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Abstract

Emissions trading with output-based allocation (OBA) of emissions allowances is gaining popularity as a means to address sectoral equity issues related to the use of market-based instruments in pollution control. Using a dynamic general equilibrium framework, this paper assesses the potential equity-efficiency trade-off between OBA and alternative emissions trading systems, with special attention to the heterogeneity among energy-intensive industries. Because abatement is achieved at a higher marginal cost with OBA, it is less efficient than emissions trading systems in which permit revenues are used to reduce payroll taxes. Nonetheless, the implicit output subsidy in OBA improves the distributional outcome of the abatement policy to the benefit of energy-intensive industries as a whole. The simulation results also suggest that energy-intensive industries that do not produce energy would be the main beneficiaries of OBA. In the new carbon-constrained environment, energy intensive industries that produce energy could not benefit significantly from OBA.

Résumé

Le système de permis échangeables avec allocation basée sur la production (SPAP) ne cesse de gagner de popularité en tant que moyen pour atténuer les problèmes d'équité sectorielle liés à l'utilisation des instruments de marché dans le contrôle de la pollution. Nous analysons dans un cadre d'équilibre général dynamique l'arbitrage équité-efficience entre le SPAP et des systèmes alternatifs de permis échangeables avec une attention particulière sur l'hétérogénéité entre les industries à haute intensité énergétique (HIE). Étant donné que l'épuration des gaz à effet de serre est réalisée à un coût marginal plus élevé avec le SPAP, ce dernier est moins efficient que les systèmes de permis échangeables recyclant les revenus à travers une réduction de la taxe sur la masse salariale. Néanmoins, la subvention implicite à la production qu'offre le SPAP permet d'améliorer l'impact distributionnel des politiques d'épuration des GES au profit des industries HIE dans leur ensemble. Toutefois, les résultats de simulation suggèrent que les industries HIE non productrices d'énergie sont les plus grands bénéficiaires du SPAP. Dans un nouvel environnement limitant les émissions de gaz à effet de serre, les industries HIE productrices d'énergie ne peuvent tellement bénéficier du SPAP.

1 - Introduction

This paper assesses the equity-efficiency trade-off of using output-based allocation (OBA) of permits to reduce GHG emissions in an emissions trading (ET) system. Most economists tend to prefer market instruments, especially a tradeable permit system, over regulatory instruments because the former make it possible to achieve the specified targets at the lowest economic cost. Referring to several studies, like Goulder et al. (1999) and Parry et al. (2002) among others, a potential drawback of carbon abatement policies with market-based instruments is the increase in firms' production costs and the resulting loss of competitiveness. This loss is potentially harmful to export-oriented industries because firms in these industries would have to compete with foreign firms that do not operate in a GHG-constrained environment.

From a political economy perspective, the implementation of the most efficient policy change could be hampered by the lack of sufficient political support. The use of market instruments to curb GHG emissions could thus trigger strong political resistance from the potentially affected sectors. The political feasibility of these policies would thus depend on the ability of their proponents to form a stable political coalition to move the policy change forward by providing appropriate compensations for the losers. Reducing the uneven distributional impact of carbon abatement policies is also a crucial dimension that should be considered. However, addressing this equity issue comes at the expense of efficiency. Thus, the challenge lies in the design of an effective emissions control policy that minimizes both the economic cost and the undesirable distributional outcome.

Some recent studies, including Bernard et al. (2001), Burtraw et al. (2001), Dissou (2005), Fischer (2001), Bovenberg and Goulder (2002), and Smith et al. (2002) have analysed the economic implications of various options designed to address the negative competitiveness impacts of GHG abatement policies. Some of these papers have analysed the efficiency impact of addressing distributional concerns in carbon mitigation policies with emissions trading. For example, Goulder (2000) has found that free allocation of less than 10% of the emissions allowances to affected industries according to their historical emissions could help achieve the desirable distributional outcome with a relatively low cost in terms of efficiency. This conclusion has been challenged by Smith et al. (2002). They have found that, should real world carbon trading schemes be taken into account, the high cost of the policy could preclude any opportunity to recycle revenue while also compensating affected firms. The latter result is not surprising as there is no single cost of achieving a certain level of emissions abatement. The implementation method also matters.

Dissou (2005) has analysed the cost-effectiveness of a performance standard system to reduce GHG emissions in an environment where market-based instruments could not be used. He has found that an optimally designed performance standard system could mitigate the GDP loss associated with carbon abatement policies.[2] In reality, addressing the uneven distributional impact of carbon abatement policies could be achieved by the redefinition of emissions property rights to provide free permits to firms. Depending on the concept of property rights used, permits could be allocated in different ways. Two methods of free permit distribution to firms have most often been considered in the literature: grandfathered allocation (GFA) and output-based allocation (OBA). In GFA, free permits are distributed to firms according to their historical emissions. In OBA, free permits are given to firms according to their current output.

According to Fischer (2001), gratis allocation of permits based on current output could be a particularly attractive form of assistance to industries that are potentially affected. In contrast to GFA, which translates into a wealth transfer to firms, the output-based allocation of free permits has some interesting impacts on firms' output decisions and on resource allocative efficiency. In particular, by linking the number of free permits to current output, OBA provides an implicit output subsidy to firms that could help them dampen the negative competitiveness impact of the GHG mitigation policy caused by increased production cost. This allocation mechanism is gaining popularity among policy makers in industrialised countries. For example, it has been proposed in some states in the U.S. for the allocation of NOx emissions allowances (Fischer, 2003); it has also been considered in Canada and some European countries as part of their GHG mitigation policies.

Some papers, like Dissou and Robichaud (2003), and Fischer and Fox (2004), have attempted to provide some numerical estimates of the impacts of using OBA in a tradeable permit system. Dissou and Robichaud (2003) considered a restricted application of OBA emissions trading to a subset of industries in Canada along with other non-market instruments, using a dynamic general equilibrium framework. They did not address the equity-efficiency trade-off. Fischer and Fox (2004) explored how well OBA can address the equity-efficiency trade-off using a static multi-country computable general equilibrium model. They found that OBA could address the uneven distributional impact of an emissions trading system with less efficiency than a system that uses permit proceeds to offset pre-existing distortionary taxes. If these papers provide interesting information on the potential implication of OBA, they ignore heterogeneity among carbon-intensive industries.

[2] Still, he has also found that the informational requirement for the design an optimal performance standard system could be so high as to preclude its use.

This paper explores further the equity-efficiency trade-off of OBA in an emissions trading system by considering heterogeneity among industries that are the most affected by GHG mitigation policies. Though all industries belonging to the latter group are energy-intensive, they do not have the same characteristics. While energy-intensive and non-fossil-energy-producing industries are only affected by the increase in production cost, energy-intensive and fossil-energy-producing industries are affected by both the increase in production and the reduction in the demand for their product. In this paper, we analyse how well OBA could address the equity-efficiency trade-off of carbon abatement policy with special emphasis on the heterogeneity among the most affected industries.

For this purpose, an extended version of the dynamic general equilibrium model developed in Dissou and Robichaud (2003) is used to analyse the potential economic implications of OBA in an emissions trading (ET) system and compare them with those of two other types of ET, namely GFA, and recycling of permit proceeds to reduce payroll taxes (RPT). As an illustration, we consider the Canadian economy, where the government has suggested the use of OBA in a subset of industries along with other non-market instruments in its Climate Change Plan of Canada. [3] It is important to note that this study is not an analysis of Canada's climate change plan. We considered a cap-and-trade domestic emissions trading in the first commitment period of Kyoto Protocol (2008-12), while this option has been ruled out in Canada's climate change plan, and the permit price is kept constant in the remaining period to its endogenous value in 2012. The policy experiments conducted in this paper are used for the purpose of illustration. They are intended to help us derive some lessons on the trade-off between equity and efficiency in GHG mitigation policies when heterogeneity among firms is accounted for.

The development and modification of the model built upon recent contributions to the literature on dynamic general equilibrium modelling and on environmental policies, such as Bovenberg and Goulder (2002), Fischer (2001), Fischer and Fox (2004) and Goulder and al. (1999), among others. The remainder of the paper is structured as follows. The next section presents an intuitive description of the model; the third section deals with data and the model's calibration. In the fourth section, simulation results are discussed and conclusions are drawn in the last section.

2 – The Model

This study uses a neo-classical growth model in which the steady state growth rate of the economy is solely determined by the population growth rate augmented by Harrod-neutral technological progress. Household labour supply is endogenous in order to capture the distortionary impact of abatement policies on the trade-off between consumption and leisure through the price system. Canada is considered a small-open economy producing tradable and non-tradable goods that considers world prices and interest rates as given. The economy is disaggregated into 15 industries, producing 19 products so as to take into account differences in energy intensity.[4] The model considers six energy products (electricity,[5] coal, natural gas, diesel, gasoline, and other refined petroleum products) that are used to satisfy firms and households' energy needs. Only relative prices affect real variables in the model; the *numéraire* is the 'nominal' exchange rate, or the conversion factor between local and foreign exchange units.[6] To disentangle the dynamics resulting from the exogenous growth of the population from the dynamics induced by policy shocks, all *real* variables are expressed in labour efficiency units. The remainder of the section provides only an intuitive description of the model; readers interested in mathematical details can obtain the list of equations, variables and parameters upon request.

2.2 – Household behaviour

Consider an economy populated by a finite number of infinitely-lived households. The representative household makes consumption, savings, and labour supply decisions. It has an unlimited access to the world capital market, where it can lend or borrow at a constant real interest rate r^*. It is liable for the country's foreign debt and its portfolio consists of foreign assets, government bonds and shares in domestic firms.

The representative household derives its current income from wages paid by firms, returns on financial assets and net transfers received from both the government and the rest of the world. The representative household pays income tax as well as consumption taxes on goods and services. It maximizes an intertemporal utility function subject to a sequence of budget constraints and an intertemporal solvency constraint. The intertemporal utility function, which is additively separable, features a constant rate of time preference and an instantaneous logarithmic utility function that is weakly separable and defined over aggregate consumption and leisure. The latter two arguments are combined using a Cobb-Douglas (C-D) functional form. By solving its optimization problem, the representative household determines the optimal paths for consumption expenditures and labour supply. Three first-order conditions of this standard optimization problem can be derived. The first is the consumption Euler equation, which

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[3] See Government of Canada (2002a, 2002b and 2005) for details on the plan.

[4] See Tables (6) and (7) for the lists of industries and products.

[5] For data availability reasons, the energy-producing industry cannot be disaggregated to distinguish different production modes, such as hydroelectricity and thermal electricity.

[6] In other words, the model's numéraire is the average price of foreign-produced goods.

specifies the trade-off between consumption in two consecutive periods. This trade-off depends on the ratio of real interest rate expressed in terms of consumption[7] and the discount factor. More precisely, an anticipated rise in the real interest rate relative to the rate of time preference induces households to substitute current consumption for future consumption.

The second first-order condition of the optimization problem is the usual trade-off between labour supply and leisure. The household supplies labour until the marginal substitution rate between consumption and leisure is equal to the ratio between the opportunity cost of leisure and the aggregate price of consumption. The third first-order condition pertains to the accumulation of financial wealth, which is the sum of the value of domestic firms, government bonds and net foreign assets. Through an algebraic manipulation of the first and third first-order equations, it can be shown that the representative household aggregate consumption depends on total wealth, which is the sum of financial wealth and human wealth. The latter depends on the discounted sum of current and future period flows (net of taxes) of labour income and net transfers received from the government and the rest of the world. As a result, any shock that alters the household income path or the stream of aggregate consumption prices can affect current household aggregate consumption expenditures. Given the importance of domestic products in the household consumption basket, GHG abatement policies that have a significant impact on relative prices could affect current household consumption.

Based on the optimal path for aggregate consumption (or consumption expenditures), the representative household allocates these expenditures among the available commodities through a cost-minimisation process in each period. A nested-CES function is used as the aggregator function to specify the relation between aggregate consumption and the quantities of various commodities consumed by the representative household. Aggregate consumption is a CES function of the aggregate of non-stationary energy goods and the aggregate of stationary energy goods. The former is a CES function of the aggregate of mobile energy goods and of another CES-aggregate of non-energy goods. The aggregate of mobile energy goods is a Cobb-Douglas function of gasoline and diesel.

The aggregate of stationary energy goods is a CES function of demand for electricity and the aggregate of stationary fossil energy goods. The latter is another CES function of the aggregate of natural gas and the aggregate of refined petroleum products. Finally, the latter aggregate is a C-D function of liquid petroleum products and "Other petroleum products".

[7] That is, the international interest rate adjusted for change in aggregate consumption price between two successive periods.

2.3 – Producer behaviour

2.3.1 – Technological specification

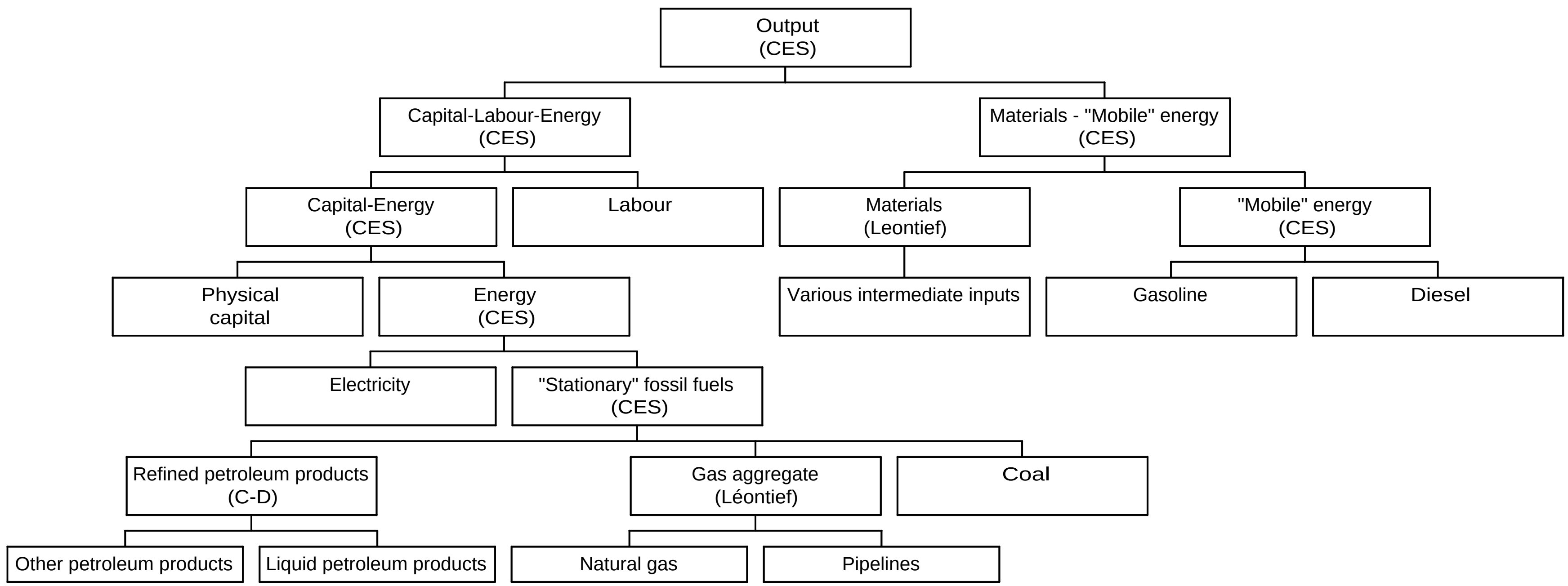
The representative firm in each industry combines labour, capital, energy and material inputs to produce a composite good that can be sold in the domestic market or exported. It has access to constant returns to scale technology and faces capital installation costs. It operates in a competitive environment in both the goods and factors markets.

Given the importance of energy in reducing GHG emissions, the specification of firm technology accounts for different substitution possibilities between not only various sources of energy, but also between energy and capital. In particular, a weakly separable production function, represented by nested CES functions, is used to represent technology. Figure 1 presents a schematic description of firm technology.

Output is a CES function of the composite value-added-energy input and of the aggregate of intermediate inputs. Labour is combined with the capital-energy aggregate input using a CES function to produce the composite value-added-energy input. The capital-energy aggregate input is another CES function of capital and the aggregate of energy inputs. The latter is a CES function of electricity and the composite of fossil energy products, which is another CES function of various "stationary" fossil energy inputs, carbon, natural gas and other refined petroleum products.

The aggregate of intermediate inputs is a CES function of the composite input of non-energy intermediate inputs and the composite input of "mobile" fossil fuel inputs. The latter is a CES function of diesel and gasoline, while the composite of intermediate inputs is a Leontief function of the other material inputs used by the firm.

Figure 1: Schematic representation of firm technology



2.3.2 – Output-based allocation of emissions in a permit trading system

Description of the system

In the permit trading system with output-based allocation of emissions, firms are provided free permits according to their current period output and BAU (business as usual) emissions intensity. The industry's emissions intensity is the ratio between its emissions and its real output. Note that the BAU emissions intensity is a predetermined value. It is different from the emissions intensity actually achieved[8] by the industry, and is observed only *ex-post*.

The gratis allocation of permits allows firms to benefit from the scarcity rent derived from holding emissions rights. They will be able to offset (at least partially) the negative effects of abatement efforts. This system has an impact on firms' behaviour, in contrast to the grandfathering system in which permit assignment is based on past emissions.

The larger is the firm output, the larger is the number of free permits they would receive. The increase in the number of free permits received reduces the net purchase of permits. Firms will therefore have a strong incentive not to reduce their output in order to receive more free permits. Instead, they are induced to reduce their emissions by lowering their emissions intensity. The latter reduction can only be achieved through investment in physical capital and/or through substitution among fossil fuels.

It is worth mentioning that the number of free permits received by firms does not necessarily cover all their needs of emissions rights. Some firms may be short of permits, while others may have excess permits. The possibility of permit trading allows firms that are short of permits to acquire them from firms with surplus or from the international permit market.

[8] The emissions intensity actually achieved is calculated from the total effective GHG emissions and the output for the current period.

Modelling the firm's abatement decisions with OBA

Given the impact of the permit allocation system on firm behaviour, the value of free permits can be viewed as an output incentive. Authors like Fischer (2001), Fischer and Fox (2004) and Goulder and al. (1999), have adopted the same approach to model the impact of output-based allocation of free permits on firms' behaviour. OBA can be modelled as a standard permit trading system in which the permit price affects both factor utilization decisions and the effective output price received by the producer. The firm's static optimization problem with OBA can be stated as follows:[9]

$$Max \quad \Pi_j = (P_j + \beta_j \overline{P})Y_j - \sum_{i-1} (w_i + \overline{P}e_{ij})x_{ij}$$

$$s.t. \qquad Y_j = f(x_{ij}) \qquad i = 1,...,n$$

where $\Pi_j, Y_j\ P_j,$ *and* β_j represent, respectively, the profit, output, output price and emissions intensity target assigned to firm j. x_{ij}, w_i, e_{ij} *and* $\overline{P}$ represent, respectively, the quantity and the price of input i used by firm j[1], the emissions factor of input i used by firm j[2], and the unit price of the tradable permit. $\beta_j \overline{P}$ represents the production incentive associated with the assigned emissions intensity target; it is expressed per unit of output. Finally, f is a linear homogeneous production function.

The first-order condition of this optimization problem is the standard equalization of the marginal product of the factor to its acquisition cost:

$$(P_j + \beta_j \overline{P}) f^{'}(x_{ij}) = w_i + \overline{P}e_{ij} \qquad \text{for } i = 1,....,n$$

where function f' represents the physical marginal productivity of input i. The permit price, $\overline{P}$, affects firm behaviour in two ways. First, it penalizes the use of the most polluting inputs and encourages firms to substitute among fossil fuels or to substitute energy for capital. Second, the higher the permit price, the higher the production incentive received by the firm and the lower the negative impact of the permit price on the firm's output. It follows that the negative impact of GHG abatement cost expenditures on firm output is reduced. Firms have less incentive to reduce their output than to reduce their emissions intensity. However, at a given permit price, total emissions could be higher in comparison to a permit trading system without output incentives. The purchase of a larger number of international permits would thus be required. In a

[9] For the sake of clarity, process emissions are ignored for the moment. They are nevertheless taken into account in the numerical version of the model.
[1] These inputs include for example various fossil energy inputs and physical capital.
[2] The emissions factor of a non-polluting input is zero.

cap-and-trade system, the endogenous price would be higher. The rationale for this result is simple. The output subsidy would increase the demand for emissions; either emissions would increase with price, or the price would increase with fixed emissions levels.

Moreover, since emissions intensity targets are assigned *ex ante* to firms, the total number of free permits could exceed firms' share in total emissions rights granted to Canada under the Kyoto Protocol. This possibility is ruled out by using a scaling-back factor for emissions intensities, α, so that the number of free permits distributed to firms equals their share of the national Kyoto target. This correction factor is an endogenous variable indicating the uniform percentage change (reduction or increase) of BAU emissions intensity necessary to achieve the above-mentioned equality. In modelling firms behaviour, the emissions intensity becomes $\alpha\beta_j$, rather than β_j.

Intertemporal optimization problem

The firm's objective is to maximize its value, which is equal to the discounted sum of net cash flows, subject to a capital accumulation constraint in the presence of adjustment costs. We assume that the representative firm in each industry has reached a level of maturity that enables it to finance investment expenditures through retained earnings. In other words, dividends paid to households are net of investment expenditures. Firms pay a tax on profits. In the short run, physical capital is immobile among sectors because of capital installation costs. At the beginning of each period, the capital stock is predetermined by the previous period's investment decision; its reallocation among sectors is achieved only in the long run through accumulation. Following Hayashi (1982), we consider a convex adjustment cost function, which is linear homogeneous in both of its arguments, i.e., investment and capital stock.

In maximizing firm value, managers determine the optimum paths for investment, labour, energy inputs and other intermediate inputs. Firms use the production factor up to the point where its marginal product equals its price. The optimum level of investment is determined to equalize the marginal cost of investment to the shadow price of capital, i.e., the marginal benefit (evaluated in terms of change in firm value) of changing the capital stock by a unit. The firm's marginal cost of investment includes not only the purchase price of capital goods, but also the additional capital installation costs that the firm must incur. The marginal benefit of the investment takes into account the marginal impact of investment on profits of the current and future periods. Thus, this marginal benefit is the discounted sum of present and future marginal gain of physical capital. This marginal gain is the sum of the marginal product and the gain associated with the reduction in installation costs linked to the increase in the capital stock.

It appears that firms' investment decisions can be affected through two main channels: the purchase price of capital goods and the marginal product of capital that depends mostly on the producer price received by the firm. On the one hand, an increase in the purchase price of capital goods has a negative impact on investment demand. On the other hand, an increase in the producer price (net of taxes and incentives) has a positive impact on investment.

2.4 – The government

The government's behaviour is simple. It collects taxes on goods and services, as well as on household and corporate incomes. It consumes goods and services (constant in real per efficiency units), enacts transfers to households. In each period, government balance is kept constant at its BAU level through changes in its lump-sum transfers to households.

2.5 – Other components of demand and Canada's relations with the rest of the world

Total domestic demand for each commodity is the sum of demands by households, firms (for intermediate uses and investment) and the government. We assume that firms' total investment demand[12] is a Leontief composite of several commodities. The demand for each commodity entering this composite is a fixed share (in volume) of firms' total investment demand. It follows that average price of the capital goods is a weighted sum of the prices of the commodities that form the composite.

We model Canada's trade with the rest of the world by adopting the traditional assumption of commodity differentiation, both on the demand and on the supply sides. Total domestic demand for each product is a CES composite of the locally produced good and the aggregate of imports. The latter is another CES function of the commodity imported from the United States and imports from the rest of the world. An expenditure minimization rule allows the determination of the optimal composition of the composites. In particular, the ratio between demands from two competing origins (local and foreign) of the commodity depends on their price ratio. An increase in the relative price of the locally produced good is detrimental to local producers.

[12] Including installation costs.

On the supply side, we assume that output produced by each representative firm is a CET (Constant Elasticity of Transformation) composite of domestic sales and aggregate exports. Another CET function is used to aggregate exports to the United States with exports to the rest of the world. A revenue-maximizing rule allows the determination of the optimal composition of supply in each market. In this condition, the ratio between sales on the domestic market and exports depends on the ratio of the prices obtained in these two markets. A decrease in the relative price of domestic sales will favour exports.

In each period, the current account deficit adds to the level of foreign debt. The current account deficit is the sum of the trade deficit, net government and household transfers abroad and net purchases of international tradable permits.

2.6 – Equilibrium and steady state conditions

The absence of non-convexities in household preferences and in firm technology guarantees the existence of a competitive intertemporal equilibrium with rational expectations for the economy represented in this model. This equilibrium consists of a sequence of prices and quantities and stock variables such as:

a. Households and firms satisfy the optimal conditions arising from the maximization of their objective functions;
b. All agents respect their budget constraints;
c. Transversality conditions are met for the stocks of physical capital, for household total wealth and for the levels of government and foreign debts;
d. A temporary equilibrium is achieved in each period in all goods and factors markets.

In this neo-classical model, the steady state of the economy is defined as a state in which all flow and stock variables, expressed in efficient labour units, are constant. In other words, non-detrended variables increase at the exogenous growth rate of the population augmented by Harrod-neutral type technological progress. The imposed transversality conditions in addition to the selected functional forms guarantee the existence of this steady state.

3 – Data, calibration and numerical solution strategy

Given the complexity of the model, no effort was made to find an analytical solution to the system of highly non-linear equations that results from firm and household behaviour. Instead, we opted for a numerical solution. The model was calibrated on a horizon of 150 periods (years) using data projected from the social accounting matrix (SAM) and the sectoral emissions table built for the year 2010.[13] The observed total labour supply, including technological progress,

[13] 2010 is the median year for the first commitment period 2008-2012.

was standardized to one. All variables expressed per efficient unit were constant over the entire simulation horizon in the reference situation, where the assumption of the steady state was adopted. In addition, for simplicity, we assumed that involuntary unemployment is zero in the reference situation.[14] The projected 2010 SAM was built using data from the 2000 national accounts, the detailed structure of the 1996 input-output table and an average GDP growth rate of 2.3% between 2000 and 2010. The value of 2.3% was selected as the growth rate of the population including technological progress. This value is the implicit growth rate of GDP compatible with forecasts of GHG emissions in 2010 in the AMG report (1999).[15] Table (1) presents the structure of the projected SAM for 2010 for the Canadian economy.

The detailed sectoral emissions table by fuel type was built using sectoral emissions data produced by Statistics Canada and emissions forecasts contained in the AMG (1999). It was possible, using the SAM data and the emissions table, to calculate emissions factors for different fossil fuels and the emissions intensities by industry.

Table (2) presents the values used for various behavioural parameters. These values, which were borrowed from previous studies on Canada, such as Ab Iorwerth et al. (2000) and Wigle (2001), are not very different from the values used in many other general equilibrium models of Canada or the United States. Table (3) presents the sectoral distribution of emissions in 2010.

The calibration of the model involves using the SAM, parameters borrowed from other studies, first-order conditions, and steady state conditions to recover the other parameters in the behavioural functions and the values of non-observed variables in the model in order to reproduce the reference situation. To this end, we used the calibration procedures frequently employed in static and dynamic general equilibrium models. Dissou (2002), Keuschnigg and Kohler (1994), and Mansur and Whalley (1984) provide details on the calibration methods of these models.

The numerical solution of a general equilibrium model with an infinite horizon requires truncating the simulation horizon in order to have a finite number of periods. The general rule is to select a sufficiently large number of periods to allow the economy to achieve a new steady state after a shock, while imposing terminal conditions associated with the steady state to minimize errors due to the truncation. The selected 150-year simulation horizon is large enough for this model. The model was solved numerically by treating it as a "two-point boundary problem" in

[14] Including the real value of the involuntary unemployment rate will only affect the calibrated value of total labour supply in the reference situation.

[15] The growth rate takes into account energy efficiency as well as higher levels of emissions in some industries (energy) so as to reflect higher anticipated sectoral growth.

which the initial conditions are set for the state variables and the terminal conditions are imposed on the jumping variables. We used the "Extended Path" method suggested by Gagnon (1990) to solve the non-linear system of equations that contains difference equations.

4 - Simulations

4.1 - Description of the simulations

The main purpose of this paper is to assess the potential impacts of using an output-based allocation of emissions in a DET system to address the negative competitiveness impacts of carbon abatement policies. We considered three policy experiments in which we compared the impacts of using OBA with those of two other systems: the grandfathering allocation of emissions (GFA) and the use of permit proceeds to reduce payroll taxes (RPT). In GFA, permits are freely distributed to firms according to their historical emissions. No public revenue is raised in this tradeable permit system. As the allocation method has no behavioural impact on firms, it is equivalent to a wealth transfer to firm owners who are domestic households. In the RPT tax simulation, the permit proceeds corresponding to Canada's emissions rights are used to reduce the labour tax rate. In the trading system with OBA, emissions credits corresponding to firms' share in Canada's total emissions rights are redistributed to them according to their output and their BAU emissions intensity[16].

To make the policy alternatives comparable, we imposed the same restriction for aggregate GHG emissions in all three cases. Under the Kyoto Protocol, Canada must reduce its GHG emissions to 6% below the 1990 level, or to 571 MT during the first commitment period (2008-12). This corresponds to a gap of 240 MT in 2010, compared to the anticipated level, if no specific measures were taken to alter the emissions path. All domestic economic agents are required to hold permits for all their emissions. In all simulations, we considered a cap-and-trade domestic emissions trading (DET) system during the first commitment period. In this period, the marginal cost of abatement (permit price) is determined endogenously in order to achieve the emissions gap[17]. From 2013 on, we kept the permit price constant at its 2012 level and allowed emissions to grow. Kyoto's objectives would then be met by relying on Kyoto mechanisms, i.e., on buying international permits[18]. Moreover, government balance was kept constant in every period at the BAU level by adjusting its lump-sum transfers to households.

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[16] Canada's emissions rights belong to both firms and households. The constant share used is based on the distribution of emissions in the BAU situation.

[17] The forecasted emissions gap in 2010 is 240 Mt; however, because 50 MT of emissions (landfill gases, etc.) are not "priceable", i.e. it would be difficult to use a tradeable permit system to control them, we consider a gap of 190MT.

[18] Permits would be bought at the 2012 marginal cost of abatement. As Canada would likely be a net buyer of international permits, this price would be higher than the international permit price.

To better understand the differences between the three simulations, we focus our discussions on the basic mechanisms at play in the first simulation, and then show how results change in the two others.

4.2 –Results

Unless otherwise mentioned, all the results presented in this paper are expressed as a percentage deviation from the reference situation. Permit prices are expressed in constant 2000 $Can.

4.2.1 – Reducing GHG emissions with an emissions trading system with GFA

The results of this simulation are contained in Tables (4)-(10). During the first commitment period, the permit price necessary to achieve the 190 MT emissions gap would be $48 per ton of CO_2 in 2010. In 2012, it reaches $56. The permit price affects the prices of polluting goods and thus all relative prices in the economy. It has both direct and indirect effects, characterized by changes in production costs, composition of aggregate demand and in household welfare.

Aggregate impacts

Referring to Table (4), household welfare would decrease as a result of the carbon abatement policy with GFA even though shareholders receive some scarcity rents. The estimated measure of welfare loss over their entire lifetime period is –2.9%[19]. In 2010, real GDP at market price and real GDP at factor cost would decline by, respectively, 2.2% and 2.5%. The total level of employment would fall by 0.74% and the real exchange rate would depreciate by 1.7%. Real household consumption and real investment would fall more than GDP at market prices, by 2.9% and 9% respectively in 2010. Real exports would fall only 1.9%, while real imports would decline by 4.1%. The more pronounced negative impact on household consumption and investment compared to other GDP components is not surprising. Since households and firms have forward-looking behaviour, consumption and investment do not depend solely on contemporary variables; they are also affected by the state of the economy in future periods. The growing emissions gap over time would put upward pressure on the purchase of international permits and have a negative impact on the current account balance. It follows that foreign debt would increase as well. Their net wealth would therefore decline as a result of the growing gap.

In 2010, the 190MT reduction of emissions would be achieved mainly by firms that would reduce their emissions by 175 MT, i.e., 27% decrease in comparison to the BAU level. The

[19] This measure of welfare change is not directly comparable with the one reported in static models. Our measure is an indication of the percentage change in the household consumption stream in the BAU situation that would yield

remaining gap would be achieved by households who would lower their emissions by 15 MT (-19.0% in comparison to BAU).

It is interesting to note that these aggregate results differ significantly form those found in other studies on abatement policies in Canada like Dissou and Robichaud (2003) and Government of Canada (2002) for two main reasons[20]. First, the emissions reduction target with tradeable permits in this study is much higher than the ones used by the others. In this study, Canada is supposed to close the whole 190MT gap domestically, while the other studies allow the purchase of international permits during the same period. This suggests that the marginal cost of abatement in the policy experiment considered in this study is higher. Second, the use of tradeable permits is extended to all economic agents in this paper, while it was restricted to only the large final emitters in the other papers.

These aggregate results, which summarize the impact of the policy change on the Canadian economy as a whole, do not provide information of the variety of sectoral adjustments. The sectoral impacts that generated these results are discussed below. We provide intuitive explanations and highlight the main transmission mechanisms at play.

Sectoral impacts

Since not all industries would be affected similarly, we make a distinction between different categories of industries. On one hand, we distinguish energy- or carbon-intensive industries, also called large final emitters (LFEs), from the others (non-LFEs). On the other hand, we differentiate fossil energy-producers from the others among LFEs[21].

Tables (6) and (7) present the sectoral impacts of the abatement policies on sectoral output, employment and investment. Figures in Table (6) suggest that the impact on sectoral GDP in 2010 would vary between –26% for Coal Industry, and + 2.2% for Other Manufacturing Industry. In general, the energy-producing LFEs are the hardest hit, followed by non-energy producing LFEs. The other non-energy-intensive industries that belong to the non-LFE group are the least affected. Interestingly, sectoral GDP in Other Manufacturing Industry would increase in 2010 as the consequence of the change in demand composition. This is because users shift away from polluting and energy-intensive goods.

The decline in output observed in some industries is the consequence of firms' abatement efforts. Everything else equal, the requirement to hold costly permits increases the cost of using fossil fuel inputs and thus the output prices. For example, the user prices of fossil energy

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the same utility level as the one with the policy change. See Dissou (2002) and Goulder and Eichengreen (1992) for details on the computation of this welfare measure.

[20] For example, the GDP cost of the carbon abatement policy with perfect competition in Dissou and Robichaud (2003) is –0.06% in 2010.

products would increase as shown in the second column of Table (8), where natural gas would experience the largest increase (102.1%). Changes in relative prices induce some substitution effects among inputs to minimize production cost. In the case of fossil fuel inputs, firms substitute the most polluting input for the least polluting one. Moreover, the decrease in the use of fossil fuels in production would lower the marginal productivity of labour and put a downward pressure on real wage. As a consequence, labour supply would fall.

With regard to the sectoral distribution of output change according to industry categories, all LFEs' GDP would decrease by 4.9%, while non-LFEs' GDP would fall by 1.6% in 2010 (Table 4). Among LFEs, energy producers would experience a 21.9% fall in their GDP, while non-energy producing LFEs' GDP would decline by only 2.3%. In comparison to the 2.5% decrease in total GDP at factor cost in 2010, the relative contribution of energy producers to the burden of the carbon abatement policy with a GFA would be 33%, while their share in base-run GDP at factor cost is only 5% (Table 9). In contrast, the relative contribution of non-LFE industries to total GDP change would be 46% while their base-run GDP is 72%.

The same pattern of the sectoral distribution of the burden of carbon abatement with GFA, in which energy producers bear a significant share, is also observed when variables other than sectoral GDP are considered. For example, as shown in Tables (6) and (7), employment investment, exports and domestic sales would decrease more in energy producing LFEs than in others.

4.2.2 –Reducing GHG emissions with an emissions trading system with OBA

In comparison with the previous simulation, all industries are provided free permits according to their output and the BAU emissions intensity. The latter parameter was adjusted by a common scale-back factor in order, to equate the number of distributed free permits with industries' share in Canada's assigned emissions rights. Then, households receive a lump-sum transfer representing the value of their shares in Canada's assigned emissions rights. We maintain the assumption that the whole gap of 190 MT must be achieved domestically during the first commitment period.

In 2010, the endogenous permit price would now be $76 per ton of CO_2. In comparison, it was $48 in the previous simulation with GFA. Real GDP at market prices and real GDP at factor cost would decline by, respectively, 0.6 and 0.8% in 2010. The measure of household welfare change would now be –2.2% in comparison with –2.9% in the previous simulation.

The differences in the aggregate impacts of the two simulations are mainly explained by differences in the sectoral impacts brought by the difference in the permit allocation scheme. In

[21] The last column in Table (9) presents the GDP share of each category in the base run situation.

contrast to GFA, OBA does have a behavioural impact through the implicit output subsidy. This implicit subsidy is most beneficial to industries with the largest emissions intensity in the BAU.

As in the previous simulation, the increase in the production cost, which results from the permit trading system, induces an upward shift of the supply curve. This upward shift is, at least partially, offset by a downward movement on the supply curve that is generated by the subsidy. Still, a major drawback of this output incentive is the higher value of the marginal abatement cost (permit price) that would in turn have a negative impact on output and resource allocation. With OBA, the higher the permit price is, the higher the subsidy would be. With pre-existing distortions in resource allocation on the supply side (production taxes), the implicit subsidy provided by OBA could be seen as a revenue-recycling scheme to reduce these distortions.

Besides, the implicit output subsidy does benefit all production factors, including labour, whose total demand would increase. It induces an increase in total labour supply through an increase in real wage. However, it is worth noticing that this recycling method introduces additional distortions because the subsidy rate depends on BAU emissions intensities that are not the same in all industries.

The welfare results in the two simulations support the hypothesis that non-revenue-raising market-based instruments induce more welfare loss than instruments that raise revenues. In the simulation with OBA, a part of the permit proceeds has been used to reduce pre-existing distortions in resource allocation on the supply side of the economy, while no public revenue has been raised in the simulation with GFA. As shown in Parry et al (1999) and Goulder et al. (1999), a non-revenue-raising tradeable permit system could be a very costly way to achieve environmental objectives in the presence of pre-existing distortions.

The third column in Table (6) show the impact on sectoral GDP in 2010 that would even increase in more than one industry, as was the case in the simulation with GFA. It is interesting to note that LFEs' GDP would decrease by 1.21% vs. 4.9%, and non-LFEs' GDP would fall by 0.7% vs. 1.6% in the simulation with GFA (Table 4), referring to the sectoral distribution of the output impact according to industry categories. The contribution of LFEs to the overall industry burden of the carbon abatement policy would now decrease to 41% with output-based allocation compared to 54% in the simulation with GFA. Thus, in 2010, OBA has not only reduced the GDP impact, but has also improved the sectoral distribution of the burden between LFEs and non-LFEs in favour of the former.

However, if the LFE group in general would benefit from OBA, the within-distribution of the burden between sub-categories would worsen at the expense of energy producer industries. As shown in Table (4) non-energy producing LFEs would be the greatest beneficiaries of OBA.

Their GDP would increase by 1.2%, in comparison to a decrease of 2.3% in the simulation with [22]GFA.ecause of the reduction in the use of fossil energy products by other industries, energy producers would not benefit that much from OBA. Their GDP would still fall by 17% with OBA, in comparison to 21.9% with GFA. It ensues that the relative contribution of energy producers to the fall in overall GDP at factor cost would be 79%, while that of non-energy producers would be –39%.

Overall, in comparison to GFA, the OBA scheme helps dampen, at least for energy-intensive industries as a whole, the negative impacts of the increase in production cost induced by the requirement to buy permits.

4.2.3 –Reduction in payroll taxes

The main difference in this simulation with the two previous ones is the recycling method of permit proceeds that are used to reduce payroll taxes. Adjustments in the labour tax rate were applied equally to all industries.

In 2010, the endogenous permit price would be $50 per ton of CO_2. This is lower than the one with OBA and higher than the one with GFA. The measure of household welfare change with RPT would be –1.2%, against –2.1% and –2.9% respectively with OBA and GFA. Real GDP at market prices would decline by 1.1% in 2010 in comparison to –0.6% and –2.2% respectively with OBA and GFA. Household labour supply would increase by 0.5%, in comparison with 0.4% with OBA and –0.7% with GFA.

The difference in the aggregate impacts of this simulation compared with the others stems mainly from the positive impact the reduction in the tax rate on labour has on the labour supply. The reduction in the labour tax rate has a positive impact on labour supply, which increased by 0.53% and was available to all industries. This increase in labour supply is different from the one observed in the simulation with OBA. In the latter simulation, the rise in labour supply was a consequence of the targeted production incentive provided by the permit allocation scheme that had a positive impact on aggregate labour demand and thus on labour supply. Households have been able to benefit more from the rise in real wage in comparison to OBA, as their real consumption decreased less (-1.2% vs. –2.1%). The main explanation for this result is that the user prices of carbon-intensive products increase less with RPT than with OBA as the permit price is lower in the former than in the latter. As explained earlier, a major drawback of OBA is the substantial rise in the price of permits due to a lower incentive to reduce output. Because of

[22] In these industries, the impact of the subsidy on supply outweighs that of the increase in production cost that has been contained, thanks to a significant change in emissions intensity. However, in the long-run GDP would decrease by 1.2% as the consequence of the increasing emissions gap.

the higher price increase in OBA in comparison to the simulation with RPT, the negative impact on welfare of the abatement policy is thus lower with the latter than with the former.

The negative impact on LFEs is much higher than in the simulation with OBA. This is because recycling of permit revenue in the simulation with RPT is not primarily targeted to the industries that are the most affected by the abatement policy. GDP in LFE and non-LFE industries would fall by 3.8 and 0.6%, respectively, compared to -1.2 and –0.7% in the simulation with OBA (Table 4). This result is not surprising since in the simulation with RPT, the reduction in labour tax rate benefits all industries, and especially those that are more labour intensive. In contrast, OBA is more beneficial to carbon-intensive industries. The fall in total GDP at factor cost is much higher than in the simulation with OBA, -1.5% vs. -0.8%, but is lower than that in the simulation with GFA (-2.5). Surprisingly, energy producing LFEs are much more affected than in other simulations, as their GDP would fall by 22.1% in comparison to 17.0 and 21.9%, respectively, in OBA and GFA simulations. A potential explanation for this result is that these industries would not benefit that much from the reduction in the labour tax rate because they are more capital intensive than others are.

For all LFE industries, their relative contribution to overall GDP decrease would be 71% with RPT vs. 41% with [23]OBA.his suggests that the distributional impact of RPT recycling is generally favourable for the energy-intensive industries than in the simulation with OBA. The trade-off between efficiency and equity in the two recycling methods is clear. While the negative welfare impact of the carbon abatement policy with RPT is lower than that of OBA, it clearly has a less unequal distributional impact when viewed from the energy-intensive industries as a group. However, as mentioned, energy producers are not necessarily better off in terms of equity with OBA in comparison to RPT. Their relative contribution to GDP decrease with RPT is 38% lower than with OBA (Table 9). This result suggests that when accounting for heterogeneity, OBA does not necessarily improve the distributional outcome of GHG abatement policy with emissions trading. The main beneficiaries of OBA would be the non-energy-producing LFE industries.

5 – Concluding remarks

Addressing the uneven distributional outcomes of GHG abatement policies with market-based instruments may be a prerequisite for these policies to get the required political support. Permit trading systems with OBA of emissions allowances are gaining popularity among policy makers in several countries because of their ability to mitigate the abatement cost burden on the most energy intensive industries. As emissions allowances are linked to firms' output, OBA provides an implicit output subsidy that helps them lower their prices. As in many cases, addressing equity issues comes at the expense of efficiency.

We used an intertemporal and multi-sector general equilibrium model to examine, in a second-best setting with pre-existing distortions, the equity-efficiency trade-off of OBA. We compared the welfare and distributional impacts of OBA with two other systems: (i) emissions trading with GFA and (ii) emissions trading with revenue devoted to reduction in payroll taxes (RPT). Our simulation results suggest that the welfare cost of OBA is higher (70%) than that of RPT. Even though the two systems may be considered as different modalities of permit revenue recycling, the efficiency cost of OBA is higher because it achieves emissions abatement at a higher marginal cost (permit price), which is more harmful to resource allocation than RPT. Still, as suggested by the theory, the welfare cost of OBA is lower than that of GFA because the latter does not raise any public revenue that could be recycled in order to generate efficiency gains. With pre-existing distortions like taxes - production taxes for example - the implicit output subsidy provided in OBA would help in reducing the negative tax-interaction effects induced by the permit cost.

Using the relative contribution of different categories of industries to the overall carbon mitigation burden as equity indicator, we found that OBA produces the least uneven distributional outcome for energy-intensive industries considered as whole. For example, in 2010, the contribution of all energy intensive industries to the fall in total GDP at factor cost with OBA would be 42% and 24% lower than with, respectively, RPT and GFA. Moreover, the impact on GDP with OBA would be lower than the impact with the other instruments.

Still, an important lesson derived from the simulation results is that OBA does not improve the distributional outcome of GHG abatement policies with emissions trading when heterogeneity among energy intensive industries is accounted for. The greatest beneficiaries of OBA of emissions allowances would be non-energy producing energy-intensive industries whose relative contribution to total GDP would fall (to the point of being negative), while it would be positive in the other two policy experiments. These industries would be able to benefit from the output incentives provided by this allocation mechanism. In contrast, as far as fossil-energy-producing industries are concerned, the distributional outcome would be worse with OBA. Their relative contribution to GDP fall would increase by 39% and 140%, in comparison with,

[23]The GDP share of LFEs in BAU is 28%.

respectively, RPT and GFA. Because of the new carbon constrained environment, fossil energy producers could not benefit significantly from free permits that are linked to output.

References

AMG (1999): *Canada's Emissions Outlook: An Update*, National Climate Change Process, Ottawa, Canada.

Bernard, A. L., C. Fischer and M. Vielle (2001): Is There a Rationale for Rebating Environmental Levies?, *Resources for the Future Discussion Paper*, 01/31.

Bovenberg, A. L. and L.H. Goulder (2002): "Neutralizing the Adverse Industry Impacts of CO2 Abatement Policies: What Does it Cost?" in A. L. Bovenberg and L. H Goulder, eds. *Environmental policy making in economies with prior tax distortions*, pp. 609-49, New Horizons in Environmental Economics, Cheltenham, U.K..

Burtraw, D., K. Palmer, R. Bharvirkar and A. Paul (2001) "The Effect of Allowance Allocation on the Cost of Carbon Emission Trading", *Resources for the Future Discussion Paper, 01–30.*

Dissou, Y. (2002): "Dynamic Effects in Senegal of Regional Trade Agreement among UEMOA Countries," *Review of International Economics*, 10, 177-199.

Dissou, Y. and V. Robichaud (2003) Contrôle des émissions de GES à l'aide d'un système de permis échangeables avec allocation basée sur la production: Une analyse en équilibre général calculable, Department of Finance Working Paper 2003-18, Ottawa, Canada.

Dissou, Y. (2005) Cost-effectiveness of the Performance Standard System to Reduce CO2 Emissions in Canada: A General Equilibrium Analysis, in Resource and Energy Economics, vol. 27, 3, 187-207.

Fischer, C. (2001): Rebating Environmental Policy Revenues: Output-Based Allocations and Tradable Performance Standards, *Resources for the Future Discussion Paper* 01/22

Fischer and Fox (2004): Output Based Allocation of Emissions Permits: Efficiency and Distributional Effects in a General Equilibrium Setting with Taxes and Trade, *Resources for the Future Discussion Paper 04-37*

Gagnon, J. E. (1990): "Solving Stochastic Growth Model by Deterministic Extended Path," *Journal of Business Economics and Statistics*, 8, 35-38.

Goulder, L. H., and al. (1999): "The Cost- Effectiveness of Alternative Instruments for Environmental Protection in a Second-Best Setting," Journal of Public Economics, 72, 329-360.

Goulder, L. H. (2001): "Confronting the Adverse Industry Impacts of CO2 Abatement Policies: What Does It Cost?" *Resources for the Future - Climate Change, Economics and Policy: an RFF Anthology*, pp. 125-33.

Government of Canada (2002a): *Discussion Paper on Canada's Contribution to Addressing Climate Change*, Ottawa, Canada.

Government of Canada (2002b): *Climate Change Draft Plan: Achieving Our Commitments Together*, Ottawa, Canada.

Government of Canada (2005): *Moving Forward on Climate Change: A Plan for Honouring our Kyoto Commitment*, Ottawa, Canada.

Hayashi, F. (1982): "Tobin's Marginal q and Average q: A Neo-classical Interpretation," *Econometrica*, 95, 151-193.

Keuschnigg, C, and W. Kohler (1994): "Modeling Intertemporal General Equilibrium: An Application to Austrian Commercial Policy", *Empirical Economics*, 19, 1, pp. 131-64.

Mansur, A. H. and J. Whalley (1984): "Numerical Specification of Applied General Equilibrium Models: Estimation, Calibration, and Data" in *Applied General Equilibrium Analysis, 1984*, pp. 69-127, Cambridge, New York and Sydney: Cambridge University Press.

Parry, I. W. H, et al. (2002) "When Can Carbon Abatement Policies Increase Welfare? The Fundamental Role of Distorted Factor Markets" in A. L. Bovenberg and L. H Goulder, eds. *Environmental policy making in economies with prior tax distortions*, pp. 609-49, New Horizons in Environmental Economics, Cheltenham, U.K. Northampton, Mass.: Elgar; distributed by American International Distribution Corporation, Williston, Vt.,

Sterner, T. and L. Höglund (2000): "Output-Based Refunding of Emission Payments: Theory, Distribution of Costs, and International Experience", *Resources for the Future Discussion Paper* 00/29.

Wigle, R. (200l): "Sectoral Impact of Kyoto Compliance," *Industry Canada Research Publications Program*, WP 34.

Table 1: Characteristics of the projected social accounting matrix for Canada for 2010

Industries	GDP at factor cost (shares %)	Household consumption (shares %)	Exports (shares %)	Imports (shares %)	Exports as % of output	Domestic sales as % of output	Imports as % total domestic demand	Domestic goods as % of total domestic demand
Agriculture	2.7	1.4	3.2	1.3	19.9	80.1	8.5	91.5
Mining	1.4	0.0	2.4	1.0	41.3	58.7	20.8	79.2
Coal	0.1	0.0	0.4	0.3	68.8	31.2	58.3	41.7
Crude Oil and Natural Gas	3.6	0.3	6.5	2.3	59.9	40.1	32.5	67.5
Pulp and paper	2.6	1.1	7.1	2.9	49.6	50.4	26.5	73.5
Cement	0.1	0.0	0.1	0.0	32.2	67.8	8.7	91.3
Iron and Steel	0.5	0.0	1.1	1.5	29.4	70.6	33.5	66.5
Non-ferrous Smelting	0.5	0.0	4.4	2.1	76.9	23.1	59.2	40.8
Chemicals	1.7	1.4	3.8	6.4	37.1	62.9	47.4	52.6
Other Manufacturing products	13.4	19.8	52.8	64.7	55.0	45.0	57.4	42.6
Refineries	0.1	1.4	1.4	1.0	20.0	80.0	14.5	85.5
Gas Pipelines	0.9	0.6	0.7	0.2	25.1	74.9	7.2	92.8
Electricity	2.6	2.3	0.4	0.1	5.0	95.0	0.6	99.4
Transport Industry	3.1	2.2	3.0	2.2	20.4	79.6	14.4	85.6
Services	66.6	69.2	12.8	12.5	4.9	95.1	4.3	95.7
Non-competitive Imports	0.0	0.2	0.0	1.5	-	-	100.0	0.0
Total	100.0	100.0	100.0	100.0	-	-	-	-

Source: Statistics Canada, data from various sources and authors' calculations

-: not relevant

Tableau 2: Behavioural parameters' values

Parameters	Values
Substitution elasticity between value added-energy and intermediate inputs	0.2-0.7
Substitution elasticity between labour & capital-energy	1.0
Substitution elasticity between capital & energy	0.25-0.8
Substitution elasticity between electricity & fossil energy	0.5-0.7
Substitution elasticity between stationary fossil fuels	0.4-0.7
Substitution elasticity between other intermediate inputs & mobile fossil fuels	0.2-0.8
Substitution elasticity among mobile fossil fuels	1.0
Capital adjustment cost parameter	3.0
Rate of capital depreciation	0.06
Population growth rate including Harrod-neutral technological progress(%)	2.3
Substitution elasticity between imports and domestic goods	0.75-2.5
Substitution elasticity between exports and domestic goods	2.0
Substitution elasticity among same industry products*	2.0
World interest rate (%)	6

Sources: Various studies

** For multi-products industries*

Table 3: Sectoral emission shares in BAU in 2010

Industries	Shares in total industrial emissions (%) *
Agriculture	13.6
Mining	1.0
Coal	0.6
Crude Oil and Natural Gas	15.1
Refineries	5.0
Gas Pipelines	4.7
Electricity	18.5
Pulp and paper	2.2
Cement	2.0
Iron and Steel	2.8
Non-ferrous Smelting	2.6
Chemicals	5.3
Other Manufacturing products	3.7
Transport industry**	9.9
Services	13.0
Total	100.0

Source: Statistics Canada, Natural Resources Canada, Domestic Emissions Trading Working Group and authors' calculations

** Industrial emissions do not include those related to transportation activities, i.e., from mobile sources, like gasoline, diesel.*

*** Emissions in the transport industry are not identical to emissions related to transportation activities, which are carried out in several other industries. The transport industry is defined as the one that has transportation as its main activity.*

Table 4: Impacts on some aggregate variables in 2010 from various simulations

Percentage deviation from reference situation unless otherwise mentioned

	Grandfathering allocation of permits	Output-based allocation of permits	Labour tax rate reduction with permit revenue
Welfare change*	-2.9	-2.1	-1.3
GDP at market prices	-2.2	-0.6	-1.1
GDP at factor cost	-2.5	-0.8	-1.5
All Large Final Emitter I (LFE) industries	-4.9	-1.2	-3.8
LFE Energy Producers	-21.9	-17.0	-22.1
LFE Non-Energy Producers	-2.3	1.2	-1.0
Non-LFE industries	-1.6	-0.7	-0.6
Employment	-0.7	0.4	0.5
Household aggregate real consumption	-2.3	-2.1	-1.2
Total real investment	-8.9	-3.5	-7.3
Total real exports	-1.9	1.2	-0.6
Total real imports	-4.1	-2.0	-3.1
Real exchange rate**	1.7	1.4	1.9
Permit price ($2000 per ton of CO_2)***	48	76	50

Source: Simulation results

** See text for the interpretation of the indicator of welfare change*

*** A positive number is equivalent to depreciation*

The permit price has been kept constant at its 2012's value from 2013 on

Table: 5 Impacts on emissions in 2010 from various simulations

	Grandfathering allocation of permits	Output-based allocation of permits	Labour tax rate reduction with permit revenue
Total abatement in Mt of CO2	190	190	190
Total abatement as % of BAU	25	25	25
Industrial abatement in Mt of CO2	175	170	175
% change from BAU	-27	-26	-27
Household abatement in Mt of CO2	15	20	14
% change from BAU	-19.0	-30.2	-19.1
Non 'priceable' emissions*	50	50	50
Remaining gap in MT of CO2	0	0	0

Source: Simulation results

**These are emissions that are non priceable in a DET system like landfill gases*

Table 6: Sectoral impacts on output, employment, and investment in 2010 from various simulations

(Percentage deviation from the reference situation)

Industries	Value added			Employment			Real investment		
	Grandfathering allocation of permits	Output-based allocation of permits	Labour tax rate reduction with permit revenue	Grandfathering allocation of permits	Output-based allocation of permits	Labour tax rate reduction with permit revenue	Grandfathering allocation of permits	Output-based allocation of permits	Labour tax rate reduction with permit revenue
Agriculture	-2.6	-4.4	-1.4	-1.0	-3.7	0.5	-7.4	-9.4	-5.3
Mining	-7.8	5.7	-7.1	-6.3	7.8	-5.2	-19.1	9.0	-17.5
Coal	-26.0	-22.2	-26.2	-25.5	-22.3	-25.5	-50.3	-43.7	-50.5
Crude Oil and Natural Gas	-21.8	-16.8	-22.0	-20.7	-14.6	-20.6	-40.5	-31.4	-40.7
Pulp and paper	-0.2	3.8	1.0	3.3	6.3	5.0	-1.9	6.6	0.6
Cement	-19.5	2.6	-18.7	-13.2	11.6	-12.2	-33.5	-8.4	-32.5
Iron and Steel	-6.6	3.2	-5.4	2.5	14.3	4.5	-8.8	10.3	-6.1
Non-ferrous Smelting	-21.8	11.5	-21.8	-18.3	16.8	-17.9	-45.2	19.4	-44.6
Chemicals	-8.2	0.8	-7.6	-5.5	3.8	-4.4	-14.6	1.4	-13.2
Other Manufacturing products	2.2	1.1	3.9	4.0	2.0	6.0	0.5	-0.2	3.6
Refineries	-20.9	-19.3	-20.7	-7.0	-3.6	-6.0	-19.6	-14.7	-18.9
Gas Pipelines	-21.4	-18.2	-21.5	-17.9	-13.2	-17.8	-33.0	-27.1	-33.3
Electricity	-8.9	1.3	-8.1	6.6	24.7	8.4	-17.5	-3.4	-16.7
Transport Industry	-3.3	2.5	-2.3	-2.4	3.4	-1.1	-8.1	2.4	-6.6
Services	-1.4	-0.6	-0.4	-0.7	-0.3	0.4	-4.7	-2.3	-3.5

Source: Simulation results

Table 7: Sectoral impacts on supply, demand and international trade in 2010 from various simulations

(Percentage deviation from the reference situation)

Products	Total supply			Total exports			Domestic sales			Total domestic demand			Total imports*		
	Grandfathering allocation of permits	Output-based allocation of permits	Labour tax rate reduction with permit revenue	Grandfathering allocation of permits	Output-based allocation of permits	Labour tax rate reduction with permit revenue	Grandfathering allocation of permits	Output-based allocation of permits	Labour tax rate reduction with permit revenue	Grandfathering allocation of permits	Output-based allocation of permits	Labour tax rate reduction with permit revenue	Grandfathering allocation of permits	Output-based allocation of permits	Labour tax rate reduction with permit revenue
Agriculture	-4.4	-6.2	-3.3	-11.7	-16.9	-11.1	-2.6	-3.6	-1.4	-2.1	-2.9	-0.9	3.6	5.9	5.2
Mining	-8.3	5.7	-7.6	-5.5	7.5	-4.6	-10.3	4.4	-9.7	-11.2	3.7	-10.7	-15.0	1.3	-14.6
Coal	-26.4	-22.7	-26.6	-26.8	-23.3	-27.1	-25.5	-21.5	-25.5	-26.7	-22.4	-26.7	-24.9	-20.7	-24.8
Crude Oil	-20.8	-14.7	-21.0	-22.4	-15.0	-22.6	-18.3	-14.2	-18.3	-17.2	-13.9	-17.1	-15.9	-13.7	-15.6
Natural Gas	-21.9	-18.3	-22.0	-22.4	-15.0	-22.6	-21.3	-22.3	-21.3	-20.6	-21.5	-20.6	0.0	0.0	0.0
Pulp and paper	0.4	4.4	1.6	1.7	6.5	2.9	-0.8	2.3	0.3	-1.5	1.0	-0.4	-3.5	-2.5	-2.6
Cement	-20.4	0.6	-19.9	-54.7	0.2	-55.6	-6.6	0.8	-5.6	0.5	0.9	2.0	92.3	1.4	100.5
Iron and Steel	-3.3	8.1	-2.0	-7.0	15.3	-6.0	-1.8	5.0	-0.4	-0.3	2.4	1.1	2.5	-2.4	4.2
Non-ferrous Smelting	-20.4	13.3	-20.3	-22.2	14.3	-22.3	-14.4	10.0	-13.9	-8.9	7.1	-8.0	-5.9	5.8	-4.7
Chemicals	-8.2	1.5	-7.6	-11.1	2.8	-10.8	-6.5	0.7	-5.7	-4.2	-0.3	-3.3	-1.6	-1.4	-0.4
Other Manufacturing products	1.8	1.0	3.4	3.4	1.7	5.2	-0.3	0.0	1.2	-2.4	-1.0	-1.1	-3.9	-1.7	-2.8
Gasoline	-14.4	-12.3	-14.2	-25.4	-14.2	-25.8	-12.9	-12.0	-12.6	-11.3	-11.8	-10.9	1.7	-9.8	3.0
Diesel	-18.9	-16.2	-18.9	-25.4	-14.2	-25.8	-17.8	-16.6	-17.7	-17.1	-17.1	-16.9	-9.4	-18.8	-8.7
Liquid petroleum products	-23.4	-18.7	-23.7	-25.4	-14.2	-25.8	-21.8	-22.5	-22.0	-22.6	-24.4	-22.8	-18.1	-30.0	-18.0
Other refined petroleum products	-27.2	-19.5	-27.6	-25.4	-14.2	-25.8	-30.5	-29.4	-30.9	-35.1	-40.2	-35.5	-35.2	-42.0	-35.6
Pipelines	-20.0	-16.4	-20.1	-22.9	-0.9	-23.1	-19.0	-21.8	-19.1	-18.8	-23.1	-18.8	-15.0	-38.4	-14.9
Electricity	-3.1	8.9	-2.1	-16.2	20.0	-15.9	-2.4	8.3	-1.4	-2.3	8.2	-1.3	13.6	-2.3	15.5
Transport	-4.0	1.7	-3.0	-6.6	4.8	-5.8	-3.3	0.9	-2.3	-3.1	0.7	-2.1	-2.0	-0.6	-1.0
Services	-1.4	-0.6	-0.4	4.3	2.7	6.0	-1.7	-0.8	-0.8	-1.9	-0.9	-1.0	-4.0	-2.1	-3.3

Source: Simulation results

** The large change in cement import is partly explained by its low share in total domestic demand in the base run (less than 9%)*

Table 8: Impacts on consumer prices of selected fossil energy products in 2010 from various simulations

(Percentage deviation from the reference situation)

Energy products	Grandfathering allocation of permits	Output-based allocation of permits	Labour tax rate reduction with permit revenue
Natural gas	102.1	157.3	108.6
Gasoline	25.2	30.0	26.8
Diesel	37.9	52.3	40.3
Liquid petroleum products	36.1	49.5	38.3
Other refined petroleum products	68.3	107.7	72.5

Source: Simulation results

Table 9: Relative sectoral contribution (%) to total change in GDP at factor cost in 2010 from various simulations

Industry categories	Grandfathering allocation of permits	Output-based allocation of permits	Labour tax rate reduction with permit revenue	GDP share in base run situation
All Large Final Emitter I (LFE) industries	54%	41%	71%	28%
LFE Energy Producers	33%	79%	57%	5%
LFE Non-Energy Producers	22%	-39%	14%	23%
Non-LFE industries	46%	59%	29%	72%

Source: simulation results

Table 10: Long-run impacts on some aggregate variables from various simulations (2030)

Percentage deviation from reference situation unless otherwise mentioned

	Grandfathering allocation of permits	Output-based allocation of permits	Labour tax rate reduction with permit revenue
Welfare change*	-2.9	-2.1	-1.3
GDP at market prices	-2.9	-1.9	-2.0
GDP at factor cost	-3.3	-2.3	-2.5
Large Final Emitter Industries	-7.7	-4.9	-6.7
Energy producers	-31.4	-29.2	-31.8
Non-energy producers	-4.1	-1.2	-2.9
Non-Large Final emitter Industries	-1.7	-1.2	-0.9
Employment	-1.0	-0.3	-0.1
Household aggregate real consumption	-2.5	-2.2	-1.6
Total real investment	-5.9	-5.1	-5.5
Total real exports	-4.8	-2.2	-3.6
Total real imports	-4.2	-3.1	-3.4
Real exchange rate**	1.3	1.2	1.4
Permit price ($2000 per ton of CO_2)***	56	91	60

Source: Simulation results

** See text of interpretation of the indicator of welfare change*

*** A positive number is equivalent to depreciation*

The permit price has been kept constant at its 2012's value from 2013 on