuels instead of coal. According to Nordhaus (2006), a carbon tax is a dynamic Pigouvian pollution tax that ‘balances the marginal social costs and marginal social benefits of additional emissions’ (p. 4).

Given that taxes are an instrument that have a long history and have been implemented in many jurisdictions, they are relatively well understood, which contributes to their ease of implementation. The supporters of carbon tax (Metcalf 2007[1], Mankiw 2007) highlight that this system is a very transparent and familiar tool, while the fact that transaction costs are insignificant clearly represents an advantage. Implementing a carbon tax would also offer a stable price for carbon, which is the opposite of a cap and trade instrument. Nordhaus (2006) suggests that a price-based policy instrument does not encourage corruption, as a carbon tax would lead to revenues only from taxation on domestic consumption and, in the absence of emission permits, firms/industries would not be encouraged to lobby the regulators for special interests. The revenue that a carbon tax raises may be directed back to the tax payers (revenue recycling) or may be used to finance environmental programs and funds. At the same time, a carbon tax may be gradually increased so not to represent a burden for consumers. The carbon tax can be implemented at various levels: production, distribution, or final use of the fossil fuels and thus it can impact the producers or consumers differently. Moreover, carbon taxes can be implemented both upstream and downstream of an industry, taxing both producers and consumers.

However, among the main drawbacks of a carbon tax are that it is not a politically popular measure, as another tax affects mostly the low income population. In addition, a carbon tax, as a price based mechanism, would not contribute to fixing a specific target on the amount of GHG emissions reductions as a cap and trade system does. The carbon tax opponents argue that this policy does not offer the opportunity to reduce emissions

where it is cheaper (e.g. Kyoto Protocol framework) and to trade the emission rights globally. As a response, Nordhaus (2009) details that a globally implemented carbon tax can be a strong element in an international agreement given that each participatory country would guarantee a minimum domestic carbon price.

As mentioned before, allowing trade of emission rights or cap-and-trade policy is a quantity-based policy instrument. In the literature of emissions trading, one can find them referred to as tradable permits, GHG units, quotas, allowances⁵. Under a cap and trade policy, companies that emit greenhouse gases need to hold a number of permits equal to the number of tons of carbon dioxide equivalent that they will release into the atmosphere. Furthermore, the permits can be freely traded on the emissions market as there are companies that can abate their emissions at a lower price that will sell their extra permits, and companies that abate emissions at a higher cost that need to buy permits. This implies that firms or industries have a strong incentive to reduce their emissions as much as possible, and make significant profits from selling the permits allocated. The supporters of a GHG international emissions trading system consider that this is an efficient policy instrument that brings down the overall cost of GHG emissions abatement as it is more advantageous to buy emission permits from another participant country with excess supply if this is cheaper than the marginal investment required to reduce emissions. The main advantage of a cap and trade is that it does establish a specific emission reduction target, both domestically and internationally, through setting a specific upper limit on emissions.

Concerning the downside of trading the rights to emit greenhouse gases, the transaction costs involved (e.g. informing and monitoring) may reach important amounts, much higher than in a carbon tax case. Another sensitive point of a cap and trade policy is that, given that this policy is administratively designed to be implemented in the upstream of an industry only (e.g. producers level), the price of tradable permits may be driven up easily when a group of firms or individuals is interested in increasing their profits. The opponents of the cap and trade system strongly argue about the unknown transaction costs that a country may incur and how this is going to impact the marketable price of the permits (Kolstad, 2005).

⁵ The term 'permits' is mostly employed along this research.

The criticisms brought to the cap and trade system are also related to the trading component of the policy. Specifically, by creating a market for carbon, those who purchase the rights to pollute will not reduce GHG emissions. Permit distribution is another issue, as permits can be allocated for free or can be auctioned. If permits are auctioned, the money obtained constitutes revenue that can be directed to low income population affected by the increase in price and to funding climate change related research. Permits grandfathering allocation method implies assessing each sector's share of output in total production. Thus, if permits are allocated for free according to firms' output, they will perform as an implicit subsidy to output.

The European Union's experience (Neuhoff, 2007) with the first phase of permit allocation shows numerous negative effects when permits are distributed for free (or 'grandfathered'⁶). EU countries experienced significant energy utility price increases as companies raised their prices as a result of introducing the policy, even though the companies had received the permits for free. These companies have registered 'windfall profits' (Sijm et al., 2006). At the second round of permit allocation, the EU distributed fewer permits for free, but the more trade sensitive industries claimed that the increased costs creates serious competitiveness issues for them and they even threatened to relocate (Ecofys, 2006).

At the beginning of 2010, the US was contemplating introducing a cap and trade policy where around 85 percent of the permits will be distributed for free and only 15 percent auctioned. The high percentage of grandfathered permits represented a debate topic in the US and Canadian newspapers, which blamed the regulators for actually creating 'corporate welfare' (Goldstein 2010, Carney 2009, Mankiw 2009).

Emissions intensity are defined as a ratio of emissions to some economic or production indicator (e.g. unit of production or GDP). Thus, emission intensity might be reduced, but output or total amount of emissions may increase (Ellerman and Wing, 2003). Therefore, when an economy or industries register economic growth, even if the intensity of emissions is under a certain limit, the quantity of emissions released in the atmosphere will be increased. The trading aspect of emissions intensity is similar to the cap and trade one. Companies that achieve a lower emission intensity than the regulated

⁶ The process known as 'grandfathering' refers to the initial allocation of permits, which are given for free to existing firms based on their historical output or emissions

rate will be able to sell this surplus to the firms that can not achieve the intensity rate. As an example, the Canadian federal government had previously proposed to implement emission intensity rates per unit of production that are capped and can be traded both domestically and internationally. Intensity caps are established through a baseline-and-credit system, where the baseline represents firms' emission intensity targets.

The main criticism brought to the emission intensity is that its intensity specificity may not actually decrease the quantity of emissions. Under an emission intensity policy, a government can not guarantee that a specific level of emissions reductions is going to be achieved. It is also difficult to forecast a country's real emissions reductions as firms can increase their output as long as they respect the intensity established. Following the previous example, trying to respect its Kyoto obligations, the Canadian government may adjust over time the intensity rate and Large Final Emitters can face an uncertain target from one year to another (Allan and Baylis, 2005). Regarding emissions intensity advantages, they were designed to encourage industrial or sector growth and to favour innovation.

2.1.3.3 The point of regulation

Another factor that contributes significantly to correcting externalities and reducing emissions is the point in the economic system where the regulation is implemented, also known as the point of regulation. The point of regulation can be established in the upstream (e.g. coalmine or refinery gate), in the downstream (e.g. gasoline station) of an industry or hybrid approaches. In other words, establishing the point of regulation means that the policy makers decide which entities are responsible and required to submit allowances that cover their emissions for each compliance period.

There is still no clear consensus as to which point of regulation offers the most advantages as the point of regulation need not be coincident with the emissions point. When the point of regulation is decided to be in the upstream of an industry, reducing the cost of abatement at this stage means that emissions abatement costs will be passed on to the final product consumers. Paltsev et al. (2007) highlight that the mitigation cost to be

passed on to consumers depends on the elasticities of demand and supply of the regulated products and the specific market forces.

In the downstream sector, the regulated entities are the direct emitters of greenhouse gases. Therefore, the downstream point of regulation can be at the point of combustion or the quantifiable process-related emissions. Among the main disadvantages of a downstream point of regulation can be identifying and covering all emission sources along with their respective administrative costs. At the same time, the compliance costs of implementing a GHG emission reduction policy at this point may represent an incentive for final users to find technical innovation solutions or use inputs that are less emission intensive.

In these circumstances, policy makers can decide the point of regulation anywhere in the system or a hybrid approach after accounting emission sources, the amount of emissions to be mitigated and cost effective mitigation strategies for each particular industry (Hargrave, 2000). As an example, it would not be feasible to regulate the oil industry at the point of distribution as the refining processes would not be accounted for. In this case, it would be more efficient to regulate oil industry at the refinery level. However, hybrid approaches should be carefully considered to avoid double-counting which would create higher compliance costs.

2.1.3.4 Pollution haven and industrial flight

Along with other relevant concepts used within this thesis, pollution haven and industrial flight represent phenomena that may occur given that the emissions reduction instrument mode and level of implementation is at countries' own discretion.

Setting the environmental standards below socially efficient levels or failing to enforce environmental standards with the hope of attracting foreign investment from countries with more strict regulations is known as creating a *pollution haven* (Neumayer, 2001). Copeland and Taylor (2004) differentiate between the *pollution haven effect* and *pollution haven hypothesis*. Pollution haven effects exist when tightening up the pollution policy in one country leads to a marginal rise in the production of a dirty good in another country. Meanwhile, the pollution haven hypothesis is motivated by the trade

liberalization which will ‘drive firms away from countries with strict pollution laws’ (Fullerton, 2006). The existence of the pollution haven effect is necessary to validate the pollution haven hypothesis. Copeland and Taylor (2004) also argue that, the presence of the pollution haven hypothesis becomes evident when trade liberalization leads to a shift of production from countries with more restrictive regulations to countries with more relaxed pollution regulations.

There is no international consensus about implementing a specific policy for decreasing greenhouse gas emissions. Kyoto signatory or non-signatory countries can implement all the policies mentioned before or any combination of them that helps to reduce their emissions. As long as policies differ across jurisdictions one can imagine that, in a Kyoto-signatory country with a cap and trade policy, multi-product firms might find an incentive to shut-down one of their plants, make a profit from selling the allocated permits and move the firm to another country which, not being a Kyoto-signatory state, has lower GHG emission obligations. Whether pollution havens exist or not, has remained an open debate for researchers (Dean et al., 2003, Jaffe et al. 1995, Mani and Wheeler 1997, Kolstad and Xing 1998, Keller and Levinson 2002, Copeland and Taylor 2003, Eskeland and Harrison 2003, Millimet and List 2004, among others).

In this context, in the interest of attracting capital, countries may be tempted to further relax their environmental regulations, which would lead to what is known as a ‘*race to the bottom*’ of environmental standards. Hence, a country with laxer regulation could become a pollution haven, as firms belonging to other jurisdictions/countries may find it more profitable to relocate. As an opposite effect, governments can try to prevent firms’ relocation by deliberately not strengthening their environmental legislations and thus, contributing to the creation of an ‘ecological dumping’ world, a process known as *the chill effect* (Bagwell and Staiger, 2001).

Eskeland and Harrison (2003) consider that pollution havens occur as a consequence of the *comparative advantage*⁷ attained by the industries from countries with more lenient environmental policies and lower pollution control costs. Consequently, industry location/relocation will be strongly impacted, as well as industries’ structure and trade patterns. The issues occur when interpreting comparative

⁷ Comparative advantage being based on relative productivity differentials which determine international specialization (Balassa, 1989).

advantage from a social perspective, where one considers that opportunity costs should include the externality. Thus, without a regulation, an industry may have an apparent comparative advantage, but when a regulation is implemented, this may no longer be the case.

The particular significance of pollution haven occurs from its position as a direct link between environmental regulations and trade flows of various countries (Taylor, 2004). Wheeler (2002) states that at the center of the pollution haven debate remains the domestic government's willingness to promote growth through environmental measures even though polluting firms can be owned by either domestic or foreign investors and the products obtained may be destined to domestic or import markets.

Regarding industrial flight, Kolstad and Xing (1998) point out that stringent environmental regulations have a strong effect on industry location and that different policies among countries will induce specialization and capital movement to the country with weaker regulations. In this context, the industrial flight occurs when overly stringent environmental regulations cause increased production costs for polluting companies which have incentives to 'fly' to countries with weaker environmental regulations. The authors present the following arguments that may determine industrial flight hypothesis. Firstly, strong environmental policies increase production costs as they require certain equipment. Secondly, the waste disposal capacity is restricted, and, last but not the least, severe environmental regulations often prohibit the use of particular input or outputs.

In the context of a global policy harmonization and similarly with the pollution haven case, industrial flight has received attention from policy makers since the '70s. Levinson (1996) summarizes early attempts⁸ by industrialized countries to appeal to the United Nations for preventing industrial flight towards developing countries. Further on, the US Federal Water Pollution Control Act of 1970 required a study on the competitive effect of environmental regulations on US firms and solutions that could have led to international harmonization.

Some authors see pollution haven and industrial flight as two sides of the same coin that capture the implications of different environmental standards between different countries (Clapp and Dauvergne, 2005). At the same time, it should be highlighted that

⁸ The 1972 Stockholm Conference on the Human Environment.

the industrial flight is one of the factors that contributes to the creation of pollution haven effects, while the reverse may not always be true. The reason is that industries can expand or contract through internal redistribution of factors of production. This is the basis for models of international trade and the primary theoretical basis for trade induced pollution havens. Capital mobility between countries can speed up or strengthen the process but this is not necessary for pollution havens to emerge.

Another interesting differentiation between pollution haven and industrial flight is made by Zarsky (OECD, 1999). She argues that pollution haven hypothesis has two versions. The industrial flight version means that polluting industries will escape the high environmental standards from the domestic country and relocate to countries with lower compliance and abatement costs, which exist because of lower environmental standards. This is known as the 'push' factor, as firms are pushed out of their jurisdiction by the high compliance costs. The 'pull factor' represents the decision of certain jurisdiction to employ low environmental standards to attract dirty industries.

With regard to the empirical evidence of pollution haven, Levinson and Taylor (2008) acknowledge the lack of significant evidence for proving pollution haven effects and highlight that among possible sources of bias may be data heterogeneity, endogeneity and aggregation issues. They also mention that another possible explanation may be the low value of pollution abatement efforts. Furthermore, they consider that even though there are differences in approaching the issue (previous research being divided into plant location decisions and international trade studies) an important bias can come from the econometric techniques used. For instance, cross-sectional data make it difficult to account for unobserved characteristics of industries or countries and their relationships with the environmental regulations in place. Hence, the authors use a fixed effects model, which finally proves to understate the pollution haven effect. Their solution is to use a two stage least squares (2 SLS) estimation, whose estimates are more robust and consistent than the fixed effects estimates.

In an attempt to clarify why the evidence of pollution haven is so vague, Neumayer (2001) and Brunnermeier and Levinson (2004) summarized the literature on pollution havens. The authors highlight that, as long as the econometric approach and the scopes of the studies are quite different, the outcomes cannot be generalized. However,

they identify the main hypotheses tested with regard to pollution haven as well as the critiques of each study presented.

Table 1-1.: Pollution haven hypotheses reviewed by Neumayer, Brunnermeier and Levinson

Neumayer (2001)	Brunnermeier and Levinson (2004)
Hypotheses	
1. Differences in environmental standards affect the allocation of investment flows;	1. Economic activity shifts to jurisdiction with less strict environmental regulations;
2. Developing countries' production and exports have become increasingly pollution intensive;	2. Trade liberalization encourages an inefficient race to the bottom;
3. Pollution-intensive industries flee the high-standards countries.	3. Trade liberalization shifts polluting economic activity toward countries that have less strict environmental standards.

Both studies highlighted that, even with the weak statistical evidence of pollution havens existence, the policy makers' interest and the public concern have repeatedly raised the issue of environmental regulations versus environmental quality. Brunnermeier and Levinson (2004) explain that empirical studies that have employed cross-sectional analyses find that environmental regulations have an insignificant effect on firm location decisions. At the same time, studies that controlled for heterogeneity and/or endogeneity using panel data or other instruments have found statistically significant pollution haven effects. However, the authors conclude that the reviewed studies can only show the capital and goods flow's sensitivity to differences in environmental regulations but cannot prescribe policy conclusions based only on these results.

Neumayer (2001) discusses the elusiveness of pollution havens due to the weak empirical results and proposes a wide range of policy options. Among the policy measures to be taken into account are: harmonization of environmental standards, minimum standards and proper enforcement of agreements by governments. Moreover, following the idea of competitive advantage, given the lower standards a country may have, direct restrictions such as import bans, tariffs, quotas and voluntary restrictions are also considered. Last, but not the least, the author suggests that when dealing with

developing countries, assistance for political-institutional capacity building and local empowerment should be offered by international organizations.

Given the complexity encountered by policy makers when imposing appropriate environmental standards for their own socio-economic situation, arguments arise now from defining and/or measuring the severity of environmental policies. Eventually, stringent environmental regulations can cause increased production costs for firms, which in turn may lead to effects on firms' competitiveness, industry location and a country's trade structure, with little impact on global emissions reduction.

2.2 Domestic Pollution Policy in Globalized Markets

2.2.1 Competitiveness

Policy makers and general public have always been concerned with the implementation of emission reduction policies and the costs they involve. Debate topics are further related to the magnitude of these expenses in the short or medium term and their uncertain effectiveness in the long term. Nevertheless, political debates are ongoing about the best policy choice given country's economic and social circumstances, as well as the alleged environmental strictness.

Participating in the Kyoto Protocol raises competitiveness issues for the governments involved, especially for countries dependent on emissions intensive industries or whose economy is expanding. Furthermore, if the respective industry is particularly exposed to exports and imports, it will face serious competitiveness issues from the countries that did not ratify Kyoto. Competitiveness of various sectors has become a source of concern for the European Commission as a result of the pressure from heavy industries from the member countries. Sectors such as aluminium, cement and lime (Euractiv, 2008) have requested some free emission allowances to help avoid industry relocation.

As a result, the European Commission for Environment, together with various European research institutions, have been closely researching these issues. For instance,

the Climate Strategies group⁹ report advises a sector oriented allocation of permits. They acknowledge sectors' sensitivity when coping with the cost and competition issues while achieving GHG emission reductions. For example, the report suggests that, while the cement sector is the most probable to suffer from the increase in cost, the steel industry is the sector more open to trade. Further on, the literature that focuses on the competitiveness loss issue for the European cap and trade system, relates competitiveness with the free granting of emissions allowances. In this context, Smale et al. (2006) and Reinaud (2005) highlight that the grandfathering of the emissions permits instead of using the auctioning allocation method will lead to over-compensating certain industries involved.

A study by McKinsey and Ecofys (2006) reveals that, for certain industries (steel, pulp and paper, cement, refining, and aluminium), there is a lower percentage of the current emission permits allocated that would be enough just to cover industries expenses without over-compensating them. Neuhoff et al. (2007) call to attention that previous studies have indeed shown the positive impact of allowances on competitiveness at the aggregate sectors level, but little information is provided regarding what is happening at a firm or sector level and "...the distributional consequences of the scheme".

In a report issued by the Climate Strategy group, Neuhoff et al. (2007) analyze, among other issues, the European Union Emissions Trading Scheme (EU ETS) mechanisms in the context of *carbon leakage*¹⁰ and competitiveness in various industries. They conclude that for few sectors free allocation should be reduced to zero, while for other sectors, international negotiations should consider state-based sector agreements and border adjustments as options for reducing carbon leakage. The authors also acknowledge the relocation possibility for other sectors because of the carbon leakage issue. They conclude that the use of free emissions allocations is not the adequate instrument for addressing leakage and relocation aspects.

In conclusion, the competitiveness issues that occur when introducing complex environmental policies are indubitable. These issues represent a continuous debate as

⁹ Non-profit company, funded by UK's Carbon Trust and hosted by University of Cambridge, which brings together international researchers with the aim of carrying independent assessments on international climate change policy. Many of their submissions can be found on the European Commission Environment website.

¹⁰ Carbon leakage concept refers to the negative effects of GHG emissions reductions within Kyoto Protocol: reducing emissions in one country also implies offsetting them through higher emissions in other countries which do not have binding caps.

under the World Trade Organization (WTO) rules trade liberalization may direct governments not to set optimal environmental policies because of the constraints of their trade instruments and policies (Sheldon, 2006). Porter (1999) reminds that there are two possible ways of solving the race to the bottom issue: one is to reduce the disparities by using 'green countervailing duties' such that environmental costs of both high standard countries and low standard countries are equalized. The second one is harmonizing environmental regulations across countries or jurisdictions (Esty, 1994). Given the various socio-economic interests and development stages of each country, this is not an easily achievable goal.

2.2.2 International Agreements and Enforcement

The importance of climate change international agreements is closely related to race to the bottom. It is argued that countries are likely to decrease their environmental standards in their willingness to attract foreign investment and keep domestic business at home. This is why harmonizing emissions standards through international agreements could eliminate the race to the bottom hazard.

Levinson (1996) mentions the 1972 Stockholm Conference on the Human Environment as an early attempt to harmonize environmental regulations. Among the issues raised at the meetings, industrialized countries requested certain environmental regulation that would prevent industrial flight from countries with more severe legislation. Developing countries argued that economic growth involves pollution. Levinson also notes that even the North American Free Trade Agreement (NAFTA) brought into light the disputes between environmentalists and trade economists regarding issues such as the environmental harm and the possible barriers to trade that may occur.

For instance, Porter (1999) highlights that trade economists have questioned whether the harmonization of emission standards is a protectionist measure that would deter developing countries from using their advantage of exporting pollution intensive goods. He finds that the race to the bottom likelihood does not happen in countries with high environmental standards, but it has a significant impact, due to competitive pressures, on low standard countries.

Many environmental agreements, including the ones related to climate change, have been signed and agreed on at national and international levels. Klevorik (1996) highlights that when trying to find common grounds for harmonizing environmental standards, there are the fundamental disagreements that need to be understood first and then solved. This process, together with the difficulty of reaching measurable standards for various socio-economic conditions of the parties involved, suggests the high degree of transparency that should characterize any agreement. This reveals the vital role of the international GHG reductions institutions.

2.3 International GHG institutions

2.3.1 Brief History

Environmental and climate change problems have always been international topics of interest, but the discussions related to them had become more and more concentrated in the last half of the 20th century.

A fundamental document to be mentioned is the Brundtland Report (United Nations, 1987), which is considered representative of the growing awareness regarding environmental issues. In 1987, the World Commission on Environment and Development (WCED) convened by the United Nations (UN) publishes ‘Our Common Future’ report, also known as the Brundtland Report. The report is considered a stepping stone in developing long-term environmental strategies and policies, and uniting development and environment for achieving what is known now as ‘sustainable development’ to the year 2000 and beyond. Moreover, the report drew attention and linked the concepts of global equity, resources redistribution towards less developed countries and environmental maintenance. Although the report was criticized at the time for forecasting errors, it remains a fundamental reference for initiating global environmental actions.

In 1988, following numerous climate change discussions such as whether our planet was warming or cooling, the United Nations created the Intergovernmental Panel on Climate Change (IPCC), which brought together renowned scientists from all over the world. Two years later, the IPCC (1990) released its first report whose main conclusion was that the planet has been warming because of GHG accumulation in the atmosphere.

In 1989, the Brundtland Report was debated in the UN General Assembly, which decided to organize a UN Conference on Environment and Development, the famous Earth Summit that took place at Rio de Janeiro, Brazil, in 1992¹¹. Over 160 nations signed the international treaty that later on became the Framework Convention on Climate Change. The conference agreed on the Rio Declaration on Environment and Development which sets out 27 principles supporting sustainable development.

The countries that ratified the Rio Convention agreed to organize yearly a Conference of Parties (COP). The first Conference, which took place in Berlin in 1995, encouraged identifying policies that would contribute to reducing GHG emissions and enhancing GHG sinks, and also specified time-frames for objectives.

As a result of international cooperation, for overcoming the negative impacts of climate change, in 1994, the United Nations Framework Convention on Climate Change was established. Its main goal was achieving steady and safe atmospheric concentrations of GHG in the long term.

At the Third Conference of Parties (COP3), held in Kyoto, Japan, in December 1997, developed countries agreed to specific targets for cutting their emissions of greenhouse gases. A general framework was defined, with specifics to be detailed over the next few years. The discussions and negotiations of the framework became known as the Kyoto Protocol which is going to be detailed in the following sections. However, at this conference, the US proposed to just stabilize emissions and not to reduce them, while the European Union called for a 15% reduction. Eventually, industrialized countries were committed to an overall reduction of emissions of greenhouse gases to 5.2 percent below 1990 levels for the period 2008 – 2012.

2.3.1.1 The IPCC

The policy makers concern about climate change and global warming led to negotiating international agreements like the Kyoto Protocol, as well as to establishing the Intergovernmental Panel on Climate Change (IPCC). The IPCC is an intergovernmental organization that was established in 1988 by the World Meteorological

¹¹ This was the second Earth Summit, but the first successful one. The first Summit took place in Nairobi, Kenya, in 1982, but it failed to reach any significant agreements.

Organization (WMO) and the United Nations Environment Program (UNEP). The initial task attributed to IPCC (IPCC, 1990) was to prepare a report describing all relevant aspects of climate change impacts and to formulate realistic response strategies. This meant genuine co-operation among thousands of top scientists around the world; it meant that for the newly created Intergovernmental Panel to succeed, it had to build itself with transparency and credibility.

IPCC provides at regular intervals an assessment of the state of knowledge on climate change, as well as Special Reports and Technical Papers on topics where scientific information is necessary. The IPCC reports maintain their characteristic of being policy relevant and not policy prescriptive. The relevance and importance of the First Assessment Report follows from the fact that it was used as basis for negotiating the United Nations Framework Convention on Climate Change (UNFCCC). Moreover, the fruitful relationship between UNFCCC and IPCC represented a framework for interactions between science and policy makers.

The IPCC Third Assessment Report (2001) estimated that in the interval 1990 – 2100, the global average surface temperature is projected to increase by 1.4 to 5.8 degrees Celsius. Thus, immediate and worldwide concentrated effort is required to strive to restrain the emissions. The Third Assessment Report (IPCC, 2001) brought new and stronger evidence of global warming due to the increase in GHG emissions accumulation, and therefore more awareness from governments and/or private sectors regarding this issue.

The Fourth Assessment Report (IPCC, 2007) has concluded that the climate is unequivocally warming and that the increase in the greenhouse gas emissions is *very likely* due to the increase in the average temperatures since the middle of the 20th century. Based on this conclusion, the European Commission has decided to take action such that the global average temperature does not increase more than two degrees above the pre-industrial levels. However, in the Fourth Assessment report, the IPCC has estimated that this is possible if emissions are reduced between 25 to 40 percent by 2020 and 80-95% by 2050 (IPCC, 2007). The Fifth Assessment Report is intended to be published in 2014.

2.3.2 Kyoto Protocol

As mentioned before, the Kyoto Protocol was created as an international environmental treaty by the UNFCCC. The text of the Convention (UNFCCC, 2004, p.1) states that the primary goal of the Protocol is to stabilize GHG emissions in the atmosphere “at a level that would prevent dangerous anthropogenic interference with a climate system”.

The Kyoto Protocol, known also as the Framework Agreement on Climate Change was signed in December 1997 by 84 countries¹² (UNFCCC, 2009 [1]) that agreed to specific targets for cutting their emissions of GHG to 5.2 percent below 1990 levels by the 2008-2012 commitment period (Jaccard et al., 2002). Canada ratified the treaty in December 2002, committing to reduce its greenhouse gas emissions to 6 percent below 1990 levels, by 2008-2012.

The Protocol came into force in 2005, 90 days after being ratified by 55 of the parties accounting for 55 percent of 1990 Annex 1¹³ countries emissions. This milestone was reached once Russia ratified the agreement on November 18th, 2004. However, a notable exception from ratification remains the United States of America.

The Kyoto Protocol acknowledges four greenhouse gases that are covered by international agreement: carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, and two groups of gases: hydrofluorocarbons and perfluorocarbons. Among the greenhouse gases presented, further analysis of this research is going to concentrate on CO₂ related issues.

Three Kyoto Mechanisms will support Annex 1 countries in meeting their targets for GHG abatement: Joint Implementation (JI) between Annex 1 countries (Kyoto Protocol, article 6), Clean Development Mechanism (CDM, Kyoto Protocol, article 12) and International Emissions Trading (IET, Kyoto Protocol, article 17).

The Joint Implementation (JI) mechanism was created with the goal of supporting collaboration among Annex 1 countries to partially achieve their commitment by investing in abatement projects that reduce GHG emissions from a certain baseline.

¹²As of October 2009, 184 countries had ratified the Kyoto Protocol.

¹³The Annex 1 countries are: Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, European Community, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom of Great Britain and Northern Ireland, United States of America.

On the one hand, the Clean Development Mechanism (CDM) has the aim of supporting the sustainable development of non-Annex 1 parties through capacity building and capacity transfer. The other purpose is to facilitate Annex 1 countries to meet their abatement commitments by initiating abatement projects in the non-Annex 1 countries.

The International Emissions Trading (IET) offers to an Annex 1 country that exceeds its GHG allocation the opportunity to buy the rights to emit GHG from another Annex 1 country that emitted less GHG than its quota.

As of spring of 2009, the issues encountered by the European Union Emissions Trading System (EU ETS) are related mainly to the characteristics of each industry involved and the permit allocation methods (whether they are auctioned or distributed for free). Neuhoff et al. (2007), McKinsey and Ecofys (2006) found that while many sectors lose profits and competitiveness from policy, other sectors gain short-term profits from the current trading system.

Kyoto Protocol has many supporters but also opponents among environmentalists and economists (Mendelsohn 2007, Hilsenrath 2009, Prins and Rayner 2007, etc.). Thus, to some, Kyoto Protocol is seen as an inefficient institution whose costs are higher than the benefits, with a trading scheme that will actually achieve far less than the numbers proposed, and will not contribute at all to slowing down the global warming process.

As of 2004 (UNFCCC, 2004), the information regarding the actual achievements of Kyoto Protocol in reducing greenhouse gas emissions (considering 1990 as a base year) reveals that Denmark, Germany, the United Kingdom, Australia and Norway respected their commitment and accomplished even more than their obligations. The Eastern European countries registered emission reductions as their economies declined or because of shutting down many of the inefficient polluting plants. There still is a long and unknown path to be followed in reducing emissions and trading them, however, the EU countries as main Kyoto supporters believe that they can attain their obligations.

2.3.2.1 Future horizons

The future of the Kyoto Protocol was discussed in December 2009 at the UN climate change conference held in Copenhagen, Denmark. The 2009 negotiations, also known as the Copenhagen Accord, were intended to focus on establishing new

commitments (15 to 30 percent below business as usual) for both developed and developing countries, creating an effective market for carbon trade and finding solutions for financing the appropriate measures for reducing GHG emissions (European Commission, 2009). The pre-conference report “Towards a comprehensive climate change agreement in Copenhagen” (European Community, 2009) brought to attention the necessity of cooperation between developed and developing countries. The crucial importance of a cohesive effort was led by the main aim of the negotiations: to limit the global average temperature increase to less than 2 degrees Celsius compared to the pre-industrial level. The report acknowledges that this could be possible if the greenhouse gases peak before 2020 and then could be cut to less than 50 percent of 1990 levels by 2050.

However, the outcome of the Copenhagen negotiations did not meet the expectations. The result of the negotiation ranged from being considered “not a full success” (de Boer, 2010) and not “everything that everyone had hoped for” (Ki-moon, 2009) by UN representatives to a “total failure” by environmental activists and journalists all over the world. The 12 days of discussions did not convince the 119 world leaders to walk out with a legally binding agreement and new commitments to reduce GHG emissions. The main reason was that developing countries argued that developed countries should put more effort and finances into reducing emissions, as in their opinion, the former are to be held solely responsible for the current emissions accumulation in the atmosphere. The consensus achieved were that global temperature should be limited to no more than two degrees Celsius increase and developed countries will raise 100 billion dollars a year by 2020 to help ameliorate climate change effects in developing countries. However, even the actions agreed upon are not clearly stated, for instance it was not decided how much each country will contribute to the Climate Fund or which country will benefit from it. Regarding emission reduction issues, there is no long term (2050) agreement on emission cuts, while for the medium term commitments (2020), participant countries are expected to submit their targets until January 31, 2010 to the UN representatives. However, on January 31, 2010 only 20 out of 194 nations officially stated their emission reduction targets and actions to be taken. The following UNFCCC Annual Meeting took place in December 2010 in Mexico City. Its outcome was as well

an agreement and not a binding treaty and it pretty much mirrored the Copenhagen Agreement result. The next Conference of the Parties is expected to take place at the beginning of December 2011 in Durban, South Africa.

2.4 Evolution of Domestic GHG Policies

2.4.1 Introduction

Global warming currently represents one of the fundamental issues that governments all over the world confront when formulating environmental policies. Although countries contribute differently to the greenhouse gas accumulation, all of them are affected, and, at the same time, each of them is taking different measures for reducing carbon emissions.

Despite the international controversies regarding the scientific proof of climate change as human-induced phenomenon, the growing global concern has led most of the governments to participate in environmental agreements. Nevertheless, given the transboundary specificity, the punch line remains that the climate change would happen as a result of the entire quantity of greenhouse gas emissions accumulated in the atmosphere and would affect all nations regardless of each country's contribution to emissions.

However, as the chance of an international agreement where all the countries in the world consent to implement similar mechanisms and measures for reducing carbon dioxide emissions represents utopia, governments need at least to reach some common points in the current international environmental agreements. Definitely, coupling the economic power of each country with their political orientation, free riding incentive and the unknown of climate change manifestation and timing, the image of ideal international agreements is far from being simple. Given the context of common environmental action, creating rules that would make each participant government happy, it is a state impossible to achieve. One of the major disputes of the protocol arises from delineating the emission rights allocation between developed and developing countries.

The signatory countries, whether they ratified the Protocol or not, have started implementing various emission reductions policies. Definitely, two of the reasons that

influence the success of the agreement are, on the one hand, the emission reduction mechanisms proposed and, on the other hand, the environmental policy that each government will implement for achieving its targets (Nordhaus, 2009).

2.4.2 European Union

All EU countries ratified Kyoto and are currently trading permits under the European Union Emissions Trading Scheme (EU ETS). Despite the predominant view that cap and trade systems are useful, and the passage of twelve years after the creation of the Kyoto protocol (1997), the EU has been the first and, until recently, the only one¹⁴ to have implemented a cap and trade system to deal with greenhouse gas emission reduction.

The EU countries, 15 by that time, had ratified the Kyoto Protocol in 2002. The emissions produced by EU countries amount to 22 percent of the world's total greenhouse gases. Their commitment is to reduce their emissions by 8 percent from 1990 levels by 2012. However, few countries have committed to reduce their emissions more than requested. For instance, Sweden and Germany announced an intended 21 percent cut from 1990 levels by 2010, while United Kingdom has set a 20 percent reduction. Other countries have joined the EU¹⁵ since then but they already had their individual targets. According to a 2007 report of the European Commission (European Commission, 2007), in their latest constitution, the E.U countries have registered a drop in emissions of 7.9 percent. However, the emissions of the initial 15 signatory countries have fallen by only 1.5 percent.

Although the EU countries are using the flexible mechanisms proposed by the Kyoto Protocol, the scheme that ensures that the greenhouse gas emissions are reduced at least cost is the EU ETS which was the first international trading mechanism for emissions. The first phase of the EU ETS introduced in 2005¹⁶, achieved trading permits that cover 17 percent of the carbon dioxide emissions in the entire world (Ellerman and Buchner, 2007).

¹⁴New Zealand has an Emission Trading Scheme established since 2008, in which, due to political delays, only the forestry sector has registered trading activities. Other sectors of the economy have different entry dates in the trading scheme. Australia was planning to start using a similar trading scheme in 2010, but on April 2010, the Australian Prime Minister announced that the implementation is postponed until 2012, after the end of Kyoto's Protocol commitment period.

¹⁵ 27 countries form the EU as of October 2011.

¹⁶ EU ETS had already become operational before Kyoto Protocol entered into force, in January 2005.

The Climate Change section of the European Commission comprises the latest information about the international negotiations that took place in Copenhagen in December 2009. The EU countries have decided to commit to tougher emission cuts independent on what other signatory countries decide about their own emissions reductions. Thus, the EU decided to commit to an ambitious 20 percent emissions reduction by 2020, compared to 1990 levels (European Commission, 2009). Furthermore, if the other developed countries will decide on comparable targets and proper reductions to be taken by developing countries, the EU stated its willingness to increase its commitment to 30 percent.

2.4.3 The United States

The US signed the Kyoto Protocol but did not ratify it because the American administration felt that the US economy would be harmed if costly environmental measures were implemented. Since 1997, the US Senate has questioned the efficacy of the Protocol, given that it did not require fast growing developing countries such as China and India to reduce their emissions.

The main policy framework of the US is a complex one. Issues such as energy security, pollution reduction and sustainable economic development are supported through promoting biofuels, renewable energy, and advanced nuclear technology with the aim of achieving economic and environmental benefits (US Department of State, 2007).

Based on estimated GDP loss and developing countries insufficient participation, the Clinton administration did not submit the Kyoto Protocol for ratification and the arguments recurred for the next administrations. In 2002, the Bush administration had announced that the main policy at the federal level was going to consist of emissions intensity reduction up to 18 percent until 2012. However, the main criticism brought to this policy was that actually this intensity reduction allows an increase in the overall US emissions (Krugman, 2002).

Despite the reluctance of the US federal government to ratify Kyoto, many US states and cities have tried to organize various institutions or agreements in an effort to prove to the federal government that greenhouse gases can be reduced at low cost. An example is the Regional Greenhouse Gas Initiative (RGGI), which includes ten US

states¹⁷, and implements an emissions cap and trade system for power plants. A second example is the Western Climate Initiative, which is an independent organization started by a few US states and Canadian provinces, as well as one state in Mexico¹⁸, with the aim of reducing GHG emissions. A third example, the Midwestern Greenhouse Gas Reduction Accord¹⁹, has similar goals.

Moreover, international partnerships have been developed. The Asia Pacific Partnership on Clean Development and Climate has brought together Australia, Canada, China, India, Japan, Korea and the United States for achieving common goals related to energy security, pollution reduction and climate change deterrence²⁰.

On May 20, 2009, the House Energy and Commerce Committee passed the American Clean Energy and Security Act (H.R. 2454, US Senate 2009) which intended to create a national cap and trade program that limits the amount of GHG emissions of power plants, manufacturers and oil refiners. The emitters were to be allocated allowances, free in the beginning of the program and auctioned later. Regarding the renewable energy, the bill stipulated that by 2020 the electricity demand should be met by using 20 percent renewable energy, out of which 5 percent is to constitute electricity savings. The bill passed the approval of the House of Representatives in June 2009 (H.R. 2454, US Senate 2009). The 2010 federal budget proposed to support the cap and trade program had with the following targets: reducing GHG emissions to 14 percent below 2005 levels by 2020 and to 83 percent below 2005 levels by 2050 (Eber, 2009). The Bill was supposed to receive the US Senate approval at the end of 2010, but in July 2011, the Bill ended up being rejected by the American Senate.

After dropping the Bill, in all media releases and future US climate change plans, cap and trade policy implementation priority seem to have been replaced by clean energy goals. As of the fall of 2011, the Environmental Protection Agency (EPA) is now issuing regulations under the federal Clean Air Act that requires emitters to control GHG emissions by installing best available technologies. In addition, over the last 20 months,

¹⁷ Participant states: Maine, New Hampshire, Vermont, Connecticut, New York, New Jersey, Delaware, Massachusetts, Maryland, Rhode Island. Observers: Pennsylvania, District of Columbia, Eastern Canadian Provinces, and New Brunswick are observers in the process. <http://www.rggi.org/states.htm>

¹⁸ Participant states: Arizona, California, New Mexico, Oregon, Utah, Washington. Observers: Colorado, Kansas, Nevada, Wyoming (the US), Ontario, Quebec, Saskatchewan (Canada), Sonora (Mexico).

¹⁹ Participants: Minnesota, Wisconsin, Illinois, Indiana, Iowa, Michigan, Kansas, Ohio, South Dakota and the province of Manitoba (Canada). http://hometownsource.com/index.php?option=com_content&task=view&id=3098&Itemid=29

²⁰ <http://www.asiapacificpartnership.org/english/default.aspx>

the US president's administration has been announcing the most stringent fuel economy standards that have ever been issued for the US. Initially, the plans have stipulated that, all car and light trucks produced between 2012-2016, meet the average fuel economy standards²¹ of 35.5 miles per gallon by 2016. Moreover, it was calculated that this plan would reduce GHG emissions by 900 million metric tons and would also reduce oil consumption by 1.8 billion barrels by 2016. Further on, in August 2011, fuel efficiency and emissions standards were released for commercial trucks, vans and buses made between 2014 and 2018. These standards are expected to reduce oil consumption by 530 million barrels of oil during the four years. However, the US still does not have in place a price for carbon.

Among other efforts toward climate change mitigation in the US, the only voluntary GHG emission reduction trading system, the Chicago Climate Exchange²² (CCX) was the first US trading emission sources and trading offsets in North America. CCX was established in 2003 and, until 2010 was operated by a public company. In 2010, CCX was bought by the European company Intercontinental Exchange (Lavelle, 2010). Few months after the acquisition, Climate Exchange announced that it will cease trading carbon credits, but it will continue to assist carbon exchanges. Although CCX has always advertised its transparency as a vital institution to mitigate GHG emissions in North America, the company was exposed to political scandal since the beginnings. Speculations about important American politicians who supported, funded or contributed to the existence of CCX along its lifespan started to subside only a while after the acquisition. Briefly, for part of the mass-media, CCX had constituted the classical example of rent-seeking shield for opportunists. Far from drawing any conclusions with this respect, the hot media debates (Efstathiou, 2009) on CCX's real aims, financial evolution and policy makers' intentions illustrate media's intensely focus on the assumed vested interests in the GHG emissions reduction sector.

²¹ This standard refers to manufacturer's annual fleet of cars or trucks production.

²² <http://www.chicagoclimatex.com/>

2.4.4 Canada

The evolution of Canadian policy regarding GHG emission reductions has followed an expected learning curve, starting from simple voluntary actions to more and more refined compulsory activities. The main tendency of the Canadian government with regards to climate change policy has been acknowledging the necessity of stimulating technology development, promoting the use of incentives, and encouraging investment stability. At the same time, another important aspect has been to encourage behavioural change in consumers and industries that will further stimulate developing new markets (Government of Canada, 2002 [1]).

The Canadian federal government attitude towards climate change in the interval 1990-2002 was characterized through the promotion of voluntary action, increased funding and an incentives-based approach. Thus, prior to the 2002 Kyoto ratification, measures (Government of Canada, 2006) implemented by the federal government ranged from establishing programs like the Efficiency and Alternative Energy (1991) program to creating the Climate Change Action Fund through the federal budget (1998) or to facilitating national consultations for the Climate Change Plan of Canada (2002 [2]), initiatives that are going to be detailed further on.

In 2002, Canada became the 99th country to ratify the Kyoto Protocol. Within the Protocol it is mentioned that during the period 2008 – 2012, Canada committed to reduce its greenhouse gas emissions by 6 percent below the level of 1990, which means a reduction of approximately 129 MT CO₂e (carbon dioxide equivalent) per year during the 2008-2012 commitment period (Fulton et al., 2005). However, this was considered a difficult target to reach given that in 2003, Canada's emissions were 24 percent above 1990's level (Environment Canada, 2007 [1]).

Over time, the Canadian government has been issuing and refining different strategies for cutting GHG emissions. Briefly, the two main streams of reductions have been oriented towards the activities of big polluting companies (known as the Large Final Emitters or LFEs) and towards sequestering carbon in agricultural or forestry sinks (known as domestic offset credits). However, given the focus of this research, the following review will focus only on the Large Final Emitters regulations. According to the Canadian government, approximately 700 firms (Government of Canada, 2005) were

responsible for almost half of Canada's GHG emissions, of which less than 100 are responsible for about 80 percent of those emissions.

Based on the existing regulations and measures, in April 2005²³, the Canadian government issued an updated climate change plan called Moving Forward on Climate Change: A Plan for Honouring Our Kyoto Protocol (Government of Canada, 2005). As the Large Final Emitters were forecasted to contribute approximately 50 percent of Canadian emissions by 2010, various tools were established to help LFEs meet their emission intensity targets in the most cost effective way. The LFE system comprises companies in the mining and manufacturing, oil and gas, and thermal electricity sectors. The LFEs options for compliance were: reducing their own emissions through investments in their own facilities, purchasing emission reductions from other LFEs that exceeded their target, and buying domestic offset credits or eligible international Kyoto units²⁴.

As a financial incentive to exceed their targets, the LFE could invest in technology developments and consider them as compliance activity. The Greenhouse Gas Technology Investment Fund introduced in the 2005 Federal Budget, was designed to support domestic innovative technologies that can reduce GHG emissions. The contributions to the Fund were designed to help promote technological innovation and reductions beyond the 2008-2012 interval.

However, according to the 2005 Climate Change plan (Government of Canada, 2005) there are two types of emissions that LFEs should reduce: fixed process emissions and other types of emissions measured in tonnes of CO₂ equivalent emissions. This distinction is essential, as reducing the levels of fixed process emissions can only be done by lowering production entirely because there is no alternative technology that will reduce them. For example, when extracting limestone (used to produce cement and lime), the process involves releasing carbon dioxide into the atmosphere. The issue is that this is the only way known so far for extracting limestone. In contrast, existing technology have allowed industries to reduce other types of emissions without lowering production, particularly through fuels switching.

²³ The 2002 plan established that in the 2008 – 2012 interval the average annual emission reduction target of the LFEs would be 55 million tonnes (Mt) CO₂ emissions (CO₂e). In 2005 the target decreased to 45 Mt CO₂ emissions.

²⁴ Units issued under the Kyoto Protocol regulations; they are divided in the following categories: Emissions Reduction Units (ERU), Certified Emissions Reductions (CER) or Removal Units.

Under the 2005 Climate Change plan, to account for these differences in the two types of emission reductions, fixed process emissions had a 0 percent reduction target while other emissions had a 15 percent intensity reduction target relative to a 2010 business-as-usual (BAU). LFE companies could comply by reducing their own emissions, buying credits from other LFEs, Clean Development Mechanism (CDM) and Joint Implementation (JI) credits, "greened" international permits (Assigned Amount Units or AAUs) and domestic offsets or Technology Investment Units. According to the above mentioned plan, the Technology Investment Units represented investments in technology development as a compliance option for LFEs. They had a cost of \$15/tonne CO₂e and would be limited to 9 Mt, which meant that the LFE target would be met through domestic reductions, offset and Kyoto credits (Government of Canada, 2005).

While there has been some recent progress in the development of Canadian GHG emission reduction policy, the Canadian government also had some drawbacks. On April 5, 2006 Canadian mass-media reported that the new conservatory government had decided that federal funding for climate change programs in the new fiscal year would be reduced by 40 percent and 15 climate change programs were to be cut. These government decisions led to great concern among environmentalists, scientists and opposition parties. In response, ninety top Canadian scientists²⁵, in an open letter to the Prime Minister, insisted that the government develop a national strategy on climate change or risk devastating consequences for the country's ecosystems, economy and society.

While the government actions discussed above indicate a sometimes confused direction on GHG emissions reduction strategy, the balance of activity indicates that the government's policy shift did not define the Canadian attitude towards climate change issues at that time. One year later, the *Regulatory Framework for Air Emissions* (Environment Canada, 2007 [2]) was released. The plan outlines reductions in GHG emissions and air pollutants that are to be achieved by setting up measures for the following sectors: electricity generation produced by combustion, oil and gas, forest products, smelting and refining, iron and steel, some mining, and cement, lime and chemicals. Moreover, the Canadian policy addressed issues of indoor air quality, emissions from transportation sources, and emissions from consumer and commercial

²⁵ France-Press Agency (AFP), April 19, 2006.

products. Regarding air pollutants, national emission caps were fixed as percentage reductions from 2006, the new base year, with air pollutants reductions coming into force by 2012. Following a progressive approach, the existing Large Final Emitters have to reduce their emission intensity²⁶ by 6 percent each year. The base year of production for the firms considered is 2006; thus, the expected emissions intensity cuts are 18 percent by 2010. A continuous reduction of 2 percent each year after 2010 was proposed for achieving a 26 percent reduction in intensities by 2015. Regarding Canada's position on *carbon leakage*, the Regulatory Framework for Air Emissions clearly specifies that, as long as emission-intensity system ties targets to production, credits will be earned only through cleaner production. Thus, firms will not be allowed to claim emission reduction credits by shutting down production or moving production out of Canada.

In March 2008, Environment Canada published another regulatory framework that details the mandatory reductions for industry as well as new measures for the oil sands and electricity sectors. The new regulation proposes tough measures to be followed such that, according to the Government commitment, by 2020 it will be possible to achieve the 20 percent total emission reduction proposed in the 2007 plan. Moreover, the long-term goals include a proposed 60 to 70 percent emissions reduction by 2050 which are intended to establish Canada as a low emission-economy. The plan lays down the targets for each of the industrial sectors, the creation of a carbon emissions trading market as well as the carbon offset system as an option for Canadians who want to contribute to GHG reductions. The regulations regarding Large Final Emitters highlight that the emission intensity reduction target for each sector remains 18 percent – as mentioned in the previous framework. However, companies will be free to choose how to reduce their emissions among the following: in-house reductions, contributions to a technology fund, access to emissions trading and the offset system, and access to the CDM.

By tying emission reduction targets to production, Canadian regulations have taken into account the sell-and-move issues. With regard to GHG emission, the current Canadian Regulatory Framework for Air Emissions has clearly specified that “firms will not be able to claim emission reduction credits by shutting down production for economic

²⁶ Emission intensity measures the amount of emissions per some unit of economic output. It can be unit of production, GDP, GNP, etc.

reasons or obtain credits for moving productions out of Canada” (p. 10). While the intent of the regulation is straightforward, it may stifle new investments in emission reduction when it involves the shutdown of a plant. Designing effective mechanisms that can distinguish economic from environmental reasons, or the relocation of production in a multi-plant multi-product company, could prove very difficult.

It is interesting to note that the Canadian government had considered shifting the current emission-intensity policy to fixed emission caps for the 2020-2025 interval. This shows that the regulators had taken into account the possible expansion of trading emission reductions not only with the European Union but also with the US.

2.4.5 Other Conflict of Interests among Involved Countries

2.4.5.1 Developing versus developed countries

In 1997 UNFCCC has framed Kyoto Protocol to operate under the idea of “common but differentiated responsibility” which means that developing countries have a different status than developed and transition countries. Developing countries are not considered to have contributed to the current share of emissions and, given their low share of emissions per capita, should be supported by a climate change fund initiated by developed countries. However, developing countries still share the responsibility of reducing emissions by establishing their own absolute targets and planning emission reduction actions. The issue arises from the fact that, since Kyoto Protocol inception, developing countries like China and India have displayed a rapid economic development, thus emitting high levels of greenhouse gas and positioning themselves as main contributors for emissions in the future. China is currently considered to emit the largest amount of total GHG emissions, surpassing even the United States’ on per capita emissions are lower than major industrialized economies. However, it is difficult to show real data as long as China does not release information about its carbon dioxide emissions, although it claims to be very actively involved in finding solutions for climate change challenges.

The fact that developing countries, especially China and India, do not have binding targets represents one of the reasons why the United States refused to ratify the

Kyoto Protocol. Furthermore, during the 2009 Copenhagen climate change negotiations the US position was firm in stressing that it is essential that developing countries, especially China, should also have firm GHG emissions commitments in any future international agreement.

2.4.5.2 Border tax adjustments and protectionism issues

Both EU and US considered accompanying climate policies (either cap and trade or carbon tax) with border measures applied on imports from countries who have a less strict environmental policy (LaFleur and Rosaasen, 2011). The terminology mostly employed for border measures are border tax adjustments (BTAs) or border carbon adjustments (BCAs). This tax would be levied by countries which have higher production costs due to respecting carbon mitigation policies upon goods produced in carbon intensive countries. Initially, a few EU countries considered implementing these measures due to US refusal to ratify Kyoto Protocol (Hontelez, 2007), but the European Commission did not want to strain the trade relationships with the US. Another major reason was that the World Trade Organization (WTO) regulations on BTAs are not clear with respect to taxing inputs that are not physically incorporated into the final product (McCorriston and Sheldon, 2005).

From the US point of view, the American Clean Energy and Security Act proposes the cap and trade system, which would protect the US borders by using BTAs on carbon intensive imports. This measure is targeted primarily at emitters such as China, India and Brazil, which, under their developing countries status, do not have binding emissions under the Kyoto Protocol. The difference between employing border taxes between the EU and the US is that in the proposed US legislation, the GHG intensive countries would have to buy GHG emission permits (US Senate, 2009), which may represent less of a challenge for WTO rules than the European version.

Furthermore, the Clean Energy Act proposes employing low carbon standards for energy intensive goods, which has already raised protectionism issues versus using Canadian cement, chemicals, and especially fuel derived from Alberta's oil sands. Canadian environmentalist forums and newspapers have started pointing out the protectionist repercussions of the American climate bill measure for the proposed cap and

trade system. Mach (2009) is warning the issue of restricting imports of higher carbon fuels such as oil sands can be a challenge under the WTO rules. Under international trade rules, how a good is produced should not be a ‘determining factor in purchasing decisions’ (p. 1).

2.5 Conclusions

In the light of the above, the diverse range of GHG emissions reduction mechanisms employed by various countries along with the participation in the Kyoto Protocol raises competitiveness issues for the governments involved, especially for countries dependent on emissions intensive industries or whose economy is expanding. At the same time, if a particular industry is more involved in trade, it can face severe competitiveness issues from the countries that did not ratify Kyoto. Some of the above sections have detailed the competitiveness issues of various sectors when introducing environmental policies which have become a source of concern for the European Union. These issues represent a continuous debate as under WTO rules trade liberalization will deter governments from seeking optimal environmental policies because of the constraints created for their trade instruments and policies (Sheldon, 2006).

The lack of international harmonization in GHG emission reduction policies and governments’ incentives to manipulate trade through environmental policy may lead to a race to the bottom in governments’ environmental standards (Bagwell and Staiger, 2001), and subsequently to pollution havens or industrial flight phenomena. Narrowing down the consequences of different environmental regulations at industries level, there are competitiveness issues that occur among trade dependent industrial sectors whatever the choice of emissions reduction policy. Neuhoff et al. (2007) make a distinction that competitiveness is more important at the firm or sector level, as at the country level, in long run, the exchange rates will adjust to compensate for possible competitiveness losses. The ‘chain’ effect that takes place within an industry, when the government decides the stringency of its climate policy, leads to competitiveness issues which in turn can determine loss of profitability and market share. Therefore, when countries all over

the world experience various stages of economic development, harmonization of environmental regulations is not a straightforward achievable goal.

Each industry sector reacts differently when an environmental policy is implemented. In this respect, the final result is impacted by the degree of exposure to trade of the economy, industry specific characteristics, market structure and the degree of vertical integration.

In the light of the above, policy impact and efficiency may have a higher complexity, different motivations and interpretation when the industry subjected to GHG emission reductions is vertically integrated. As previously noted, while a carbon tax can be implemented at a consumer of an input or output level, a cap and trade can be implemented only in the upstream of an industry, as administratively it would not be feasible to trade permits at the final consumer level.

When a government is implementing environmental policies, a vertical market structure allows identifying in more depth what determines the final price of the product or where most of the transaction costs occur. The question that arises is which level is going to be more affected? If and to what extent are the producers of crude oil influenced by the impact of this policy?

Given these circumstances, the following chapter will seek insights and compare and contrast the policies presented earlier within an industry's vertical market structure.

CHAPTER 3

EQUIVALENCE OF REGULATORY INSTRUMENTS IN A VERTICAL MARKET

3.1 Introduction

Chapter 2 introduced GHG emission reduction policy instruments by examining the environmental and economic consequences of their implementation at an international level and identified the need to decipher the effects of the policies at an industry level. To this end Chapter 3 explores carbon taxation and cap and trade instruments within a vertical industry market structure.

This chapter contributes to an interesting important debate among senior economists whether a carbon tax or tradable permit system is the best policy instrument to reduce greenhouse gas emissions. Nordhaus (2006) and Metcalf (2009) and others argue that carbon taxes should be the policy of choice, while Keohane (2009) and others argue that cap and trade systems are the superior instrument. Those in favour of a carbon tax argue that this price based instrument can create effective incentives, it can create a revenue source to reduce income tax and other distortionary taxes, has no price risk for firms, and it is simpler to administer with lower transactions costs (Stavins, 1995). Those in favour of cap and trade argue that very little is known about the marginal cost of abatement, so a quantity based market instrument is superior as it will allow a more precise target achievement; cap and trade systems tend to be more politically acceptable because they are less transparent, that transaction costs are minimal when dealing with large final emitters, and finally, the experience with the SO₂ emission trading was an unqualified success. This important debate stands in sharp contrast with the well known result in the environmental economics literature which states that in the presence of perfect competition and in the absence of uncertainty, a carbon tax and a cap and trade system (where the permits are auctioned) are equivalent with regards to the level of abatement, the price of carbon and the price of carbon intensive goods.

The existing literature on the choice of GHG emission reduction instruments has focused more on the policies' efficiency and cost-effectiveness and less on rent and total economic surplus distribution (Stavins, 2008). At the same time, many of the industries

subjected to GHG emission reductions are vertically integrated. Moreover, in the environmental trade literature to date, little discussion has occurred on the effects of employing environmental policies in vertical structured industries (Hamilton and Requate, 2004). For these reasons, this chapter examines a vertical market structure with input substitution, to analyze the equivalency of the two policies. The revealed differences in efficiency and welfare impacts between the policies are an additional consideration for policy makers.

The chapter compares these competing policy instruments by examining under what conditions a carbon emissions tax policy (price based) and a cap and trade policy (quantity based) are (and are not) quasi-equivalent. Building on a growing literature, the chapter examines these policies within a vertical industry structure and shows that input substitution can be an additional source of non-equivalency. The analysis begins by exploring the two policies equivalency in a simple market under restrictive assumptions (perfect competition and absence of uncertainty), then in a vertically structured market, first under fixed proportions assumption and then when input substitution is allowed in the vertical structure.

The conclusion drawn at the end of this chapter is that the two policies generally are not equivalent. They can be quasi-equivalent when implemented on the same good or level within a vertical market structure. They can also be quasi-equivalent regardless of the level of implementation within the vertical structure with a fixed proportions technology within a closed economy, but even in this case can differ substantially in where the rents accrue. However, in the more general case of open economy and/or substitution among inputs is possible, the quasi-equivalence quickly breaks down when policies at different levels in the vertical structure are compared. A cap and trade system imposed in the upstream of LFEs producing substitutable inputs will be less effective and less efficient than a generally distributed carbon tax.

The chapter is organized in four parts. Section 3.2 introduces the graphical and theoretical illustration of the quasi-equivalence between a carbon tax and a cap and trade policy in a simple market. Section 3.3 develops a vertical market structure, and illustrates policies' enforcement at all the levels and their quasi-equivalency from a distributional point of view. Section 3.4 presents the importance of input substitution possibility when a

regulator chooses the GHG emission reduction instrument. Section 3.5 concludes the chapter and focuses on key components of vertical linkage in both the upstream and downstream markets of an industry.

3.2 Quasi-Equivalence

3.2.1 Carbon Tax and Cap and Trade Policies – Graphical Analysis in a Simple Market

A well known result in the environmental economics literature is that in the presence of perfect competition and in the absence of uncertainty, a carbon tax and a cap and trade system (where the permits are auctioned) are quasi-equivalent, which implies that they are equivalent with regard to the level of abatement, the price of carbon and the price of carbon intensive goods, and only differ in terms of rent distribution. This important result is illustrated in a simple graphical framework as point of departure for the remainder of the chapter, which discusses other sources of non-equivalency including those identified in the literature, and those differences that arise in a vertical market structure.

For a better understanding of the concepts of equivalency, quasi-equivalency and non-equivalency of cap and trade versus carbon tax, and prior to exposing the first model, the following definitions should be presented and explained.

Definition 1: one policy is said to be *equivalent* to the second one, if both policies, when set at appropriate levels, yield the same prices, quantities and welfare distribution. E.g.: in a closed economy, a tax on producer is equivalent with a tax on consumer.

Definition 2: one policy is said to be *quasi-equivalent* to the second one, if both policies, when set at appropriate levels, yield the same prices and quantities but differ in welfare distribution. E.g.: under certainty, an auctioned cap and trade and a carbon tax policy are quasi-equivalent as they differ in welfare distribution, as further shown.

Definition 3: One policy is said to be *non-equivalent* to the second one, if both policies, even when set at appropriate levels, yield different prices and quantities. E.g.: command and control instruments are not equivalent to a carbon tax as costs will differ

(Helfand, 1991); tariffs and quotas are non-equivalent in the presence of monopoly (Bhagwati, 1965).

Figure 3-1 illustrates the above definitions.

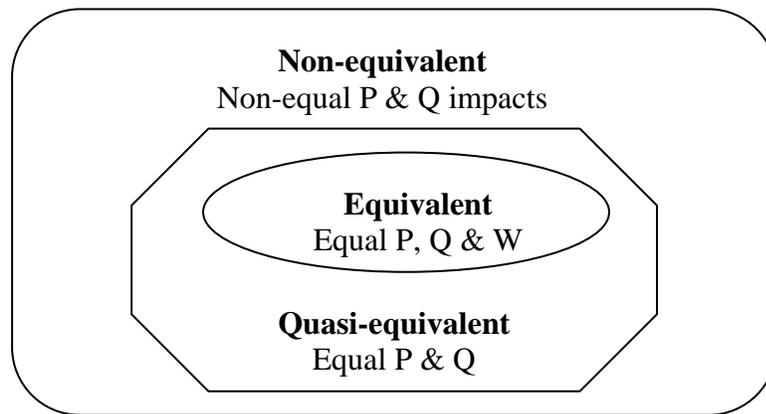


Figure 3-1.: Equivalency, quasi-equivalency and non-equivalency representation

Based on the above definitions, Figure 3-1 can be interpreted as follows: the equivalency is included in the quasi-equivalency, as long as prices and quantities (P & Q) are the same, and the difference consists of welfare distribution (W). Thus, it can be said that the contour of the equivalency set is represented by the welfare distribution attribute. Meanwhile, non-equivalent is everything outside the octagon. Similarly, the contour of the quasi-equivalency concept (the octagon) is represented by the market impacts in the sense that it has non-equal prices and quantities. Therefore, non-equivalent policies are neither equivalent nor quasi-equivalent. However, it should be mentioned that the mapping of the policies in the above diagram will change under different conditions and assumptions such as market power, vertical structures or input substitution. In other words, the quasi-equivalency in the current framework can quickly break down into non-equivalency in a different framework of assumptions.

Returning to the basic illustration of quasi-equivalency, it should be noted that it involves the market before and after enforcing an emission reduction policy for any good whose production process leads to releasing carbon emissions produced in fixed

proportions to output²⁷. Given the fixed proportion, the vertical axis shows the output price, the horizontal axis shows the quantity of output, which is also equivalent with emitting a certain quantity of carbon dioxide. Under the restrictive assumptions of perfect competition and complete information, while rent distribution differs, the policies result in the same price and quantity outcomes and hence are quasi-equivalent.

The incidence of a carbon tax at a firm level is illustrated in Figure 3-2. Before introducing the tax, the optimal quantity and price are determined by supply and demand, Q' and P' , while consumer and producer surplus are represented by area FCP' and $P'CA$ respectively. After introducing the tax, the quantity of output is reduced to Q'' , and implicitly emissions from producing the output are reduced as well (which represents a gain for the environment). The price that consumers pay increases to Pd and consumer surplus is reduced to $FHPd$. Meanwhile, the new price after tax that producers get is a lower one, Ps , and producer surplus decreases to $PsGA$, while the area $PdHGPs$ represents government revenue. As a result of output and emissions reduction there is an environmental damage reduction, and the improvement in the environment is shown by area $HKCG$ ²⁸. However, triangle HCG represents the loss, while, triangle HKC illustrates the net welfare gain as a result of introducing the carbon tax.²⁹

²⁷ The investigation further developed assumes that abatement takes place only through reductions in output alone (i.e. enforcing a carbon tax or a cap and trade policy).

²⁸ The per unit externality is described by the distance $Pd - Ps$.

²⁹ It should be noted that, in a perfect competition environment, the decrease in the producer surplus implies an initial drop in the firms' profits. This comes as an effect of the decrease in price that producers experience after the tax is enforced. Thus, some firms will downsize, releasing some fixed factors of production, or exit the market if they can not cope with the price decrease. This is the reason why, under the new price Ps , profits will rise to zero again and producer surplus is $PsGA$.

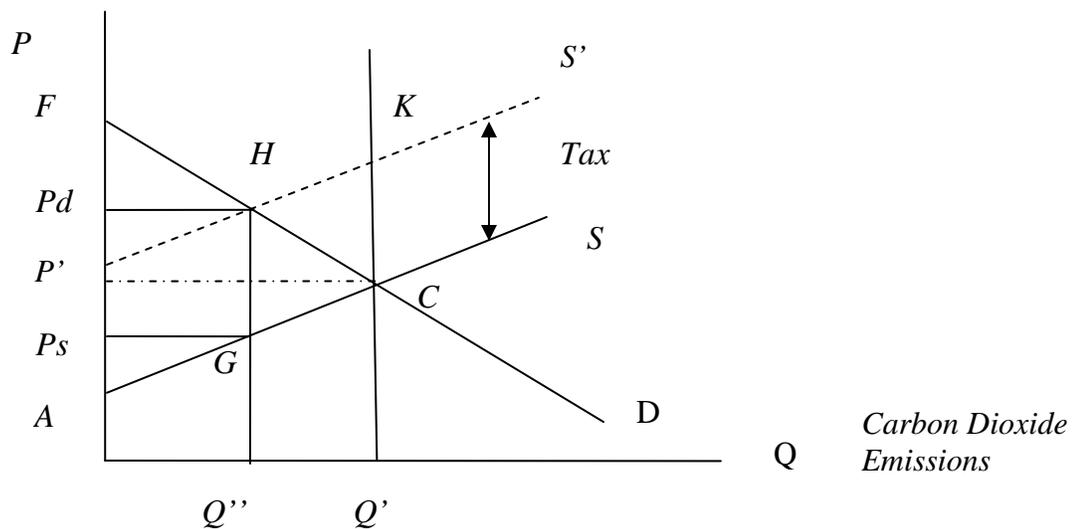


Figure 3-2.: Producer and consumer surplus at a firm level, before and after implementing a carbon tax

A cap and trade policy can be set such that to yield the same results as a carbon tax policy. As illustrated in Figure 3-3 if government will allocate free permits to the firms up to a quantity of Q'' the supply will be restricted to Q'' , which will increase the price of output to Pd . At this quantity, some firms will be willing to pay a $Pd - Ps$ for a permit that would enable them to expand output. Similarly, a firm would be willing to accept this amount to sell a permit, and forgo their margin last unit of production. This permit value, which reflects to price of carbon in this market, creates an additional marginal opportunity cost of production. The supply curve S will shift vertically up to S' by the price of a permit. After introducing the cap, the output is reduced to Q'' , the new output price increases to Pd , consumer surplus is reduced to $FHPd$ and producer surplus increases to $PdHGA$. The new producer surplus is made up by triangle $PdHPS$ and rectangle $PsHGA$, which is the additional producer surplus resulting from the rents accruing to permit allocation. $HKCG$ is the improvement in the environment and HKC shows the net gain in social welfare. While equivalent in all other respects, the additional

rents that accrue to permit holders, in the case of a free allocation of permits of Q'' , is quasi-equivalent to a carbon tax of $Pd - Ps$.

A cap and trade policy where the permits are auctioned can be fully equivalent to a carbon tax under competitive markets and complete information. As noted above, when a cap and trade policy is implemented with an auction to allocate Q'' emission permits, firms will bid on permits up the point where it will not be profitable anymore to purchase additional permits (in the Figure 3-3 an amount $Pd - Ps$). This point corresponds to the values of permits being equal to the price of carbon. In this case, the firms pay the government for any rents that accrue from permit holding. This policy, where the permits are auctioned, is fully equivalent to a carbon tax, where firms will lose producer surplus, consumer will lose consumer surplus, emissions will be reduced and revenue will be generated for the government.

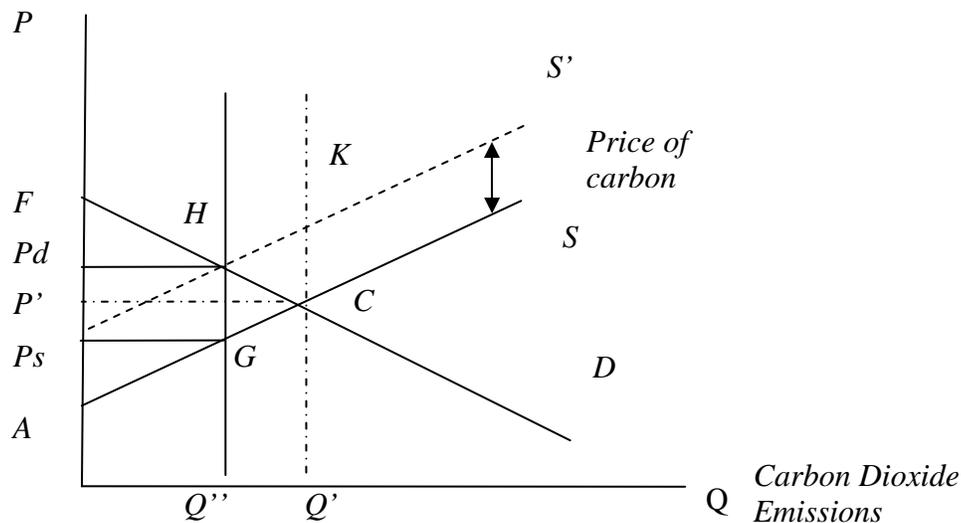


Figure 3-3.: Producer and consumer surplus at a firm level, before and after implementing a cap and trade policy

Comparing the effects of introducing a carbon tax with a cap and trade policy, the difference consists in a reduction of producer surplus. So practically, the efficiency impacts from imposing the two policies are identical, but differ in the distribution of the

surplus. With a carbon tax in place, the difference between the price paid by the consumer and how much it costs a producer to obtain the good constitutes revenue for the government. Under a cap and trade policy with grandfathered permits the owner of the permit receives a rent equal to the difference between the selling price and the cost of production.

Given the distributional implications, there is an ongoing debate whether GHG emission permits should be grandfathered, auctioned or allocated as a combination of grandfathering and auctioning. In the auctioning process, once the regulator decides the cap on emissions, she issues a certain number of permits that can be regularly auctioned and emitting firms can purchase credits for their emissions. The advocates of auctioning highlight that grandfathering can encourage non-efficient incumbent firms to continue producing as long as they receive permits for free. At the same time, grandfathering can represent a barrier to entry for new firms who have to buy permits from the existing firms.

The permits allocated for free represent a valuable asset for the receiving firms. The possibility of holding a share of these assets creates incentives for the industries involved to lobby the regulator. This behaviour is known in the economic literature as rent-seeking activity, which is characterized as a socially wasteful activity that leads to inefficient outcomes (Paltsev et al., 2007). Thus, given the rent-seeking opportunity that grandfathering leads to, LFEs have an incentive to lobby the regulators for allocating the permits for free based on historical output.

Among others, Metcalf (2007[2]), Dinan and Rogers (2002) and Parry (2004) investigate the distributional results of a cap and trade policy with freely allocated permits and find that grandfathered permits lead to rents accrued to shareholders. While a cap and trade system with a free allocation of permits is quasi-equivalent to a carbon tax, the existence of rent seeking incentive could have implications for the choice of policy instrument and how it is administered. Firms' rent seeking activities can also influence the total supply of permits that the regulator decides to distribute (Ellerman and Buchner 2007, Hanley and MacKenzie 2010). Implicitly, the amount of emissions to be abated (or the size of the cap) and the price of the permits would be impacted by the rent seeking activities. For example, a stringent cap determines a high value of the permits and thus a

higher value of the rents captured by firms. Vice-versa, it can be said that the size of the rents captured by firms depends on the size of the cap enforced for a specific industry.

Related to the relationship between the industry's elasticity of supply and demand and the rents extracted, Goulder and Parry (2008) investigate a cap and trade policy where the emission rights are distributed for free. They found that the rents that firms extract can overcompensate their compliance costs. They explain this situation through the value of the elasticity of supply relative to the elasticity of demand for that industry; e.g. the greater the relative elasticity of supply, the greater the increase in price and the greater the size of the rents. A permit system that restricts the level of a certain economic activity provides positive rents to holders of permits. Society can choose to implement various policies related to GHG emissions reductions, but the actual choice that would be implemented is going to be influenced by the rent-seeking activities that might be available to the interested groups of individuals or firms.

3.2.2 Carbon Tax and Cap and Trade Policies under Uncertainty

This section details first the main conditions that lead to policies quasi-equivalency, e.g. uncertainty and imperfect information, and then discusses other conditions that contribute to the non-equivalency of the two policies such as the existence of transaction costs and rent seeking.

As mentioned in Chapter 2, carbon tax is a price regulatory instrument while a cap and trade is a quantity regulatory instrument. Both policies place a price on CO₂ emissions³⁰, but they differ in the choice of policy instrument. A carbon tax places an explicit price of CO₂ emissions which leads to the adjustment of the quantity of emissions corresponding to the tax level. Meanwhile, a cap and trade policy sets a specific quantity of emissions and allows the price of emissions to adjust accordingly (Murray et al., 2008). Under certainty, the two policies can be set to obtain the same emissions reduction, but under uncertainty, this is not achievable. The reason is that in the real world, regulators are confronted with uncertainty and incomplete information regarding the exact structure of the cost and benefits curves (Baumol and Oates, 1988). Thus,

³⁰ In most jurisdictions several greenhouse gases are included in policy, but are measured in terms of CO₂ equivalents.

policy makers cannot know ex-ante the effect that the tax would have on the quantity of emissions and the effect that the emissions cap will have on the price. So there will be differences between the desired effect of any of the policies and the actual outcome in the market. For instance, in the context of international GHG emissions, the uncertainty issues are particularly severe as the damage value of the emissions accumulated can not be assessed. The following paragraphs explore these issues in more detail.

Starting in the mid seventies numerous economists have argued that, both in practice and theory, Pigouvian taxes and emission permits are equivalent only under perfect certainty. Thus, Weitzman (1974), Adar and Griffin (1976), Roberts and Spence (1976), Baumol and Oates (1988), Stavins (1997) and many others show that under uncertainty, taxes and emissions permits can yield significant differences in both emission reductions and social welfare. Indeed, as long as the regulator has perfect information about the marginal cost and marginal benefit functions, it can enforce a Pigouvian tax where marginal cost equals marginal benefits. Alternatively, the regulator's decision to enforce a cap and trade system will be based on determining the aggregated amount of emissions that needs to be abated and then issuing a number of permits such that the amount of emission reductions is at the level that equates marginal cost and marginal social damage (Stavins, 1997). Allowing trade in permits among firms equates marginal cost of emission reduction across firms, thereby minimizing the aggregate cost of abatement (Lipsey and Chrystal, 2007) and the permits market will determine the market clearing price. Thus, in both cases, the same amount of emissions is reduced, and the shadow price of emissions is the same.

Baumol and Oates (1988) outline the differences between a tax and an emission permit system in a perfect competitive market setup, considering firstly the case where the marginal benefits curve is unknown to the regulator and then, when the marginal cost curve is subject to uncertainty. The authors illustrate that uncertainty regarding the position of the marginal benefits curve will result in either too low or too high emission reductions, but the abatement results are similar for both policies considered. Thus, analyzing the impact of not knowing ex-ante the position of the marginal benefits curve does not offer additional information about the different impact of the two policies. In contrast, the authors argue it is the uncertainty on the marginal cost function that brings

out the differences between the two policies. Baumol and Oates (1988) show that when the marginal cost curve is actually positioned lower than initially estimated, an emission permits system will achieve lower than optimal emissions reductions, while a carbon tax will attain more emission than planned. If the actual marginal cost curve is on a higher position than the expected one, the reverse is true. Further on, it is shown graphically and mathematically that, for each of the policies, the slopes of the two curves will impact both the magnitude of the emissions reduction distortions and the producer and consumer surplus. Baumol and Oates (1988) confirm Weitzman (1974) theorem, and state that, under the same assumptions as above, the two policies will determine the same magnitude of the welfare loss only when the slopes of the two curves are equal. A tax would be the preferred instrument by a social welfare maximizing regulator when the marginal cost curve is steeper than the marginal benefits curve and vice-versa. However, the authors do not support a specific policy over the other; they prefer to acknowledge both policies' drawbacks in a world of uncertainty and imperfect information.

Just as a simple example of climate change related uncertainty is the vast range of values attributed to the social marginal damages of GHG emissions. Metcalf (2009) underlines that a carbon tax should be set such that to maximize social welfare and the optimal tax value should be based on emissions' social marginal damages. Indeed, Stern (2007) estimates the social cost of carbon dioxide at \$85 per ton, while Nordhaus (2009) estimates a value of \$11 per ton of carbon dioxide equivalent. The IPCC report (2007), based on a survey of 100 estimates, attributes a possible range of values from \$3 to \$95 per metric ton of carbon dioxide. Even if the report explicitly considered risk in their estimation, they still suggest that the net damage costs of climate change may be even higher over time.

Stavins (1995) makes a compelling argument that transaction costs should be considered in GHG emissions instrument choice, given the uncertainty created by transaction costs. He argues that transaction costs are often substantial with trading systems and these must be included in any examination of efficiency across instruments. Metcalf (2009) argues that governments are very experienced in collecting taxes, which reduces potential transaction costs in carbon tax schemes. Governments have also recognized transaction costs in the design of emission trading systems, thus, rather than

having a system where all firms and households can participate, these systems are typically targeted toward large final emitters. Taxes, on the other hand, can be applied at many different levels including the retail and small business level. As it will be shown later, the ability to implement a policy at any level in a vertical structure is particularly important in the presence of international trade when policies are not harmonized.

As previously mentioned in Section 3.2.1, another issue that should be taken into account when the government implements policies for certain industries is the possibility of creating rents and thus, rent-seeking behaviour for the industries involved. In the context of implementing a tradable permits scheme, this case requires policies that can be updated without creating undesirable incentives for government or for the regulated entities.

However, along with and besides uncertainty, imperfect information, transaction costs or rent seeking, there are other criteria that need to be considered when assessing GHG emissions reduction policies, as will they impact policies' quasi-equivalency. According to Stavins (2008), the decision factors mostly employed when deciding to implement a GHG emission reduction policy are cost efficiency, environmental effectiveness and distributional equity. As policy efficiency is related to its ability to maximize net benefits, it implies the existence of correct information on the cost and benefits of abatement, which are quite difficult to estimate in the current context of the challenges raised by climate change (Baumol and Oates 1988, Stavins 2008).

The environmental effectiveness criterion addresses the necessity of assessing which of the policy instruments would achieve the proposed carbon emissions target and which one of them would create more incentives towards the development and adoption of new GHG emissions reduction technologies. Both market-based (e.g. carbon taxes, cap and trade) and command and control instruments (emission or performance standards) are considered to encourage the development and adoption of new technologies (Downing and White 1986, Jung et al. 1996, Tietenberg 1985). However, there is no consensus on which one of them is a better alternative (Montero 2002, Bruneau 2004). Thus, Montero concludes that in the presence of oligopoly, when considering the induced output effects derived from lower abatement costs, standards can offer stronger incentives than emission permits, while in perfect competition conditions, permits are equivalent to

emissions standards and superior to performance standards. Bruneau (2004) shows that actually, under perfect competition, performance standards generate stronger incentives to innovate than emission permits when production costs are accounted for. Meanwhile, Requate (2005) argues that under perfect competition, market-based instruments perform better than the command and control ones regarding the adoption and development of advanced abatement technologies.

The dispute on whether the cap and trade or carbon tax policy generate stronger incentives for technological innovation is ongoing. With regards to invention and innovation stages, Fischer et al. (1998) found that an unambiguous ranking of policies depends on the number of polluting firms, the environmental benefit functions and the innovator's ability to spillover the benefits to other firms. Milliman and Prince (1989) and Jung et al. (1996) examine firms' incentive for technology diffusion as the anticipated changes in producer surplus and found that auctioned permits provided the best incentive for adoption, followed by taxes and free allocated permits. On the other hand, Parry (1998), assuming that free and auctioned permits and emission taxes are equivalent before diffusion occurs, concludes that a tax is a superior instrument to permits. The authors explain their findings through the lower equilibrium permit price due to technology diffusion; thus, firms have lower incentives to adopt.

Summarizing the above, carbon dioxide emissions represent a negative externality which can be corrected (meaning finding the social optimal level of emissions) only through regulators intervention. In the absence of uncertainty and in the presence of perfect competition conditions, the two policies are equivalent and have similar outcome. However, when accounting for the existing uncertainty over the marginal damages and abatement costs curves and their respective slopes, the two policies are no longer equivalent (Metcalf, 2009). While there is an extensive literature on assessing the efficiency and cost-effectiveness of the two policies, the same is not true for the analysis of distributional impacts.

The remainder of this chapter acknowledges previous findings and the quasi-equivalency of the two policies, but highlights the importance of considering the economic surplus distribution when deciding which is the instrument of choice for reducing GHG emissions. If the welfare loss or redistribution is straightforward to

graphically illustrate for a single firm, the situation becomes more complex when analyzing it in a vertical market system. The following section graphically compares and contrasts the distributional effects of a carbon tax and a cap and trade policy in a vertical market structure with fixed proportions when considering permit trade and the point of regulation. The analysis of vertical market structures under variable proportions is performed in Chapter 4.

3.3 Quasi-Equivalence in Vertical Markets Structures

3.3.1 Vertical Markets Structures, Rent Seeking and Environmental Policies

The present section focuses on key components of vertical linkage in both the upstream and downstream markets of an industry when enforcing a carbon tax and a cap and trade policy. The goal of this analysis is to investigate the welfare distribution quasi-equivalence of the two policies. Little attention has been paid so far in the literature on the effects of vertical markets on the design of domestic or international environmental policies (Hamilton and Requate, 2004). This is particularly important for trading systems, where permits are often allocated to large upstream firms to reduce transaction costs. The analysis initially employs a simple fixed proportions comparative static model within a vertical market system; the more general case of input substitution is developed later in this chapter.

The importance of modeling environmental policies in a vertical market structure comes firstly from the high occurrence of vertically structured industries: oil, coal and natural gas, automobile industry, etc. Hamilton and Requate (2004) argue that even the state trading enterprises with their payment arrangements actually are a vertical structure mechanism. The authors analyze a non-cooperative environmental policy game between governments where a domestic exporter is considered in a vertical market structure. They highlight the high degree of sensitivity and the importance of the impact of vertical structures when environmental regulation is levied on a polluting input when trading an intermediate or final downstream good.

In this context, the current analysis compares two GHG emission reduction instruments, carbon tax and cap and trade in a vertical market setting under the

assumption of fixed proportions technology. The analysis of the distributional impacts of the policies illustrates that, when the policies are setup to determine the same GHG emissions reduction, they determine the same impact on producer and consumer surplus at all the levels except for the surplus (rent) that accrues in the cap and trade case. Thus, this result shows the quasi-equivalency of the two policies under fixed proportions assumption.

3.3.2 Carbon Tax and Cap and Trade Policies – Graphical Analysis in a Vertical Market Structure with Fixed Proportions

A fixed proportion model is defined through the non-substitutability among the production factors involved. The non-substitutability of inputs implies both a fixed proportions technology and a closed economy where traded substitutes for inputs are non-existent. A fixed proportions model employed in vertical markets means that the inputs that enter at each stage of the vertical system cannot be substituted one for the other. Moreover, as the amount of output increases proportionally, the required amount of each input increases by the same proportion. In turn, as long as output is associated with GHG emissions, the latter will increase as well, each time the inputs will increase proportionally. Thus, under fixed proportions assumption, this pattern will repeat irrespective of production, consumption or efficiency. Furthermore, as earlier mentioned in the present chapter, when a GHG emissions regulatory policy is implemented in a market equilibrium, there will be rent distribution. Under the conditions underlined above, when enforcing a GHG emission reduction policy in a fixed proportions vertical market system, rent distribution will be affected firstly by the choice of input where the policy is applied and secondly by the choice of policy instrument. This is one of the reasons why, a similar analysis with the same assumptions but performed on a different sector which employs other inputs may infer a totally different research outcome.

A vertical market system illustrates the chain of technological processes that inputs pass through until they reach the final consumer in an output form. The graphical representation of vertical integrated firms shows the relationships between the upstream and downstream markets, and how the changes at any level in the system lead to welfare

impacts throughout the system. Therefore, a vertical market system will allow observing what is happening in the downstream markets when a GHG emission reduction policy is employed upstream. In other words, how distributional impacts of implementing the emissions reductions at a certain level propagate in the system and who will bear the burden of this reduction.

The vertical system employed in the following analysis is developed with three layers that illustrate the production, processing and retail level³¹. For this analysis perfect competition conditions are assumed, while for graphical ease the input supply curves and output demand curve are assumed to be linear. The competitive equilibrium in the vertical market occurs where the sum of input costs per unit of output produced is equal to the price of the output produced. Under the fixed proportions assumption, the carbon dioxide emissions released into the atmosphere are always directly proportional to input use and output.

The methodology of deriving the final user supply and the derived demand curves for each input for factors used in fixed proportions in a vertical markets system is straightforward to derive. When the horizontal scale for each input is expressed in terms of units of output, the supply function for the retail level will be the vertical sum of all the upstream marginal cost curves, such that the marginal cost of a retail unit equals the sum of the marginal costs of the corresponding inputs used in production (Malla, 1996).

Although under fixed proportion technology the total economic surplus is the same at each level, the magnitude of consumer (downstream) and producer (upstream) surplus will differ according to slope of supply or derived demand at each level³². The following section presents the graphical illustrations.

3.3.2.1 Enforcing a carbon tax in a vertical market structure

As previously explained, under a fixed proportions technology inputs are combined in the same proportion regardless of their relative prices. The increase in average cost (which is the price in competitive markets) due to a tax on any input is equal

³¹ The last layer in the vertical market is labelled as retail and it embeds as well the wholesale stage.

³² In turn, the supply and demand at each level depend on the supply and demand curves of the upstream and downstream firms within the system.

to the per unit tax rate multiplied by the number of input units required to produce one unit of output. Therefore, it is the sum of taxes that will matter for price levels, not the level where they are applied. In other words, in fixed proportions technology, it does not matter where the tax is enforced, the impact is the same regardless of the point of regulation. For instance, assuming that a tax is enforced on a processor's output, the impact of the tax will determine a wedge between the price of the final good and the price received by the processor. The processor will produce where his marginal cost of processing equals the derived demand for processing services minus the per unit tax. The resulting reduction in the quantity processed will cause a proportional reduction in the quantity of final product sold, an increase in the product's price and a reduction in consumer surplus. Because of fixed proportions technology, there will be a corresponding proportional reduction in the quantity of each input used, a decrease in these inputs' price and thus, a loss in the surplus of inputs' producers. Furthermore, under fixed proportions, any combination of input and product tax that has the same total impact on per unit cost will have the same impact on the quantity of final product sold and the quantity of inputs demanded. Because of this identity, the impact on prices and producer surplus will be identical regardless of where the tax is imposed.

In this context, the following figures have as main aim detailing the graphical representation of enforcing a carbon tax at various levels of the vertical market system. Figure 3-4 illustrates the effects of implementing a carbon tax at the retail level. As a result of the per unit tax, the marginal cost curve shifts upward determining a new equilibrium while the quantity of output/emissions is reduced by Q^* minus Q_I . The effects of this shift at retail level impact the upstream derived demands. The new demand for the processing level is vertically derived by subtracting the sum of the retail and production marginal cost curves from the retail demand. Similarly, the derived demand at the production level is the result of vertically subtracting the sum of retail and processing supplies from the retail demand. Consequently, the new derived demands for processing and production will shift downwards. At the retail level, the new equilibrium will diminish both producer and consumer surplus. Meanwhile, at the processing and production level, as a result of the drop in demand (i.e. lower sales), both producer and consumer surplus diminish.

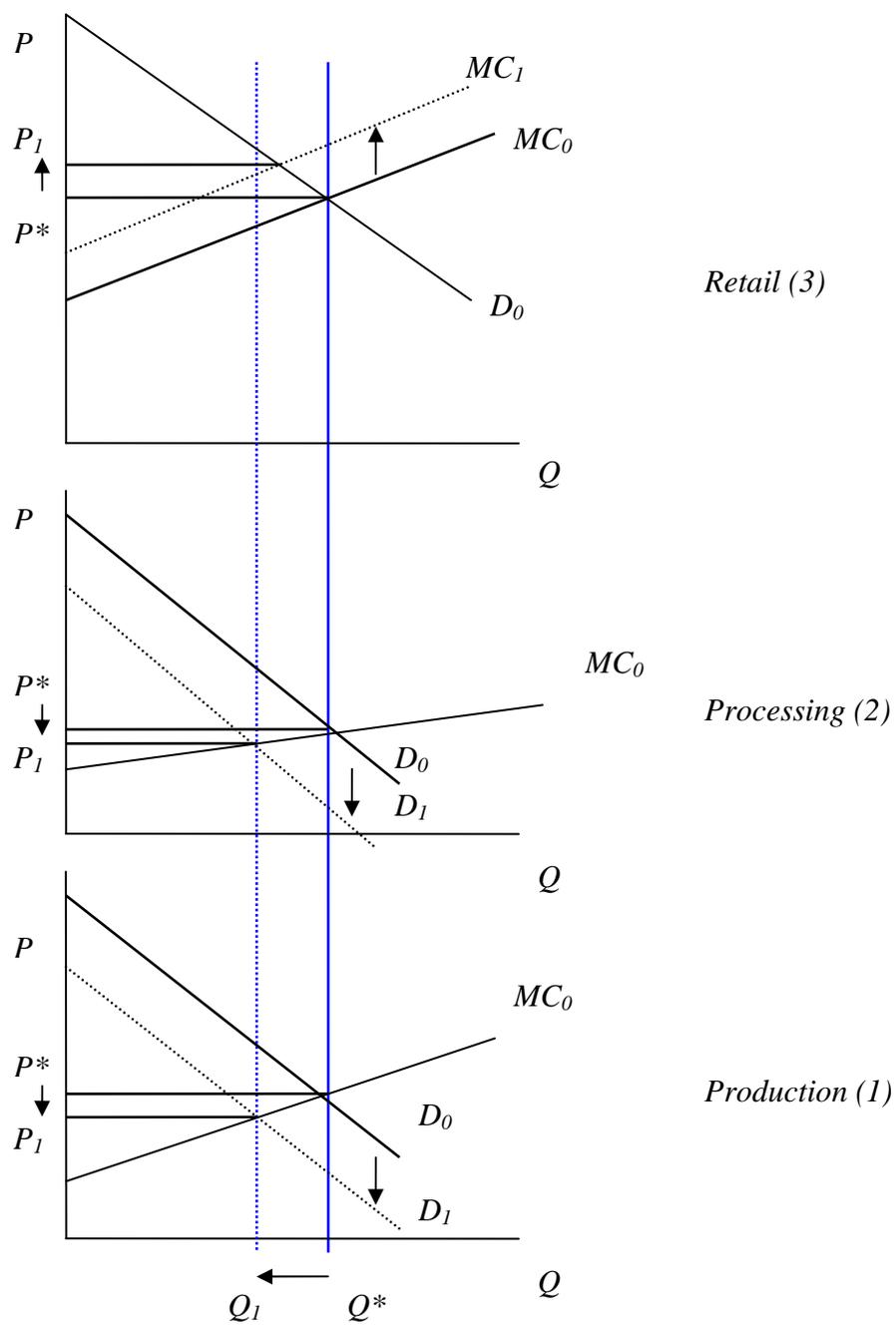


Figure 3-4.: The impact of enforcing a carbon tax at retail level in a fixed proportion vertical market structure

The next case investigated assumes that the carbon tax is enforced at the processors' level, as illustrated in Figure 3-5. As explained at the beginning of this section, enforcing the policy will also shift the marginal cost curve upwards, reducing both producer and consumer surplus. This shift will propagate downwards and upwards in the vertical market system determining an upward shift of the retail supply curve and a downward shift of the production derived demand. Therefore, producer and consumer surplus will have lower magnitudes at both production and retail levels.

Recalling the above, Figures 3-4 and 3-5 illustrate that under fixed proportions, the impact of a carbon tax in a vertical market structure is equivalent regardless of the level of implementation.

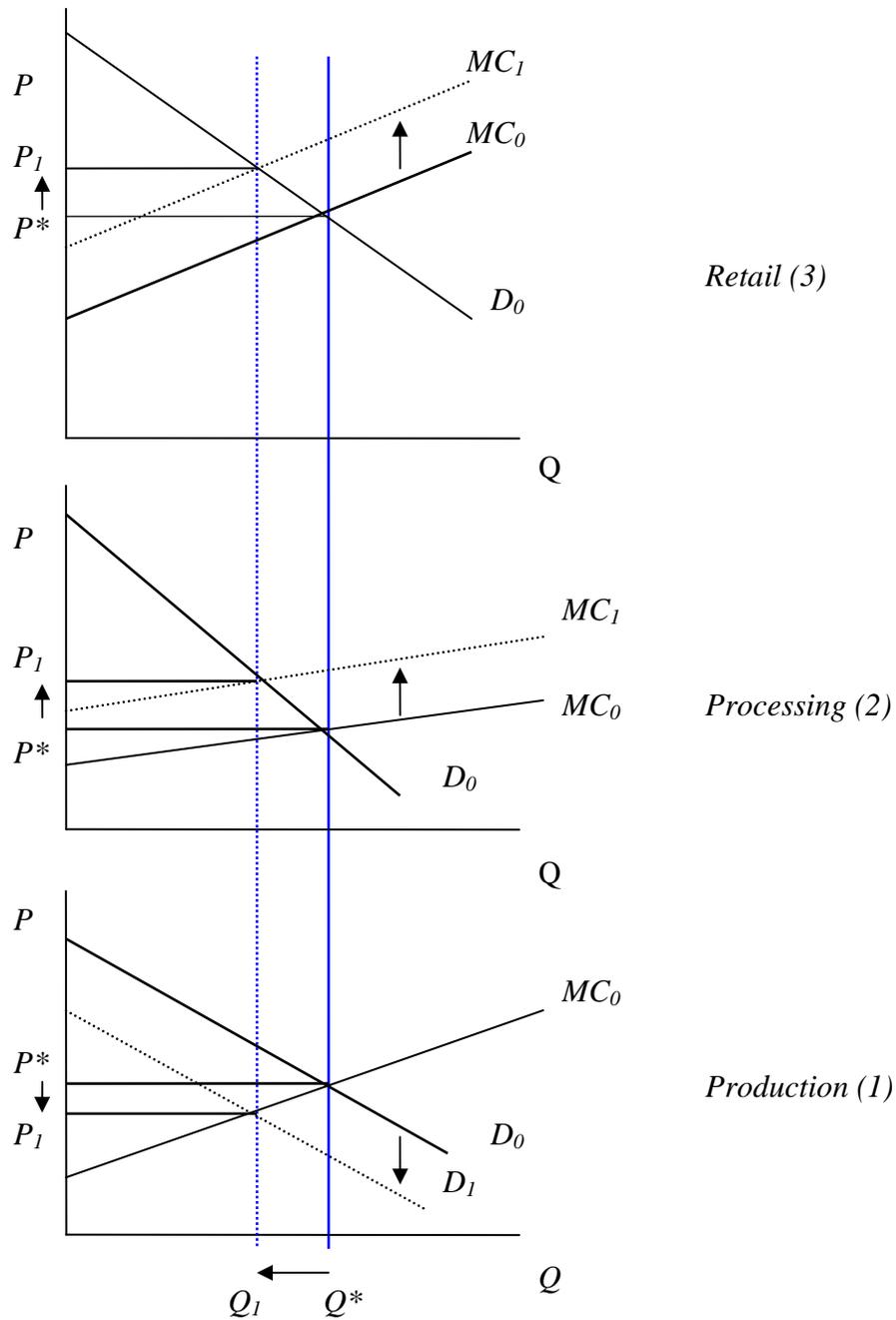


Figure 3-5.: The impact of enforcing a carbon tax at processing level in a fixed proportion vertical market structure

The enforcement of a carbon tax at the production level will lead to an upwards shift of the marginal cost at retail level and a downward shift of the derived demand for the processing stage, leading to a lower consumer surplus and producer surplus for retailers and lower producer surplus for processors.

3.3.2.2 Enforcing a cap and trade policy in a vertical market structure

The investigation continues with the analysis of enforcing a cap and trade policy at various levels in the vertical market structure. As shown in Figure 3-6, it is assumed that emissions are capped at retail level by the same value that the carbon tax induced in the above analysis, Q^* minus Q_1 .

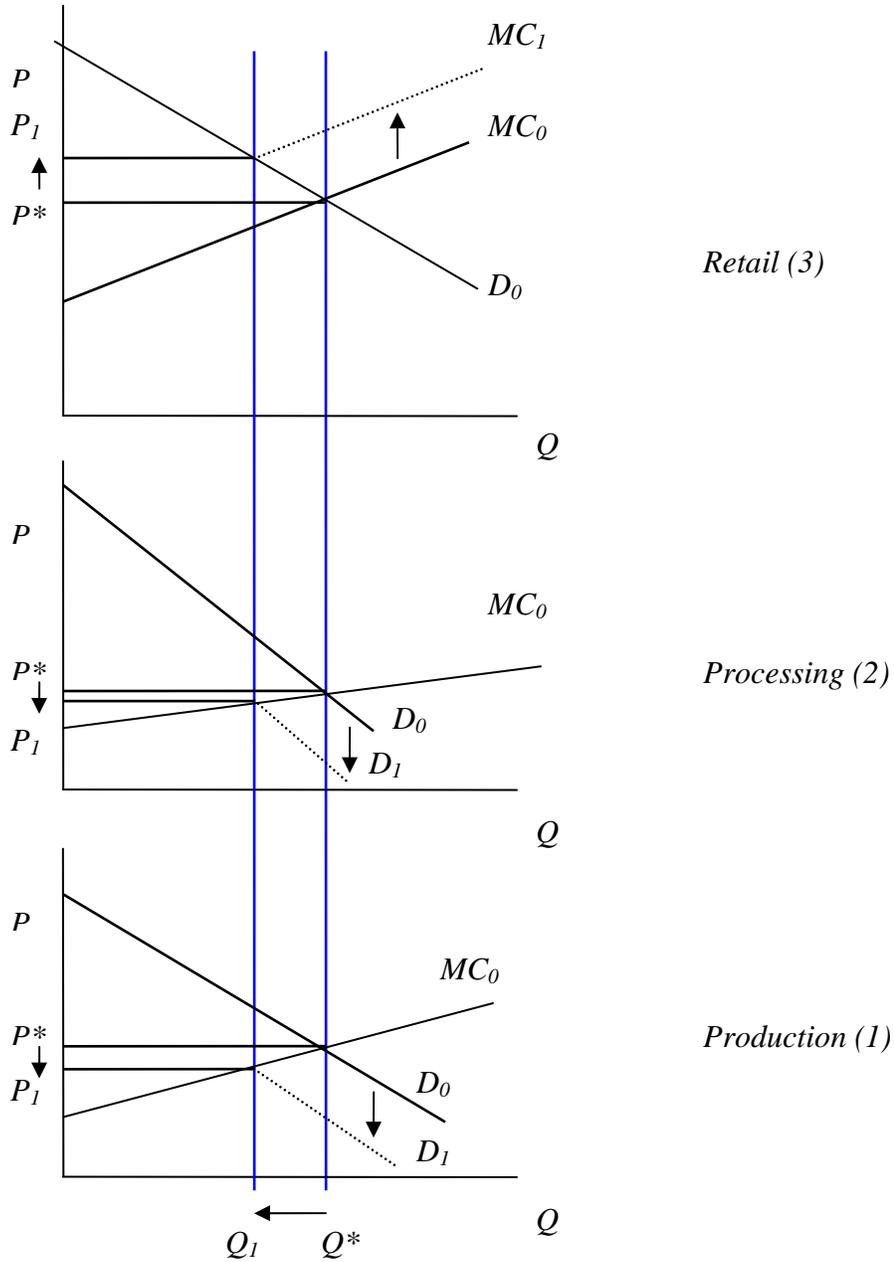


Figure 3-6.: The impact of enforcing a cap and trade policy at retail level in a fixed proportion vertical market structure

The graphical representation shows that, according to the new policy, retailers will receive freely allocated permits as long as they limit their output at Q_I . When this limit is overcome, retailers will incur the cost of buying permits such to comply with the new regulation. This is the reason why firms' marginal cost kinks upwards at Q_I and shifts upwards for any higher quantity of output than Q_I . This shift propagates similarly in the upstream and downstream of the system as the derived demands will also kink at Q_I and then shift downwards. The reason is that, as mentioned earlier in the chapter, when the firm releases one more unit of emissions than allowed, it has to buy emission reduction permits from other firms, which increases firm's marginal cost. According to production pricing regulations, the firm will distribute this increase in marginal cost for the entire quantity emitted, not only for the last unit (McKinsey and Ecofys, 2006).

Regarding the welfare distribution, at the retail level, consumer surplus decreases while producers earn rents as previously shown on Figure 3-3. However, the welfare changes at the other two levels show that consumers extract rents and producer surplus magnitude is lower than before introducing the policy, just like in the carbon tax case.

Comparing the two policies under the assumption of fixed proportions technology, carbon tax and cap and trade have similar welfare distribution effects along the vertical market system, apart from the rents that producers earn at the retail level, where the cap is introduced.

When implementing the cap at the processing level, the derived demand and supply shifts and the new equilibrium will be similar to the carbon tax case. However, the difference is that for cap and trade the derived curves will kink where the cap is placed. As a result of introducing the cap at the processors level, processors extract rent, consumers lose surplus, while upstream primary producers lose surplus.

When the cap is placed at the primary production level, rents are extracted at that level and all marginal cost curves in the downstream of the vertical market system will kink upwards, thus determining lower consumer surplus and rents for processors. Therefore, it can be stated that under fixed proportions, the impact of a cap and trade in a vertical market is equivalent regardless of the level where it is implemented.

The above graphical development confirms that a carbon tax and a cap and trade policy are quasi-equivalent in a fixed proportions vertical market structure. Specifically,

both policies determine the same effects along the vertical market system, with the key difference that for cap and trade with freely allocated permits, producers at the level where the policy is introduced will gain rents. So it is the value of the freely distributed permits that gives firms who receive them the opportunity to gain windfall profits. Actually this value can be accounted later as an opportunity cost of holding the permits by the firms that received them, so the profits in the sector will be driven to zero again. As with a single market case, when permits are auctioned, all producing sectors and consumers lose the same amount of the rent regardless of which level in the vertical structure the policy is administered. In the case where permits are grandfathered or given to the sector, the level which is granted the permits will capture rents at the expense of the upstream and downstream participants.

The graphical representation of both cap and trade and carbon tax under fixed proportions show that the impact of a cap and trade and carbon tax is quasi-equivalent regardless of the level of incidence. The quasi-equivalence means that the two policies have the same effect within the vertical market structure at all possible levels of enforcement, except for the rents that accrue for cap and trade. Therefore, *cap and trade and carbon tax are quasi-equivalent under fixed proportions regardless of the level where the policies are enforced.*

The result of quasi-equivalence in the vertical market structure is derived with the very strong assumption of a closed economy with a fixed proportion technology. Allowing some technical substitution among inputs requires variable proportions modeling. The existence of quasi-equivalence in variable proportions is examined in Section 3.4, below. However, in a variable proportions model, the effect of enforcing a GHG emissions reduction policy at any level of the vertical market structure will propagate less in the upstream and downstream firms as long as input substitution is available.

In this context, Section 3.4 has the aim of illustrating the importance of input substitution when the price of a domestic input increases as a result of enforcing a GHG emission reduction policy and there is a possibility to substitute the domestic input with a foreign one. In a vertical market structure, where there are available foreign inputs that could be nearly perfect substitutes for the domestic input, deciding which domestic inputs

would be subject to a carbon tax or a cap and trade policy could really matter. The subsequent analysis begins with a brief reminder of the basic economic concepts related to input substitution and then comparing and contrasting non-substitutability and substitutability effects.

3.4 The Choice of GHG Emission Reduction Policies and Input Substitution

In the case of GHG emissions reduction, the ability to substitute inputs could have a profound impact on the incidence of a carbon policy. The greater the substitution among inputs, the more important it is to tax those inputs associated with GHG emissions. The presence of foreign inputs that could be nearly perfect substitutes for domestic inputs suggests that, in a vertical market system, the choice of which inputs to be subjected to carbon tax or cap and trade policy could really matter.

Unlike the case of fixed proportions, when the elasticity of substitution is not zero, the taxation of one input can impact other inputs in very different ways. When there is a large elasticity of substitution, the taxation of one input could increase the derived demand for other inputs and have a very limited impact on marginal cost. Thus, the degree of substitutability between inputs profoundly affects the economic impact of increasing the price of one input. For instance, assuming input substitution possibility instead of fixed proportions on Figure 3-4, enforcing a GHG emissions reduction policy at any level of the vertical market structure will propagate less in the upstream and downstream firms as long as input substitution is available; this means that prices, quantities and welfare will be impacted to a lesser degree.

The following discussion is useful for illustrating the different impacts of the elasticity of substitution on the cost of production when only the price of one input increases. For instance, when a government unilaterally enforces a domestic GHG emission reduction policy on a specific industry through an increase in the price of a single input, the result will be an increase in the domestic good's price. In this case, it is interesting to reveal the effects of this price increase on the production cost of the input when there is a possibility to substitute the domestic input with a foreign one.

In a very simple formulation, when referring to production functions, the degree to which two inputs can be substituted for each other when relative input prices changes

is known as elasticity of substitution. When a production function has the property that inputs are economically combined in constant (fixed) proportions, regardless of relative input prices, it is known as a Leontief or fixed proportions technology. This implies that when increasing only one of the inputs, without a proportional increase in the other one, output will not increase.

In general, isoquants are used to illustrate producers' problem to combine two inputs³³ to maximize output and minimize costs. When moving on an isoquant from one point to another, it is shown how one input can be substituted for the other one while holding output constant. On the other hand, holding one input constant and reducing the other one has to reduce output. Figure 3-7 shows the isoquants of a Leontief technology.

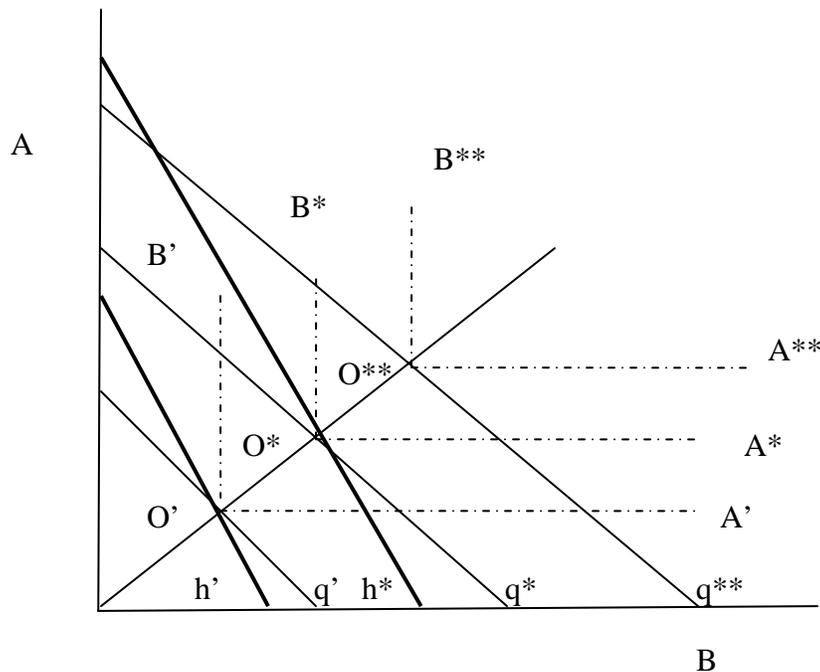


Figure 3-7.: Leontief isoquants

The L-shaped isoquants that are shown along the expansion path on Figure 3-7 illustrate that for any particular output there is a specific combination of inputs A and B which can not be substituted. In other words, elasticity of substitution is zero. The optimal input combination of Figure 3-7 are O' , O^* and O^{**} for isoquants $A'B'$, $A*B^*$

³³ In production economics, labour and capital are the two inputs usually employed.

and $A^{**}B^{**}$ respectively. The isocost curves q' , q^* , q^{**} , h' and h^* show the combination of the two inputs that can be purchased at fixed input prices for a given total cost. The isocost curves denoted q and h show that although there is a variety of input combination that can be purchased for a given cost, output for any given cost will be maximized along the expansion path.

When the elasticity of substitution increases³⁴, the isoquants will still show the combination of inputs that produce the same quantity of output, but in contrast to the Leontief relationship, in this case the inputs can be substituted one for another, as shown in Figure 3-8.

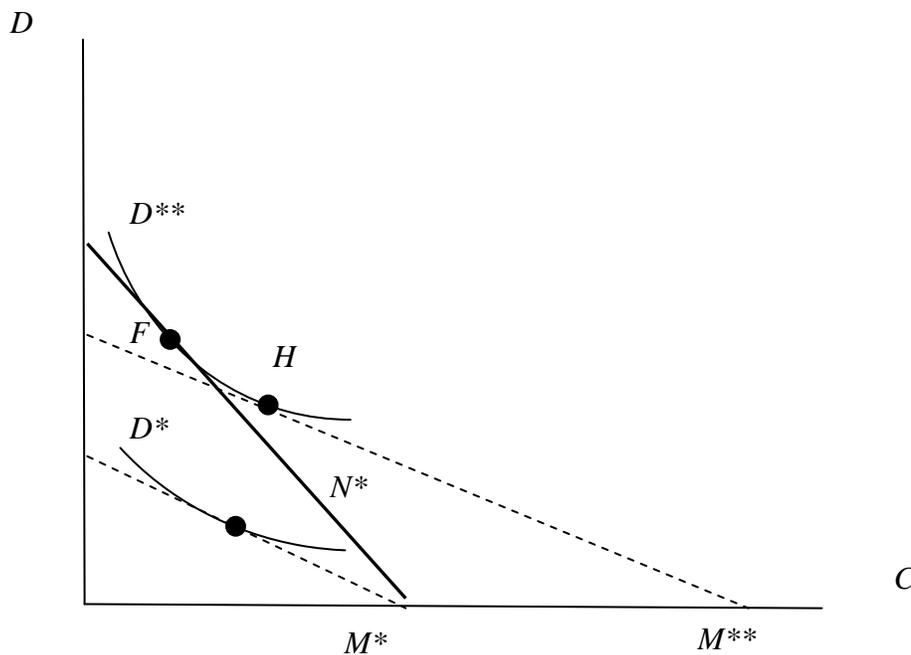


Figure 3-8.: Isoquants for substitutable inputs

Isoquants D^* and D^{**} show different quantities of output that can be obtained for different input prices. The figure also shows that if output was initially produced on isoquant D^{**} at point H , when the price of only one input increases and input substitution is allowed, the new isocost will be N^* and not M^{**} anymore. It also shows that it is more expensive to produce the same output, and the new equilibrium is point F .

³⁴ The case relevant for the analysis is to assume a positive elasticity of substitution which implies that the isoquants are strictly convex

Further, Figure 3-9 is employed to illustrate the possible effects of a price increase on the production cost of an input when there is a possibility to substitute the domestic input with a foreign one. This situation can occur when a government unilaterally enforces a domestic GHG emission reduction policy on a specific industry through an increase in the price of a single input. Therefore, Figure 3-9 illustrates the effects of an input price increase on cost with and without input substitution.

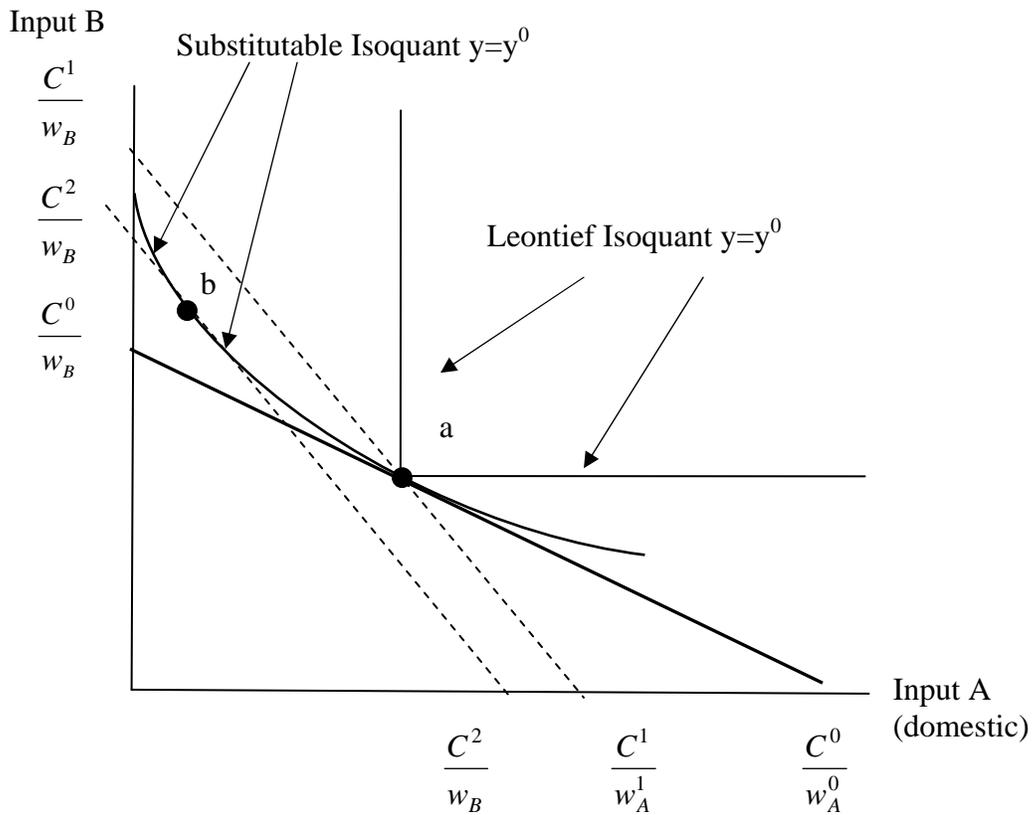


Figure 3-9.: The impact of an input price change on cost with and without substitution

Suppose a firm starts producing at point a , minimizing the cost of producing at y^0 units of output. The isocost line corresponding to this point, $\frac{C^0}{w_B} \frac{C^0}{w_A^0}$, is the same for both production functions. Assuming that the price of input A (the domestic input) increases to w_A^1 , in the case of Leontief production function, the combination of inputs

remains at point a and the cost increases to C^1 . The increase in the production cost can be calculated as the units number of input A times the input price increase. This means that the cost can be increased to any arbitrary level by increasing the price of a single input. In the case of the substitutable production function, an increase in the price of input A would cause a shift in the cost minimizing input combination to point b and lead to a reduction in the number of units of input A and to an increase in the number of units of input B . Compared to the Leontief case, the cost does not increase as much, as the new value is C^2 . This can be easily seen on the vertical axis as the price of input B is assumed to be fixed. If inputs A and B were perfect substitutes, an increase in the price of input A would result in a complete substitution for input B , and the cost would not increase at all. Unlike the case of fixed proportions, when the elasticity of substitution is not zero, the taxation of one input can impact other inputs in very different ways. When there is a large elasticity of substitution, the taxation of one input could increase the derived demand for other inputs and have a very limited impact on marginal cost. Thus, the degree of substitutability between inputs profoundly affects the economic impact of increasing the price of one input.

In the case of GHG emissions reduction, the ability to substitute inputs could have a profound impact on the incidence of a carbon policy. The greater the substitution among inputs, the more important it is to tax those inputs associated with GHG emissions. In the presence of trade and the availability of foreign inputs that could be nearly perfect substitutes for domestic inputs suggests that, in a vertical market system, the choice of which inputs to be subjected to carbon tax or cap and trade policy could really matter.

The trade and environment literature widely acknowledge that free trade has a significant impact on welfare distribution; trade can lower welfare in the absence of environmental regulations or it can raise it in the presence of near optimal emission targets (Bruneau 2005, Copeland 1994, Krutilla 1991, Beers and Bergh 1996). In this context, Bruneau (2005) acknowledges the gains from trade when market-based instruments are employed for reducing GHG emissions. He shows that identifying the level of emissions is not a sufficient condition for achieving gains from trade, the

necessary one is the *mode of regulation*, meaning the emission reduction instrument of choice.

With the aim of exploring the differences between fixed and variable proportions regarding welfare distribution when enforcing a carbon tax and a cap and trade policy in a vertical market structure, a Muth model is employed in Chapter 4.

3.5 Conclusions

The international concern with global warming and the debate on common efforts and actions for limiting the greenhouse gas emissions have induced a variety of domestic policy responses. In theory, governments choose policies that are most efficient in achieving environmental goals keeping in mind their social and political interests. Nordhaus and Yang (1996) emphasize that it is the implementation of domestic policies that will ultimately determine the performance of international agreements.

The economic surplus redistribution, as a result of introducing any of the two policies, will depend on a large number of factors: the cost of the policy, the consequent shifts in affected output's demand and supply, the structure of the industry and its exposure to trade, etc. In this context, Paltsev et al. (2007) and Stavins (2008) highlight the importance of assessing not only policies' impacts on costs, but also the distributional implications and who will bear the ultimate distributional burden. For example, as a result of enforcing an emission reduction policy, some firms may experience windfall profits (Sijm et al., 2006), while others firms can be negatively affected through a decrease in the demand of their products and profits. However, these firms' suppliers and final consumers will be affected, as the welfare effects of enforcing a climate change policy will be transmitted through market prices. Within the focus of this dissertation, distributional impacts of the two policies are also examined and assessed in Chapter 4, firstly under the assumption of fixed proportions technology in a vertical market system and later when input substitution is possible in the vertical market structure. The investigation illustrates the policies' quasi-equivalency in fixed proportions and their non-equivalency when input substitution is allowed.

In conclusion, this chapter examines the equivalence of carbon taxes and cap and trade policies within a simple market and a vertical market structure. The results show that in the very special case of a closed economy, with a fixed proportion production technology, with perfect competition and with no uncertainty, a carbon tax policy and cap and trade are quasi-equivalent in the sense that the gain in total economic surplus and pollution abatement is equal regardless of the level in the vertical system where either policy is implemented. However, in the case of cap and trade, rents are extracted as a result of introducing the policy, and occur at the point in the vertical system where they are imposed. The policies remain equivalent from a rent distribution perspective only when the permits are auctioned off. These results suggest implementing a cap and trade system at the Large Final Emitters level will generate economic rents for these industries.

When the far more general case of input substitution was modeled, equivalency breaks down and the point of regulation matters a great deal. The first best policy outcomes can only be achieved when the emissions associated to each input and output are priced, which may require regulation at every level of the vertical structure. The result is particularly pronounced when identical or highly substitutable inputs are available through international trade. This result is particularly troublesome for cap and trade policies where the costs of implementing a system for each input would require a great deal of transaction costs.

These results are not surprising. Paltsev et al. (2007) recognize the importance of the level where the allowances are allocated and highlight that, when considering the distributional impacts of a cap and trade policy, the focus of regulators should be on who eventually bears the economic cost of the policy and even try to direct the revenue from auctioning permits or from distribution of free allowances to them.

In Chapter 4 the impact of input substitution is examined in more detail by constructing a Muth model which can more formally relax the assumption of fixed proportions and quantitatively model the incidence of alternative policy choices in the presence of input substitution which includes measuring possible leakage to unregulated jurisdictions (Bushnell and Chen, 2009).

CHAPTER 4

CARBON TAX VERSUS CAP AND TRADE IN A VERTICAL MARKET SETTING

4.1 Introduction

In the previous chapter, the quasi-equivalence between a carbon tax and a cap and trade policy was shown to exist even in a vertical structure. In the special case of fixed proportions modeling in a closed economy, the point of regulation did not affect the efficacy of the policy, but it did affect rent distribution for cap and trade when permits were grandfathered. In a more general case of variable proportions, the analysis showed that the point of regulation could affect both the efficacy of the policy and rent distribution. This result is particularly important because, unlike carbon taxes, which are easy to impose at multiple points in a vertical structure, most cap and trade policies are restricted to large upstream firms because of transaction costs.

This chapter builds on Chapter 3 by using a simple Muth model of the oil sector in Canada to illustrate the impact of carbon policies in the presence of foreign competition in refining within a vertical market made up of crude oil, refining and retail levels. The Muth model, which simulates the vertical relationship among markets, has the ability to represent both fixed proportions and variable proportions. For a more precise representation of trade within a vertical structure and, unlike previous literature on the matter, the Muth model is modified to incorporate a nested Constant Elasticity of Substitution (CES) production function. This model format allows the employment of a greater elasticity of substitution between domestic and ROW refining while maintaining more limited substitution between the other vertical market levels. Using a model of an existing sector allows a better assessment of the extent that policy instrument choice could affect economic outcomes.

To illustrate the imposition of a carbon tax policy in this industry, when input substitution is not possible, it is assumed that a carbon tax of \$15 per tonne of CO₂ is introduced at the same time at the final consumers' level and at the processors' (refiners') level. This carbon tax policy is compared to an analogous cap and trade policy implemented only at the processors' level. These two policies are maintained when input substitution is allowed for refining within the vertical structure, which provides an

opportunity to compare the effects of a carbon tax policy and a cap and trade policy when there is trade in refining services.

It is acknowledged that the institutional global effort and GHG emissions reduction policies are directed towards mitigating climate change effects, and thus, improving overall social welfare. While recognizing the broader aspects of improving social welfare through reducing climate change effects, the present welfare analysis mainly captures the changes that occur in the economic surplus.

The remainder of this chapter is organized as follows: Section 4.2 introduces the role of the elasticity of substitution in trade models and its use in Muth models. Section 4.3 introduces the model and discusses numerical simulations for carbon tax and a cap and trade policy with no (limited) trade and in the presence of trade. Section 4.4 presents the conclusions of the analysis.

4.2 The Elasticity of Substitution and Muth Model

As illustrated in the latter part of Chapter 3, the effects of carbon policy within a vertical market structure will be impacted by input substitution when the assumption of fixed proportions is relaxed. This is a well known result in the literature. Freebairn et al. (1983) and Wohlgenant (1993) reveal that both the magnitude and the distribution of the benefits differ. The authors acknowledge that when a fixed proportions technology is analyzed, the distribution of research benefits is not impacted by the type of technical change or the stage where it occurs, while for variable proportions it does matter. Holloway (1989) separates the marketing sector into distribution and processing for illustrating that more of the benefits are distributed to those producers who are closer to the stage where technical change is implemented.

In the case of carbon policy, variable proportions and input substitution can exist within the vertical structures involving large final emitters through the production technology that allows the physical substitution of inputs in the production function, e.g. the substitution of capital for labour, or through international trade where foreign produced inputs can substitute for domestically produced inputs.

Variable proportions in production technology has been studied empirically for decades. Price movement among factors of production induces input substitution. While fixed proportions can exist for some portions of the production space due to chemical or physical relationships (e.g. 2 Hydrogen plus 1 oxygen = 1 H₂O), in general there is some ability to substitute inputs for one another (Berndt and Christensen, 1973).

The other source of input substitution that is relevant for domestic policy analysis is the ability to substitute foreign produced factors of production and goods for domestically produced factors and goods. Regarding the substitution between foreign and domestic goods, Armington (1969) introduced the idea that foreign imports are imperfect substitutes for domestically produced goods. The product differentiation concept that he uses is related directly to the product's physical attributes, but, more generally, could reflect the spatial location of products along the border. Elasticity of substitution is a concept extensively used by trade policy economists when analyzing how tariff or tax policies influence the trade opportunities, employment, economic welfare and other macroeconomic variables that are specific to a country (McDaniel and Balistreri, 2001).

Blonigen and Wilson (1999) estimate elasticities between US domestic and foreign products across more than 100 sectors and find that a higher degree of foreign ownership in the downstream sectors of an industry generates a higher elasticity of substitution between domestic and foreign goods. The authors also reveal that limited competition leads to lower elasticity of substitution. Furthermore, Vos (2008) reviews various studies with econometrics estimates of Armington elasticities and concludes that the higher the value of the elasticity of substitution the greater the trade creation.

In the case of carbon policy there is often a great deal of foreign trade in energy intensive industries. Crude oil, steel, natural gas, gasoline, electricity are few examples of factors of production that move across borders. In an industry like auto manufacturing, some components can make several trips across international borders during the manufacturing process. It is therefore reasonable to assume that policies which make domestically produced factors of production more expensive relative to foreign produced factors will result in input substitution.

To illustrate the effect that input substitution could have on the efficacy of carbon tax versus cap and trade, a model of the oil refining gasoline sector in Canada is built,

while explicitly recognising that some of the oil consumed in Canada is refined in the rest of the world (ROW). The stylized model of the gasoline consumed is produced using retail services in Canada, refining in Canada, refining in the ROW and oil produced in Canada levels. The model is first used to simulate carbon tax versus cap and trade in a situation where all inputs are used in fixed proportion. Second, simulations are carried out when there is significant substitutability among inputs.

To assess how input substitution can affect the incidence of carbon policies, a Muth model is used. As shown in Chapter 3, a graphical representation of the various scenarios of a price increase effect for one or two substitutable inputs, with constant output, can be carried out on an isoquant map. However, for a more general case of several inputs, with endogenous determination of output, the graphical representation of variable proportions in a vertical structure is quite challenging and somewhat un insightful. In his seminal paper, Richard Muth (1964) developed a model using comparative statics that measures the impact of changes of the output demand and factor supply curves on the downstream markets using their price elasticities and elasticity of substitution among factors.

The Muth model has been developed and particularly applied on the relationship between the elasticity of demand and supply and the distribution of benefits from R&D (research and development) in agricultural production. Although R&D in agricultural production is not related to the focus of this thesis, it is still interesting to reveal the impact of the elasticity of substitution and point of regulation in a different context. Research carried on by Alston (1991), Alston et al. (1995), Freebairn et al. (1983), Wohlgenant (1993) and Mullen et al. (1988, 1989), Gray et al. (2000) focuses on the distribution of research benefits in multistage production settings for various agricultural products. Using various assumptions and modeling setups, the main idea that emerges from this literature is that the benefit distribution depends not only on the elasticity of substitution between inputs, but also on the production structure, the technical change specificity, and the stage where the technical change takes place.

For instance, Alston and Scobie (1983) explain that, although the elasticity of substitution plays a major role, the type of technical change and the stage where it manifests will determine where most of the research benefits will be directed. The

authors point out that a higher elasticity of substitution will lead to increased gain for producers when technical change takes place at other levels of production. Further on, based on empirical evidence, Mullen et al. (1988) reinforce the crucial impact of the elasticity of substitution magnitude in the distribution of research gains.

4.3 The Theoretical Model

The variable proportion model developed by Mullen et al. (1989), Alston et al. (1995) and Gray et al. (2000) is modified for comparing and contrasting carbon tax and cap and trade policy under the assumptions of fixed proportions and input substitution possibility.

In this investigation it is assumed that the oil sector has four inputs provided at three levels in the vertical structure. As shown in Figure 4-1, starting from upstream, input four (at first level) represents the quantity of crude oil that is ultimately sold only in Canada. The second level, refining, is made up of two inputs: input two is the ROW oil refining; input three is Canadian oil refining. This structure allows the explicit recognition of international trade among inputs. Input one, the retail services provided in Canada, represents the third level in the vertical structure. The main goal of separating inputs two and three is to represent the potential choice of the industry to refine oil in either Canadian or ROW refineries according to their profit maximizing decisions. Out of all refined products that can be obtained from crude oil, only gasoline was chosen as representative product, not only due to its importance, but also because of the information availability regarding elasticities and quantities refined, distributed and their respective prices.

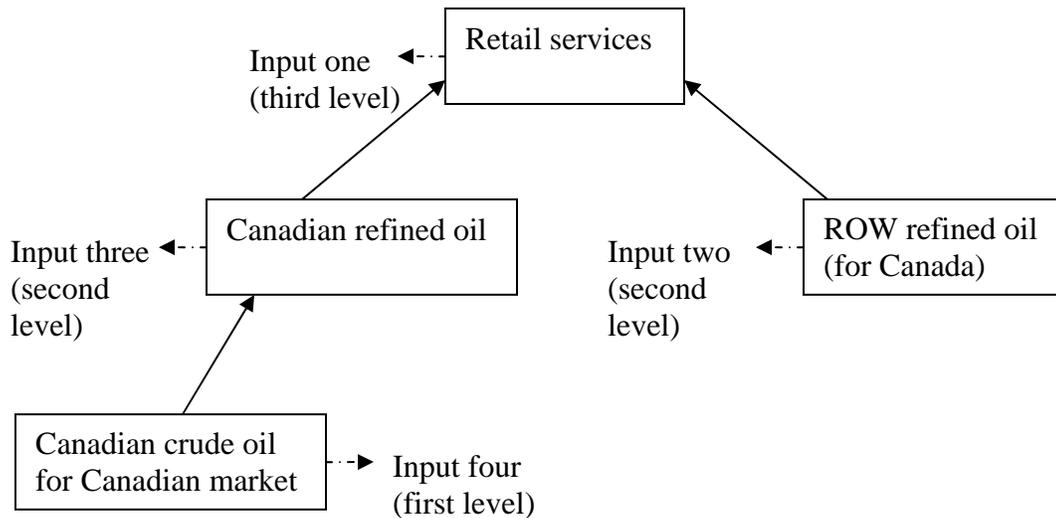


Figure 4-1.: The vertical market model with three levels and four inputs

In general, the assumption of fixed proportions implies that the elasticity of substitution used in the model is zero. For technicality reasons, assuming this value in the following Muth model will not reveal the impacts that propagate in the system, so it is assumed that the elasticity of substitution under fixed proportions is 0.0001. Moreover, in the present setup of the Muth model where Canadian and ROW refining services are within the same vertical market system, it can not be simulated a ‘no trade’ scenario, but one where there is trade, and both refining services, domestic and foreign, are used in fixed proportions. This is the reason why the results obtained for the fixed proportion assumption have an informative role only, and are not further compared to the second scenario where input substitution is possible as a consequence of assuming that trade is allowed.

To illustrate the introduction of a carbon tax policy when input substitution is not possible, it is assumed that a carbon tax of \$15 per tonne of CO₂ is introduced at the same time at the final consumers’ level and at the processors’ (refiners’) level. This carbon tax policy is compared to an analogous cap and trade policy implemented only at the processors’ level. These two policies are maintained when input substitution is allowed for refining within the vertical structure.

Regarding the point of regulation choices for the model, there is ongoing debate whether a carbon tax should be implemented in the upstream (producers level) or downstream (consumers level). For instance, Metcalf (2007[2]) favours a carbon tax levied in the upstream and argues about the ease of implementation of such a tax, given that the number of producers (oil, coal, natural gas) is limited and thus, the costs of administration are much lower. In a very much discussed carbon tax system proposal, Mintz and Olewiler (2008) suggest replacing the current Canadian federal fuel excise tax with a broader environmental tax designed to reduce GHG emissions. The federal fuel excise tax is applied only to gasoline, diesel and aviation fuel, while other GHG emitting sources of energy, such as natural gas used for transportation or coal used for generating electricity, are not under this tax incidence (Government of Canada, 2008 [2]). Mintz and Olewiler (2008) propose to convert the fuel excise tax to a carbon tax equivalent which would be extended to other fuels in proportion to their carbon content. One of the main arguments behind this proposal is that, by applying this tax at consumer level, the price signal leads to reduced consumption and emissions. Courchene (2008) recognizes the merits of Mintz and Olewiler carbon tax model but highlights the need to account for the carbon emissions that result from the production process “for creating these fossil fuels in the first place (refineries for oil and gas, etc.)” (p.11). In this context, the current investigation assumes that the carbon tax is introduced at the levels where most carbon emissions take place: the consumers and refiners’ level.

As per current existing literature knowledge, in the simulation part of the Muth model, under the assumption of fixed proportions, the same (close to zero) elasticity of substitution is employed between all inputs. With the aim of a precise representation of input substitution with trade between input two (ROW) and three (Canada), a nested CES production function is employed.

If a CES production function exhibits constant elasticity of substitution among inputs, a nested CES production function uses different nests (levels) which allow the introduction of the appropriate elasticity of substitution between inputs. The nested CES production function implies output is a function of inputs and factors shares. Moreover, the nested CES function allow employing the factor shares and the elasticities of

substitution that take a particular value to calculate the specific values of the other elasticities of substitutions (Bovenberg and Goulder 1996, McDougall 2009).

$$Y = A \left[s_4 X_4^{-T} + (s_2 + s_3) \left(\left(\frac{s_2}{s_2 + s_3} \right) X_2^{-R} + \left(\frac{s_3}{s_2 + s_3} \right) X_3^{-R} \right)^{-T/R} + s_4 X_2^{-T} \right]^{-1/T} \quad (4.1)$$

$$T = \frac{\sigma_{14} - 1}{\sigma_{14}} \quad (4.2)$$

$$R = \frac{\sigma_{23} - 1}{\sigma_{23}} \quad (4.3)$$

$$\sigma_{12} = \sigma_{13} = \sigma_{24} = \sigma_{34} = (s_2 + s_3)\sigma_{23} + (1 - s_2 - s_3)\sigma_{14} \quad (4.4)$$

Where Y = output, X_1 = retail services, X_2 = Refining services ROW, X_3 = Refining services Canada, X_4 = crude oil, s_1 = factor share retail services, s_2 = factor share refining services Canada, s_3 = factor share refining services ROW and s_4 = factor share crude oil. σ_{ij} represents the elasticity of substitution between two inputs, while A is a constant efficiency parameter.

The elasticity of substitution values obtained using a nested CES for fixed and variable proportions are presented later.

In the Muth model, the basic equilibrium equations of the variable proportions technology are modeled in a small country assumption considering a competitive industry producing a homogenous product.

$$P = c(w_1, w_2, w_3, w_4, t_1) \text{ market clearing condition (gasoline supply for consumers)} \quad (4.5)$$

$$P = f(y, t_2) \text{ Canadian consumers demand for gasoline} \quad (4.6)$$

$$x_1 = h_1(w_1, w_2, w_3, w_4, t_3)y \text{ demand for retail services} \quad (4.7)$$

$$x_2 = h_2(w_1, w_2, w_3, w_4, t_4)y \text{ demand for refined oil from ROW refineries} \quad (4.8)$$

$$x_3 = h_3(w_1, w_2, w_3, w_4, t_5)y \text{ demand for refined oil from Canadian refineries} \quad (4.9)$$

$$x_4 = h_4(w_1, w_2, w_3, w_4, t_6)y \text{ demand for crude oil} \quad (4.10)$$

$$w_1 = g_1(x_1, t_7) \text{ supply of retail service} \quad (4.11)$$

$$w_2 = g_2(x_2, t_8) \text{ supply of ROW gasoline} \quad (4.12)$$

$$w_3 = g_3(x_3, t_9) \text{ supply of Canadian gasoline} \quad (4.13)$$

$$w_4 = g_4(x_4, t_{10}) \text{ supply of crude oil} \quad (4.14)$$

Table 4-1 introduces the symbols employed in the above equations.

Table 4-1.: Definition of symbols used in the Muth model

f	wholesale demand of gasoline
c	cost function for gasoline
y	quantity of gasoline (final output)
p	price per unit of gasoline
h_i	$h_i = h_{1-4}$ – demand for: retail services (e.g. from gas stations), refining services from ROW, refining services from Canada and crude oil respectively
g_i	$g_i = g_{1-4}$ – supply of: retail services, services from the ROW refineries, services from Canadian refineries and crude oil respectively
w_i	$w_i = w_{1-4}$ – price of: pre-tax gasoline at retail level, refining services from ROW, refining services from Canada and crude oil respectively
x_i	$x_i = x_{1-4}$ – quantity of: gasoline at retail level, refining services from ROW, refining from Canada and crude oil respectively
t_i	$t_i = t_{3-6}$ – exogenous shifter of: demand of retail services, refining services from ROW, refining services from Canada and crude oil respectively $t_i = t_{7-10}$ – exogenous shifter of: supply of retail services, refining services from ROW, refining services from Canada and crude oil respectively t_1 = exogenous shifter of gasoline supply for final use t_2 = exogenous shifter of consumers' final demand

The industry output (y), the price per unit (p), the quantities of the factors used by the industry (x_i), and the factor prices (w_i) are the endogenous variables of the model. The exogenous variables are the t_i variables which illustrate the potential parallel shifts in either supply or demand.

By totally differentiating equations (4.5) to (4.14) we can observe how the endogenous variables react when exogenous variables change. Following mathematical manipulations developed by Muth (1964), Alston et al. (1995), Mullen et al. (1989) and Gray et al. (2000) the above system of equations can be expressed in terms of relative changes and elasticities. The symbols used are defined in Table 4-2.

$$Ep = s_1Ew_1 + s_2Ew_2 + s_3Ew_3 + s_4Ew_4 + Et_1 \quad (4.15)$$

$$Ep = \frac{1}{\eta}Ey + Et_2 \quad (4.16)$$

$$Ex_1 = \eta_{11}Ew_1 + \eta_{12}Ew_2 + \eta_{13}Ew_3 + \eta_{14}Ew_4 + Et_3 + Ey \quad (4.17)$$

$$Ex_2 = \eta_{21}Ew_1 + \eta_{22}Ew_2 + \eta_{23}Ew_3 + \eta_{24}Ew_4 + Et_4 + Ey \quad (4.18)$$

$$Ex_3 = \eta_{31}Ew_1 + \eta_{32}Ew_2 + \eta_{33}Ew_3 + \eta_{34}Ew_4 + Et_5 + Ey \quad (4.19)$$

$$Ex_4 = \eta_{41}Ew_1 + \eta_{42}Ew_2 + \eta_{43}Ew_3 + \eta_{44}Ew_4 + Et_6 + Ey \quad (4.20)$$

$$Ew_1 = \frac{1}{\varepsilon_1}Ex_1 + Et_7 \quad (4.21)$$

$$Ew_2 = \frac{1}{\varepsilon_2}Ex_2 + Et_8 \quad (4.22)$$

$$Ew_3 = \frac{1}{\varepsilon_3}Ex_3 + Et_9 \quad (4.23)$$

$$Ew_4 = \frac{1}{\varepsilon_4}Ex_4 + Et_{10} \quad (4.24)$$

Table 4-2.: Definition of symbols used in the derived Muth model

ε_i	elasticity of supply for each of the levels
η	own price elasticity of demand for gasoline
s_i	cost share of gasoline, refined gasoline from the ROW, refined gasoline from Canada and crude oil
σ_{ij}	elasticity of input substitution
$Ep, Ey,$ Ew_i, Ex_i, Et_i	relative change of gasoline prices, quantity of gasoline for final consumers, input prices, quantities, exogenous shifters

There are a few assumptions essential for solving the mathematics part of the model and rewriting it in elasticities form. One of them is that the production function used is characterized by constant returns to scale. Mullen et al. (1988) explain that this assumption is made to show that the industry cost function is separable between input prices and output. Moreover, equation (4.16) imposes the long run condition that product price equals minimum average total cost. Equations (4.17) to (4.20), which describe the output constrained demands for inputs, are obtained by applying Sheppard's lemma to the total cost functions, and thus, allows cross-price elasticities to be expressed in terms of cost shares and elasticity of substitution.

Previous assumptions and mathematical manipulation of the equations allow writing the system using matrices, as follows:

$$\begin{bmatrix} 1 & 0 & -s_1 & -s_2 & -s_3 & -s_4 & 0 & 0 & 0 & 0 \\ 1 & -1/\eta & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & A_1 & A_5 & A_9 & A_{13} & 1 & 0 & 0 & 0 \\ 0 & -1 & A_2 & A_6 & A_{10} & A_{14} & 0 & 1 & 0 & 0 \\ 0 & -1 & A_3 & A_7 & A_{11} & A_{15} & 0 & 0 & 1 & 0 \\ 0 & -1 & A_4 & A_8 & A_{12} & A_{16} & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & -1/\varepsilon_1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & -1/\varepsilon_2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & -1/\varepsilon_3 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & -1/\varepsilon_4 \end{bmatrix} * \begin{bmatrix} Ep \\ Ey \\ Ew_1 \\ Ew_2 \\ Ew_3 \\ Ew_4 \\ Ex_1 \\ Ex_2 \\ Ex_3 \\ Ex_4 \end{bmatrix} = \begin{bmatrix} Et_1 \\ Et_2 \\ Et_3 \\ Et_4 \\ Et_5 \\ Et_6 \\ Et_7 \\ Et_8 \\ Et_9 \\ Et_{10} \end{bmatrix}$$

Where:

$$\begin{aligned} A_1 &= s_2\sigma_{12} + s_3\sigma_{13} + s_4\sigma_{14}, & A_2 &= -s_1\sigma_{12}, & A_3 &= -s_1\sigma_{13}, & A_4 &= -s_1\sigma_{14}, & A_5 &= -s_2\sigma_{12}, \\ A_6 &= s_1\sigma_{12} + s_3\sigma_{23} + s_4\sigma_{24}, & A_7 &= -s_2\sigma_{32}, & A_8 &= -s_2\sigma_{42}, & A_9 &= -s_3\sigma_{13}, & A_{10} &= -s_3\sigma_{23}, \\ A_{11} &= s_1\sigma_{13} + s_2\sigma_{32} + s_4\sigma_{34}, & A_{12} &= -s_3\sigma_{34}, & A_{13} &= -s_4\sigma_{14}, & A_{14} &= -s_4\sigma_{24}, & A_{15} &= -s_4\sigma_{34}, \\ A_{16} &= s_1\sigma_{14} + s_2\sigma_{24} + s_3\sigma_{34} \end{aligned}$$

Regarding the elasticity of substitution values, in the case of fixed proportions, the inputs' non-substitutability property implies that the elasticity of substitution at all levels

of the vertical market system has very low values, i.e. $\sigma_{ij} = 0.0001$. Thus, for the fixed proportions case, in the nested CES production function all elasticity values are set at 0.0001.

In the case of variable proportions, the main aim is to allow input substitution between Canada and ROW refined gasoline (σ_{23}), by assuming an elasticity of substitution of 10. At the same time, it is assumed that crude oil and final consumption elasticity remain in fixed proportions (σ_{14}), which implies that the elasticity of substitution is 0.0001. Based on these assumptions, employing the nested CES production function (equation 4.4) determines a greater elasticity substitution than in the fixed proportions case for the rest of the inputs. Hence, computing the nested CES production function (equation 4.4) when σ_{23} equals 10 and σ_{14} equals 0.0001 reveal that the values for σ_{12} , σ_{13} , σ_{24} and σ_{34} are 2.2 as illustrated in Table 4-3.

Table 4-3.: Elasticity of substitution values assumed for variable proportions

σ_{ij}	Crude Oil (1)	Canadian refined (2)	ROW refined (3)	Retail Services(4)
Crude Oil (1)		2.2	2.2	0.0001
Canadian refined (2)			10	2.2
ROW refined (3)		10		2.2
Retail Services (4)		2.2		

Source: own calculations

4.3.1 Scenarios and Assumptions of the Model

When the percentage change in the exogenous shifters is known, the matrix format enables the relative changes in the endogenous variables to be calculated. Knowing the elasticities of demand and supply, the elasticity of substitution, the value of the cost shares, the approximate value of the exogenous shifts, Muth model allows obtaining fairly accurate approximations for the endogenous variables and implicitly for the magnitude of producer and consumer surplus along the vertical market system. Table 4-4 introduces the values of the parameters used in the simulations. For the following calculations it is assumed that the price of emitting one ton of carbon dioxide is \$15 per

ton, which is the ceiling price for carbon dioxide that the Government of Canada assured when ratified the Kyoto Protocol. The interpretation of this value is that each ton of emission reductions would produce \$15 worth of avoided damage.

Table 4-4.: Parameter values used in the simulation

	Quantity (billion litres)	Value (billion dollars)	Dollars/ Litre	Factor Shares³⁵	Price Elasticity
Output					
Retail Canadian Gasoline Demand	40.0500³⁶	39.1289	0.9770³⁷		-0.8000³⁸
Pre-tax Retail Demand	40.0500	20.4255	0.5100³⁹	1.0000	-0.4176 ⁴⁰
Factors of production					
Retail Services	40.0500	1.6340	0.0408	0.0800	1.4700⁴¹
ROW Refining	7.2818	0.8170	0.1122	0.0400	2.7700⁴²
Canadian Refining	32.7682	3.6766	0.1122	0.1800	0.2500⁴³
Canadian Crude for Canada	40.0500	14.2979	0.3570	0.7000	1.1000⁴⁴
C02 emissions at \$15/ton					
Gasoline Burning	40.0500	1.3751	0.0343		
ROW Refining	7.2818	0.0437	0.0060		
Canada Refining	32.7682	0.1966	0.0060		

Note: the bold numbers are inputted and form the base assumption. All other numbers are calculated from them to ensure consistency.

Source: own calculations

The cost of carbon dioxide emissions per litre of gasoline burned is calculated as the quantity of GHG emitted when burning one litre of gasoline (2.289 kg of CO₂/litre, Natural Resource Canada 2006) multiplied by the proposed price of emitting one tonne of carbon (\$15/ton of CO₂). The cost of emission reductions from upstream and refining⁴⁵

³⁵ Factor shares are employed in equation (4.15) and in the matrix.

³⁶ Natural Resources Canada (2006).

³⁷ Natural Resources Canada (2006).

³⁸ Gallini (1983), in the model is the own price elasticity of demand. It is employed in equation (4.16).

³⁹ Natural Resources Canada (2006).

⁴⁰ Calculated as the product of the own price elasticity of demand and the pre-tax retail demand divided by the retail Canadian gasoline demand, it is employed in the matrix.

⁴¹ Yang and Hu (1984), employed in equation (4.21) and in the matrix.

⁴² Own calculations. employed in equation (4.22) and in the matrix.

⁴³ Considine (2002), employed in equation (4.23) and in the matrix.

⁴⁴ Krichene (2002), employed in equation (4.24) and in the matrix.

⁴⁵ Value estimated by Nagy and Gray (2006) assuming a value of CO₂ equivalent of \$15 per permit.

(Nagy and Gray, 2006) per litre of crude oil refined (measured in \$/litre), and assumed the same for Canada and ROW, have a similar formula.

$$\text{Emissions Gasoline Burning} = 2.289 \text{ kg/l} * 0.015 \text{ \$/kg} = 0.0343 \text{ \$/l} \quad (4.25)$$

$$\text{Emissions Refining} = 0.04 \text{ kg/l} * 0.015 \text{ \$/kg} = 0.0060 \text{ \$/l} \quad (4.26)$$

4.3.2 Scenario 1 – Fixed Proportions

The first scenario assumes an economy with a fixed proportions technology and hence no (very limited) ability to substitute ROW refining for Canadian refining. It should be mentioned at this point of the analysis that this scenario has an informative aim only, as the results cannot be compared with the variable proportions scenario.

The carbon tax is imposed at two levels in the vertical market system: on the amount of gasoline supplied for final use and at the Canadian processing level for taxing the carbon emitted in the process of refining. Thus, the two exogenous shifts modeled are at t_1 , which is defined as the exogenous shifter of gasoline supply for final use⁴⁶, and at t_9 , which is the exogenous shifter of the Canadian refined gasoline supply. The exogenous shift parameters represent equilibrium displacements relative to an initial equilibrium (Alston, 1991).

The magnitude of the exogenous shift for the gasoline supplied for final use, t_1 , is calculated as the product of the cost of emissions per litre of gasoline burned and the Canadian retail gasoline demand, divided by the value of the pre-tax retail gasoline demand, as follows:

$$\text{Exogenous shift } t_1 = (0.0343 \text{ \$/l} * 40.0500 \text{ bill. l}) / 20.4255 \text{ bill. \$} = 0.067 = 6.7\% \quad (4.27)$$

Similarly, the second exogenous shift at the refineries level, t_9 , is obtained by multiplying the cost of emission reductions from upstream and refining with the quantity of Canadian refined gasoline and divided to the value of Canadian refined gasoline:

$$\text{Exogenous shift } t_9 = (0.0060 \text{ \$/l} * 32.7682 \text{ bill. l}) / 3.6766 \text{ bill. \$} = 0.053 = 5.3\% \quad (4.28)$$

⁴⁶ The motivation for choosing T_1 as an exogenous shifter is that a carbon tax is a per unit tax on the amount of gasoline supplied for final use regardless of the amount of retail services that are embodied in it.

Given that a cap and trade can be implemented only in the upstream of an industry⁴⁷, the second case of the first scenario assumes that a cap and trade policy is introduced at the refiners' level, which is t_9 . Regarding the exogenous shift magnitude at t_9 , the calculation is based on the value of a permit. Thus, it is assumed that a permit's value should embed the amount of carbon emitted in both processes of refining and burning one litre of gasoline, for the proposed price of \$15/ton of CO₂. Hence, the exogenous shift magnitude at the refiners' level is obtained by dividing the value of a permit to the refining margins:

$$\text{Exogenous shift } t_9 = (0.0343 \text{ \$/l} + 0.0060 \text{ \$/l}) / 0.0918 \text{ \$/l} = 0.439 = 43.9\% \quad (4.29)$$

Further in the investigation, the Muth model is developed with the aim of calculating the magnitude of producer and consumer surplus based on the percentage and relative changes (Mullen et al. 1989, Alston et al. 1995). Moreover, according to Mullen et al. (1989), the sum of these formulas represents the total change of the industry from an initial equilibrium to a future one. Both papers mentioned specifically that the surplus measures are correct if assuming linear supply and demand functions and parallel shifts of the curves as a result of the exogenous shifts.

$$CS = py(Et_1 - Ep)(1 + 0.5Ey) \quad (4.30)$$

$$PS1 = w_1x_1(Ew_1 - Et_7)(1 + 0.5Ex_1) \quad (4.31)$$

$$PS2 = w_2x_2(Ew_2 - Et_8)(1 + 0.5Ex_2) \quad (4.32)$$

$$PS3 = w_3x_3(Ew_3 - Et_9)(1 + 0.5Ex_3) \quad (4.33)$$

$$PS4 = w_4x_4(Ew_4 - Et_{10})(1 + 0.5Ex_4) \quad (4.34)$$

⁴⁷ As previously mentioned, cap and trade policy was designed to be implemented in the upstream of an industry; the implementation of this policy in the downstream may lead to administrative issues due to the very high transaction costs involved.

4.3.2.1 Scenario 1 – Carbon tax versus cap and trade when input substitution is not allowed – impacts on prices and quantities

The aim of this scenario is to reveal the changes in prices, quantities, welfare and cost of emissions along the vertical market system under the assumption of input non-substitutability. Table 4-5 compares the results of introducing a carbon tax versus a cap and trade policy under the assumption of input non-substitutability. The table presents the parameter values used for each of the simulation case, the exogenous shifts for each scenario and the changes in prices and quantities that occur along the system as a result of implementing each of the policies under fixed proportions.

Table 4-5: Changes in prices and quantities for a carbon tax and a cap and trade policy under fixed proportions

Parameters	Fixed prop.	Fixed prop.
Own price elasticity of demand	-0.418	-0.418
Elasticity of supply retail services	1.470	1.470
Elasticity of supply ROW refinery	2.770	2.770
Elasticity of supply Canada refinery	0.250	0.250
Elasticity of supply crude oil	1.100	1.100
S1 = Factor share retail services	0.080	0.080
S2 = Factor share ROW refined	0.040	0.040
S3 = Factor share Can. refined	0.180	0.180
S4 = Factor share of crude oil	0.700	0.700
Elast. of substit. between crude – final consumption levels	0.0001	0.0001
Elast. of substit. between ROW – Canada refineries	0.0001	0.0001
Policy Instruments (exogenous shifts)	Carbon tax	Cap and trade
Consumer Carbon tax (%) - t_1 : consumer level (in \$/l this is 0.0343)	0.067	0.000
Refiner Carbon tax (%) - t_9 : refinery level (in \$/l this is 0.006)	0.053	0.000
Refiner carbon trading Permit value (%) - t_9 : refinery level (in \$/l this is 0.0403)	0.000	0.439
Price and Quantity Impacts		
Change in pre-tax gasoline price ⁴⁸ for final consumption (%)	4.824%	4.953%
Change in the quantity of gasoline final consumption (%)	-2.014%	-2.068%
Change in price of retail services (%)	-1.370%	-1.407%
Change in price refining services ROW (%)	-0.727%	-0.746%
Change in price refining services Can. (%)	-2.710%	35.615%
Change in price of crude oil (%)	-1.831%	-1.880%
Change in retail services (%)	-2.015%	-2.068%
Change in quantity refined oil from ROW (%)	-2.015%	-2.068%
Change in quantity refined oil from Canada (%)	-2.014%	-2.071%
Change in quantity of crude oil (%)	-2.014%	-2.068%
Change in CO ₂ from burning (%)	-2.014%	-2.068%
Change in CO ₂ from Can. refining (%)	-2.014%	-2.071%
Change in CO ₂ from ROW refining (%)	-2.015%	-2.068%

Source: own calculations

⁴⁸ The pre-tax gasoline price refers to the price of gasoline before the provincial, sales or transit taxes.

The simulation values for the two policies are relatively close, though not identical, as the elasticity of substitution assumed was not zero and because of rounding the values obtained. If, in the present Muth model, it is assumed that the elasticity of substitution is zero, the simulation results are zero, and thus not-representative. This is the reason why it was decided to employ a value close to zero. For an elasticity of substitution of 0.0001, introducing a carbon tax at the consumers' and refiners' level implies an increase in the pre-tax gasoline price and a decline in the quantity of gasoline for final consumption. Except for the final retail price, all prices fall as a result of the drop in the demand. Consistent with the fixed proportions assumption, the change in the quantity of inputs used decreases proportionally along the vertical market system.

A cap and trade policy implies similar results to a carbon tax even though the magnitude of the exogenous shift at the refiners' level is much higher for a cap and trade policy versus a carbon tax. One notable exception is the Canadian price of refining services which, as a result of introducing a cap and trade policy only at Canadian refineries' level, increases by a considerably large amount (35 percent). Relating the results of this scenario with previous literature findings, Freebairn et al. (1983) conclude that the distribution of benefits within the vertical market system is independent of where the innovation applies in the system. The scenario presented above confirms this finding, in the sense that the distribution of surplus within the vertical market system is independent on where the exogenous shift occurs in the system.

4.3.3 Scenario 2 – Variable Proportions

The goal of Scenario 2 is to determine the impact of the two policies on prices and quantities, the economic welfare redistribution within the system and the environmental impact when input substitution is allowed. Hence, the carbon tax and the cap and trade policy are introduced at the same levels and with the same magnitude as in the previous scenario.

In this scenario the difference consists in setting the elasticity of substitution between crude oil and final consumption (σ_{14}) to 0.0001, which means that no

substitution is allowed between these levels, while allowing substitution between refined gasoline from Canada and ROW (σ_{23}) with a value of 10. Other substitution values were considered during the simulation process, but given the pattern in the results, they were not considered significant. As in the previous scenario, the carbon tax is imposed at two levels in the vertical market system: on the amount of gasoline supplied for final use (t_1) and at the Canadian processors level for taxing the carbon emitted in the process of refining (t_9). Meanwhile, the cap and trade policy is introduced only at the refiners' level (t_9).

4.3.3.1 Scenario 2 - Carbon tax versus cap and trade when input substitution is allowed – impacts on prices and quantities

Table 4-6 presents the impact of introducing a carbon tax versus a cap and trade policy on prices and quantities along the vertical market system under the assumption of input substitutability. The table presents the parameter values used for each of the simulation case, the exogenous shifts for each scenario and the changes in prices and quantities that occur along the system as a result of implementing each of the policies when input substitution is allowed at the refining level.

Table 4-6: Changes in prices and quantities for a carbon tax and a cap and trade policy under variable proportions

Parameters	Var. prop.	Var. prop.
Own price elasticity of demand	-0.418	-0.418
Elasticity of supply retail services	1.470	1.470
Elasticity of supply ROW refinery	2.770	2.770
Elasticity of supply Canada refinery	0.250	0.250
Elasticity of supply crude oil	1.100	1.100
S1 = Factor share retail services	0.080	0.080
S2 = Factor share ROW refined	0.040	0.040
S3 = Factor share Can. refined	0.180	0.180
S4 = Factor share of crude oil	0.700	0.700
Elast. of substit. crude – final consumption levels	0.0001	0.0001
Elast. of substit. between ROW – Canada refineries	10.000	10.000
Policy Instruments (exogenous shifts)	Carbon tax	Cap and trade
Consumer Carbon tax (%) - t_1 : consumer level (in \$/l this is 0.0343)	0.067	0.000
Refiner Carbon tax (%) - t_9 : refinery level (in \$/l this is 0.006)	0.053	0.000
Refiner carbon trading Permit value (%) - t_9 : refinery level (in \$/l this is 0.0403)	0.000	0.439
Price and Quantity Impacts		
Change in pre-tax gasoline price final consumption (%)	4.941%	1.747%
Change in the quantity of gasoline final consumption (%)	-2.063%	-0.730%
Change in price of retail services (%)	-1.490%	0.773%
Change in price refining services ROW (%)	-1.348%	1.653%
Change in price refining services Can. (%)	-1.842%	5.288%
Change in price of crude oil (%)	-1.838%	0.953%
Change in retail services (%)	-2.190%	1.136%
Change in quantity refined oil from ROW	-3.733%	4.579%
Change in quantity refined oil from Canada (%)	-1.797%	-9.653%
Change in quantity of crude oil (%)	-2.022%	1.049%
Change in CO ₂ from burning (%)	-2.063%	-0.730%
Change in CO ₂ from Can. refining (%)	-1.797%	-9.653%
Change in CO ₂ from ROW refining (%)	-3.733%	4.579%

Source: own calculations

The results illustrate that for carbon tax, given the increase in the final price of gasoline and the drop in the demand at the final level, the prices for refining services decrease. Under the assumption of a higher elasticity of substitution for the ROW, the change in price of refining services ROW is lower than the corresponding price change in Canada. As a result, this makes Canadian refining services more competitive (in the sense that services are cheaper than in ROW) and thus retailers substitute away from the ROW refining services. As far as the quantity supply at the refinery level is concerned, due to the decreased demand at the final level, the quantity supplied will drop. This decline will be higher for the ROW compared to Canada because of the lower adjustment in the ROW refining prices, as shown above.

Comparing the two policies, for cap and trade the pre-tax gasoline price increase is significantly lower compared to the carbon tax case, namely, less than 40 percent of the price increase after introducing a tax. The reason for this lower value is the absence of a GHG emission reduction policy at the final consumers' level. As a result, the drop in the quantity of gasoline consumed is lower than under a tax.

Turning to the prices at the refining level, implementing a cap and trade policy leads to a significant increase in the price of Canadian refining services. In contrast, in the carbon tax case, the price impact is determined not only by the tax at refiners' level, but also by the decline in the final demand due to the simultaneous tax at consumers' level. This is the reason why, for the carbon tax, the Canadian refining services price decreases, while for a cap and trade policy it increases significantly. As a result of this price increase, the demand for Canadian refined oil decreases. As retailers have the option to substitute Canadian refined oil with cheaper ROW oil, the demand for ROW oil increases. Thus, the new equilibrium corresponds to a lower quantity of Canadian refined oil, higher quantity of ROW refined oil and higher refineries' prices, particularly for Canada.

The last three rows of Table 4-6 show the percentage change in carbon dioxide from gasoline burning, as well as Canadian⁴⁹ and ROW refining. With this respect, the most efficient policy is the carbon tax, as it reduces CO₂ released from gasoline burning the most. Indeed, numerically, the highest percentage reduction belongs to the cap and

⁴⁹ Total Canadian GHG emissions in 2009: 690,000 kt CO₂, out of which, fossil fuel production and refining, petroleum refining and upgrading, fossil fuel production, and fugitive sources oil amount to 133,530 kt CO₂ (Environment Canada, 2011).

trade policy effects, at the refiners' level, but it should be noted that the bulk of CO₂ emissions are released from gasoline burning⁵⁰, and not from crude oil refining. Further calculations on emissions reduction are presented in the following section.

4.3.3.2 Carbon tax versus cap and trade when input substitution is allowed – impacts on welfare and cost of emissions

This table illustrates the welfare changes along the vertical system, revenues, rents and cost of emissions changes that carbon tax and cap and trade policies determine under the assumptions of input substitutability.

Table 4-7: Welfare and emission changes for a carbon tax and a cap and trade policy when input substitution is allowed

	Variable prop.	Variable prop.
Welfare Impacts (\$ millions)	Carbon tax	Cap and trade
Change Consumer Surplus	-998,817	-355,524
Change Producer Surplus Retail	-24,081	12,698
Change in Producer Surplus ROW Refining	-10,806	13,816
Change in Producer Surplus Canadian Refining	-261,961	-1,351,102
Change in Producer Surplus Canadian Crude Oil	-260,145	137,003
Change in Private Surplus Canada	-1,545,003	-1,556,923
Change in Canadian Tax Revenue	1,539,818	0
Change in Permit Value	0	1,458,220
Change in Canadian Market Surplus	-5,185	-98,704
Change in the Cost of Emissions Canada	-31,908	-29,011
Change in the Cost of Emissions ROW	-1,631	2,001
Change in the Global Cost of Emissions	-33,539	-27,010
Change in Welfare Canada	26,723	-69,693
Change in Welfare ROW	-9,175	11,815
Change in Welfare World	17,548	-57,877
Tons of Global GHG Reduction per \$ of Canadian Cost	-0.4312	-0.0182
Economic Cost per Ton of Carbon	0.0036	0.0312

Source: own calculations

The analysis of the welfare distribution for a carbon tax reveals that Canadian consumers are the most affected, followed by Canadian refiners and Canadian crude oil

⁵⁰ Approximately 80 percent of GHG emissions are produced from gasoline burning; the rest of 20 percent of emissions is produced from crude production, refining, transportation and distribution, Keesom et al., 2009 (p. 2).

producers. The consumers' surplus reduction has a high value as consumers have to reduce consumption while at the same time having to pay a higher price. Canadian refiners and crude oil producers lose a large amount of surplus as they have to lower their supply and also charge a lower price. By adding up the surplus at each of the vertical market levels for the Canadian market, *Canadian Private Surplus* is obtained. Its value is negative due to the surplus loss at each level, while the main component of the *Canadian Private Surplus* is the consumer surplus loss amount.

As expected from the price and quantity changes, when inputs have a high degree of substitutability, the welfare distribution for a cap and trade policy is different than the previous case. Canadian refiners experience a substantial welfare loss, while consumers' surplus loss amounts to about one third of the corresponding loss under a carbon tax. The reason for refiners' significant surplus loss is due to the sharp decline in the quantity of gasoline supplied. Consumers lose less than in the carbon tax case as the change in equilibrium price and consumption levels is not as high. At the same time, all other producers gain as a result of introducing the cap and trade policy. Crude oil producers have a positive surplus in this case as under a higher crude oil price they have the incentive to produce more and turn to export for the excess supply.

However, a carbon tax creates additional financial benefits, namely the carbon tax revenue. The *Change in Tax Revenue* that the government collects after introducing the carbon tax is calculated as follows:

$$\begin{aligned} \text{Change Canadian tax revenue} = & T1 * \text{value of Canadian pre-tax retail demand} * \\ & (1 + \text{change in quantity of gasoline for final consumers}) + T9 * \\ & \text{value of Canadian refined gasoline} * (1 + \text{change in quantity of Canadian refined}) \end{aligned} \quad (4.35)$$

Further, by adding up the Change in Private Surplus Canada and the Change in Canadian Tax Revenue, the Change in the Canadian Market Surplus is determined.

Regarding the calculation of financial benefits for a cap and trade policy, as graphically shown in Chapter 3, there is rent creation at policy's level of enforcement, which is the Canadian refiners' level. Employing an analogous formula as in the carbon tax case, the magnitude of producers' rents is calculated as:

$$\text{Change in permit value} = T9 * \text{value of Canadian refined gasoline} * (1 + \text{change in quantity of Canadian refined gasoline}) \quad (4.36)$$

Comparing the two policies, a cap and trade policy under variable proportions generates lower rents for refiners than the revenue captured under carbon tax.

Based on the above result and the *Change in Private Surplus Canada*, the *Change in Canadian Market Surplus* can be computed by adding up the two values. Input substitution availability for a cap and trade policy is associated with a significant loss in the *Canadian Market Surplus*, while the loss registered for carbon tax has much lower values.

Further in the investigation, insights about the environmental impact and efficiency of the two policies can be obtained using the results and data available. The *Change in Cost of Emissions* after implementing both policies, for Canada and the ROW respectively, can be calculated employing the following formulas:

$$\begin{aligned} \text{Change in cost of emissions Canada} = & \text{change in quantity of gasoline} \\ & \text{for final consumers} * \text{value of emissions from gasoline burning} + \\ & \text{change in quantity of Canadian refined gasoline} \\ & * \text{value of emissions from Canadian gasoline refining} \end{aligned} \quad (4.37)$$

$$\begin{aligned} \text{Change in cost of emissions ROW} = & \text{change in quantity of gasoline refined by ROW} \\ & * \text{value of emissions from ROW gasoline refining} \end{aligned} \quad (4.38)$$

Hence, the *Change in the Global Cost of Emissions* is the sum of emissions costs in Canada and the ROW. It should be noted that for a cap and trade policy there is a lower reduction in cost of emission. The rationale is that, although there is a much higher decline in the quantity of emissions at refiners' level, this effect is outweighed by the higher emissions from gasoline burning at consumers' level.

Comparing the cost of emissions in the ROW, in the case of a tax, a lower amount of GHG emissions is emitted due to the lower ROW supply in Canada. The opposite is true for a cap and trade policy where more emissions are released for the higher production supplied in Canada.

In turn, when calculating the change in the *Global Cost of Emissions*, the ROW values and the higher quantity of gasoline demanded by Canadian consumers imply a larger gap between the two policies. However, it is important to point out that by introducing any GHG emissions reduction policy, Canada would price carbon dioxide and Canadian emissions would be mitigated, but when the ROW does not have a similar carbon reduction policy in place, there are still going to be carbon emissions someplace else when refining crude oil. At the same time, carbon from burning gasoline will still be emitted in Canada, being released into the atmosphere by burning the gasoline supplied by the ROW countries.

Based on these results, Changes in Welfare for Canada can be further calculated by adding up the Change in Private Surplus Canada and the Change in Canadian Tax Revenue, and subtracting from the result the Change in the Cost of Emissions Canada. Similar calculations are undertaken for determining the Change in Welfare for ROW. As expected, the Change in Welfare World sums up the former and the latter changes.

The welfare distribution results of the policies are presented in Figure 4-2. *Canadian Private Surplus* is negatively affected by introducing any of the GHG emission reduction policies. However, the higher loss in *Canadian Market Surplus* is determined by the cap and trade policy because of the lower rents that refiners capture in this scenario. At the same time, Figure 4-2 illustrates that *Consumer Surplus* is more negatively impacted when a carbon tax is implemented.

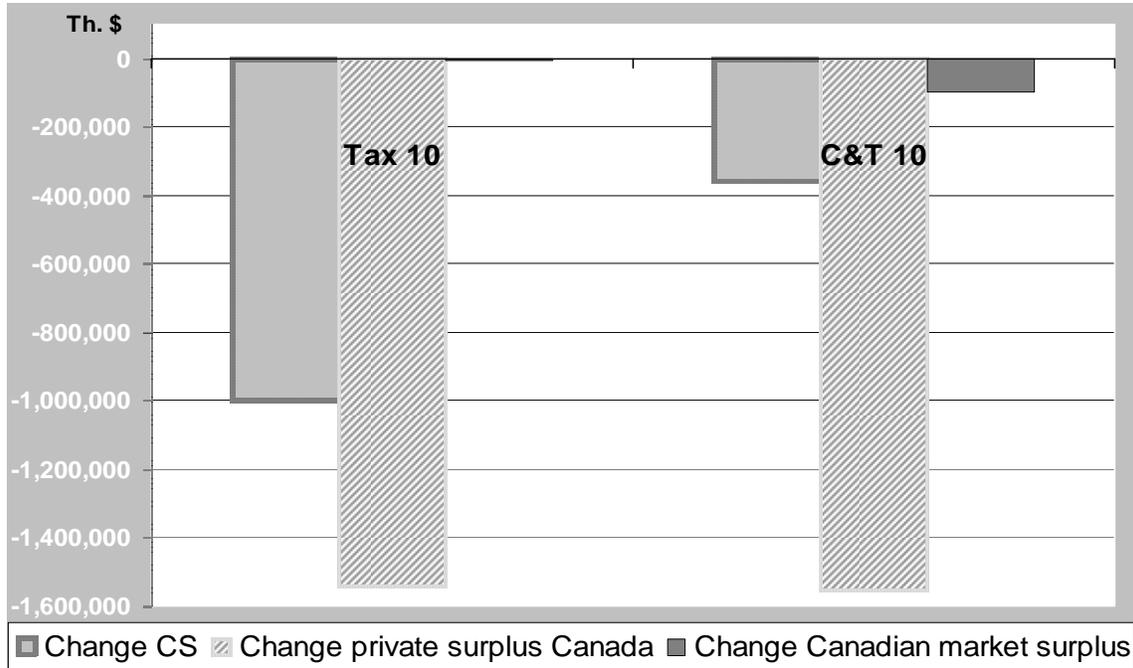


Figure 4-2.: Welfare changes for carbon tax and cap and trade policies under variable proportions

Given that the Canadian welfare is negatively impacted by the cap and trade policy and that the same policy creates positive surplus for the ROW countries, it is not surprising that the global loss is negatively affected. When comparing a carbon tax and a cap and trade policy, it is the cap and trade policy that generates the loss in the global welfare, while when a carbon tax is implemented there is a surplus in world welfare.

The coefficients computed up to this point allow calculating the *Tons of Global GHG Emissions Reductions per Dollars of Canadian Cost*. This value is obtained by dividing the *Change in the Global Cost of Emissions* to 15 \$/ton and dividing again the result to the *Change in Canadian Market Surplus*. The results illustrate the reduction in tons of GHG emissions per dollars of Canadian cost, e.g. for carbon tax, there is a reduction of 0.4312 tons of carbon per dollar of Canadian cost, while for a cap and trade policy the reduction is of 0.0182 tons of carbon per dollar of Canadian cost.

As a reciprocal of this formula, the *Economic Cost per Ton of Carbon* is further computed as the ratio of the *Change in Canadian Market Surplus* and the quantity of emissions reductions from burning and refining. In the same line with the above

coefficient, the values obtained reveal that the most efficient policy is carbon tax when input substitution is possible.

4.3.4 Sensitivity Analysis

The following graphical illustrations aim at comparing the impacts of the two policies analyzed for various elasticity of substitution values. Simulation analysis is performed for observing policies' impact on welfare and cost of GHG emissions when the industry gradually opens to trade; hence, the elasticity of substitution takes values from 0.0001 to 10. In the simulations performed, still a modest substitution is allowed between crude oil and retail services ($\sigma_{14} = 0.0001$), while gradually higher values are considered for illustrating the opportunity of more trade taking place between Canadian and ROW refined gasoline (i.e. σ_{23} takes values from 0.0001 to 10).

Figure 4-3 presents the response of the Canadian crude oil/refining market to introducing a carbon tax, when the elasticity of substitution takes values from 0.0001 to 10 between Canada and ROW. Although there is little variation in the results, given that a similar graphical illustration for cap and trade policy follows, the aim of this figure is to highlight the different impacts of the two policies for the current assumptions.

In Figure 4-3, the losses of Canadian crude oil suppliers and refiners are in a close range value when the system moves from fixed to variable proportions. However, for elasticity of substitution values higher than 1, the results overlap, which illustrate that when more trade takes place, the more the surplus loss of Canadian crude oil producers and the better off the Canadian refiners. Meanwhile, for very low or very high elasticity of substitution values, *Consumer Surplus* has large negative values which decrease slightly when more input substitution is allowed. In contrast, although with significant negative values, the *Change in Private Surplus* is insensitive to increasing values of elasticity of substitution, mainly because of the Canadian refiners' surplus increase.

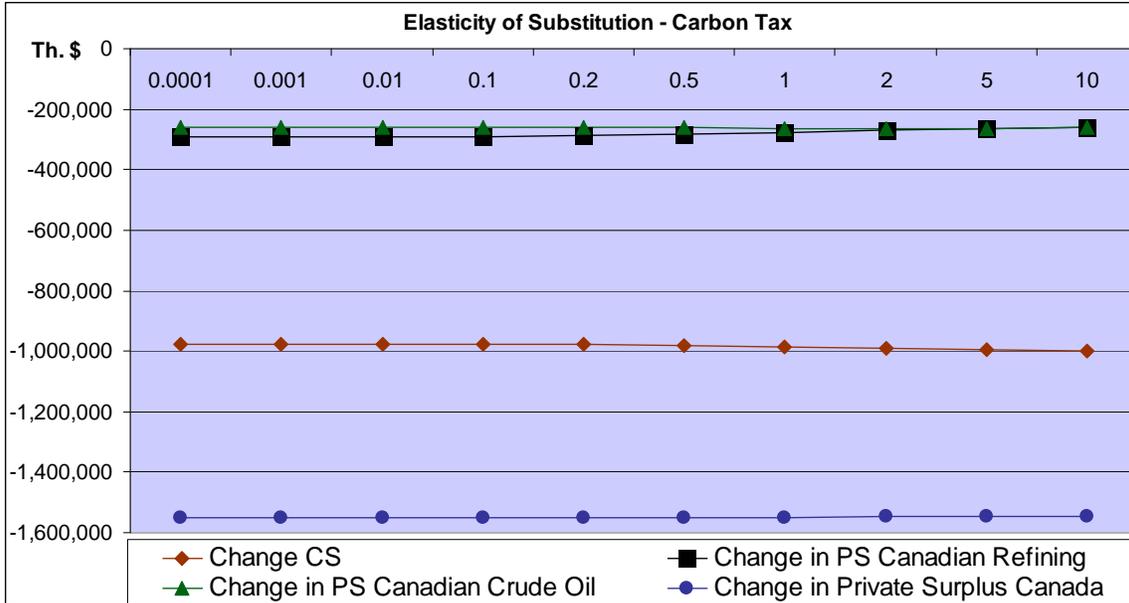


Figure 4-3.: Welfare effects of carbon tax when the elasticity of substitution ranges between 0.0001 and 10

The same simulations are performed in the case of a cap and trade policy, as illustrated on Figure 4-4. Welfare distribution is very differently impacted by this policy when compared to carbon tax. Thus, implementing a cap on emissions at refiners' level only leads to a large surplus for consumers and crude oil producers when trade is gradually allowed in the system. For the same elasticity of substitution values, Canadian refineries are the most drastically affected, with a substantial surplus loss under variable proportions. However, the *Change in Private Surplus* trend illustrates that this effect is outweighed by the increase in consumers and crude oil producers gain.

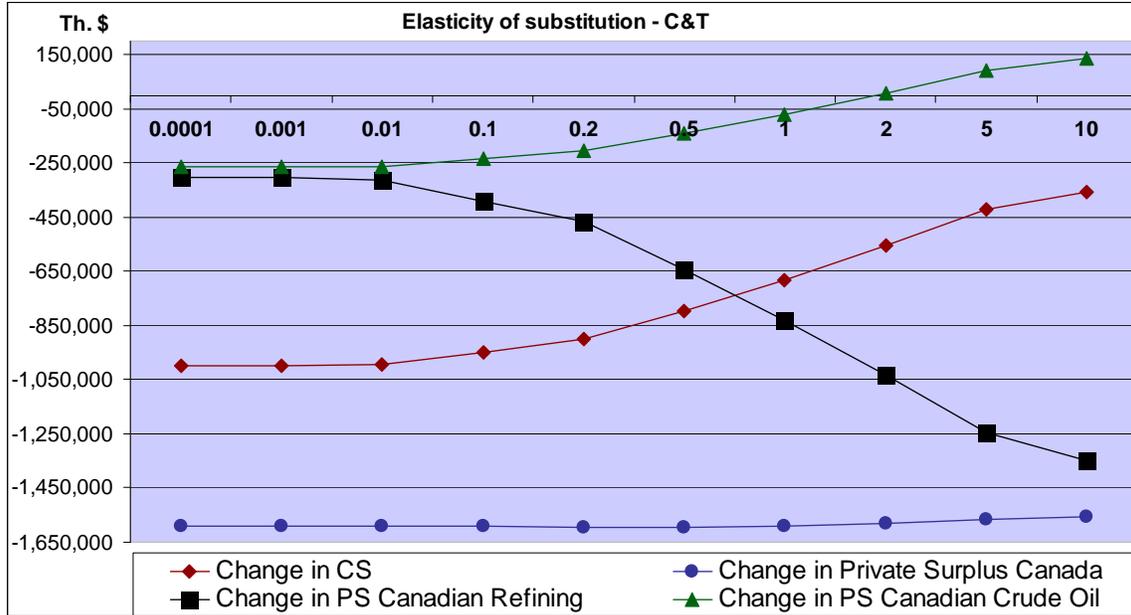


Figure 4-4.: Welfare effects of a cap and trade policy when the elasticity of substitution ranges between 0.0001 and 10

Regarding the environmental impact, the changes in *Canadian* and *Global Cost of Emissions* for both policies are presented in Figure 4-5. The figure illustrates the superiority of carbon tax policy, particularly when input substitution is high. In the case of a carbon tax, when more trade is allowed in the system, the cost of Canadian carbon emissions monotonically decreases. The decrease in the *Global Cost of Emissions* is sharper, given that it accounts for the ROW cost of emissions as well. Meanwhile, for a cap and trade policy, the change in *Canadian* and *Global Cost of Emissions* has a substantial upward trend when input substitution is gradually allowed.

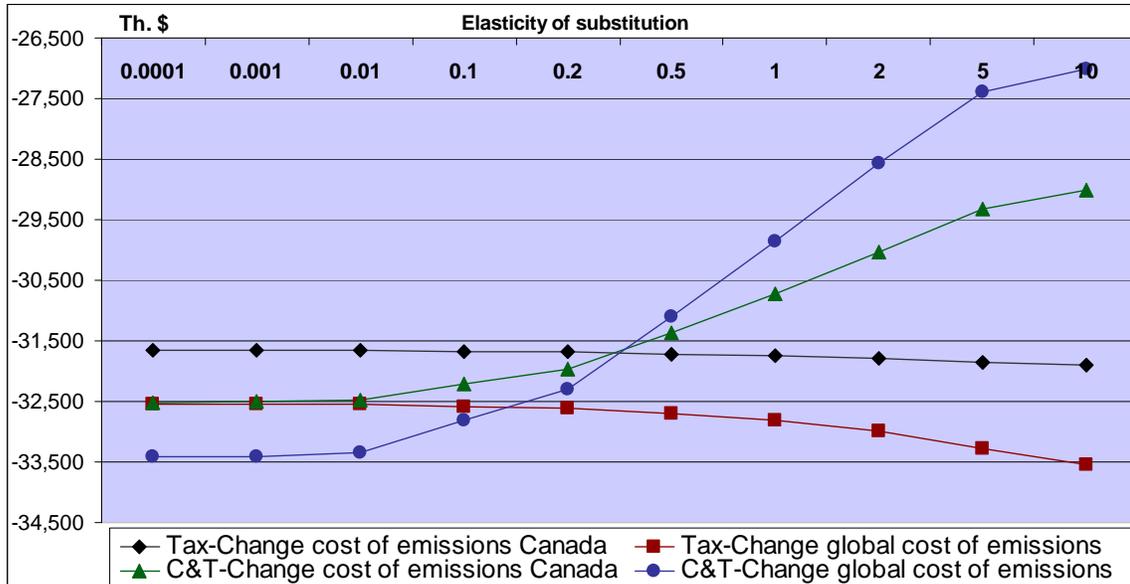


Figure 4-5.: Environmental benefits of carbon tax and cap and trade policies in Canada and ROW when the elasticity of substitution ranges between 0.0001 and 10

Further in the investigation, Figure 4-6 shows the elasticity of substitution values impact on the Canadian and global welfare for both carbon tax and cap and trade policies. Once again, carbon tax is preferred over cap and trade, as more trade determines higher and steadily increasing welfare values for a tax, while there is a significant drop in welfare determined by a cap and trade policy.

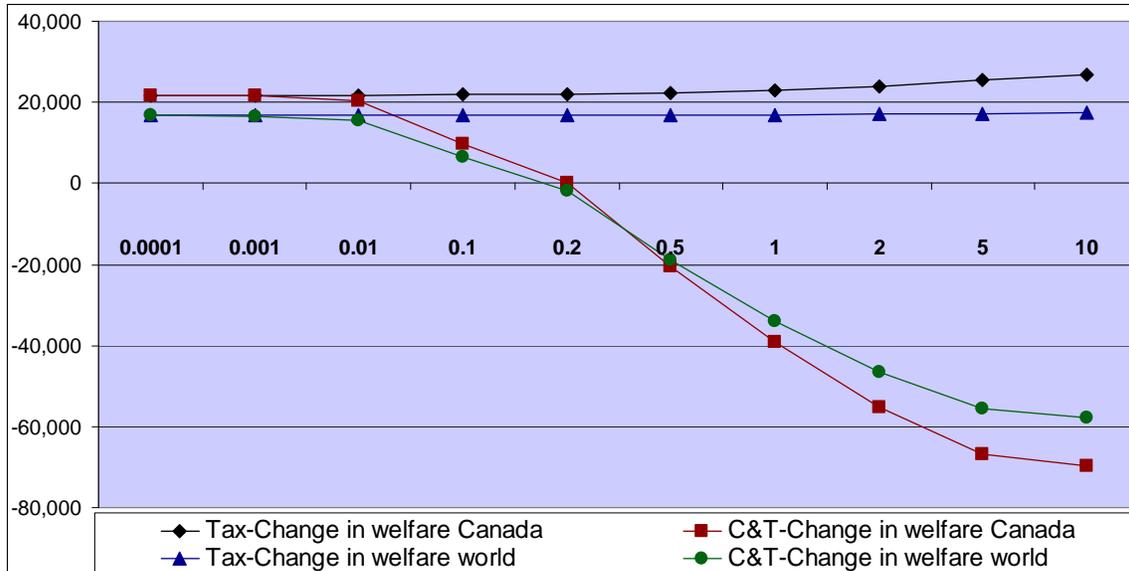


Figure 4-6.: Net benefits of carbon tax and cap and trade policies in Canadian and ROW when the elasticity of substitution ranges between 0.0001 and 10

In conclusion, from the simulations and graphically illustrations performed, the above results reveal that, under free trade, when weighing the effects of welfare distribution and GHG emission reductions, a carbon tax is a preferred instrument for reducing GHG emissions. The sensitivity analysis performed also reveals that the results obtained are consistent with the findings of Alston and Scobie (1983) and Mullen et al. (1988) as higher values of the elasticity of substitution impact differently the prices, quantities and implicitly surplus distribution within the vertical market system. Moreover, consistency of results with Alston (1991) can be extrapolated under input substitution possibility as the incidence of carbon tax on total surplus (either Canadian or world) differs from the incidence of cap and trade.

4.4 Conclusions

The results of the simulations illustrate two major points. To begin with, the analysis of the impacts of a carbon tax and a cap and trade policies on prices, quantities and welfare distribution of firms in a closed economy are similar. Hence, the Muth model and the simulations developed in this chapter confirm the Chapter 3 results: in a closed economy a cap and trade policy and a carbon tax are quasi-equivalent.

In the second scenario, when the elasticity of substitution is assumed to be 10, consumer surplus is negatively affected in both scenarios, more seriously for a carbon tax than for the cap and trade. However, the difference between these policies is that a carbon tax can be designed as revenue neutral, which means that the government can keep little, if any, of the revenue raised by taxing carbon. The government can return this money to the consumers through direct rebates or decide that other taxes be reduced. Although, under limited trade, the two policies have a close value for the consumer surplus loss, their trends are opposite when more trade is allowed. Thus, when the elasticity of substitution takes values from 0.0001 to 10, carbon tax implies an insignificant decrease of consumer surplus. Meanwhile, cap and trade implies a considerable reduction in consumer surplus loss.

With regards to producer surplus for cap and trade policy, in contrast with carbon tax, a higher degree of substitution between inputs increases the Canadian refineries loss. Moreover, the more trade is allowed, the higher the ROW surplus. This shows that when inputs and final outputs are traded with countries that do not have a similar policy in place, a cap and trade instrument is harmful for the domestic industry, while dirty foreign firms increase output and surplus to the detriment of the domestic industry. Therefore, in a free trade world, implementing a cap and trade policy with the aim of stabilizing the level of GHG emissions is not an efficient policy as long as foreign input substitutes are available.

Regarding the GHG emissions mitigation, a carbon tax is a preferred instrument over a cap and trade policy for its ability to reduce more GHG emissions and at a much lower economic cost per ton of emissions. The issue remains that, under free trade, for this specific product with a relatively inelastic demand, consumers have the option to buy the gasoline from the ROW and still emit almost the same amount of GHG. For this

particular industry, the results of the current analysis illustrate that cap and trade is not an efficient instrument to mitigate GHG emissions due to its very high cost and low quantity abated.

Whether carbon tax or cap and trade represent the solution for mitigating GHG emissions have polarized the literature and the mass-media all over the world. Metcalf (2009), Nordhaus (2006), Stavins (1995, 2008) and others support the effectiveness of carbon tax, while Keohane (2009), Murray et al. (2008), Ellerman and Buchner (2007) argue in favour of cap and trade. Regarding carbon tax impacts on fossil fuels, Goulder (1995) highlights that carbon tax distortions depend on the level of prior taxes on or existing subsidies to these fuels (p. 273). Therefore, the cost efficiency of a carbon tax is impacted by how carbon tax revenues are used and the nature of pre-existing taxes. For instance Metcalf (2007[2]) estimates that a tax of \$15 per metric ton of CO₂ will increase the petroleum products price by 13% and this tax will be passed on other industries where petroleum products represent inputs. The cap and trade effects on the US petroleum industry confirm some of the findings of this chapter (EPRINC, 2008). The authors of the report identify that a cap and trade would increase the costs of energy intensive inputs and petroleum firms would not be able to pass on all the increase, particularly if there is possibility to substitute from foreign sources. Moreover, other adverse effect identified when implementing a cap and trade refer to a reduced demand for petroleum products. At the same time, the authors acknowledge that the emission permits distributed to the domestic petroleum firms may represent “opportunities to profit” (p. 21). Last, but not the least, Paltsev et al. (2007) point out that how much of the mitigating cost is passed on to consumers depends on the elasticities of supply and demand for various goods and services. The results of this chapter illustrate that in the current framework that employs a Muth model and data from a particular industry, a carbon tax performs better than a cap and trade.

As a possible solution to the above results, if cap and trade is the instrument of choice to mitigate GHG emissions in Canada, there will be more significant emission reduction if Canada would consider imposing border tariffs adjustments (BTAs). In this respect, Neuhoff (2007) discusses various industries particularities and challenges and argues for a free permit allocation for certain sectors along with considering BTAs for

other sectors so as to prevent carbon leakage. As Chapter 2 outlines, BTAs have been a controversial import measure under the WTO/GATT (General Agreement of Tariffs and Trade) rules and still it is not clear whether and which policy format can be implemented. Moreover, by imposing BTAs to its trading partners, Canada can achieve real GHG emission reductions without harming its economy. The revenue raised from BTAs can be used towards climate change funds, investment in less emission intensive technology, GHG mitigating actions, etc. However, introducing cap and trade in the absence of BTAs gives this policy the status of second best instrument of choice due to its lack of efficiency in redistributing industry surplus and achieving real emission reductions.

Furthermore, when Canadian producers lose surplus as a result of implementing a cap and trade mechanism and this surplus is directed to dirty foreign industries, Canadian firms may have the incentive to sell their business and emission permits, and relocate to other jurisdictions which are not as strictly regulated for reducing their GHG emissions. In practice, this situation is experienced by certain European industries and companies which threaten to relocate if they do not receive enough permits for free to cover the expenses undertaken for emissions reduction (Neuhoff et al., 2007). However, these circumstances are valid for certain industries, and the relocation decision depends on the degree of exposure to trade, the specificity of the industry (whether it is an emission intensive industry), as well as on the market structure.

Regarding carbon tax implementation effects outside the framework of this model – in the real world, it is interesting to note that, a \$15/ton of CO₂ carbon tax, which means additional 3.5 cents/litre of gasoline (Metcalf, 2007[2]) has led to many arguments and much opposition. Meanwhile, the price fluctuation, as well as the steady increase in the gasoline price (approximately 30 cents/litre price increase⁵¹ in the interval 2007-2011) seems to be much more easily accepted by consumers.

So far, the results of this research acknowledge the environmental and economic trade offs that a social planner has to consider when deciding which policy to implement for achieving real emissions reductions. However, it is obvious that under strict environmental regulations industrial flight may represent a solution for certain industries. The outcome of the present investigation illustrates that extending a cap and trade system

⁵¹http://www.torontogasprices.com/retail_price_chart.aspx?city1=Toronto&city2=USA%20Average&city3=Canada%20Average&crude=n&tme=60&units=ca

without other accompanying measures such as a BTA, it may not be the much sought after panacea of GHG emission reductions.

In this context, the next chapter explores firms' incentives to relocate to less severely regulated jurisdictions using the comparison of a cap and trade policy versus an emissions intensity one.

CHAPTER 5

RELOCATION INCENTIVES IN THE PRESENCE OF CAP AND TRADE VERSUS EMISSION INTENSITY

5.1 Introduction

The previous chapter indicates that, under free trade, the two different GHG emission reduction policies can lead to different economic welfare distribution effects. In practice, the ongoing experience of European policy makers regarding the cap and trade policy warns that the design of such a policy and the implementation details, such as the number of permits allocated per industry, may lead firms to either gain financial advantage or to lose market share and profits. Furthermore, heavy industries in Europe (e.g. aluminium, steel, etc.) under climate change legislation threatened the European Commission with relocation to countries with less strict environmental policy if they did not receive free emission rights (European Commission, 2008).

Thus, industry relocation becomes a policy consideration as long as the stringency and form of GHG emission reduction policies implemented across countries are so different that they create incentives for firms to move to jurisdictions with less strict environmental regulations. This consideration particularly applies to the cap and trade system which creates additional incentives to relocate due to firms' ability to trade the emission permits allocated.

In this context, this chapter explicitly considers firms' incentives to relocate when the regulator has the option to implement either a cap and trade policy or an emission intensity one. The choice of the two policies is motivated by the fact that the Canadian government has chosen to implement an emission intensity trading system, but intends to change to cap and trade in the 2020-2025 interval. The Canadian emission intensity rates are capped per unit of production and can be traded both domestically and internationally⁵². Meanwhile, the US considered a cap and trade system as the main policy for GHG emissions reductions. China, like Canada, has indicated it will implement an intensity regulation.

⁵² Intensity caps are established through a baseline-and-credit system, where the baseline represents firms' emission intensity targets. Firms that emit less than the mandated baseline will receive tradable credits, which are calculated as the difference between each firm's target and its actual intensity multiplied by the yearly production (Environment Canada, 2007 [2]).

This chapter compares and contrasts LFEs incentives to relocate when the domestic social planner decides to reduce GHG emissions. Using a two-country, three stage sequential game, the model identifies each firm's profit, relocation incentives, and resulting national social welfare when the domestic social planner chooses to reduce carbon emissions using either a cap and trade (Scenario 1) or an emission intensity system (Scenario 2). A series of simulations and sensitivity analysis for each of the scenarios are used to quantify, under certain circumstances, the effects of the policies on social welfare and on pollution haven creation.

The results show that, when considering the consequences of other countries' policy choices, pollution havens as a result of capital flight are more likely under cap and trade regulation. For example, one can imagine that, in a Kyoto-signatory country with a cap and trade policy, multi-product firms have an incentive to shut down one of their plants, make a profit from selling their allocated permits and move production to another country which, not being a Kyoto-signatory state, has lower GHG emission obligations.

The current Canadian regulations are still under revision and might not take into account all possible scenarios that firms can legally consider regarding their mobility across borders and relocation decisions. Since the framework is unclear about how to identify the shift in production due to economic reasons, this chapter investigates the incentive to do so.

The chapter is organized as follows: Section 5.2 presents the socio-economic issues created when implementing different environmental policies worldwide. The two following subsections introduce the conclusions of previous research on pollution haven and industrial flight concepts. Section 5.3 explains the theoretical model and compares and contrasts the results of the simulations and sensitivity analysis for both cap and trade and emissions intensity policies. The chapter ends with the conclusions of the simulation and sensitivity analysis.

5.2 Environmental Regulations in a World of Pollution Havens and Industrial flight

Designing policies to deal with domestic environmental concerns is a complex task and must take into account the industry, consumers, and interest groups involved.

Developing policies to deal with global GHG emissions is an inherently difficult challenge as well because, in addition to domestic impacts, policies of one country affect other countries through trade or capital markets. In the case of GHG pollution in a global context, domestic regulators have to consider the possible environmental impacts of other countries' policies when assessing the overall environmental performance. Given the impossibility of a global government, this can require negotiating international agreements for dealing with transboundary issues that reflect public and international policy concerns. These circumstances are clearly explained by Ulph (1997) who argues that trade and environment interact through three main aspects. First, if international trade affects the pattern of production and consumption of that country and in turn, they negatively impact the environment, then it can be considered that trade impacts the environment. The corollary is that, if environmental policies are enforced with the aim of correcting production and consumption externalities, trade will be affected too. Second, production and consumption in one country may have global environmental effects (through transboundary pollution) in which case, the trading partner country has an incentive to use trade policy as an instrument to reduce damage. Third, trade policies are often part of enforcing international environmental agreements.

Environmentalists and economists debate whether or not the benefits of trade liberalization are outweighed by the damage brought to the environment through increased production and consumption (Copeland and Taylor, 2004). In this context, when the focus comes on enforcing GHG emission reductions policies, their trading mechanism and global effects, the situation is even more elusive to analyze. Ulph (1997) highlights that the international competitiveness that trade promotes may encourage domestic industries to lobby for less stringent environmental policies.

Research has identified other facets with respect to pollution regulations and their consequences. Most important are international competitiveness and relocation of polluting industries. Both competitiveness and relocation issues may lead to a pollution haven phenomenon, which can take place in a region or country that expands industries that pollute the environment due to its weak or poorly enforced environmental regulations (Copeland and Taylor, 2004). Some of this growth in domestic production can arise from industrial flight, whereby firms leave stringent environmental regimes and invest in

jurisdictions with weaker regulations. As explained in Chapter 2, industrial flight represents the *action* of moving to a country with less strict environmental standards that polluting companies face, while a pollution haven represents the *result* of having low environmental standards that attracts polluting industries (either domestic or foreign). Capital mobility between countries may speed up and strengthen the pollution haven creation, but capital flight is not necessary for pollution havens to emerge.

The form of regulation will matter as well. In general, cap and trade will generate a stronger incentive to move. The intent of tradable permits is to allow firms that invest in abatement to benefit through permit sales. But firms can generate excess permits by moving some production abroad. Governments may not be able to identify the reason so may be in no position to do much about it. The idea is that excess permits under cap and trade can be sold even if firms generate the excess permits by reducing output as opposed to improving abatement. However, under emission intensity regulations, firms that reduce output have no permits to sell. Hence, cap and trade will introduce an additional incentive to move. For example, in practice, to operationally and legally distinguish between multi-plant firms that are making production adjustments to reduce GHG from those that are strategically moving production out of country is nearly impossible. For instance, suppose an electrical utility shuts down an American coal fired plant while it builds fully offsetting American wind generation capacity and simultaneously contracts with a new Canadian coal fired affiliate to meet demand growth. Did the sale of the permits from the American coal fired plant go to finance new wind generation or did it go to the Canadian affiliate? Or, as another example, suppose an American car producer closes four car plants and opens two truck plants over a three year period and emissions fall by 30 percent. Should any permits be revoked? Further, how do we measure changes in output?

Further on, assuming a case where a firm *K* closes its only plant which was a large GHG emitter. A new firm, *J*, buys these permits to set up a new, more efficient plant in the US and then sells any residual permits to help finance the new plant. Is the sale of permits allowed? What if the permits are sold by company *K* to company *X* and the new company *J* purchases permits from company *Y*? These examples and the questions that follow illustrate that implementing cap and trade regulations will be a

challenging issue given that firms may have the incentive to relocate some of their production abroad.

5.2.1 Industrial Flight

As pollution haven and industrial flight concepts were introduced in Chapter 2, the present section focuses mainly on reminding few aspects related to industrial flight.

In general, in the literature related to trade and environment, the research hypotheses assume that lax environmental regulations can lead to pollution havens while strict regulations lead to industrial flight. Kolstad and Xing (1998) reason that stringent environmental regulations have a strong effect on industry location and that different policies among countries will induce specialization and capital movement to the country with weaker regulations. They explain that the industrial flight occurs when overly stringent environmental regulations cause increased production costs for polluting companies, which have incentives to ‘fly’ to countries with weaker environmental regulations. The authors present the following arguments that may determine industrial flight. Firstly, strong environmental policies increase production costs as they require certain equipment. Secondly, the waste disposal capacity is restricted, and, last but not the least, severe environmental regulations often prohibit the use of particular inputs, outputs or processes.

Briefly summarizing the main features of the literature review on industrial flight concept, in the early 2000s, the research was focused on using various econometrics techniques and modeling for identifying whether there is positive or negative evidence of industrial flight. As in the pollution haven case, the results are polarized and there are no clear conclusions of whether stringent environmental regulations influence industrial flight or not (Millimet and List, 2004, Albrecht 1998, List et al. 2003, Dean et al., 2003). In parallel, the industrial flight hypothesis has been researched in relationship with foreign direct investment (FDI). The motivation is that FDI has expanded as a result of trade and investment liberalization at a global level. As FDI has been mainly directed towards developing countries, regulatory differences between developed and developing countries have raised concerns about environmental and social impacts (Zarsky, 1999).

In 2002, Keller and Levinson researched the effects of pollution abatement costs on foreign direct investment (FDI). Using panel data, the authors verify the possible creation of pollution havens in various US states that have different environmental regulations and they obtain negative results. They suggest that few of the reasons why the pollution haven hypothesis is not supported by conclusive evidence are related to using cross-sectional data (and thus not controlling for unobserved heterogeneity) and also to the challenges of quantifying various environmental regulations.

Kolstad and Xing (1998) test the industrial flight hypothesis, while acknowledging that FDI is a more sensitive proxy than other variables. Their results show that, regarding intensive polluting industries, there are significant negative effects of environmental legislation stringency on FDI that are leading to industrial flight; meanwhile, less intensive polluting industries are not affected. They argue that this is an expected result which was not captured in previous research that employed econometric modeling given the difficulty to quantify endogenous variables such as the effects and the degree of stringency of environmental regulations.

Herath et al. (2005) examine the factors affecting the location choice of hog, dairy and fed-cattle sectors in the US for the interval 1976-2000. This paper addresses two new and interesting aspects: developing an environmental stringency index, as well as various instrumental variables that control for the possible endogeneity bias between livestock production decisions and regulatory stringency. The authors' findings reveal that the hog and dairy sectors are increasingly moving production away from traditional production regions. They identify that the relocation could be due to the tightening of compliance requirements and enforcement which can increase the relative costs of abatement.

In the last years, unilaterally implemented GHG emission reduction policies by certain governments have raised concerns about carbon leakage, which has been explored in the literature along with industry relocation aspects. The motivation is that firms' alternative to relocate internationally is considered to make carbon leakage even worse (Fullerton, 2011). For instance, considering industry relocation to countries with a less stringent climate change policy as a main reason for carbon leakage, Oikonomou et al. (2006) analyze the relocation effect of previous environmental regulations in the iron and steel sectors, differentiating between Annex 1 and non-Annex 1 countries. First, the

authors conclude that the results of previous research should be differentiated into energy-intensive and conventional energy-intensive sectors, as the results for the two categories should not be interpreted similarly. Second, they observe that there is a limited effect of climate change policy on location decisions. In their opinion, factors like market size, growth and wages have more weight when firms contemplate relocation. However, other authors have found evidence of carbon leakage associated with Kyoto Protocol. Paltsev (2001) identified that the carbon leakage rate from Annex B Kyoto countries is of 10% while Elliot et al. (2010) find a rate of 20%.

In the EU, as a results of industry groups continuing to argue the threat of EU ETS against their international competitiveness, carbon leakage issues and industry relocation threats have already been addressed in the EU ETS⁵³ through requested border protective measures that can be considered ‘border adjustments for GHG-intensive imports’ (Monjon and Quirion, 2010, p.3). The authors acknowledge that while there is limited evidence on firms’ international competitiveness threat, in theory, a different carbon price determines changes in the trade patterns, which leads to relocation, and further, to operational or investment⁵⁴ carbon leakage.

Some earlier research anticipates these circumstances and tries to find solutions. Sheldon (2006) presents a thoroughly review of pollution haven effects, relocation incentives and race to the bottom and suggests that WTO rules regarding import tariffs should have more flexibility such that to allow countries to “...renegotiate their bound tariffs if unilateral changes in their environmental policies would increase access to their countries”.

In this context, Gros (2009) argues that border measures, such as carbon tariffs, should be in place against imports from developing countries with no or low binding GHG emission reductions. He concludes that, for a small carbon tariff, this solution would increase global welfare and at the same time would raise revenue to support poor developing countries to reduce their GHG emissions.

Obviously, given the complexity encountered by policy makers when imposing appropriate environmental standards for their own socio-economic situation, arguments

⁵³ Actually through Directive 2009/29/EC which revises EU ETS.

⁵⁴ Graichen et al., (2008) define operational leakage as occurring from production relocation from existing installations to production facilities outside the EU ETS scheme; investment leakage occurs as a result of a redirection of investments from Europe to regions without similar climate policies.

arise now from defining and/or measuring the severity of environmental policies. Eventually, stringent environmental regulations can cause increased production costs for firms, which in turn may lead to effects on firms' competitiveness, industry location and country's trade structure.

5.3 The Model

The following model focuses on the hypothesis that the incentive to relocate to a pollution haven is far less with the emission intensity regulation than with a cap-and-trade regulation. With emission intensity rates, a firm shutting down production to move to the pollution haven would not have saleable permits, whereas with a cap and trade system the firm could relocate production to the pollution haven and sell emission permits domestically. When this exodus effect to the pollution haven is taken into account, emission intensity rates could be a superior instrument to limit GHG emissions.

The interaction between firms and policy makers is modeled as a three stage sequential game and is solved through backward induction. The agents involved in the game are the policy maker (government) that decides the level of emissions and the firms (LFEs) that emit greenhouse gases under perfect competition. The goal of the policy maker is to choose a level of emissions that maximizes domestic social welfare. It is assumed that the policy maker accounts for the relocation of domestic firms. When assessing the domestic social welfare, the policy maker takes into account the pollution generated by all its firms regardless the jurisdiction in which emissions were generated.

The LFEs goal is to maximize profit by choosing where to produce and how much. Once the policy maker decides the emission target, depending on how efficient they are at reducing emissions, firms can decide to comply with the regulations and remain in the domestic country or relocate to jurisdictions with lower environmental standards and abide by their standards. As profit maximizers, firms' relocation decisions are based on their fixed costs of setting up a new plant, the costs of relocation, and the benefits of staying. This means they account for potential sale of emissions. In the case of cap and trade, firms have the ability to sell their permits in the domestic market when they leave. This will lead to the situation where there are more emission permits in the

domestic market for a fewer firms and a lower price. Hence not all firms will choose to leave. In the case of emissions intensity policy, once firms start relocating, the government can allow higher emission intensities for the firms that stay. Again, not all domestic firms will find it profitable to relocate.

In the first stage of the game the domestic government chooses the stringency of GHG emissions that would maximize social welfare under a cap and trade or an emissions intensity policy. In the second stage, domestic firms observe the regulation and decide whether to stay or relocate. In the third stage, firms, which take as given the stringency and the type of policy decided by the government, maximize profits by choosing their output.

The solving procedure for backward induction implies solving first the third stage which reveals the quantity, price and profits of the firms. Stage two presents firms' motivation to relocate or not and the equilibrium conditions. Stage 1 shows the regulator's choice of emissions stringency when considering social welfare maximization.

As this investigation compares and contrasts government and firms' decisions firstly under a cap and trade and then under an emissions intensity policy, the following section comprises a scenario for each of the policies.

5.3.1 Theoretical Framework

5.3.1.1 Scenario 1: Cap and trade policy

The theoretical framework of the model includes two countries, the domestic or Home (country H) and Foreign (country F). In this scenario, the regulator in Home decides to implement a cap and trade policy. The social planner in Foreign also has an environmental policy in place but with higher levels of emissions than in the domestic country.

The model is solved using backward induction, which means that the third stage of the model is solved first. In this stage, a price-taking representative LFE takes profit maximizing decisions in a perfectly competitive industry. In the absence of regulation, the domestic and foreign industries are composed of M , and respectively N , homogenous firms. Each firm i produces q_{iH} , and correspondingly q_{iF} units of output at an emission

rate of r_{iH} and r_{iF} . The emission rate r_i is defined as the ratio of the quantity of emissions of a firm and the analogous units of output, e.g. $r_i = \frac{e_i}{q_i}$. e_i denotes the quantity of emissions such that $e_i = r_i q_i$ and thus aggregate emissions can be written as $E = \sum_{i=1}^M e_i$.

STAGE 3: Each firm maximizes profit subject to the cap on emissions. Since all firms are identical, there are no trades in equilibrium. That is, the equilibrium price of emission permits will ensure that no firm wishes to buy or sell permits. Hence, this can be modeled as non-tradable permits system with an implicit permit price.

The domestic social planner decides the number of permits that are distributed among LFEs (E_H) and implicitly establishes the optimal levels of emissions for maximizing its country's social welfare. The constrained profit function that each domestic agent maximizes under a fixed world price for output can be stated as:

$$\Pi_{iH} = pq_{iH} - \frac{\beta q_{iH}^2}{2r_{iH}} \text{ such that } E_H = r_{iH} q_{iH} , \quad (5.1)$$

where pq_{iH} represent the revenue and $\frac{\beta q_{iH}^2}{2r_{iH}}$ is the quadratic cost function.

Firms' costs are increasing in output and decreasing in emission intensity. Note that the cost function used is a reduced form. One could explicitly include abatement as a firm choice. That is, the firm would choose output and abatement simultaneously given their individual cap on emissions. But as long as there are one-to-one relationships between abatement, output, and emissions, the choice of output and the intensity of emissions implicitly determine abatement. The cost function can capture this in reduced form by focusing on output and intensity choices only.

Based on equation (5.1), the first order conditions are obtained by deriving the Lagrangean equation with respect to output (q_{iH}), emission rate (r_{iH}) and the Lagrangean multiplier (λ).

$$L = pq_{iH} - \frac{\beta q_{iH}^2}{2r_{iH}} + \lambda(E_H - r_{iH} q_{iH}) \quad (5.2)$$

$$\frac{\partial L}{\partial q_{iH}} = p - \frac{\beta q_{iH}}{r_{iH}} - \lambda r_{iH} = 0 \quad (5.3)$$

$$\frac{\partial L}{\partial r_{iH}} = \frac{\beta q_{iH}^2}{2r_{iH}^2} - \lambda q_{iH} = 0 \quad (5.4)$$

$$\frac{\partial L}{\partial \lambda} = E_H - r_{iH} q_{iH} = 0 \quad (5.5)$$

Solving the above system of three equations and three unknowns, optimal values are obtained for the emission rate r_{iH} and the output q_{iH} . The value obtained for λ represents the shadow value of the permits or the permits price.

$$q_{iH} = \left(\frac{2pE_H}{3\beta} \right)^{0.5} \quad (5.6)$$

$$r_{iH} = \left(\frac{3\beta E_H}{2p} \right)^{0.5} \quad (5.7)$$

$$\lambda = \frac{0.27 p^{1.5}}{(\beta E_H)^{0.5}} \quad (5.8)$$

The results show that output is increasing in prices and allowable domestic emissions, which means that higher market prices or more permits distributed lead to more output. The intensity is increasing in the number of permits and decreasing in prices, while the shadow value of permits (or permit price) is decreasing in permits and increasing in prices.

To focus on the domestic regulators problem, it is assumed that there is no cap on total foreign emissions. However, firms are not unregulated as the foreign country has a constraint on firms' emission rates. By assumption, though, the foreign emission rate is assumed to be higher (but at the same time it can take lower values) than the rate allowed

in Home: $r_{iF} \begin{matrix} > \\ < \end{matrix} r_{iH}$.

$$\Pi_F = pq_{iF} - \frac{\beta q_{iF}^2}{2r_{iF}} \text{ such that } r_{iF} = \bar{r}_{iF} \quad (5.9)$$

The Lagrangean equation for the above constrained maximization and the first order conditions are:

$$L = pq_{iF} - \frac{\beta q_{iF}^2}{2r_{iF}} + \lambda(r_{iF} - \bar{r}_{iF}) \quad (5.10)$$

$$\frac{\partial L}{\partial q_F} = p - \frac{\beta q_{iF}}{r_{iF}} = 0 \quad (5.11)$$

$$\frac{\partial L}{\partial r_{iF}} = \frac{\beta q_{iF}^2}{2r_{iF}^2} + \lambda = 0 \quad (5.12)$$

$$\frac{\partial L}{\partial \lambda} = r_{iF} - \bar{r}_{iF} = 0 \quad (5.13)$$

Solving the above, given that r_{iF} is constant and known, similar to the case of domestic firms, output is a function that increases in prices and intensity:

$$q_{iF} = \left(\frac{p\bar{r}_F}{\beta} \right) \quad (5.14)$$

The maximum value of the profit is obtained by inserting the optimal values of the output and emissions in the profit function. This value is employed in the simulation section.

STAGE 2: Based on anticipated domestic output and rate of emissions obtained from the profit maximization, firms are faced with the decision to stay or relocate. Firms' decision to move to Foreign is based on the costs of relocation, the value of permit sales, and the benefits to staying. Thus, in the second stage of the game, the equilibrium condition is that the fixed costs of relocation to the foreign country must be lower than the expenses of reducing carbon dioxide emissions in the domestic country, as shown in the following equilibrium conditions.

The first equilibrium condition shows that, with the exception of their profits and the value of the emission permits, LFEs have a range of fixed costs (F) that will lead them to relocate.

$$\Pi_i^H = \Pi_i^F - F \quad (5.15)$$

where: Π_i^H is domestic firm's profit, Π_i^F is foreign firm's profit, while F stands for the fixed costs of the firm.

At this point, firms are indifferent whether to relocate or not. When a firm relocates, it will bear the appropriate fixed costs for setting up the plant in the new location. The second equilibrium condition states that, if these fixed costs diminish a firm's profit in the foreign country below the level of its domestic profit less the compliance costs (CC), relocation is not worthwhile.

$$\Pi_i^H - CC = \Pi_i^F \quad (5.16)$$

Thus, assuming no other reasons to move, the break-even point for relocation $F = CC$ is determined by the relationship between the costs of respecting the cap on emissions and the possible fixed costs of relocation.

At this point, it is necessary to underline the assumption that firms that are able to relocate are going to sell the permits they have already received to the firms that remain in the domestic country. The importance of the relocation costs that firms incur when moving comes from the possible costs range that could diminish the incentive to move. On the one hand, there are the costs that the LFE incurs when investing in technology or equipment that helps reduce its GHG emissions. With an absolute cap, the emitter would bear the costs of trying to become more efficient and would incur the risk of having to restrict its output. However, under these circumstances there is one more incentive for relocation: the value of the previously allocated permits to the LFEs; permits that constitute a valuable asset because of the trading opportunity. Thus, the equilibrium conditions refer to costs of relocation, fixed costs and profits. Hence, the profit of the firms that stay in the domestic country is still a function of revenue and costs less the value of the permits that are sold in the domestic country by the firms that leave:

$$\Pi_H = pq_H - \frac{\beta q_H^2}{2r_H} - \lambda E_H \frac{M}{I} \quad (5.17)$$

The profit of the firms that relocate include the value of the emission permits sold minus the fixed costs of relocation:

$$\Pi_F = pq_F - \frac{\beta q_F^2}{2r_F} + \lambda E_H \frac{M}{I} - F \quad (5.18)$$

where I is the number of firms that remain in the domestic country, M represents the number of existing firms before implementing any emissions reduction policy, E_H is the number of permits distributed by the regulator.

Further in the analysis of the factors that impact relocation, the number of firms that remain in the domestic country (I) depends on the number of permits distributed by the regulator (E_H) as well as on the fixed costs incurred for relocation. Therefore, the variables of interest are E_H (as a policy variable – the cause) and I (as an endogenous variable – the effect of choosing E_H), since the grounds of the analysis attempt to reveal their roles and impacts on each other as well as their impact on social welfare.

In this context, in equilibrium, the zero profit condition of this model is expressed in equation 5.19. The condition states that, in equilibrium, the domestic firms profits minus the value of the emission permits bought from the firms that relocate equals the profits of firms that relocate to Foreign less the fixed costs of relocation,

$$\Pi_H - \lambda E_H = \Pi_F - F(M - I) \quad (5.19)$$

With the aim of exploring the relationship between E_H and I Equation 5.19 can be written as follows:

$$\Pi_H = \Pi_F - F(M - I) + \lambda E_H \quad (5.20)$$

where $(M - I)$ represents the number of firms that relocate.

It is observed that equation 5.20 can be totally differentiated with respect to the number of permits. The values of both profit functions for home and foreign (equations 5.6, 5.7, 5.8 and 5.14) were replaced in the above formula and the total differentiation yields:

$$\frac{dI}{dE_H} = \frac{1}{\frac{E_H}{I^{-1}} + \frac{F\beta^{0.5}}{0.13p^{1.5}E_H^{-0.5}\left(\frac{M}{I}\right)^{0.5}}} \quad (5.21)$$

The end result has a positive sign which shows that there is a positive relationship between E_H and I . The interpretation is that an increase in the emission cap induces fewer firms to leave the home. This result is justified by the fact that with a greater

number of permits distributed among the remaining LFEs, firms would be able to emit more and certainly spend less on abatement.

Recalling the assumption that firms that relocate are going to sell the permits they have already received to the firms that remain in the domestic country. Thus, for incorporating this assumption in equation (5.20), E_H was adjusted (multiplied) by M / I (the ratio of the total number of domestic firms to the number of firms that remain) for both the social welfare and zero profit functions.

STAGE 1: In the first stage on the game, the government chooses the stringency of regulation to maximize social welfare. The regulator values the sum of producer surpluses generated from home production as well as the pollution generated by all its firms regardless of their location. Thus, when the social planner chooses the emission cap, total emissions damage also matter:

$$\max_{E_H} SW = \Pi_H I - D[(r_{iH} q_{iH} M) + (M - I)r_{iF} q_{iF}] \quad (5.22),$$

D corresponds to the damage caused by the emissions and it is assumed to be a linear function (index). In other words, the social welfare function is shown as the difference between the profit of the firms that stay in the domestic country and the emissions damage of the domestic firms that stay and the domestic firms that relocate⁵⁵.

Given the seven constraints (the first order conditions for both jurisdictions and the zero profit conditions), the seven endogenous variables and the non-linear nature of the social welfare function, optimal solutions and comparative static results were very difficult to derive analytically. As the previous mathematical development shows, it was possible to solve the equations up to a point and sign them, but it was needed to, at least, roughly quantify them and reveal the magnitude of their effects for each of the policies. This allows comparing and contrasting the outcome of the two policies, as well as the sensitivity of the variables employed, in the three stage game over a range of parameter values.

The formulas obtained from solving the Lagrangean, such as output, emission intensity, and shadow values, along with the optimal profit functions, the zero moving condition and the social welfare function were inserted in an Excel file. As will be shown

⁵⁵ If the social planner was concerned with only domestic emissions, domestic welfare would be higher, but she would ignore the adverse effects of pollution generated elsewhere.

in the simulation section, based on the parameter values of the exogenous variables (such as price, fixed costs of relocation, damage coefficient, total number of domestic firms, etc.) and the formulas previously introduced, the endogenous variables are calculated using the optimization software Solver. The non-linear constraint optimization algorithm numerically finds the rate of emissions that maximizes social welfare subject to each of the first order conditions and the zero profit condition to firms being maintained. Comparative statics were derived by examining the changes to social welfare and the endogenous variables by changing exogenous variables and parameters.

Therefore, given the complex mathematical manipulation of the above function, for illustrating the relationships between the variables involved and the social welfare, excel simulations and comparative statics were performed for both Scenarios 1 and 2, and further detailed in Section 5.4.

5.3.1.2 Scenario 2: Emissions intensity policy

The second scenario is the implementation of an emission intensity policy by home. While the cap and trade system was designed to reduce total emissions, the emissions intensity system reduces average emissions intensity⁵⁶. Thus, the two policies will have a different impact on both output and the quantity of emissions. As noted by others, the emission intensity system contains an inherent output subsidy which encourages additional output (Helfand 1991, Bruneau 2005).

STAGE 3: In the third stage of the game, as in Scenario 1, firms maximize profits by selling their output on the world market and emitting greenhouse gases. The profit function is the same as above. The constraint differs because the regulator sets an emissions intensity value H_{iS} that is valid for the entire industry, where H_{iS} is defined as the ratio of emissions per unit of output⁵⁷. As previously mentioned, in this scenario it is assumed that no emission permits or allowances are distributed to the firms. Thus,

⁵⁶ Recalling the definition currently employed by the Canadian government, emissions intensity is defined as greenhouse gas emissions per unit of production. The set-up of this ratio suggests that production, and implicitly, emissions can be increased as much as intended as long as emissions per output are reduced (Environment Canada, 2007 [2]).

⁵⁷ Both r_{iH} and H_{iS} represent the rate of emissions. The notation differs to show that the rate of emission is differently defined in each scenario; however, both parameters define the same variable.

$$\Pi_H = pq_{iH} - \frac{\beta q_{iH}^2}{2H_{iH}} \text{ such that } H_{iH} = \bar{H}_{iS} \quad (5.23)$$

The Lagrangean equation for the above constrained optimization and the first order conditions with respect to output, emissions and the Lagrangean multiplier are:

$$L = pq_{iH} - \frac{\beta q_{iH}^2}{2H_{iH}} + \lambda(H_{iH} - \bar{H}_{iS}) \quad (5.24)$$

$$\frac{\partial L}{\partial q_{iH}} = p - \frac{\beta q_{iH}}{H_{iH}} = 0 \quad (5.25)$$

$$\frac{\partial L}{\partial H_{iH}} = \frac{\beta q_{iH}^2}{2H_{iH}^2} + \lambda = 0 \quad (5.26)$$

$$\frac{\partial L}{\partial \lambda} = H_{iH} - \bar{H}_{iS} = 0 \quad (5.27)$$

As the rate of emission is known from the constraint, first order conditions allow calculating optimal values for output q_{iH} .

$$q_{iH} = \frac{p\bar{H}_{iS}}{\beta} \quad (5.28)$$

The above result illustrates that firms choose the maximum intensity allowed when deciding their output. Under perfect competition assumptions, their output ensures that marginal costs equal marginal revenues.

The foreign country has its profit function and a constraint that shows that there is no specific GHG emissions reduction policy. However, keeping the same measurement unit, the emission intensity level in the foreign country S_{iF} is going to be higher (but, as in the previous scenario, it can be lower) than in the domestic country. Moreover, a very important assumption for comparing the two scenarios is that the level of allowed emissions is assumed have the same value for both cap and trade and emission intensity implemented in the foreign country: $r_{iF} = S_{iF}$.

Thus, the profit formula for each firm of the foreign country is the following:

$$\Pi_F = pq_{iF} - \frac{\beta q_{iF}^2}{2S_{iF}} \text{ such that } S_{iF} = \bar{S}_{iF} \quad (5.29)$$

In this case the Lagrangean equation and the first order conditions are:

$$L = pq_{iF} - \frac{\beta q_{iF}^2}{2S_{iF}} + \lambda(S_{iF} - \bar{S}_{iF}) \quad (5.30)$$

$$\frac{\partial L}{\partial q_F} = p - \frac{\beta q_{iF}}{S_{iF}} = 0 \quad (5.31)$$

$$\frac{\partial L}{\partial S_{iF}} = \frac{\beta q_{iF}^2}{2S_{iF}^2} + \lambda = 0 \quad (5.32)$$

$$\frac{\partial L}{\partial \lambda} = S_{iF} - \bar{S}_{iF} = 0 \quad (5.33)$$

$$q_{iF} = \frac{p\bar{S}_{iF}}{\beta} \quad (5.34)$$

As expected, the results are similar to the previous case, the difference consisting in the higher emissions intensity allowed in Foreign.

STAGE 2: As in Scenario 1, based on their compliance costs and fixed costs of relocation, firms choose whether to move across the border or remain in Home. It should be noted that no emission permits are distributed, in this case. As a consequence of the emissions limitation and the inherent increased costs, domestic LFEs are enticed to displace their business to Foreign.

Thus, in the second stage of the game, the equilibrium condition is that the fixed costs of relocation to the foreign country must be lower than the expenses of reducing carbon dioxide emissions in the domestic country, as shown in the following equilibrium conditions.

$$\Pi_i^H = \Pi_i^F - F \quad (5.35)$$

where: Π_i^H is domestic firm's profit, Π_i^F is foreign firm's profit, while F stands for the fixed costs of the firm.

At this point, firms are indifferent whether to relocate or not. The second equilibrium condition states that, if the fixed costs of setting up the plant diminish a firm's profit in the foreign country below the level of its domestic profit less the compliance costs (CC), relocation is not worthwhile.

$$\Pi_i^H - CC = \Pi_i^F \quad (5.36)$$

Thus, assuming no other reasons to move, the break-even point for relocation $F = CC$ is determined by the relationship between the costs of respecting the emissions intensity imposed and the possible fixed costs of relocation.

In this scenario, the profits of the firms that relocate are diminished by the costs of relocation, but they have the advantage of a higher intensity allowed in Foreign.

$$\Pi_{iF} = pq_{iF} - \frac{\beta q_{iF}^2}{2r_{iF}} - F \quad (5.37)$$

Further, the zero profit condition in equilibrium states that, the domestic firms profits should equal the profits of firms that relocate to Foreign less the fixed costs of relocation:

$$\Pi_H = \Pi_F - F(M - I) \quad (5.38)$$

thus, if firms close up and sell, they will get only the value of their business, but no permits.

STAGE 1: Anticipating firms' location, output, and emission decisions, the policy maker decides the stringency of the intensity regulation that maximizes domestic social welfare.

The social welfare maximization implies using an analogous function to the one introduced in the earlier scenario. The difference is that, under an emission intensity policy there are no permits to be distributed to the firms, and thus, they are not captured in the equation.

$$\max_{H_H} SW = \Pi_H I - D[(H_{iH} q_{iH} M) + (M - I)q_{iF} S_{iF}] \quad (5.39)$$

When implementing this policy, the social planner is interested in choosing a level of intensity H_H that will maximize the social welfare of its country.

5.3.2 Simulation Results

In general, the three-stage game above can be solved analytically. However, given the complex social welfare function form, the results are better understood when employing simulations, as they allow varying important parameters to identify under which circumstances the two policies differ. The equations and constraints previously discussed were introduced in Microsoft Excel spreadsheets. For both cap and trade and

emission intensity settings, the endogenous variables such as output, profits, emissions rates, number of permits etc. were introduced in Excel as formulas representing the profit maximization's first order conditions. Using Solver Excel, optimal values for the endogenous variables were found by assuming various values of the exogenous parameters with particular attention to market price (P) and environmental damages (D).

In turn, the endogenous variables are embedded into the social welfare functions. Maximizing social welfare implies that the profits of the firms that stay are the same as the profits of the firms that leave (equation 5.19), a constraint that was taken into account for both scenarios.

Further in the research, sensitivity analysis of the endogenous variables implies attributing a wide range of values to two of the exogenous variables: the damage coefficient and the domestic output price. For comparison purposes, the same values of the exogenous variables are employed in both Scenario 1 and 2.

5.3.2.1 Cap and trade policy

The simulation process reveals that certain values attributed to the exogenous variables lead to maximizing social welfare, while respecting all the constraints imposed in the optimization process. The main conditions to be respected in the optimization process are that social welfare function must be maximized under the zero profit constraint, while allowing the number of permits issued (E_H) and the number of firms that decide to stay in the domestic country (I) to vary. Given the nature of the simulation process, the focus of the analysis is not on the percentage or magnitude changes of each parameter, but on the pattern of changes from the equilibrium solutions found. Table 5-1 presents the initial values of the exogenous variables in a cap and trade scenario that maximize social welfare as well as the values of the endogenous variables. The initial simulation (absence of regulation) uses 200 firms, a market price of 150 units, a damage coefficient of 0.5, and a rate of emissions in the foreign country of 200 units per unit of output⁵⁸. The welfare maximizing cap and trade target is then identified.

⁵⁸ The Excel formulas used for simulations are presented in the Appendix.

Table 5-1.: Values of exogenous and endogenous variables that maximize social welfare while respecting all constraints under a cap and trade policy

Exogenous variables	Value of exogenous variables	Endogenous variables	Values of endogenous variables that maximize social welfare
p	150	E_H	850
r_F	200	q_H	7.9
D	0.5	r_H	107
M	200	I	176
		q_F	30
		Π_H	897
		Π_F	2,250
		SW	2,596

Source: own calculations

The results obtained validate the modeling approach and the numerous constraints involved. Thus, one of the consequences of a lax environmental policy is that the output and profit obtained in the foreign country are higher than in the domestic country. Out of the 200 existing domestic firms, 24 (12 percent of them) consider it more profitable to sell their permits and relocate abroad⁵⁹.

Sensitivity analysis is performed with the aim of observing the pattern of the endogenous variables when a range of values is attributed to specific exogenous values of damage and market prices. Further on, it is investigated how the domestic total emissions, number of permits distributed to firms, emissions rate, capital flight and social welfare are impacted when the output price takes values between 100 and 165 units, and the damage coefficient takes values from 0.1 to 6. The other exogenous variables have the same values as shown in Table 5-1.

The sensitivity analysis begins with Table 5-2, which presents the optimal total emissions given the range of prices and damage coefficients by enforcing a cap and trade policy. The total emissions in the domestic country are calculated as the product between the number of firms, their output and their average emissions rate.

⁵⁹ In the Solver simulations, another constraint imposed was using integer numbers (e.g.: no decimals).

Table 5-2.: Total Home emissions under a cap and trade (thousand tons)

		Output price (units)													
D A M A G E C O E F F. (units)		100	105	110	115	120	125	130	135	140	145	150	155	160	165
	0.1	134	149	165	181	198	215	232	250	268	286	305	324	344	363
	0.2	97	108	119	131	143	155	168	180	193	207	220	234	248	262
	0.3	81	90	99	109	119	129	140	151	162	173	184	196	208	220
	0.4	71	79	88	97	105	115	124	134	143	153	164	174	184	195
	0.5	65	72	80	88	96	105	113	122	131	141	150	159	169	179
	0.6	61	68	75	82	90	98	106	114	123	131	140	149	158	167
	0.7	57	64	71	78	85	93	100	108	116	124	133	141	150	159
	0.8	54	61	67	74	81	88	96	103	111	119	127	135	144	152
	0.9	52	58	65	71	78	85	92	100	107	115	122	130	138	147
	1	50	56	63	69	75	82	89	96	104	111	119	126	134	142
	2	41	46	52	57	63	69	75	81	87	94	100	107	114	121
	3	38	43	48	53	58	63	69	75	81	87	93	100	106	113
	4	36	41	45	50	55	61	66	72	78	84	90	96	102	109
	5	35	39	44	49	54	59	65	70	76	82	88	94	100	106
	6	34	39	43	48	53	58	63	69	74	80	88	94	100	106

Source: own calculations

The results shown in Table 5-2 illustrate that a higher output price leads to higher total emissions: the regulator allows emissions to rise since the higher profits available contribute to welfare. At the same time, when more weight is placed on damages, the total emissions decline. However, when the damage coefficient takes values between 0.1 and 2 and the price ranges from 100 to 140, the price effect overcomes the damage effect as the gradual increase in emissions is more significant than the decrease determined by a higher damage coefficient. Given the low rate of reduction in the optimal emissions when the damage coefficients takes values between 2 to 6, it can be stated that emissions are more sensitive to changes in the damage coefficients when they have low values.

More insights about the pattern of the total emission presented in Table 5-2 are revealed by the average emission rate in the domestic country. Thus, Table 5-3 shows that, when a cap and trade policy is in place, the average emissions rate follows the same pattern as the total emissions. As in the previous table, the value of the emission rates decreases at a lower rate when the damage coefficient decreases by 1 unit, compared to the reduction registered when the damage coefficient decreases by 0.1 units. It should be noted that the Home emission rate rises above Foreign in some circumstances. That is, if price is high and damage low, the Home regulator allows an increase in the rate of emissions.

Table 5-3.: Home emissions rate under cap and trade (tons per unit of output)

		Output price (units)													
D A M A G E C O E F F (units)		100	105	110	115	120	125	130	135	140	145	150	155	160	165
	0.1	155	162	168	174	179	185	191	196	202	207	213	218	223	229
	0.2	112	117	121	126	130	134	139	143	147	151	155	159	163	167
	0.3	94	98	102	105	109	113	116	120	123	127	130	134	137	141
	0.4	83	87	90	94	97	100	103	107	110	113	116	119	123	126
	0.5	76	79	83	86	89	92	95	98	101	104	107	110	113	116
	0.6	71	74	77	80	83	86	89	92	95	97	100	103	106	109
	0.7	67	70	73	76	79	81	84	87	90	93	95	98	101	103
	0.8	64	67	70	72	75	78	81	83	86	89	91	94	97	99
	0.9	61	64	67	70	72	75	78	80	83	86	88	91	93	96
	1	59	62	65	67	70	73	75	78	81	83	86	88	91	93
	2	49	51	54	56	59	61	64	66	68	71	73	75	78	80
	3	45	47	50	52	54	57	59	61	64	66	68	71	73	75
	4	43	45	48	50	52	55	57	59	61	64	66	68	71	73
	5	42	44	46	49	51	53	55	58	60	62	65	67	69	71
	6	41	43	45	48	50	52	54	57	59	61	65	67	69	71

Source: own calculations

Another representative endogenous variable used to explain the total emissions results is the number of firms that decide to stay in the domestic country. This variable shows the magnitude of capital flight for given values of the exogenous variables after implementing a cap and trade policy. Thus, Table 5-4 illustrates the LFEs decision to relocate when the damage coefficient and output price vary.

The sensitivity analysis simulations illustrate that out of 200 initial firms, for the lowest price and the lowest value of the damage coefficient, 5 percent of firms decide to relocate. Even when the output price increases, the capital flight phenomenon persists; e.g. for a price of 165 units and a damage coefficient between 4 and 6, 12.5 percent of firms relocate to the country with less strict environmental regulations. Obviously, capital flight intensifies when the output price has a higher range of values. Relating these results with the figures shown in Table 5-3, one possible explanation is that, even though firms can increase their profit in the domestic country, given that they receive more permits from the regulator when the output is more expensive, they are more tempted to make a profit from selling their permits and relocate to another jurisdiction where they are not bounded to a certain magnitude of emissions.

Table 5-4.: Number of firms that remain in Home under cap and trade

		Output price (units)													
D A M A G E C O E F F (units)		100	105	110	115	120	125	130	135	140	145	150	155	160	165
	0.1	190	189	189	188	187	186	185	184	183	182	181	180	176	175
	0.2	190	189	188	187	186	185	184	183	181	180	179	178	177	175
	0.3	189	188	187	186	185	184	183	182	180	179	178	176	175	174
	0.4	189	188	187	186	184	183	182	181	180	178	177	176	174	173
	0.5	188	187	186	185	184	183	182	180	179	178	176	175	174	172
	0.6	188	187	186	185	184	182	181	180	179	177	176	175	173	172
	0.7	188	187	186	184	183	182	181	179	178	177	175	174	173	171
	0.8	188	186	185	184	183	182	180	179	178	176	175	174	172	171
	0.9	187	186	185	184	183	181	180	179	177	176	175	173	172	170
	1	187	186	185	184	182	181	180	178	176	175	174	173	171	170
	2	186	185	184	182	181	180	178	176	175	174	173	171	169	168
	3	186	184	183	182	180	179	178	176	175	173	172	170	169	167
	4	185	184	183	181	180	179	177	176	174	173	171	170	168	166
	5	185	184	182	181	180	178	177	175	174	172	171	169	168	166
	6	185	184	182	181	180	178	177	175	174	172	171	169	168	166

Source: own calculations

In conclusion, the simulation tables previously introduced show that higher prices lead to greater output and capital flight. At the same time, the existing firms' intensity rises. The net effect is fewer firms emitting at higher intensities. This leads to greater emissions as the intensity effect dominates the effect of capital flight. Meanwhile, rising damages have the opposite effect on emissions. When the regulator imposes stricter regulations, they induce more capital flight and lower intensities.

The simulations for this scenario continue with attributing the same range of values to the exogenous parameters with the aim of observing their impact on the domestic social welfare. Table 5-5 illustrates the resulting social welfare in Home. For any price, larger environmental damages reduce social welfare. These results confirm one of the main assumptions of the model: for a social planner who takes into account global environmental damage, the more financial weight is attributed to environmental damage, the more social welfare is negatively affected.

The interaction of price and damages yields an interesting pattern. For low damages, as shown on the non-shaded region of Table 5-5, social welfare increases with output prices. However, for larger damages, the shaded region of the table illustrates that social welfare decreases with higher prices. The intuition is that social welfare decreases when emissions rise as the regulator competes for market share as well as capital.

Table 5-5.: Home social welfare under cap and trade (thousand dollars)

		Output price (units)													
D A M A G E C O E F F (units)		100	105	110	115	120	125	130	135	140	145	150	155	160	165
	0.1	55.7	62.9	70.4	78.3	86.6	95.2	104	113	123	132	143	153	164	175
	0.2	39.9	45.1	50.5	56.2	62.2	68.4	74.9	81.5	88.3	95.3	102	109	117	124
	0.3	26.3	29.8	33.4	37.2	41.2	45.3	49.5	53.8	58.2	62.6	67.2	71.7	76.2	80.8
	0.4	13.9	15.7	17.7	19.7	21.7	23.8	25.9	28.0	30.1	32.2	34.2	36.1	37.9	39.5
	0.5	2.1	2.4	2.7	3.0	3.2	3.4	3.5	3.4	3.3	3.0	2.5	1.9	1.0	-0.03
	0.6	-9.2	-10.4	-11.7	-13.1	-14.6	-16.3	-18.2	-20.3	-22.7	-25.2	-28.1	-31.3	-34.7	-38.6
	0.7	-20.3	-22.9	-25.8	-28.8	-32.1	-35.7	-39.5	-43.7	-48.2	-53.0	-58.2	-63.9	-69.9	-76.7
	0.8	-31.2	-35.2	-39.6	-44.3	-49.3	-54.7	-60.5	-66.7	-73.3	-80.4	-87.9	-96.0	-104	-113
	0.9	-41.8	-47.4	-53.2	-59.6	-66.3	-73.5	-81.2	-89.4	-98.1	-107	-117	-127	-139	-150
	1	-52.4	-59.3	-66.7	-74.6	-83.1	-92.1	-101	-111	-122	-134	-146	-159	-173	-187
	2	-154	-174	-197	-220	-245	-272	-300	-330	-362	-395	-430	-467	-506	-546
	3	-252	-287	-324	-363	-404	-449	-495	-545	-597	-652	-710	-770	-834	-900
	4	-350	-398	-450	-504	-562	-624	-689	-758	-831	-907	-988	-1,072	-1,160	-1,253
	5	-448	-509	-575	-645	-720	-799	-882	-971	-1,064	-1,162	-1,265	-1,373	-1,486	-1,604
	6	-545	-620	-700	-786	-877	-973	-1,075	-1,183	-1,297	-1,416	-1,542	-1,674	-1,812	-1,956

Source: own calculation

Legend:



Low damage coefficients and high prices lead to positive and increasing social welfare values

Large damage coefficients and high prices lead to negative and decreasing social welfare values

5.3.2.2 Emissions intensity policy

Turning to emission intensity regulations, in the optimization process performed for Scenario 2, the level of emissions (H_{iH}) and the number of firms that do not relocate (I) are allowed to vary and find their optimal values such that the social welfare is maximized. The exogenous parameters have the same values as in Scenario 1, given the aim of comparing the social welfare and the rest of endogenous variables for both scenarios. Recall that the scenarios differ in that, under intensity regulations, each firm must achieve the intensity target but total emissions are not capped. Further, firms cannot sell permits.

Table 5-6 shows the values of the exogenous variables. It also illustrates that emission intensity regulations lead to higher social welfare than in the cap and trade setting for the initial price and damages.

Table 5-6.: Values of exogenous and endogenous variables that maximize social welfare while respecting all constraints under an emissions intensity policy

Exogenous Variables	Value of exogenous variables	Endogenous variables	Values of endogenous variables that maximize social welfare
P	150	q_H	13.4
S_F	200	H_H	118
D	0.5	I	183
M	200	q_F	30
		Π_H	1,010
		Π_F	2,250
		SW	10,065

Source: own calculations

The values obtained illustrate that for the same price, environmental damage and number of firms as in Scenario 1, maximizing social welfare in the domestic country is achievable through a higher output. When enforcing an emission intensity policy, fewer firms than in the cap and trade scenario are tempted to relocate, although they are allowed to emit more in the foreign jurisdiction.

The investigation continues with a sensitivity analysis similar to Scenario 1. Table 5-7 illustrates the impact of different output prices and damage coefficients on the LFEs total emissions. Total emissions are calculated as the product of emissions rate, output and number of firms that remain in Home.

When the social planner decides to implement an emission intensity policy, for the lowest value of the damage coefficient, total emissions register very high values which increase at a sharp rate for each incremental unit of the output price. Briefly, for any given damages, higher prices lead to more emissions. For any price, greater damages lead to fewer emissions. This is the same as in the cap and trade although, in the present scenario, the emissions are much more sensitive to parameter values.

For the values of the damage coefficient in the range 0.1 – 0.4, it is easily noticeable that the output price effect overcomes the environmental damage effect. One explanation for the high value of the total emissions in the domestic jurisdiction is that LFEs have no limits in producing as much output as profitable if they keep the emission rate under a specific limit. When the damage coefficient is higher than 0.4, the increase in the total emissions has similar values with the first scenario's total emissions when the damage coefficient is 0.1. However, the non-shaded region of the table indicates that, the environmental damage effect radically overcomes the price effect when the damage coefficient has a weight of 0.6 and above. The motivation is that total emissions decline at a much higher rate in Scenario 2 than in Scenario 1. Further on, for a damage coefficient of 0.6 and above, when comparing Table 5-2 with Table 5-7, there are considerably lower emissions registered in the domestic country under an emission intensity system than when a cap and trade policy is in place.

Table 5-7.: Home total emissions under emission intensity (thousand tons)

		Output price (units)													
		100	105	110	115	120	125	130	135	140	145	150	155	160	165
D A M A G E C O E F F (units)	0.1	1,753	2,175	2,712	3,409	4,331	5,584	7,340	9,897	13,804	20,158	31,367	53,518	105,278	264,345
	0.2	358	424	500	589	694	816	962	1,136	1,346	1,602	1,920	2,321	2,834	3,507
	0.3	223	182	212	246	285	328	378	435	500	574	661	761	880	1,020
	0.4	89	104	120	139	159	183	208	237	270	306	347	393	445	505
	0.5	59	68	79	91	104	119	136	154	174	196	221	248	279	313
	0.6	42	49	57	66	75	86	97	110	124	140	157	176	196	219
	0.7	32	38	44	50	58	66	75	84	95	107	119	133	149	166
	0.8	26	30	35	40	46	53	60	68	76	85	96	107	119	132
	0.9	21	25	29	33	38	44	50	56	63	71	79	88	99	109
	1	20	21	24	28	32	37	42	48	54	60	68	75	84	93
	2	7	8	9	11	13	15	17	19	22	25	28	31	35	39
	3	4	5	6	7	8	10	11	13	15	17	19	21	24	27
	4	3	4	5	5	6	7	9	10	12	13	15	17	20	22
	5	3	3	4	5	5	6	7	9	10	12	13	15	17	19
	6	2	3	3	4	5	6	7	8	9	10	12	14	16	18

Source: own calculations

Legend:



Output price effect overcomes the environmental damage effect

Lower total emissions under emissions intensity system than under cap and trade, for damage coefficients above 0.6

Table 5-8 illustrates that the average rate of emissions is similar to total emissions, higher prices lead to higher intensities and larger damages to lower intensities.

In the table, the white area shows that, when comparing these results with their cap and trade policy equivalent figures (Table 5-3), irrespective of the output price, when the damage coefficient is higher than 0.3, the emission intensity policy determines much lower rates of emissions. The shade of grey shows that, for low marginal damages and higher prices, Home intensities can rise above Foreign's (assumed to be 200). Generally though, the emission rates in Home are lower than in Foreign. The intuition for this result is that high output prices in combination with low marginal damages may determine the opening of new domestic plants. This can be verified in the subsequent simulation which focuses on the number of firms that stay Home.

Table 5-8.: Home emissions rate under emission intensity (tons per unit of output)

		Output price (units)													
D A M A G E C O E F F (units)		100	105	110	115	120	125	130	135	140	145	150	155	160	165
	0.1	291	315	341	370	404	443	490	547	618	709	833	1009	1285	1778
	0.2	135	144	152	162	171	182	193	205	218	232	248	266	286	310
	0.3	129	95	100	106	111	117	123	130	137	144	151	160	168	178
	0.4	68	72	76	80	84	88	93	97	102	107	112	117	122	128
	0.5	56	59	62	65	68	72	75	79	82	86	90	94	98	102
	0.6	47	50	53	55	58	61	64	67	70	73	76	79	83	86
	0.7	41	44	46	49	51	53	56	59	61	64	67	70	73	76
	0.8	37	39	41	43	46	48	50	53	55	57	60	62	65	68
	0.9	34	36	38	40	42	44	46	48	50	52	55	57	59	62
	1	34	33	35	36	38	40	42	44	46	48	51	53	55	57
	2	19	20	21	23	24	25	27	28	30	31	33	34	36	38
	3	15	16	17	18	19	21	22	23	24	26	27	28	30	31
	4	13	14	15	16	17	18	19	21	22	23	24	26	27	28
	5	12	13	14	15	16	17	18	19	20	21	23	24	25	27
	6	11	12	13	14	15	16	17	18	19	20	22	23	24	25

Source: own calculations

	Low marginal damages and higher prices can lead to higher Home intensities than in Foreign
	Emission intensity policy determines lower intensity rates than under cap and trade

Another parameter comprised in the total emissions calculations is the number of firms that remain in Home after implementing the intensity policy. Simulations results are shown in Table 5-9.

As with cap and trade, higher damages lead to greater capital flight since the optimal intensity in Home falls further below than in Foreign. Similarly, higher prices lead to less capital flight as firms can increase their profits through output sale. For low damages though, rising prices can lead to opening new plants⁶⁰ in Home. However, for larger damages, there is a net outflow of firms.

The grey shaded area on Table 5-9 illustrates the possibility of opening new domestic plants for higher output prices and low environmental damage values. While an increased number of firms may contribute to a high social welfare, as domestic firms' profits are a component of the social welfare, there will be a significant negative impact on the magnitude of total domestic emissions. Another plausible explanation for the capital creation in Home is that firms have no limits in producing as much output as profitable if they keep the emission rate under a specific limit.

The results show that firms decide to relocate to Foreign when more value is placed on the environment (the damage coefficient is above 0.3) and for any output price. Comparing this scenario with the cap and trade one, for most of the parameters' values there is less capital flight under an emissions intensity policy than under a cap and trade system. However, the same number of firms decides to relocate in both scenarios for the upper end of the parameters range for environmental damage and output price.

⁶⁰ Another explanation for this result could be that firms from Foreign can relocate Home; however, the present model addresses the Home firms' problem and not Foreign firms'.

Table 5-9.: Number of firms that remain Home under an emissions intensity policy

		Output price (units)														
D A M A G E C O E F F (units)		100	105	110	115	120	125	130	135	140	145	150	155	160	165	
	0.1	207	209	212	216	221	227	235	245	258	276	302	339	398	507	
	0.2	195	196	196	196	197	198	199	201	203	205	208	211	216	221	
	0.3	192	192	191	191	191	191	191	191	191	191	192	192	193	194	196
	0.4	191	190	189	189	188	188	187	187	186	186	186	186	186	186	186
	0.5	190	189	188	187	186	186	185	184	184	183	183	182	181	181	
	0.6	189	188	187	186	185	184	184	183	182	181	180	179	179	178	
	0.7	189	188	187	186	185	184	183	182	181	180	179	178	177	176	
	0.8	188	187	186	185	184	183	182	181	180	179	177	176	175	174	
	0.9	188	187	186	185	184	183	181	180	179	178	176	175	174	173	
	1	188	187	186	185	183	182	181	180	178	177	176	175	173	172	
	2	187	186	185	183	182	181	179	178	176	175	173	172	170	168	
	3	187	186	184	183	181	180	178	177	175	174	172	171	169	167	
	4	187	185	184	183	181	180	178	177	175	173	172	170	168	167	
	5	187	185	184	182	181	180	178	176	175	173	171	170	168	166	
	6	187	185	184	182	181	179	178	176	175	173	171	170	168	166	

Source: own calculations

Legend:

-  Home firms can open new plants for low values of the damage coefficient and high output prices
-  Higher damage coefficients lead to capital flight, while higher prices lead to less capital flight

Table 5-10 shows the resulting social welfare under the emission intensity policy. As expected, larger damages lead to lower welfare. However, higher prices need not raise welfare.

The grey shaded region in Table 5-10 illustrates that for damage coefficient values lower than 0.6 social welfare values increase along with the increase in output price. Conversely, for damage coefficient values from 0.6 and on, social welfare monotonically decreases. Consistent with the previous findings, when comparing the two scenarios, for most of the parameters considered, implementing an emission intensity policy leads to a higher social welfare.

Table 5-10.: Social welfare Home under an emission intensity policy (thousand dollars)

		Output price (units)													
		100	105	110	115	120	125	130	135	140	145	150	155	160	165
D A M A G E C O E F F (units)	0.1	133	158	187	221	261	308	366	438	529	646	806	1,036	1,395	2,037
	0.2	55.2	64.4	74.7	86.3	99.3	113	130	148	169	192	219	250	286	328
	0.3	28.4	33.1	38.3	44.1	50.6	57.7	65.7	74.4	84.2	94.9	106	120	135	152
	0.4	9.1	14.8	17.3	20.0	23.0	26.4	30.2	34.3	38.9	44.0	49.7	56.0	63.0	70.8
	0.5	1.1	1.5	2.0	2.5	3.2	3.9	4.8	5.8	7.0	8.4	10.0	11.9	14.1	16.6
	0.6	-8.3	-10.3	-10.5	-11.7	-13.0	-14.4	-15.8	-17.2	-18.7	-20.2	-21.7	-23.2	-24.6	-26.0
	0.7	-16.6	-19.0	-21.6	-24.4	-27.3	-30.5	-33.9	-37.5	-41.2	-45.2	-49.4	-53.7	-58.2	-62.8
	0.8	-24.3	-27.8	-31.7	-35.9	-40.4	-45.2	-50.4	-55.9	-61.8	-68.0	-74.5	-81.4	-88.6	-96.2
	0.9	-31.5	-36.1	-41.2	-46.7	-52.7	-59.1	-66.0	-73.3	-81.1	-89.4	-98.1	-107	-117	-127
	1	-38.3	-44.1	-50.3	-57.1	-64.4	-72.3	-80.8	-89.8	-99.5	-109	-120	-132	-144	-157
	2	-100	-115	-132	-150	-170	-191	-214	-238	-265	-293	-323	-354	-388	-423
	3	-158	-182	-208	-237	-269	-303	-339	-379	-421	-465	-513	-564	-618	-675
	4	-215	-248	-284	-324	-366	-413	-463	-517	-574	-636	-701	-771	-844	-923
	5	-271	-313	-359	-409	-464	-522	-586	-654	-727	-805	-888	-976	-1,070	-1,169
	6	-328	-378	-434	-495	-560	-632	-708	-791	-879	-973	-1,074	-1,181	-1,294	-1,414

Source: own calculations

Legend:

- For lower damage coefficients, social welfare increases with the increase in output price
- Social welfare decreases monotonically for damage coefficient values above 0.6

5.3.2.3 Summary of results

For a better assessment of the social welfare between the two policies, Table 5-11 presents the *difference* in social welfare between emission intensity and cap and trade. The results confirm that social welfare is generally higher for an emission intensity system.

The magnitude of social welfare depends on profits (hence the number of firms that remain in the country), their emission intensity, and the amount of output. The most important factor to impact social welfare magnitude is the presence of capital flight. Thus, the results obtained show that, under an emission intensity policy, there is less capital flight, and, for certain values, there is the possibility for capital creation. Under an emissions intensity policy, much higher values were obtained for the emission rate and output variables. Nonetheless, as shown in Region 2 – the white region of the table, the social welfare is higher under emission intensity than under its cap and trade policy counterpart. The lighter grey shaded areas, Regions 1 and 4, show that the magnitude difference between the two policies is quite noticeable. These areas illustrate that the output price effect overcomes the damage coefficient effect.

However, there is one exception from the above. As shown in Region 3 – the dark grey shaded area of the table, cap and trade has slightly higher social welfare values for low output prices of 100 to 120 and when the damage coefficient takes values between 0.4 and 0.5. This is explained by the magnitude variation of the social welfare under cap and trade (Table 5-5).

Table 5-11.: The difference between Home emissions intensity and cap and trade social welfare values (thousand dollars)

		Output price (units)													
D A M A G E C O E F F (units)		100	105	110	115	120	125	130	135	140	145	150	155	160	165
	0.1	77.9	95.5	116	142	174	213	262	325	406	514	663	883	1,231	1,862
	0.2	15.3	19.3	24.2	30.0	37.0	45.4	55.3	67.0	80.9	97.4	117	140	169	203
	0.3	2.05	3.28	4.88	6.90	9.40	12.4	16.1	20.6	25.9	32.2	39.7	48.6	59.0	71.2
	0.4	-4.78	-0.87	-0.37	0.34	1.31	2.59	4.22	6.25	8.76	11.8	15.4	19.8	25.1	31.2
	0.5	-0.91	-0.86	-0.71	-0.45	-0.04	0.53	1.32	2.37	3.71	5.39	7.46	10.0	13.0	16.7
	0.6	0.97	0.11	1.16	1.33	1.59	1.95	2.44	3.10	3.95	5.03	6.39	8.07	10.1	12.5
	0.7	3.69	3.94	4.20	4.48	4.80	5.18	5.65	6.22	6.93	7.80	8.87	10.1	11.7	13.8
	0.8	6.89	7.40	7.90	8.40	8.92	9.46	10.0	10.7	11.4	12.3	13.3	14.5	15.9	17.6
	0.9	10.3	11.2	12.0	12.8	13.6	14.4	15.2	16.0	17.0	18.0	19.1	20.4	21.8	23.4
	1	14.0	15.2	16.4	17.5	18.6	19.7	20.8	22.0	23.1	24.4	25.7	27.1	28.7	30.4
	2	54.0	59.4	64.9	70.3	75.8	81.2	86.5	91.8	97.1	102	107	112	117	122
	3	94.8	104	115	125	135	145	156	166	176	186	196	206	215	225
	4	135	150	165	180	195	211	226	241	256	271	286	301	315	330
	5	176	196	215	235	256	276	296	316	337	357	377	396	416	435
	6	217	241	266	291	316	341	367	392	417	442	468	492	517	541

Source: own calculations

Legend:

-  Region 1: Social welfare under emissions intensity has much higher values than under cap and trade
-  Region 2: Social welfare under emissions intensity has higher values than under cap and trade
-  Region 3: Social welfare is higher for cap and trade than for emissions intensity policy
-  Region 4: Social welfare under emissions intensity has much higher values than under cap and trade

Summarizing the results of the two scenarios, for a social planner who takes into account global pollution, when the environmental damage coefficient is valued at 0.4 or greater, the emissions intensity system is a superior instrument to cap and trade. The emission intensity policy leads to lower total emissions, lower intensity rates, and less capital flight.

Further, for the highest values of the damage coefficient and output price, the two policies yield similar results. Hence, when damages are very high, the two policies seem to converge. This may be explained by the environmental efficiency of each policy and their sensitivity reaction (embedded in their design) when considerable substance is attributed to environmental damage.

With regard to the social welfare comparison, Table 5-11 shows that for the same set of exogenous parameters, the emission intensity policy would be preferred over cap and trade, given social welfare's higher values. Indeed, when an emissions intensity system is in place, for lower values of the damage coefficient there is the possibility of opening new plants in the domestic country that can contribute to a much higher social welfare magnitude. This situation implies that firms' emissions have very high values and acutely damage the environment. Another explanation for the high social welfare is that the output obtained is much higher than under a cap and trade system (given the implicit output subsidy effect of an emission intensity policy) and, in turn, firms' profits are higher. For higher values of the damage coefficient than 0.4, an emission intensity system leads to decreasing values of the social welfare, although still higher than under a cap and trade policy.

Comparing the total emissions (Table 5-2 versus Table 5-7) shows that when the environmental damage is low (damage coefficient is between 0.1 and 0.6), the environmental friendlier policy is cap and trade rather than emissions intensity. On the other hand, for higher values of the damage coefficient, emissions intensity system has fewer emissions. Hence the idea that intensity measures are less environmentally friendly does not hold when damages are high, and this is the time when emissions would preferably fall. However, under cap and trade, even though damages are high, the regulator worries about capital flight.

Shifting the focus of the analysis on capital flight, a similar situation is observed when comparing the number of firms that stay in Home after enforcing the policies. For very low values of the damage coefficient, an emission intensity policy may lead to capital creation and not capital flight. When comparing this scenario with the cap and trade one, for higher damage coefficient values there is less capital flight under an emissions intensity policy than under a cap and trade system. Hence, intensity measures allow the regulator to achieve emissions targets with less concern for capital flight.

The current model setup and the sensitivity analysis actually illustrate the trade off between social welfare and environmental damage coefficient that a regulator should take into account when deciding which GHG emissions reduction policy to enforce. Very briefly, this analysis illustrates that an emissions intensity policy leads to higher social welfare and that a cap and trade determines more firms to relocate. However, these simulations bring into attention particular issues. For instance, the results illustrate that before implementing a policy, the particularities of the output that is subjected to a policy, along with each jurisdiction's specific environmental damage valuation, should be considered by the regulator. At the same time, another finding of this analysis shows the importance of correlating the two endogenous variables, as under certain circumstances, the output price overcomes the environmental damage coefficient effect and vice-versa.

5.4 Conclusions

Since the emission intensity framework proposed by the Canadian government is unclear about how the policy will specifically impact the potential relocation decisions, this chapter examines the relative incentives to do so by comparing and contrasting the economic relocation incentives under the existing emission intensity to those that would exist under a cap-and-trade.

The simulation analysis reveals that for a given target, cap-and-trade encourages firms' relocation. Under emission intensity system, fewer firms are tempted to relocate in jurisdiction with lower GHG emissions rates, but this policy does not encourage real emission reduction. In other words, implementing a cap and trade system enhances the potential pollution haven effect through the existence of tradable permits. It is difficult to

state which of the two policies is more efficient, as due to its output subsidy effect, emission intensity system can be considered only a second best policy choice.

The main point of the analysis is that social planners need to acknowledge the weak and strong features of the policies and refine them when considering real GHG emission reductions. It may be the case that cap and trade leads to too high targets, since capital flight is a bigger problem. Meanwhile, the intensity system may encourage opening new domestic plants in addition to decreasing the incentive to move out. However, whether emissions intensity systems facilitate net emission reduction below cap and trade is open.

The results of the simulations actually illustrate the trade off between global environmental benefits and domestic social welfare as a result of enforcing a GHG emission reduction policy versus no or very lax environmental regulation. The results show that under certain circumstances (perfect competition, homogenous firms and production mobility), the incentive to relocate across border in a more permissive environmental jurisdiction constitutes an option for certain industries that, for various reasons, may experience competitiveness issues. Environmental economists weigh the possibility where all governments will be tempted to relax their environmental policies and thus creating an ecological dumping (Ulph, 1997) as a result of regulatory chill⁶¹ or race to the bottom⁶² occurrences. Sheldon (2006) addresses the regulatory chill and race to the bottom in environmental standards and policies and argues that methods for countering these two phenomena are already embedded in existing GATT/WTO rules as border tax adjustments⁶³ (BTA). The author considers that based on his research and existing literature there is evidence that both trade and investment flows are affected by environmental policy (although this is not the only factor that affects them). Moreover, regulatory chill or race to the bottom can be overcome by applying more flexibly the GATT/WTO tariff bindings (or BTAs) under the condition that ‘...countries do not retain complete sovereignty over their environmental policies’ (p. 388).

⁶¹ Regulatory chill is defined as the situation where a government resists enforcing a strict environmental policy (Bagwell and Staiger, 2001).

⁶² Race to the bottom occurs when a regulator decide to reduce the stringency of its environmental regulations (Bhagwati and Srinivasan, 1996).

⁶³ In the context of GHG emission reduction policies, BTA are defined as import fees levied by carbon taxing countries on goods manufactured countries that do not tax carbon.

In practice there is a recent example to be told in this context. As mentioned in Chapter 2, BTAs have been contemplated by the US Climate Change Bill to accompany its future cap and trade policy system. The concern behind this proposal is that domestic US producers will be disadvantaged in trade relationships when the US enforces a cap and trade policy while developing countries (e.g. India and China) have none or very low binding emission targets. However, the BTAs format that the US intends to enforce is different than an import carbon fee and may not constitute a challenge under the WTO/GATT regulations. Thus, the importers of carbon intensive goods from countries with laxer environmental regulations would be obliged to buy certified emissions allowances from the federal government or from a US GHG regulatory program if they want to sell their goods in the US market. The challenging part, however, would represent assessing the carbon content of the goods imported, e.g. whether it is a final or an intermediate good, what stage of manufacturing is the most carbon intensive one that needs to be taxed (Sheldon, 2006).

Regarding the Canadian context, policy initiatives such BTAs should be assessed given the existing experience in trading carbon in a non-harmonized world and at the same time, the reality of the current global environmental context where the last Kyoto negotiations failed to accomplish global GHG emissions commitments. If Canada will decide to implement a cap and trade policy, BTAs may represent an option to consider for the Canadian regulators considering the lessons to be learned from the competitiveness and relocation issues that EU has been experiencing.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Mitigating climate change is a globally acknowledged environmental challenge. While the effects and timing of climate change are uncertain at this point, there is a convergence of scientific opinions about the necessity of a more focused global intervention to reduce greenhouse gas emissions. Despite the negotiation of international agreements, some countries are undertaking determined targets while others are delaying their actions.

The lack of political consensus was evident in the December, 2009 United Nations Climate Change Conference held in Copenhagen (and in the 2010 Cancun meeting). The main goal of the Copenhagen Accord was to renew the Kyoto Protocol and obtain a new global agreement on mitigating climate change effects beyond 2012. However, the negotiations revealed a large divergence among developed and developing countries about emission targets responsibilities. While the parties agreed that a 2 degrees Celsius increase in the global temperature should be prevented, the result was a vague non-binding agreement that failed to achieve a comprehensive global agreement with a common strategy to reduce emissions. Briefly, the achievements of Copenhagen Accord are that developing countries are going to receive financial help from industrialized nations for fighting climate change. However, the participant countries are free to set their own emission reductions with no mandatory limits. It is therefore unlikely that the Copenhagen Accord will achieve the proposed target.

The Copenhagen Accord goal of renewing Kyoto Protocol beyond 2012 was carried on by the 17th session of the Conference of Parties (COP 17) to the UNFCCC. The conference took place in Durban, South Africa, between November 28 and December 10, 2011. Among the main goals of the conference was to extend the Kyoto Protocol with a second commitment period, to reach an agreement on keeping the average global temperature rise below two degrees and to negotiate a future legally binding agreements. At the end of the two weeks of gruelling discussions, the 194 delegate members have reached an agreement and the above goals were achieved. According to the press release of the UNFCCC (2011) on Durban conference, the

participating countries have recognized the need to keep the average global temperature rise below two degrees. The delegate members have agreed to establish the “Durban Platform for Enhanced Action” to negotiate a new global agreement on climate change by 2015; this agreement will not come into effect or start to be implemented until 2020. However, the Kyoto Protocol was extended with a second commitment period which will start on January 1, 2013; this means Kyoto Protocol remains the only current legally binding instrument which stipulates emissions targets and timelines for industrialized countries. Other important measure agreed upon refers to the Green Climate Fund, which will raise \$100 millions per year aimed at helping developing countries cope with climate change adaptation issues.

The end result of the Durban conference can be seen as a step forward or not in the climate change battle. Particularly after the Copenhagen talks in 2009, it was feared that this conference will not accomplish the proposed goals. The conference lasted two more days than initially planned given that some of the participating nations’ representatives were reluctant to sign the agreement. A major achievement of the COP 17 is that, the US, India and China have agreed to reduce emissions as part of the new legal treaty. However, the three countries have only voluntary emission targets reductions until 2020, or whenever the new agreement will enter into force.

Canada’s position at the climate change talks in Durban began with signals of the intention to withdraw from Kyoto Protocol with the motivation that China, along with the rest of major polluting developing countries, is not equally bound by a legal treaty. Even though China and India showed more flexibility than expected, and ended up signing the future agreement, Canada has officially announced withdrawing from Kyoto Protocol one day after the conference ended. While several developed countries have complained for a long time about the developing nations’ lack of obligations within Kyoto, Canada becomes the first country to withdraw from the Protocol (Kennedy, 2011). The Environment Minister Peter Kent justified this decision through the failure of the previous liberal government to achieve the emission reductions cut that was promised when Canada ratified Kyoto. Further, he expressed his disbelief in the Kyoto Protocol’s chances to represent the solution for mitigating climate change globally. However, the

Minister has stated Canada's willingness to participate in an international climate change treaty "that works" and which "involves all major emitters".

So far, the lack of comprehensive global agreement has led to a mixture of GHG emission reduction policies across countries. Currently, the main emission reduction mechanisms employed by governments are cap and trade, emissions intensity and carbon tax. The wide range of policy instruments and emission reduction targets that are globally employed has further complicated the challenge of designing effective domestic policy. Under these circumstances, there are economic and environmental consequences that policy makers need to be aware of, such as industrial flight (Jenkins et al, 2002), where firms relocate from jurisdictions with strict GHG emissions reduction regulations to pollution havens, which are countries with lower emission reduction standards. For instance, the European Union experience with cap and trade policy reveals that industrial sectors can face competitiveness issues and incentives to relocate to other jurisdictions (Neuhoff 2007, McKinsey and Ecofys 2006).

Canada has explored a wide range of emission reduction mechanisms in the last two decades, but thus far has failed to implement an effective policy. The Canadian policy design became particularly complex when the United States, Canada's main trading partner, did not ratify the Kyoto Protocol. The Canadian policy started with voluntary policies and subsidies and it is currently employing a capped emission intensity system for regulating heavy industry emissions reductions. With the United States contemplating a cap and trade system, Canada has been also considering implementing a cap and trade policy starting 2020 (Government of Canada, 2008 [1]), and thus acknowledges the policy harmonization necessity. Canada continues to search for a viable GHG emission reduction policy to achieve tangible reductions in GHG emissions.

In the light of the above considerations, this dissertation focused on analyzing and comparing some economic and environmental aspects regarding carbon tax, cap and trade and emissions intensity policies in various scenarios for a Canadian emission intensive industry. The findings of this research reveal the inherent difficulty of implementing domestic cap and trade policy in the context of a international trading environment, which could be one of the reasons why international reductions in GHG emissions has been such an elusive goal.

The analysis outlined in Chapters 2 to 5, reveals that while cap and trade may be effective in a hypothetical world of single sector within in a closed economy, it will be far less effective in the real world in the presence of downstream emissions, international trade, or firm relocation. Given the administrative complexity, cap and trade systems are designed to be enforced only in the upstream of an industry even though downstream consumers are responsible for a large share of emissions. When inputs and final outputs are traded with countries that do not have a similar policy in place, a cap and trade instrument is harmful for the domestic industry, while dirty foreign firms increase output to the detriment of the domestic industry. While this can be remedied by border tax adjustments (BTAs) accompanying the cap and trade instrument, BTA's are not allowed in the WTO. Moreover, when emission permits are distributed for free, firms have additional incentives to sell the permits and relocate to countries with less stringent environmental regulations.

This dissertation addresses a number of important 'gaps' in the literature. In the existing literature little attention has been paid to the effects of vertical markets on the design of GHG emissions policies (Hamilton and Requate, 2004). Chapter 3 addresses the distributional impacts of carbon tax and cap and trade within a vertical market. The model developed in Chapter 4 builds on the model developed by Muth (1964), Alston (1995), Wohlgenant (1993), Gray et al. (2000) and others, which focus on the distribution of research benefits within a vertical market system, in a multistage production settings for various agricultural products. Chapter 4 adds to this research by employing a Muth model for exploring the price, quantity and distributional effects of the two GHG mitigation policies within a vertical market system with and without input substitution. Chapter 5 is novel in that it accounts for the saleability feature of emission permits which affects firms' relocation decisions. This is done in the context of social welfare maximization where the domestic policy maker takes into account the pollution generated by domestic firms regardless the jurisdiction in which emissions were generated.

The theoretical modeling of the thesis begins by highlighting the different economic impacts of implementing a carbon tax and a cap and trade policy in an economy. Chapters 2 and 3 describe and explain these instruments and highlight that while a carbon tax is a transparent, easy to implement and globally used instrument, a cap

and trade policy lacks all these characteristics. In perfect competition and in the absence of uncertainty, carbon dioxide abatement, carbon tax and a cap and trade system (where the permits are auctioned) are equivalent with regards to the level of abatement achieved, the price of carbon and the price of carbon intensive goods. However, under uncertainty, the policies are quasi-equivalent and differences between them consist not only in their transparency or easiness of implementation but also on welfare distributional effects.

Regarding the relative advantages of the two policies, carbon tax is a price regulatory instrument while a cap and trade is a quantity regulatory instrument. Both policies place a price on CO₂ emissions⁶⁴, but they differ in the choice of policy instrument. However, the relative GHG mitigation efficiency of the two policies will differ under uncertainty. The uncertainty that surrounds the carbon dioxide emissions damage effects, is reflected for instance in the range of social cost of carbon dioxide that researchers have been assessing. There are estimates ranging between \$11 (Nordhaus, 2009) to \$85 per ton (Stern, 2007), while the IPCC report (2007) attributes a possible range of values from \$3 to \$95 per metric ton of carbon dioxide.

Recalling some of the definitions used along this thesis, a carbon tax places an explicit price of CO₂ emissions which leads to the adjustment of the quantity of emissions corresponding to the tax level. A cap and trade policy sets a specific quantity of emissions and allows the price of emissions to adjust accordingly (Murray et al., 2008). Under certainty, the two policies can be set to obtain the same emissions reduction, but under uncertainty, this is not achievable. The reason is that in the real world, regulators are confronted with uncertainty and incomplete information regarding the exact structure of the cost and benefits curves (Baumol and Oates, 1988). Thus, policy makers cannot know ex-ante the effect that the tax would have on the quantity of emissions and the effect that the emissions cap will have on the price. So there will be differences between the desired effect of any of the policies and the actual outcome in the market.

Therefore, for observing a carbon tax and a cap and trade impact on welfare distribution within an industry, in Chapter 3 it is assumed that these policies are implemented within both a simple market and a fixed proportions vertical market system of a closed economy. Under these assumptions, a graphical analysis illustrates that, as a

⁶⁴ In most jurisdictions several greenhouse gases are included in policy, but are measured in terms of CO₂ equivalents.

result of implementing a cap and trade system, when inputs are not substitutable, rents are created and that there is economic welfare redistribution within the vertical market system. Generally, the two policies are not equivalent. They can be quasi-equivalent when implemented on the same good or level within a vertical market structure. They can also be quasi-equivalent regardless of the level of implementation within the vertical structure with a fixed proportions technology within a closed economy, but even in this case they can differ substantially in where the rents accrue. Furthermore, the strong assumption of input non-substitutability means that production, consumption or efficiency within the vertical market system are not impacted by the input and policy choices; their impact will be on rent distribution.

The analysis is continued in Chapter 4, where a Muth model of the oil sector in Canada allows comparing fixed and variable proportions in a vertical market structure, as well as simulating the welfare distribution effects of enforcing a carbon tax versus a cap and trade policy. The Muth model is modified to incorporate a nested CES production function with the aim of a more precise representation of the presence of foreign competition at the refining level when input substitution is allowed.

Firstly, under the assumptions of fixed proportions and a closed economy, a carbon tax is introduced concomitantly at consumers and Canadian refiners' level. This carbon tax policy is compared to an analogous cap and trade policy implemented only at the processors' level. These two policies are maintained when input substitution is allowed for refining within the vertical structure, which provides an opportunity to compare the effects of a carbon tax policy and a cap and trade policy when there is trade in refining services.

Under fixed proportions, similar results are obtained for the two policies regarding their impact on quantities, prices, welfare distribution and cost of emissions reduction. Hence, the Muth model and the simulations developed in this chapter confirm the Chapter 3 results: in a closed economy a cap and trade policy and a carbon tax are quasi-equivalent.

When a higher degree of substitution between inputs is allowed, the results of a carbon tax and a cap and trade policy are different. A carbon tax negatively affects consumers' surplus as, for a price that incorporates the tax, consumers have to reduce the

quantity of gasoline demanded. Canadian producers also know a surplus loss but to a lesser extent than the consumers. In contrast, enforcing a cap and trade policy at Canadian refiners' level increases the surplus of ROW refiners at a high expense for Canadian producers' surplus. Given that cap and trade is designed to be enforced only in the upstream of an industry, consumers surplus is much less affected than in the case of carbon tax. However, in this scenario, Canadian producers significantly reduce their gasoline supply on the domestic market, and thus lose a considerable large amount of surplus, and at the same time, capture less rent compared to carbon tax. This result shows that, when inputs and final outputs are traded with countries that do not have a similar policy in place, a cap and trade instrument is harmful for the domestic industry, while dirty foreign firms increase output to the detriment of the domestic industry.

Regarding the GHG emissions mitigation, both carbon tax and cap and trade mitigate the same quantity of GHG emissions in a closed economy. However, under free trade a carbon tax is a preferred instrument over a cap and trade policy for its ability to reduce more GHG emissions and at a much lower economic cost per ton of emissions. The issue remains that, under free trade, for this specific product with a relatively inelastic demand, consumers have the option to buy the gasoline from the ROW and still emit almost the amount of GHG. Regarding the cap and trade effect on GHG emissions reduction, the much lower quantity of emissions abated at a very high cost per unit of emissions, illustrates that it is not an efficient emission reductions instrument. This conclusion is supported by the computations related to the Canadian and global welfare. The results illustrate that carbon tax increases Canadian and global welfare when more trade takes place, while a cap and trade policy determines very high welfare loss for both Canada and the world.

The results obtained lead to the conclusion that trying to get optimal production and consumption of emission intensive goods through implementing a cap and trade policy is not efficient as long as free trade allows input and final goods substitution. In other words, the results show that when a cap and trade policy is implemented in the upstream of a vertically integrated industry, its efficiency is decreased by trade. At the same time, as previously mentioned, this policy can not be enforced downstream due to its administrative design, hence creating a fundamental challenge for implementation.

This outcome reinforces the idea that the choice of a domestic GHG emission reduction policy does impact the welfare distribution within an industry. In addition, when imposing a cap and trade policy in an open to trade economy, as long as there is foreign goods substitution available, and implicitly GHG emissions from them, the real magnitude of global emission reductions is questionable. Consequently, the only solution possible to achieve efficient GHG emissions reductions would be if Canada imposes border tariffs adjustments when importing these goods. However, this solution contravenes WTO/GATT rules and it is not clear yet under which circumstances or policy format it would be accepted for implementation.

In conclusion, implementing this policy with the aim of pricing carbon creates competitiveness issues for certain industries, which in turn can lead to pollution haven effects, industrial flight, or race to the bottom, etc. (Copeland and Taylor 2004, Sheldon 2006). This is consistent with the EU experience where a number of heavy industries threaten with relocation if they do not receive free emission rights to allow them to attenuate the costs occurred as a result of implementing a cap and trade policy. Cap and trade policy offers an additional incentive for firms to relocate as long as they can sell the emission permits, obtain a financial gain and continue to emit greenhouse gases someplace else. If this is the case, the next concern addressed in this research is whether emission intensity is a more efficient policy than cap and trade.

In this context, Chapter 5 steps up from a national perspective to consider global emissions, where a domestic social planner has the option to decide between enforcing a cap and trade versus an emission intensity policy. The choice of the two policies considered for the analysis is also motivated by the current Canadian policy in place and a possible US policy choice. The three stage sequential model analyzes the relocation incentives and the social welfare impact of implementing each of the two policies for a social planner who takes into account emissions generated by its industries both domestically and abroad. The assumption related to the firms' relocation incentive is explained by the fact that when a cap and trade system is in place, it is easier for firms to reduce output, sell the permits, obtain a profit and then relocate to jurisdictions with lower emissions standards.

The models developed in Chapter 5 are organized as a two-country, three stage sequential game solved through backward induction. The models examine firms' relocation incentives and their impact on the social planner's social welfare, for both policies. The results of the constrained optimization and simulations confirm that, for Scenario 1, when assuming that a cap and trade policy is in place, there is a positive relationship between the magnitude of GHG emissions decided by the regulator (or the number of permits distributed) and the number of firms that decide to sell the permits and relocate to the others jurisdictions. Meanwhile, scenario 2 assumes welfare maximization for a domestic planner who has implemented an emission intensity policy while the Foreign jurisdiction has no policy in place or lower emission rates.

The sensitivity analysis carried out for both scenarios consists of investigating the trend of domestic total emissions, number of permits, emissions rate, capital flight and social welfare for a wide range of output price and damage coefficient as exogenous variables. The sensitivity analysis comparison for the two scenarios illustrates that the policies have advantages and disadvantages according to the range of values attributed to the exogenous variables. Depending on the environmental valuation versus output price pair of values, the environmental damage coefficient effect may overcome the price effect and vice-versa. Thus, regarding the capital flight case, for higher values of the damage coefficient, the emission intensity is a superior instrument to cap and trade as fewer firms decide to relocate to Foreign jurisdictions. When examining the social welfare trend for the two policies, emissions intensity leads to higher values of it. However, when connecting all the results of the simulations it is observed that the high value of social welfare in the case of emissions intensity is determined by the much higher values of the output produced than under a cap and trade system. This result confirms the main criticism brought to emission intensity policies: it may reduce the rate of emission per unit of production, but when output increases, more emissions are released into the atmosphere.

In conclusion, these results illustrate that pollution haven effect can be enhanced when implementing a cap and trade policy through the ability of selling the emission permits and relocating. On the other hand, an emission intensity system does create an

output subsidy effect and this makes it a second best instrument to impose for achieving real emission reductions.

Summarizing the findings of this dissertation, a cap and trade policy can not be considered a first best economic instrument in the presence of downstream emissions, in the absence of environmental tariffs or with the inability to prevent firm relocation. This policy was designed to be implemented in the upstream of an industry and not at consumers' level, and it is shown that when implemented at producers' level, its efficiency is decreased by input substitution. This is where a BTA would improve the efficiency issues of a cap and trade policy singularly implemented. Furthermore, carbon tax can be a first best policy instrument if appropriately applied at all the levels and for the accurate carbon price. The fact that a carbon tax does not support emission permits trading can be addressed easily through regulations. There is the option of globally employing a carbon tax through international negotiations and if each country agrees on setting a specific carbon price level, real GHG emission reductions can be achieved without doubt. The carbon tax proponents (Nordhaus 2009, Metcalf 2009) suggest that Kyoto Protocol should be amended such that to include a global carbon tax policy.

However, the current concern to be addressed regarding policy implementation for global reductions of GHG emissions is that the international tendency is towards a cap and trade system. Recalling the results of this thesis and the literature, a cap and trade may easily lead certain industries to competitiveness issues, relocation incentives and potentially to race to the bottom in environmental standards. Thus, if Canada will decide to enforce a cap and trade policy, it should seriously consider some accompanying measures such as border tariff adjustments (BTAs).

In the current Canadian economic and environmental context, there are pro and con opinions regarding the solutions that BTAs can address. For instance, the National Round Table on the Environment and the Economy⁶⁵ (NRTEE) does not support BTAs application in Canada (NRTEE, 2009). Their main reason is that such tariffs would broadly increase production costs that would impact both producers and consumers. They suggest that a better strategy for Canada would be to maintain the current emission intensity system and wait for the 'major trading partners...have comparable carbon

⁶⁵ An independent policy advisory agency that advises the Canadian federal government.

pricing' (p. 58). As a contrary opinion, in a report written for Pembina Institute⁶⁶, Bramley and Demerse (2008) argue that a Canadian BTA would level the field 'between imported products and their Canadian competitors'. The authors argue that BTAs could be compatible under certain circumstances with WTO/GATT rules and also acknowledge possible issues that need to be considered. For instance, they show that one of the drawbacks of implementing a Canadian BTA can exempt the oil sands sector from the effects of carbon pricing. Furthermore, the authors highlight that calculating BTAs will have quantification issues when importing basic versus manufactured goods, as well as when deciding the point of imposition of a price, which can be at the point of production of the good or at the point of consumption⁶⁷. Last, but not least, a quite challenging issue would be to assess the difference in the environmental regulations severity for two trading countries and implicitly evaluating their carbon costs.

The current research acknowledges that the answer to achieving efficient and real GHG emission reductions in Canada is a policy mix that should comprise first of all a policy instrument that is compatible with the international propensity and especially with Canada's major trading partners' policy choices. This policy should be accompanied by specific measures that should overcome market barriers or failures both domestically and in trading relationships, as well as to address various industries competitiveness concerns. At the same time, regulators should decide the policy of choice after careful consideration is given to distributional impacts and after performing a comprehensive assessment of the domestic environmental damage valuation. In this context, globally implementing a cap and trade policy along with BTAs can represent a policy harmonization solution and give more chances of success to future international negotiations on climate change mitigation.

Regarding further research that can be carried out on this topic, a subject of great interest would be exploring the economic impacts of trade between two or more countries that implement BTAs in turn or at the same time. Alternatively, modeling the implementation of a global carbon tax policy and its economic, environmental and trade effects would definitely represent an important contribution to the literature.

⁶⁶ Canadian non-profit foundation which focuses on developing innovative sustainable solutions.

⁶⁷ The authors use a very good example to illustrate Kyoto's current emissions accounting practices: producing a barrel of oil in Canada is credited to Canada, but if that barrel of oil is burned in the US, then the carbon emissions are credited to the US.

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APPENDIX

Formulas used in Solver excel simulations - Chapter 5

1	A	B	C
2	Policy variables	SCENARIO 1: CAP AND TRADE	
3	Ea - # of permits	849	849.641029647182
5	Exogenous variables		
6	P – output price	150	
7	Beta – coeff.	1000	
8	rF – emission rate foreign	200	
9	F – fixed costs	70	
10	D – damage coeff.	0.5	
11	m – total # of firms	200	
12	Endogenous variables		
13	qH – output home	$=((2*B6*B3*(B11/B17))/(3*B7))^{0.5}$	$=((B6-(D15*D14))*D14)/B7$
14	rH – emission rate	$=((3*B7*B3*(B11/B17))/(2*B6))^{0.5}$	=C3/C13
15	Lamda – coeff.	$=((0.27*(B6^{1.5}))/((B7^{0.5})*(B3^{0.5})))$	=B7*C13/(2*C14*C14)
16	Ea (m/i) – adjusted Ea	=B3*B11/B17	=C3*(B11/C17)
17	I - # of firms relocating	9.99999996	176.448813804585
18	Social Welfare	$=(B6*B13-(B7*B13*B13)/(2*B14)-B10*B13*B14)*B17-(B11-B17)*B8*B19$	
19	qF – output foreign	=B6*B8/B7	=B6*B8/B7
20	Change social welfare when change Ea – number of permits	$=((0.03*(B6)^3*B11/B17)/B7^{0.5}*(0.13*(B6)^{1.5}*(B3)^{0.5}*(B11/B17)^{0.5}*(B17)^{-1})+B9*(B7)^{0.5}+(0.27*(B6)^{1.5}*(B3)^{-0.5}*(B11)^{0.5}*B17/(B7)^{0.5}*(B10*B11+(B10*B6*(B8)^2)/B7)*(0.13*(B6)^{1.5}*(B3)^{-0.5}*(B11/B17)^{0.5})*0.13*(B6)^{1.5}*(B3)^{0.5}$	
21	Profit Home	$=((0.54*(B6)^{1.5}*(B3)^{0.5})/(B7)^{0.5})-B15*((B3*(B11/B17))-B3)$	=B6*C13-(B7*C13*C13)/(2*C14)
22	Profit Foreign	$=(((B6)^2)*B8/(2*B7))+ (B15*(B3))$	=B6*C19-(B7*C19*C19)/(2*B8)
23	Moving Condition	=B9*(B11-B17)	=B9*(B11-C17)
24	Zero Profit	=B21-B22)+B9*(B11-B17)	=C21-C22+C23-(C15*C3)
29	SW	$=(B21*B17)-(B10*((B11*B25)+(B11-B17)*(B26)))$	$=(C21*C17)-B10*((C3*B11+(B11-C17)*(C19*B8))$

	A	B	C
	Policy variables	SCENARIO 2: EMISSIONS INTENSITY	
	Exogenous variables		
40	P – output price	150	
41	Beta – coeff.	1000	
42	SF – emission rate	200	
43	F – fixed costs	70	
44	D - damage	0.5	
45	m – total # of firms	200	
46	Endogenous variables		
47	qH – output home	$=((2*B40*B37*(B45/B51))/(3*B41))^0.5$	$=((B40)*C48)/B41$
48	Hh – emissions home	$=((3*B41*B37*(B45/B51))/(2*B40))^0.5$	89.8477147621663
49	Lamda – coeff.	$=((0.27*(B40^1.5))/((B41^0.5)*(B37^0.5)))$	$=B40*B40/(2*B41)$
51	I - # of firms relocating	9.99999996	182.296954158205
52	Social Welfare	$=(B40*B47-(B41*B47*B47)/(2*B48)-B44*B47*B48)*B51-(B45-B51)*B42*B53$	
53	qF – output foreign	$=B40*B42/B41$	$=B40*B42/B41$
54	Change social welfare when change Ea - number of permits	$=((0.03*(B40)^3*B45/B51)/B41^0.5*(0.13*(B40)^1.5*(B37)^0.5*(B45/B51)^0.5*(B51)^-1)+B43*(B41)^0.5+(0.27*(B40)^1.5*(B37)^-0.5*(B45)^0.5*B51/(B41)^0.5)$ $(B44*B45+(B44*B40*(B42)^2)/B41)*(0.13*(B40)^1.5*(B37)^-0.5*(B45/B51)^0.5) 0.13 (B40)$	
55	Profit Home	$=((0.54*(B40)^1.5*(B37)^0.5)/(B41)^0.5)-B49*((B37*(B45/B51))-B37)$	$=B40*C47-((B41*C47*C47)/(2*C48))$
56	Profit Foreign	$=(((B40)^2)*B42/(2*B41))+ (B49*(B37))$	$=B40*C53-(B41*C53*C53)/(2*B42)$
57	Moving condition	$=(B43*(B45-B51))$	$=B43*(B45-C51)$
58	Zero Profit	$=(B55-B56)+B43*(B45-B51)$	$=(C55-C56+C57)$
63	SW	$=(B55*B51)-(B44*((B45*B59)+(B45-B51)*(B60)))$	$=((C55*C51))-B44*((C48*C47*B45)+(B45-C51)*(C53*B42))$