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**ECONOMIC IMPACT OF CARBON  
ABATEMENT POLICIES AND MARKET  
STRUCTURE: *A Dynamic General Equilibrium  
Analysis with Imperfect Competition***

*By Yazid Dissou\*, Carolyn Mac Leod and Mokhtar Souissi\**  
*Industry Canada*

*\* Now at Finance Canada*

*Working Paper Number 35  
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### ***Industry Canada Research Publications Program***

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## **ABSTRACT**

We develop a forward-thinking dynamic general equilibrium model to study the likely aggregate and sectoral effects of carbon abatement policies in Canada. In contrast to other studies, we introduce an imperfectly competitive market structure, by considering the Chamberlinian monopolistic competition framework. The simulation results show that both energy sectors and energy-intensive sectors are highly sensitive to restrictions on CO<sub>2</sub> emissions, while other sectors benefit from the change in the composition of demand. Our results highlight the importance of incorporating an imperfectly competitive market framework in estimating the impacts of compliance to the Kyoto Protocol, particularly on welfare. The use of a perfectly competitive framework can underestimate welfare costs by as much as 30 percent as compared to a monopolistic competition framework, using conservative estimates of firms' market power.



## INTRODUCTION

In this study, we assess the welfare and growth implications of Canada's compliance to the Kyoto Protocol in the presence of imperfectly competitive markets. The prospect of global warming, caused by the accumulation in the atmosphere of greenhouse gases (GHG) generated by human activities, has led the international community to take actions to curb these emissions. In December 1997, 38 countries agreed to take appropriate cost-effective measures to reduce their carbon dioxide equivalent emissions of GHG between 2008 and 2012 to at least 5 percent below 1990 levels. Under the terms of the Protocol, Canada has agreed to limit its carbon dioxide equivalent emissions of GHG to 6 percent below its 1990 level, while the United States and the European Union have committed to a ceiling of 7 and 8 percent, respectively, below their 1990 levels.

Based on recent projections by the Analysis and Modelling Group (AMG), GHG emissions will need to be cut by almost 26.5 percent to meet the 2010 target. Since the contribution of carbon dioxide, generated mainly by the combustion of fossil fuels, represents a significant proportion of GHG emissions, the Kyoto restrictions will have a sizeable impact on energy costs. Among the various market-oriented policy instruments that could potentially be used to achieve Canada's commitment under the Protocol, this paper considers the introduction of nationally auctioned carbon permits.

Several studies based on different frameworks ranging from partial to general equilibrium analyses have provided estimates of the likely effects of compliance to the Protocol in Canada. The emerging consensus in the literature is that a general equilibrium framework is the most adequate to capture the direct and indirect impact of the Protocol. However, to our knowledge, most of the general equilibrium models developed to evaluate the economic impact of the Protocol in Canada, for example those of Bernstein, Montgomery and Rutherford (1999), McKibbin and Wilcoxon (1999) and Wigle (2001), among others, have adopted a perfect competition framework.<sup>1</sup> While this is a good starting point, it needs to be extended in order to include the non-competitive aspects of the market structure. Many studies, such as Carraro and Galeotti (1996) and Rotemberg and Woodford (1996), have shown that considering an imperfect market structure in analyzing the impact of energy price increases could be very important. For example, in their study of the impact of an energy price increase in the United States, Rotemberg and Woodford (1996) found that the impact on GDP (loss) is much higher in the presence of market imperfections than under the assumption of perfect competition. Since, in the presence of imperfect competition, the social marginal benefit of production is greater than its social marginal cost, the welfare impact of a reduction in output caused by an energy price increase will be more deleterious than it would be in a perfectly competitive framework. Moreover, a growing body of literature emphasizes the relevance of imperfect competition, not only for the analysis of sectoral price reforms within general equilibrium models, but also for the analysis of macroeconomic policies within aggregate models.<sup>2</sup>

In this paper, we develop a forward-looking, dynamic general equilibrium model with imperfect competition to study the welfare — sectoral and aggregate — effects of Canada's compliance to the Kyoto Protocol. In particular, we introduce a Chamberlinian competition framework in the analysis in order to capture firms' departure from marginal-cost pricing. We analyze both the long-term and the transitional effects of the Protocol in Canada by using a national carbon emission permit scheme for fossil fuel use as the cost-effective policy instrument required to achieve the desired level of carbon emissions. We assess the underestimation of the welfare and GDP losses, if any, associated with the assumption of perfect competition in all markets. To our knowledge, this is the first forward-looking dynamic general equilibrium model that incorporates an imperfectly competitive market structure in the analysis of the Kyoto Protocol, not only for Canada but also for any other country.

Our model builds upon recent contributions focussing on dynamic general equilibrium models with imperfect competition, such as those of Ambler, Cardia and Farazli (1999), Gali (1994), Mercenier and Yeldan (1997) and Rotemberg and Woodford (1996), among others. However, compared to all these imperfect competition models, one of the distinctive features of the model used in this study is the introduction of capital adjustment costs, which competitive and non-competitive firms alike must incur.

The remainder of the paper proceeds as follows. We present an intuitive description of the model in the next section, and we discuss the data, the calibration procedures and the numerical solution strategy in the third section. Our interpretation of the simulation results is presented in the fourth section. Some concluding remarks follow in the last section. The complete listing of the model's equations is presented in a separate annex, which is available from the authors.

## 2. THE MODEL

### Overview

We develop a multi-sector, forward-looking, dynamic general equilibrium model with imperfect competition in the product market. It is a Ramsey-type, neo-classical model where the steady state growth rate is exogenous and determined by a constant population growth rate, including Harrod-neutral technological progress. Canada is considered a small open economy that produces and consumes tradable goods, and that has free access to the international capital market.

Three types of agents are considered: households, firms and the government. The first two have optimizing behaviour, while the government's role is kept simple. The model features a disaggregation of the Canadian economy into thirteen productive sectors (see Table 1) in order to account for the sectoral differences in energy intensities. Technology is characterized by various substitution possibilities between energy and non-energy production factors, so that any post-reform structural change in production can be traced back.

Tradable goods are differentiated by their origin and destination. Ten of the thirteen productive sectors are characterized by increasing returns to scale that compel firms to price their products by applying a mark-up over their marginal costs. These firms derive market power from sales on the domestic market only, since the assumption of a small country does not allow them the possibility of setting prices in the world market. We model these sectors as being characterized by Chamberlinian large-group monopolistic competition. The ultimate users of the differentiated domestic goods produced in each non-competitive sector are only interested in their respective aggregate.

In this study, we focus only on CO<sub>2</sub> emissions generated by the combustion of fossil fuels: coal, natural gas and petroleum products. To achieve the CO<sub>2</sub> emission level established by the Protocol, a carbon emission permit with an endogenous price is applied to the domestic uses of all fossil fuels. In order to abstract from the growth effects induced by the increase in population and technological progress, we express the model's variables per efficiency units.

**Table 1**  
**Sectoral Disaggregation**

<b>Acronym</b>	<b>Description</b>
AGRIC	Agriculture, Fishing and Forestry
IRON-ST*	Iron and Steel
COAL*	Coal
PET-GAS*	Crude Petroleum and Natural Gas
OTH-MIN*	Other Minerals
PAPER*	Pulp and Paper
NON-FER*	Non-ferrous Metals
CEMENT*	Cement
REF-PETR	Refined Petroleum
CHEMIC*	Chemicals
ELECTR*	Electricity
OTH-MANUF*	Other Manufacturing
SERV*	Services

\* Non-competitive sector.

## Households

Consider an economy populated in each period by a finite number of infinitely lived households, which increases at a constant rate, including Harrod-neutral technological progress. We model the behaviour of these households by a representative household that owns the domestic primary factors of production. It has access to the international capital market, where it can borrow or lend at an exogenous constant interest rate. Its portfolio consists of shares in domestic firms, government bonds and foreign assets. Appropriate arbitrage conditions always ensure that the representative household keeps the three types of assets in its portfolio.<sup>3</sup>

In each period, the representative household receives a salary for the labour it supplies. Other income is derived from dividends received from domestic firms, interest on the other financial assets, and net transfers received from the government and the rest of the world. Furthermore, it receives all the proceeds resulting from the sale of the tradable carbon emission permits. It pays taxes on the income of primary factors and utilizes the remainder of its current income for consumption and savings purposes.

The representative household determines the optimal path of spending on each good by maximizing an intertemporal utility function subject to an intertemporal budget constraint. For derivation purposes, we restrict our attention to a preference structure that allows for the separation of the intertemporal allocation of lifetime spending from the within-period allocation of spending among goods. As a consequence, a two-step budgeting procedure may be used to allocate the household's lifetime income between consumption and savings.

At the intertemporal level, the representative household maximizes an additive intertemporal utility function, with a constant rate of time preference and an isoelastic instantaneous utility function, subject to a sequence of period budget constraints and a non-Ponzi game rule. The instantaneous utility function's argument is a Cobb-Douglas aggregate of leisure and an aggregate consumption (or consumption index). The latter is a linear homogeneous function of the household's demand for different commodities. The first-order conditions of this intertemporal optimization problem give both the laws of motion of the aggregate consumption and of wealth as the standard equation of the marginal utility of leisure to the value of marginal consumption. Solving the latter equation, it can be shown that leisure depends on aggregate consumption and real wages.

From the motion laws, we can derive an expression for the current consumption as a function of the household's total (financial and human) wealth. In a numerical context, however, this calculation is not necessary. The first-order conditions and an appropriate terminal condition are sufficient to determine the path of the consumption index. Optimal consumption reflects the relative prices of present and future consumption; an increase in the consumption price index reduces the real interest rate in terms of consumption. This makes future consumption less attractive and increases today's consumption. On the other hand, from the budget constraint, a rise in the consumption price index has an income effect on the consumption level through the household's total financial and human wealth.

Within each period, the representative household allocates its spending between different commodities according to a cost-minimization rule. The consumption index is assumed to be a Cobb-Douglas function of the different commodities, implying that consumption spending is allocated among goods in fixed shares.

## Firms

The set of productive sectors is partitioned into two subsets, representing those operating under constant returns to scale and those operating under increasing returns to scale. The non-convexities in the technology of firms belonging to the latter subset of sectors stem from the presence of fixed costs, which introduce a wedge between unit cost and marginal cost. Firms in these sectors behave non-competitively in their product markets; they set their prices by adding a mark-up to their marginal costs.

Two types of differentiation are considered on the production side of the model. First, in every sector, goods produced by firms are differentiated by their geographic destination. We model this by assuming that each firm produces a composite output, which is a constant elasticity of transformation (CET) aggregate of export goods and goods destined for domestic sales. Second, in each non-competitive sector, firms produce differentiated (though close substitute) goods for the domestic market. The composite output produced by firms in non-competitive sectors is therefore an imperfect substitute. The differentiated domestic goods produced in each non-competitive sector form a single composite good in which the ultimate consumers are interested. We postulate a Dixit-Stiglitz preference structure over the differentiated domestic goods of each sector, with the implication that each variety enters symmetrically in the aggregator function. The non-competitive firm takes advantage of its monopoly power from the knowledge of the price elasticity of its perceived demand on the domestic market. In contrast, it has no market power on the export market because of the small-country assumption. The ability to set the price on the domestic market translates into market power for the composite good, which the non-competitive firm uses in the determination of its optimal level of factor use.

While one representative firm is sufficient to model the behaviour of firms in the competitive sectors, we assume that, in each period and in each non-competitive sector, there is a finite and large number of firms, each producing one variety of the differentiated goods. With the assumption of free entry and exit, the number of firms is endogenous. In the context of Chamberlinian monopolistic competition, each non-competitive firm acts as if its competitors would not respond to its pricing strategy. In other words, the non-competitive firm sets its price by considering the prices charged by its competitors and the aggregate price in its industry as given. We will restrict our attention to the symmetric equilibrium, where all producers in each non-competitive sector charge the same price and produce the same quantity of the domestic good by using the same technology. Though this may be similar to the case where perfect competition is assumed, the situation is different here, as non-competitive firms add a mark-up to their marginal cost.

In all sectors, the composite output is produced by using labour, capital, energy and material inputs. A common property of technology in all sectors is that it allows for substitution between the various fossil fuels, for substitution between fossil and non-fossil fuels, and for substitution between energy and other inputs. This technology is described by a multi-level nested constant elasticity of substitution (CES) function. At the bottom level, coal, refined petroleum and natural gas combine to form the fossil fuel aggregate. Fossil fuel and electricity make up the energy aggregate. The latter combines with value added (composite of labour and capital) to form the capital-labour-energy composite. Finally, the capital-labour-energy composite combines with the aggregate of material inputs (non-energy commodities) in fixed proportions to form the composite output of the firm. The difference between competitive and non-competitive firms stems from the presence of fixed costs in the production function of the value-added composite. In other words, the technology of the value-added composite requires some fixed costs in terms of labour and capital, which may be interpreted as R&D expenditures, for example. Our specification of the value-added technology follows that of Ambler and Cardia (1998), and of Rotemberg and Woodford (1996):

$$VA_t^i = V^i(K_t^i, L_t^i) - f_t^i \phi^i$$

where  $VA_t^i$  represents the sectoral volume of the value-added composite,  $V^i$  is a CES function of the sectoral capital stock,  $K_t^i$ , and the sectoral labour demand,  $L_t^i$ , while  $f^i$  is the number of firms and  $\phi^i$  is a parameter related to fixed costs. In competitive sectors,  $\phi^i = 0$ . This specification assumes that capital and labour are used not only as fixed factors in non-competitive sectors, but also that they are combined in the same proportion whatever their usage, as fixed factors or variable factors.

Since  $V^i$  is a linear homogenous function, it follows that the technology of firms in non-competitive sectors is also homothetic, as is the case in competitive sectors. This property has some interesting implications to which we will return later. By making the appropriate separability assumptions, we are able to split the decisions made by firms into intertemporal and within-period optimization problems. In their intertemporal problem, firms determine the optimal path of their composite output, which they allocate within each period between the domestic and export markets.

### Intertemporal Problem

At the intertemporal level, in all sectors, firms maximize the present value of the sum of current and future net cash flows, subject to the capital accumulation constraint and in the presence of capital installation costs, so as to determine the optimal paths of their factor uses and of their composite output. As in Hayashi (1982), we consider convex and linear-homogenous installation costs (in investment and capital stock). Furthermore, we assume that firms finance their investment expenditures through retained earnings. With the assumption that firms are price takers on factor markets, and possibly price makers on product markets, the firms' intertemporal problem can be solved, giving the optimal conditions for factor uses. These conditions can be divided into two groups: those affected by the use of market power on the product market (labour and capital)<sup>4</sup> and those that are not (material and energy inputs).

Optimal conditions for the latter group are those encountered in static optimization and are therefore standard. Firms use these factors up to the point where the value of their marginal product equals their user cost. Following previous discussions, market power on the domestic market translates into market power for the composite output in the non-competitive sectors. In these sectors, firms will use the marginal revenue,  $P_{it}^v(1 - \mu^i/s^i)$  instead of the value-added price,  $P_{it}^v$ , to determine the optimal levels of primary factors.<sup>5</sup> It follows that market power reduces output. The wedge between the marginal revenue and the value-added price depends not only on the perceived price elasticity of demand of the composite output, but also on the share of value added in the composite output. The lower the share of value added in the composite output, the larger is this wedge. The intuition behind this result is straightforward as the reduction in the volume of the composite output must essentially be driven by a reduction of the value-added component.

In each period, the capital stock is predetermined by past investment, and labour is used up to the point where its marginal revenue product is equal to the wage rate. At the optimum, firms invest up to the point where the marginal cost of investment (i.e. the marginal cost of obtaining and installing capital) equals its marginal benefit,  $q_t^j$ , which is the shadow price of additional investment. By rearranging this optimal investment condition, investment can also be defined as a function of the ratio of the shadow price of capital,  $q_t^j$  and the purchase price of capital,  $P_t^k$ . Another optimal condition of the firms' intertemporal optimization problem refers to Euler's condition, which describes the motion of the shadow price of capital over time that, in turn, depends on the additional benefits generated by a marginal unit of current investment. By imposing a transversality condition, which rules out speculative bubbles, the Euler equation may be solved to yield a forward solution to the shadow price of capital. The shadow price of capital is equal to the present value of future net revenues generated by an additional unit of installed capital at time  $t$ . As the implementation of the Kyoto Protocol will affect  $q_t^j$  and/or  $P_t^k$ , it will affect the



firms' decisions to invest, hence affecting the optimal path of output. Likewise, in labour demand, non-competitive firms use the marginal revenue product of capital in the evaluation of their shadow price, which is less than the value of the marginal productivity of capital. They will therefore underinvest in comparison to a competitive situation. This underinvestment by non-competitive firms has also been noted by Keuschnigg and Kohler (1996) in an analytical framework without capital installation costs.

The departure from perfect competition may generate pure profits, which will prevent Hayashi's identity between marginal and average  $q$  to hold. This possibility is ruled out in our model with the assumption of free entry and exit in each period. As profitability increases, firms enter in the non-competitive sectors until the zero-profit condition for each individual firm is satisfied. This condition determines the number of firms in each non-competitive sector. Moreover, this equation allows us to re-establish the identity between marginal and average  $q$ , even when non-competitive firms are not price takers. In other words, referring to Hayashi (1982), in each period, the value of the firm,  $V_t^j$ , may be expressed as:

$$V_t^j = q_t^j K_{t+1}^j. \quad (6)$$

Furthermore, under the free entry and exit assumption, there will be no rationalization at the firm level in the non-competitive sectors following a change in relative prices. Indeed with an homothetic technology, the output of each non-competitive firm is constant, since it is operating at a constant scale. Any change in the output of non-competitive sectors is driven by the change in the number of firms.<sup>7</sup>

### ***Within-period Decisions***

Firms perceive their export market as different from their domestic market. Having determined the optimal path of their composite output, their objective in each period is to determine the optimal allocation of production between the two markets, with the possibility of having market power on the domestic market. Sales are maximized subject to being on the transformation frontier. We get the optimal conditions of this within-period optimization problem as follows:

$$(1) \quad EX_{jt} = (A_j^x)^{-1-\sigma_j^x} X_{jt}^s \left[ \frac{P_{jt}^x}{\delta_j^x (1-\mu_j^c) P_{jt}^s} \right]^{\sigma_j^x}$$

$$(2) \quad XD_{jt}^s = (A_j^x)^{-1-\sigma_j^x} X_{jt}^s \left[ \frac{P_{jt}^d (1-\mu_j^d)}{\delta_j^x (1-\mu_j^c) P_{jt}^s} \right]^{\sigma_j^x}$$

$$(3) \quad (1-\mu_j^c) P_{jt}^s = \frac{1}{A_j^x} \left[ (\delta_j^x)^{\sigma_j^x} (P_{jt}^x)^{1+\sigma_j^x} + (1-\delta_j^x)^{\sigma_j^x} \left[ (1-\mu_j^d) P_{jt}^d \right]^{1+\sigma_j^x} \right]^{\frac{1}{1+\sigma_j^x}}$$

where  $X_{jt}^s$ ,  $EX_{jt}$  and  $XD_{jt}^s$  are, respectively, the supplies of the composite output, the export good and the domestic good, and  $P_{jt}^s$ ,  $P_{jt}^x$  and  $P_{jt}^d$  are their respective prices.  $A_j^x$  and  $\delta_j^x$  are, respectively, the shift and share parameters in the CET function, while  $\mu_j^d$  and  $\mu_j^c$  are the market power parameters on, respectively, the domestic good and the composite output.

Equations (1) and (2) are the supply functions of the export and domestic goods, respectively. Note, in the domestic good supply function, the presence of the strictly positive parameter  $\mu_j^d = |1/\varepsilon_j^d|$ , with  $\varepsilon_j^d$  being the perceived own-price elasticity of demand of the domestic good. With Dixit-Stiglitz preferences over the differentiated goods and the assumption of a large number of firms, the perceived own-price elasticity of demand,  $\varepsilon_j^d$ , is constant and equal to the elasticity of substitution in the Dixit-Stiglitz CES function.<sup>8</sup>

At a given domestic price, non-competitive firms will supply less on the domestic market. Stated differently, for a given level of domestic supply, non-competitive firms charge a higher price in comparison to a competitive situation. Equation (3) is an expression for the Lagrange multiplier of the firms' within-period optimization problem. It is the marginal revenue generated by the sale of an additional unit of the composite output, which is equal to  $P_{jt}(1 - \mu_{jt}^c)$ ,  $\mu_{jt}^c$  being the absolute value of the inverse of the perceived price elasticity of demand of the composite output. The link between the price elasticities of the composite output and the domestic good is then established. The higher the share of the domestic good in the composite output, the stronger the market power in the composite output.

### ***The Government***

In this model, the government role is simple. It consumes goods and services,  $G_t^i$ , which are fixed in real terms,<sup>9</sup> and makes lump-sum transfers to households. It finances its spending by imposing taxes on domestic sales, imports, wages, and capital incomes and by issuing bonds. The government is required to have an intertemporally balanced budget. This requirement can be satisfied by various fiscal rules. We opted to choose government lump-sum transfers to households as the adjusting variable, such that the ratio of its debt to gross domestic product is kept constant in each period (i.e. equal to the ratio observed in the initial steady state). As discussed in McKibbin and Wilcoxon (1999), this simple rule respects the intertemporal budget balance constraint.

### **Imports and Current Account Balance**

The total domestic demand of each commodity is the sum of the demands for household and government consumption, investment and intermediate uses. It is an Armington (CES) aggregate of the domestic good and the imported good. A representative agent determines the optimal composition of this aggregate by a cost-minimizing rule. We get the standard demand conditions for the demands of the import and domestic goods, and the dual price of the CES composite good. Note that the latter is not necessarily the purchasing price of the domestic demand for all commodities. In the case of fossil fuels, this price is augmented by the price of tradable emission permits, to which we will return later in the study.

In each period, the current account deficit adds to the debt level. The transversality condition imposed on the representative household, which bears the responsibility for the foreign debt, prevents the explosion of the stock of debt. In each period, this level should be equal to the discounted sum of future current account balances. The real exchange rate is the adjusting variable enabling the fulfillment of this condition.

### ***Other Components of Total Domestic Demand***

Other components of total domestic demand for each commodity are investment demand by origin and demand for goods for intermediate use (energy and non-energy). We assume that the capital good used for investment is identical in all sectors. It is a fixed-proportion (Leontief) aggregate of various products, sold at the price  $P_t^k$ . We use the fixed coefficients of the investment matrix,  $IMAT_{ij}$ , to determine the

demand for each good for investment purposes from the knowledge of investment demands by destination sector,<sup>10</sup> which increase firms' capital stocks. The price of the capital good,  $P_t^k$ , is a weighted average of the purchase prices of the different commodities making up the capital good.

The demand for each energy good for intermediate use is the sum of individual demands by all firms. Since non-energy intermediate goods are used in fixed proportions (Leontief technology), the expression for their demand can be easily derived from the knowledge of value added.

### Carbon Dioxide Emissions and Carbon Permits

In this study, we assume that carbon dioxide emissions come from the combustion of fossil fuels, that is coal, natural gas and petroleum products. In order to reduce the level of carbon dioxide emissions in Canada, a carbon emission penalty is imposed on the consumption of fossil fuels by increasing the cost associated with their use. The requirement to purchase a tradable carbon emission permit is used to mimic the emission penalty. Permits are needed for all domestic uses (final or intermediate) of these fuels, whatever their origin (imports or domestic production).<sup>11</sup> Thus, the cost of the permit adds to the price of the Armington composite (of domestic and imported goods) of each of the fossil fuels. The required amount of tradable permits for the use of a given fossil fuel varies positively with its carbon dioxide content. Let  $e^i$  be the emission factor (i.e. the quantity of carbon dioxide in tons contained in one unit of the fossil fuel),  $P_t^q$  be the unit price of the tradable permit, expressed in \$/ton of carbon dioxide, and  $\overline{P}_{jt}^c$  be the consumption price of the fossil fuel (without permit). The purchasing price of the fossil fuel,  $P_{jt}^c$ , gross of permit, is therefore  $P_{jt}^c = \overline{P}_{jt}^c + e^i \cdot P_t^q$ . In other words, the total value of the required permits per unit of fossil fuels is  $e^i \cdot P_t^q$ .

After determining the level of the emission factor,  $e^i$ , the total level of carbon dioxide emissions may be estimated by using the level of total domestic demand for these fuels. The equilibrium unit price of the tradable permit,  $P_t^q$ , is the one that equates the total level of emissions with the desired level of emissions. The proceeds of carbon permit sales are allocated to the representative household in a lump-sum fashion, so as to have a neutral effect on the economy. Of course, other uses of the permit revenues may be considered; they yield different results from the ones obtained here. For example, the proponents of the double-dividend hypothesis have argued that the use of revenues derived from environmental taxation to reduce or replace other distorting taxes may confer additional benefits to the economy. However, other authors, like Bovenberg and de Mooij (1994a), Bovenberg and de Mooij (1994b) and Goulder et al. (1999) have rejected the double-dividend hypothesis by showing that environmental taxes exacerbate pre-existing distortions.

### Dynamics and Equilibrium Conditions

The model's dynamics are represented by two types of variables. On the one hand, there are state variables, such as the capital stock, whose current values are determined by past accumulation and, on the other hand, there are jumping variables, such as aggregate consumption and the shadow price of capital, whose current values exclusively reflect future conditions. The various transversality conditions imposed prevent the model from exploding.

An intertemporal equilibrium is represented by a sequence of prices, quantities and assets, such that all optimality conditions are satisfied, all agents respect their budget constraints, in each period there are temporary equilibria *à-la-Grandmont* in the labour and domestic goods markets, and the total level of carbon dioxide emissions is exactly equal to the desired level in each period.

The equilibrium solution of this imperfect competition model will not coincide with the central planner solution, since monopolistic firms will underinvest when there is a change in relative prices. As discussed in Rotemberg and Woodford (1995) and Gali (1994), multiple equilibria may be observed in this dynamic model with imperfect competition. Nonetheless, we keep our focus on the new local equilibrium close to the benchmark steady state.

### Calibration and Solution Strategy

The model was calibrated using benchmark data for 1995, constructed by combining data from different sources. The data were used to construct a social accounting matrix (SAM) for Canada consisting of thirteen sectors and fourteen commodities.<sup>12</sup> The sectoral characteristics of the SAM are presented in Table 4. Data on carbon dioxide emissions produced in Canada by fossil fuels in 1995, published by Environment Canada, allow us to infer the amount of carbon dioxide generated by each productive sector of the model.

The model was calibrated by assuming that the observed data is the outcome of a given steady-state equilibrium, as is standard practice in applied general equilibrium models. At this equilibrium, which represents our business-as-usual (BAU) scenario, the growth rate of real GDP is constant and equal to 2.7 percent. Following Environment Canada's projections for the AMG, Canada's total emissions of GHG are projected to grow by 14.5 percent between 1995 and 2010. Since emission growth is positively correlated with economic growth, we calibrated the emission intensity or emission factor,  $e_i$ , of each fossil fuel, which is a constant. The emission intensity is defined by the volume of carbon dioxide emissions per unit of fossil fuel; it is calculated from data on total domestic uses of fossil fuels contained in the SAM and on total carbon dioxide emissions for each fossil fuel from Environment Canada (Table 2). Moreover, using data on the sectoral uses of fossil fuels and an appropriate price normalization, we are able to compute the total amount of carbon dioxide generated by each productive sector.

**Table 2**  
**CO<sub>2</sub> Emissions and Fuel Consumption by Type (1995)**

<b>Fossil Fuel</b>	<b>CO<sub>2</sub> Emissions in Megatons</b>	<b>Domestic Consumption of Fossil Fuels in Millions of \$</b>	<b>Ratio in Thousands of Tons of CO<sub>2</sub>/\$</b>
Natural Gas	145.2	16,437.3	8.8
Refined Petroleum	216.4	17,987.8	12.0
Coal	99.3	1,265.0	78.5
Total	460.9	35,690.1	—

Source: Environment Canada, Statistics Canada and authors' calculations.

Typically, a calibration procedure involves determining the values of some behavioural parameters and some non-observable variables so as to reproduce the initial equilibrium, by using, on the one hand, observed data and first-order and steady-state conditions and, on the other hand, some behavioural parameters drawn from a literature search.

The external parameters used in the calibration process are presented in Table 3. Central to our analysis are the substitution parameters in technology. The values used in this model are relatively conservative and close to the ones used by Wigle (1999). Estimates of the size of the mark-up over marginal costs for Canadian industries are rare in the literature. We used recent estimates of these parameters provided by Industry Canada and calibrated the value of firms' market power on the domestic market,  $\mu_j^d$ . These values, which range from 20 to 30 percent, may be considered reasonable, since they are comparable to values used in other studies.<sup>13</sup> Using equation (3), we then calibrated the values of  $\mu_{jt}^c$ , the implicit firm's market power on the composite output market.<sup>14</sup> Other parameter values are drawn from studies done on Canada or the United States and are believed to be conservative as well. As the calibration procedures for the other parameters pertaining to the static and dynamic aspects of the model are common in the literature, they will not be discussed here.

**Table 3**  
**Values of Some External Behavioural Parameters Used in the Base Scenario**

Parameters	Values
Installation Cost Parameter	2.00
Elasticity of Substitution Between Value Added and Energy	0.35
Elasticity of Substitution Between the Fossil Fuel Aggregate and Electricity	0.30
Elasticity of Substitution Among Fossil Fuels	0.20
Elasticity of Substitution Between Capital and Labour	0.50
Elasticity of Substitution Between Imports/Exports and the Domestic Good	2.50
Rate of Physical Capital Depreciation	0.10
Intertemporal Elasticity of Substitution	1.00
Population Growth Rate, Including Harrod-Neutral Technological Progress (%)	2.70
World Interest Rate (%)	5.00

Source: Various studies.

**Table 4**  
**Sectoral Characteristics of the Canadian Economy in the Benchmark Data (1995)**

Industry	Value				Domestic		Domestic	
	Production	Added	Exports	Imports	Exports	Sales	Imports	Production
	(%)				(as a % of Output)		(as a % of Domestic Absorption)	
AGRIC	3.28	2.63	3.1	1.41	19.17	80.83	9.07	90.93
IRON-ST	0.84	0.58	1.31	1.54	32.21	67.79	34.12	65.88
COAL	0.12	0.14	0.42	0.26	69.41	30.59	56.18	43.82
PET-GAS	1.66	2.34	4.49	2.03	55.31	44.69	34.13	65.87
OTH-MIN	2.59	2.14	4.2	2.34	32.9	67.10	20.21	79.79
PAPER	2.05	1.72	7.17	0.98	72.05	27.95	24.56	75.44
NON-FER	1.28	0.56	4.87	2.37	78.89	21.11	62.79	37.21
CEMENT	0.24	0.19	0.12	0.04	10.14	89.86	3.26	96.74
REF-PETR	1.26	0.17	1.1	0.95	17.63	82.37	14.68	85.32
CHEMIC	1.41	1.12	3.22	4.24	46.71	53.29	51.7	48.3
ELECTR	1.79	2.83	0.41	0.05	4.48	95.52	0.53	99.47
OTH- MANUF	20.62	14.24	52.29	69.37	52.06	47.94	57.18	42.82
SERV	62.85	71.34	17.3	14.42	5.23	94.77	4.04	95.96
Total	100.00	100.00	100.00	100.00	—	—	—	—

Source: Statistics Canada and authors' calculations.

The numerical resolution of an infinite-horizon model needs truncation in time length. The rule-of-thumb is to choose a length of time sufficiently long to allow the economy to reach a new steady state after an initial perturbation. In this model, we have chosen a forty-period length horizon and solve the model using the extended-path method.<sup>15</sup>

### 3. SIMULATIONS

We run various simulations with the model in order to analyze the aggregate and sectoral impacts of the Kyoto Protocol on the Canadian economy. Our policy simulations incorporate one of the main objectives of the reform, which is to lower carbon dioxide emissions associated with the use of fossil fuels. We achieve this reduction by imposing a carbon emission penalty in each of the years in which emission limits are imposed. In practice, according to the Protocol, countries must meet their emission target over an average of the years 2008–2012. However, as in many other studies, we assume that Canada will meet its Kyoto target in 2010. Based on Analysis and Modelling Group (AMG) projections, meeting Canada's target in that year will amount to reducing GHG emissions by almost 26.5 percent compared to the business-as-usual (BAU) scenario. We keep the 2010 carbon dioxide emission level constant in subsequent years<sup>16</sup> (referred to as the “Kyoto Forever” scenario in the literature). In our study, the carbon emission penalty corresponds to the cost of the tradable permits required for the use of fossil fuels. The model determines endogenously the unit cost of the tradable permits required to achieve the assumed emission target.

Since there is uncertainty about the magnitude of some external parameters used in our calibration procedures, we run other simulations in order to test the robustness of our results. These simulations differ in the values of the parameters pertaining to either market structure, firms' technology or trade elasticities. In our main simulation, we study the impact of the reform with the base-case parameter values presented in Table 3 in an imperfectly competitive framework.

#### **Main Simulation: Impact of the Kyoto Protocol on Canada with Monopolistic Competition in the Product Market**

The results of this simulation are presented in Tables 5, 6 and 7. The price of the carbon permit required to achieve the carbon dioxide emission target is \$29.20<sup>17</sup> per ton of CO<sub>2</sub> in 2010, and dropping to \$28.30 in 2012.<sup>18</sup> The first impact of this strictly positive value of the carbon permit price is to drive up the user price of fossil fuel products: the highest increase is observed for coal — the most polluting fuel — followed, respectively, by petroleum products and natural gas. This increase in the price of fossil fuel products alters relative prices in the economy and has direct and indirect effects, characterized by changes in production costs and in the composition of aggregate demand. Since the different sectors will not be affected similarly, we make a distinction in our analysis between energy-intensive and other sectors on the production side, and between the energy-producing and other sectors on the demand side.

On the production side, as the cost of fossil fuels increases, firms substitute away from the most polluting of these products at a lower level of the technology nesting. At the middle level, electricity is substituted for the aggregate input of fossil fuels.<sup>19</sup> Finally, at a higher level, firms will substitute from energy to value added. The price elasticity of the demand for an input is a function, not only of substitution elasticities, but also of factor shares. For example, the higher the share of value added in the aggregate of value added and energy, the easier it is for firms to substitute it for the energy input. In these conditions, even though capital is not directly substituted for fossil fuel products, the substitution elasticity between capital and labour, which has an impact on the availability of value added, is also of importance in the equilibrium price of the carbon permit.

**Table 5**  
**Sectoral Impact of Kyoto Protocol on Selected Variables in % Deviation From Business-as-usual (BAU)**  
**Base Scenario: “Kyoto Forever” with Imperfect Competition**

Industry	Year	Total Energy Consumption	Fossil Energy Consumption	Non-fossil Energy Consumption	Investment	Employment	Output	Domestic Sales	Exports	Total Domestic Demand	Household Consumption	Imports
AGRIC	2010	-10.02	-12.85	-3.11	-2.97	0.41	-0.66	-0.34	-2.04	-0.18	-1.61	1.39
	2012	-10.21	-12.97	-3.49	-2.49	0.14	-0.99	-0.66	-2.38	-0.50	-1.62	1.08
	Long Run	-10.55	-13.19	-4.14	-1.17	-0.43	-1.64	-1.33	-2.96	-1.18	-1.59	0.31
IRON-ST	2010	-25.05	-32.00	-13.14	-24.47	-9.50	-11.89	-6.55	-20.58	-1.04	-5.08	9.94
	2012	-26.10	-32.83	-14.69	-20.43	-10.78	-13.77	-7.82	-23.52	-1.53	-5.66	11.07
	Long Run	-27.45	-33.80	-16.89	-13.18	-12.60	-16.64	-9.72	-28.07	-2.10	-6.61	13.28
COAL	2010	-27.74	-30.65	-23.59	-48.44	-21.42	-21.10	-28.58	-18.70	-33.52	-64.65	-37.27
	2012	-31.24	-33.95	-27.40	-45.98	-25.18	-25.12	-30.16	-23.49	-33.60	-64.55	-36.24
	Long Run	-42.93	-45.10	-39.86	-40.75	-37.70	-38.46	-35.71	-39.38	-33.53	-64.09	-31.82
PET-GAS	2010	-18.46	-23.49	-16.67	-33.85	-14.71	-13.91	-23.99	-8.03	-28.60	-18.10	-37.19
	2012	-21.06	-25.81	-19.37	-31.92	-17.28	-16.79	-24.87	-12.05	-28.69	-18.09	-35.83
	Long Run	-29.04	-33.21	-27.57	-27.40	-25.34	-25.78	-27.93	-24.49	-29.05	-18.65	-31.21
OTH-MIN	2010	-8.92	-13.92	-5.42	-10.37	-2.65	-3.00	-3.49	-2.25	-3.74	-0.59	-4.72
	2012	-9.90	-14.74	-6.53	-9.70	-3.64	-4.11	-4.48	-3.56	-4.66	-0.69	-5.39
	Long Run	-12.52	-17.07	-9.37	-7.39	-6.34	-7.22	-7.10	-7.39	-7.04	-1.10	-6.80
PAPER	2010	-2.76	-8.97	-0.94	-2.74	1.72	1.01	1.05	0.99	1.07	-1.02	1.11
	2012	-3.33	-9.37	-1.57	-2.34	1.21	0.43	0.78	0.33	0.89	-1.13	1.24
	Long Run	-4.45	-10.27	-2.76	-0.54	0.16	-0.80	0.33	-1.15	0.70	-1.44	1.84
NON-FER	2010	-17.27	-27.14	-14.07	-40.61	-11.59	-12.47	-8.71	-13.29	-5.69	-1.75	-3.89
	2012	-20.47	-29.74	-17.47	-35.33	-14.97	-15.90	-11.20	-16.92	-7.37	-1.96	-5.08
	Long Run	-28.08	-36.12	-25.51	-24.63	-23.11	-24.14	-17.09	-25.68	-11.12	-2.56	-7.51
CEMENT	2010	-10.45	-17.94	-3.57	-1.20	-0.06	-1.55	-1.18	-4.22	-1.08	-2.19	1.96
	2012	-10.32	-17.66	-3.63	-0.99	-0.01	-1.52	-1.16	-4.10	-1.06	-2.15	1.87
	Long Run	-9.94	-17.01	-3.57	-0.59	0.12	-1.38	-1.06	-3.65	-0.98	-2.01	1.60



**Table 5 (cont'd)**

<b>Industry</b>	<b>Year</b>	<b>Total Energy Consumption</b>	<b>Fossil Energy Consumption</b>	<b>Non-fossil Energy Consumption</b>	<b>Investment</b>	<b>Employment</b>	<b>Output</b>	<b>Domestic Sales</b>	<b>Exports</b>	<b>Total Domestic Demand</b>	<b>Household Consumption</b>	<b>Imports</b>
REF-PETR	2010	-32.30	-32.34	-29.05	-55.71	-27.89	-31.74	-27.42	-53.71	-21.87	-34.61	13.34
	2012	-32.26	-32.31	-29.08	-41.36	-27.31	-31.78	-27.42	-54.01	-21.78	-34.20	14.11
	Long Run	-32.38	-32.42	-29.12	-27.19	-26.65	-31.98	-27.48	-54.97	-21.54	-33.29	16.39
CHEMIC	2010	-19.21	-20.98	-14.34	-29.93	-11.69	-12.83	-8.43	-16.41	-3.96	-2.70	0.30
	2012	-20.78	-22.48	-16.12	-25.25	-13.35	-14.70	-9.74	-18.75	-4.61	-2.96	0.27
	Long Run	-23.56	-25.16	-19.18	-17.02	-16.25	-18.01	-12.06	-22.89	-5.76	-3.43	0.28
ELECTR	2010	-30.10	-30.10	0.00	-9.46	-3.62	-5.96	-5.29	-16.05	-5.23	-5.63	6.83
	2012	-29.95	-29.95	0.00	-7.66	-3.86	-6.41	-5.72	-16.98	-5.66	-5.88	7.05
	Long Run	-29.48	-29.48	0.00	-5.07	-4.34	-7.13	-6.43	-17.88	-6.36	-6.01	6.61
OTH-MANUF	2010	-3.35	-8.73	-0.52	0.71	2.32	2.04	0.75	2.99	-0.51	-0.62	-1.45
	2012	-3.46	-8.71	-0.71	0.94	2.25	1.95	0.71	2.87	-0.50	-0.64	-1.40
	Long Run	-3.32	-8.44	-0.65	1.81	2.43	2.10	0.84	3.02	-0.38	-0.63	-1.29
SERV	2010	-9.15	-13.21	-3.69	-1.61	-0.44	-0.87	-0.99	0.68	-1.05	-0.36	-2.63
	2012	-9.05	-13.03	-3.73	-1.31	-0.36	-0.83	-0.96	0.75	-1.03	-0.34	-2.64
	Long Run	-8.77	-12.61	-3.66	-0.90	-0.19	-0.70	-0.85	1.18	-0.93	-0.22	-2.84

Source: Simulation results.

**Table 6**  
**Sectoral Impact of Kyoto Protocol on Selected Prices, % Deviation From Business-as-usual (BAU)**  
**Base Scenario: “Kyoto Forever” with Imperfect Competition**

<b>Industry</b>	<b>Year</b>	<b>Consumption Price</b>	<b>Domestic Good Price</b>	<b>Output Price</b>	<b>Value-added Price</b>	<b>Shadow Price of Capital</b>	<b>Aggregate Energy Price</b>	<b>Fossil Energy Price</b>	<b>Non-fossil Energy Price</b>
AGRIC	2010	0.63	0.69	0.56	-1.70	-0.96	34.15	49.09	4.91
	2012	0.63	0.70	0.57	-1.68	-0.84	33.69	48.23	5.18
	Long Run	0.60	0.66	0.54	-1.64	-0.59	32.54	46.40	5.33
IRON-ST	2010	4.30	6.72	4.24	-6.25	-3.22	71.14	135.80	4.91
	2012	4.94	7.74	4.90	-4.43	-2.27	69.43	131.98	5.18
	Long Run	6.01	9.49	6.06	-1.01	-0.58	65.43	123.64	5.33
COAL	2010	226.54	-5.06	-1.20	-4.69	-5.69	26.29	44.72	4.91
	2012	219.53	-3.59	-0.86	-4.11	-4.71	26.04	43.99	5.18
	Long Run	203.85	2.38	0.60	-1.52	-1.20	25.37	42.60	5.33
PET-GAS	2010	20.81	-7.34	-2.61	-4.09	-3.93	12.77	39.19	4.91
	2012	20.80	-6.10	-2.19	-3.51	-3.20	12.86	38.63	5.18
	Long Run	21.64	-1.84	-0.69	-1.35	-0.89	12.78	37.78	5.33
OTH-MIN	2010	-0.41	-0.51	-0.31	-2.12	-1.67	18.90	43.37	4.91
	2012	-0.31	-0.38	-0.23	-1.96	-1.41	18.83	42.68	5.18
	Long Run	0.10	0.13	0.08	-1.23	-0.65	18.48	41.42	5.33
PAPER	2010	0.02	0.02	0.01	-1.66	-1.11	11.58	38.86	4.91
	2012	0.14	0.18	0.04	-1.64	-0.97	11.70	38.30	5.18
	Long Run	0.45	0.60	0.14	-1.45	-0.59	11.66	37.49	5.33
NON-FER	2010	0.76	2.08	0.37	-2.52	-5.61	19.03	81.03	4.91
	2012	0.98	2.70	0.49	-2.40	-4.26	18.92	79.08	5.18
	Long Run	1.60	4.46	0.82	-2.01	-0.77	18.33	75.05	5.33
CEMENT	2010	1.22	1.26	1.11	-1.60	-0.60	34.15	79.05	4.91
	2012	1.18	1.22	1.07	-1.65	-0.57	33.61	77.18	5.18
	Long Run	1.03	1.07	0.94	-1.80	-0.59	32.20	73.25	5.33

Table 6 (cont'd)									
Industry	Year	Consumption Price	Domestic Good Price	Output Price	Value-added Price	Shadow Price of Capital	Aggregate Energy Price	Fossil Energy Price	Non-fossil Energy Price
REF-PETR	2010	51.16	19.48	16.59	-11.00	-7.17	22.51	22.77	4.91
	2012	50.23	19.80	16.88	-6.66	-4.05	22.45	22.70	5.18
	Long Run	48.21	20.80	17.75	-1.59	-0.59	23.10	23.36	5.33
CHEMIC	2010	1.75	3.71	1.69	-3.41	-3.87	27.40	37.09	4.91
	2012	2.02	4.29	1.96	-2.86	-2.74	27.14	36.59	5.18
	Long Run	2.51	5.38	2.48	-1.80	-0.62	26.71	35.91	5.33
ELECTR	2010	4.91	4.93	4.64	-2.67	-1.50	144.84	144.84	0.00
	2012	5.18	5.21	4.90	-2.12	-1.11	140.71	140.71	0.00
	Long Run	5.33	5.36	5.04	-1.45	-0.60	131.67	131.67	0.00
OTH-MANUF	2010	-0.38	-0.88	-0.37	-1.64	-0.66	15.46	39.60	4.91
	2012	-0.36	-0.84	-0.36	-1.72	-0.62	15.49	39.03	5.18
	Long Run	-0.37	-0.85	-0.36	-1.86	-0.57	15.32	38.13	5.33
SERV	2010	-0.64	-0.67	-0.62	-1.60	-0.62	27.34	48.17	4.91
	2012	-0.66	-0.68	-0.63	-1.61	-0.57	27.06	47.34	5.18
	Long Run	-0.77	-0.81	-0.75	-1.74	-0.59	26.24	45.60	5.33

Source: Simulation results.

**Table 7**  
**Sectoral Impact on CO<sub>2</sub> Emissions**  
**Base Scenario: “Kyoto Forever” with Imperfect Competition**

<b>Industry</b>	<b>Year</b>	<b>Change in CO<sub>2</sub> Emissions % Deviation from Business-as-usual (BAU)</b>	<b>Contribution to Total Sectoral CO<sub>2</sub> Emissions in %</b>
AGRIC	2010	-12.89	4.11
	2012	-13.01	4.10
	Long Run	-13.24	4.10
IRON-ST	2010	-35.05	5.75
	2012	-35.80	5.69
	Long Run	-36.62	5.63
COAL	2010	-31.01	0.17
	2012	-34.29	0.16
	Long Run	-45.37	0.14
PET-GAS	2010	-24.35	0.49
	2012	-26.64	0.47
	Long Run	-33.92	0.43
OTH-MIN	2010	-14.41	1.49
	2012	-15.21	1.48
	Long Run	-17.51	1.44
PAPER	2010	-10.03	1.35
	2012	-10.41	1.35
	Long Run	-11.26	1.34
NON-FER	2010	-31.72	1.12
	2012	-34.09	1.09
	Long Run	-39.92	0.99
CEMENT	2010	-22.90	0.50
	2012	-22.57	0.50
	Long Run	-21.76	0.51
REF-PETR	2010	-32.38	28.85
	2012	-32.35	28.89
	Long Run	-32.46	28.89
CHEMIC	2010	-21.25	4.07
	2012	-22.74	4.00
	Long Run	-25.40	3.87
ELECTR	2010	-32.96	16.53
	2012	-32.77	16.59
	Long Run	-32.22	16.76
OTH-MANUF	2010	-9.40	3.70
	2012	-9.37	3.71
	Long Run	-9.08	3.73
SERV	2010	-13.35	31.87
	2012	-13.16	31.97
	Long Run	-12.74	32.18

Source: Simulation results.

The rise in the price of energy significantly increases the cost of production in the energy-intensive sectors, which, in response, raise the price of their respective product on the domestic market, their export prices being exogenous. It follows that the purchasing price (consumption price) of the energy-intensive products increases. Among these sectors, the highest price increases are observed in the iron and steel, non-ferrous, and chemical products sectors (Table 6). Since these sectors behave monopolistically on their domestic market, part of the price increase also reflects their market power on this market.

A reduction ensues in the demand for these products by households and by other firms that use them for intermediate consumption or for investment. In 2010, the production of energy-intensive sectors will have decreased by 12.5 percent, 11.9 percent and 12.8 percent (relative to the BAU scenario) in the non-ferrous, iron and steel, and chemical products sectors, respectively. Other sectors that are less dependent on energy either contract less or even expand. For example, the production of the service sector will have fallen by only 0.9 percent in 2010.

On the demand side, energy sectors are the most affected by the reduced demand for fossil fuel products. These sectors undergo large contractions, with the largest decline — 33.5 percent in 2010 — occurring in the coal sector, followed by decreases of 28.7 percent and 21.9 percent in the natural gas and refined petroleum sectors, respectively. Other non-energy-intensive sectors benefit from the change in the composition of aggregate demand. Domestic demand for their product increases, which has a positive impact on their production. For example, in 2010, the production of the “other manufacturing” sector shows a 2.0 percent gain.

In a dynamic perspective, the rise in the cost of energy has a negative impact on the returns to investment. The more a sector is dependent on energy products, the lower will be the return on its investment. This cost increase drastically reduces the price of value added in energy-intensive sectors, while it simultaneously drives up the price of the capital good. These two effects have a negative impact on firms’ incentives to invest. The reduction in demand for fossil fuel products induces firms in energy-producing sectors to reduce the size of their capital stock. In the long run, output in these sectors declines to the levels displayed in Table 5. Coal and petroleum products industries are the most affected, with a long-run decline in output of 38.5 percent and 32.0 percent, respectively, relative to the BAU case. In contrast, the non-energy sectors, which benefit from the change in the composition of aggregate demand, invest more in comparison to the BAU scenario. In the long run, investment in the “other manufacturing” sector increases by 1.8 percent.

The decrease in the price of value added experienced in many sectors is detrimental to labour, with the wage rate decreasing both in 2010 and in the longer run. The contraction and expansion effects observed in different sectors are accompanied by the traditional reallocation of labour among sectors. As expected, the energy sectors suffer the most in terms of labour use. Under the assumption of free entry and exit in non-competitive sectors, the number of firms in these sectors increases or decreases according to whether they expand or contract (see Table 6). Note that our assumptions of homothetic technology and fixed mark-up in non-competitive sectors cause firms in these sectors to operate at a constant scale; thus, the sectoral expansion or contraction is occurring solely through the start-up or closing-down of firms producing different varieties.

The total reduction in the level of carbon dioxide emissions in the productive sectors is mainly due to the decrease in the emissions of energy-intensive sectors (Table 7). Since the supply of carbon permits is fixed in each year, their price changes are exclusively due to adjustments in demand. In turn, demand is influenced by the ease of substitution away from fossil fuel products. As already mentioned, the ease of substitution depends not only on the substitution parameters in firms’ technology, but also on the share of value added and, hence, on the availability of physical capital. In 2010, when the quantitative limit on carbon dioxide emissions takes effect, the existing aggregate capital stock is the result of past investment

decisions. Following the reduction in aggregate investment in the economy (beginning in 2010), firms will have less capital stock at their disposal and, hence, less value added. In the long run, the cumulative investment decisions contribute to an increase in the aggregate capital stock. This, in turn, will help ease the substitution of value-added for energy and, therefore, reduce the price of carbon permits.

At the aggregate level, the expansion observed in some sectors is not large enough to outweigh the contraction experienced by the energy sectors and the energy-intensive sectors. Gross domestic product (GDP) at market prices decreases relative to the BAU scenario, both in 2010 and in the longer term, by 1.05 percent and 1.48 percent, respectively.

The proceeds of the sale of carbon permits are returned in a lump-sum fashion to the household sector, to fund consumption and savings. However, this additional revenue is not large enough to compensate for the decline in wages and dividend income received from firms. As a result, the representative household's permanent income decreases. In addition, the increase in the consumption price of various commodities translates into a higher price for aggregate consumption. It follows that households reduce their aggregate consumption, which produces a welfare loss estimated at 0.27 percent. It is worth calling to the reader's attention the fact that this measure of welfare change is not directly comparable with the one reported in static general equilibrium models. Our measure is an indication of the percentage change in the household consumption stream (over the whole lifetime period) in the BAU case, which will yield the same utility level as the one given by the reform. Referring to Goulder and Eichengreen (1992), given the homothetic property of the representative household's preferences, this change may also be viewed as the percentage change in its total wealth that will allow it to have, in the BAU scenario, the same intertemporal utility as the one obtained with the reform. A negative value for the welfare measure indicates a loss of welfare.<sup>20</sup>

The change in relative prices due to the increase in energy costs affects the economy's sectors differently (Table 5). It follows that the trade patterns are impacted differently among sectors. On the supply side, the energy-producing sectors and the energy-intensive sectors experience a significant decline in exports as a result of the increase in their production costs or the decrease in their composite output. Total exports fall by 0.95 percent and 3.01 percent from the BAU case, respectively, in 2010 and in the long run. The requirement of an intertemporal equilibrium in the balance of payments induces some appropriate changes in the imports of different commodities through an adjustment of the real exchange rate. At the aggregate level, total imports fall by 2.08 percent and 1.93 percent, respectively, in 2010 and in the long run. Still, the pattern of change varies from one sector to another. In some sectors, like iron and steel and petroleum products, imports increase in order to compensate for the decline in the production of domestic firms, in spite of the contraction of their total domestic demand. In other sectors, such as "other manufacturing", imports decrease despite an increase in total demand.

## Sensitivity Analysis

Given the conjectural nature of some parameter values, we performed sensitivity analyses. The first set of simulations pertains to the structure of the market, while the other relates to the values of the elasticities of substitution/transformation in technology and trade (CES and CET functions). In the first set of sensitivity analyses, we increase firms' market power by 25% in one simulation while assuming perfect competition in all industries. In the second set of sensitivity analyses, we perform five simulations in which we consider lower and higher values separately for the elasticities of substitution in technology and trade, and a combination of the lower values for the elasticities in technology and trade. The results for these different cases are presented in Tables 8 and 9.

**Table 8**  
**Sensitivity Analysis – Market Structure**

		<b>Base Scenario</b>	<b>Sensitivity Analysis</b>	
<b>Variable</b>	<b>Year</b>	<b>Imperfect Competition with Base Values for Firms' Market Power</b>	<b>Imperfect Competition with Higher Values for Firms' Market Power *</b>	<b>Perfect Competition</b>
Carbon Price (\$/Ton of CO <sub>2</sub> )**	2010	29.24	29.13	29.56
	2012	28.26	28.14	28.59
	Long Run	25.92	25.77	26.35
GDP***	2010	-1.05	-1.06	-1.02
	2012	-1.19	-1.20	-1.17
	Long Run	-1.48	-1.48	-1.47
Imports	2010	-2.08	-2.07	-2.12
	2012	-2.04	-2.04	-2.06
	Long Run	-1.93	-1.93	-1.91
Exports	2010	-0.95	-0.95	-0.95
	2012	-1.62	-1.61	-1.62
	Long Run	-3.01	-3.02	-2.96
Trade Deficit	2010	-0.36	-0.36	-0.37
	2012	-0.10	-0.10	-0.11
	Long Run	0.45	0.46	0.44
Government Deficit	2010	-1.97	-0.18	-2.32
	2012	0.03	-1.83	0.02
	Long Run	0.10	0.09	0.11
Welfare ****		-0.27	-0.30	-0.23

Source: Simulation Results.

\* Firms' market power parameters have been increased by 25 percent.

\*\* In CAN\$1995.

\*\*\* At market prices, expressed as a % deviation from business-as-usual (BAU) case.

\*\*\*\* As a % of business-as-usual (BAU) consumption stream; see text for explanation.

**Table 9**  
**Sensitivity Analysis – Technology and Trade Parameters**  
**“Kyoto Forever” Scenario with Imperfect Competition and Base Values for Firms’ Market Power**

Variable	Year	Base Scenario	Substitution Elasticities Between Capital and Labour		Substitution Elasticities in Armington and CET Functions		Low Values for Substitution Elasticities in Technology and Trade
			Lower Values	Higher Values	Lower Values	Higher Values	
Carbon Price (\$/Ton of CO <sub>2</sub> )*	2010	29.24	37.39	24.19	32.13	27.06	41.73
	2012	28.26	35.70	23.50	31.01	26.13	39.90
	Long Run	25.92	32.43	21.64	28.49	23.83	36.44
GDP**	2010	-1.05	-1.20	-0.95	-1.09	-1.02	-1.26
	2012	-1.19	-1.38	-1.07	-1.24	-1.15	-1.45
	Long Run	-1.48	-1.69	-1.34	-1.52	-1.44	-1.77
Imports	2010	-2.08	-2.19	-2.00	-2.19	-1.96	-2.36
	2012	-2.04	-2.13	-1.97	-2.16	-1.92	-2.32
	Long Run	-1.93	-2.00	-1.87	-2.07	-1.78	-2.23
Exports	2010	-0.95	-0.77	-1.06	-1.08	-0.86	-0.92
	2012	-1.62	-1.65	-1.59	-1.76	-1.49	-1.85
	Long Run	-3.01	-3.27	-2.82	-3.14	-2.84	-3.51
Trade Deficit	2010	-0.36	-0.47	-0.30	-0.35	-0.35	-0.47
	2012	-0.10	-0.12	-0.09	-0.09	-0.11	-0.11
	Long Run	0.45	0.53	0.40	0.45	0.44	0.54
Government Deficit	2010	-1.97	-2.46	-1.65	-2.13	-1.84	-2.71
	2012	0.03	0.05	0.02	0.05	0.03	0.07
	Long Run	0.10	0.12	0.08	0.10	0.09	0.13
Welfare***		-0.27	-0.32	-0.25	-0.28	-0.27	-0.33

Source: Simulation Results.

\* In CAN\$1995.

\*\* At factor costs, expressed as a % deviation from business-as-usual (BAU) case.

\*\*\* As a % of business-as-usual (BAU) consumption stream; see text for explanation.



In all of these scenarios, the direction of change of the key variables is the same as in the main simulation; only the magnitude of these changes varies from one scenario to the other. The results presented in Table 8 indicate that market structure does have a substantial impact on the measure of welfare change resulting from the implementation of the Kyoto Protocol in Canada. In a perfectly competitive framework, the welfare loss caused by the reform is 0.23 percent, compared with 0.27 percent in the imperfect competition reference case,<sup>21</sup> which amounts to an underestimation of 15 percent. When we consider the higher market power scenario, the welfare loss is evaluated at 0.30 percent, an underestimation of 30 percent compared to the perfect competition case. The impact of market structure on the welfare loss is quite straightforward, given the explanations about the mechanisms in play described previously. When production costs increase, the monopolistic firm reduces its production more than a perfectly competitive firm would do. In other words, the monopolistic firm charges a higher price for the domestic good, which produces a sharper reduction in welfare. Moreover, non-competitive firms underinvest, resulting in a lower aggregate capital stock and, thus, in lower income for households, by comparison with a perfect competition framework.

The measure of the change in welfare, which takes into account all the years spanning the representative household lifetime, is a better indicator of the impact of the reform, compared to the change in GDP, which measures the impact of the reform in a single year. Even though the difference observed in annual GDP changes from one market structure to another is not large, the welfare change does show a substantial variation between the different market structures.

The results of the sensitivity analyses done on the elasticities of substitution in technology and trade reveal the impact of these parameters on the carbon permit price. As expected, the greater the ease of substitution among production factors, the lower the price of the carbon permit and the lower the costs to the economy. Finally, the results from the sensitivity analyses done on the trade parameters indicate that the carbon permit price and the measure of welfare loss decrease with an increase in the elasticities of the Armington and the CET functions.



## 4. CONCLUSIONS

In this paper, we have developed a single-country, multi-sector and forward-looking dynamic general equilibrium model to study the welfare, growth, and sectoral effects of compliance to the Kyoto Protocol in Canada. In contrast with other studies, we do not assume that all sectors are perfectly competitive. Rather, we modelled product markets in a monopolistic competition setting. We restricted our analysis to carbon dioxide emissions, which comprise the largest share of total greenhouse gases in Canada. In particular, we consider the “Kyoto forever” scenario, where Canada achieves its emissions target in 2010 and stays at this level constantly thereafter, using a cost-effective policy instrument represented by an auction market for carbon emission permits.

We have run simulations in relation to compliance to the Kyoto Protocol, and endogenously determined the price of the carbon permit required to achieve Canada’s emission target in the appropriate years. Our analysis has allowed us to estimate the impact on output, investment, consumption, prices, GDP and welfare. As expected, the energy-producing sectors and the energy-intensive sectors suffer the most from the restriction of carbon dioxide emissions, while other sectors benefit from the change in the composition of demand. The measure of welfare change associated with compliance to the Protocol is evaluated at -0.27 percent when we assume a reasonable value for the market power of monopolistic firms. In the long run, the change in GDP relative to the BAU scenario is estimated at -1.5 percent, while the price of the carbon permit required to achieve Canada’s objective is estimated at approximately \$29.20/ton of CO<sub>2</sub> (CAN\$1995) in 2010.

Our simulation results highlight the desirability of incorporating an imperfectly competitive market structure in estimating the costs of the reform, notably on welfare. We found that the underestimation of the welfare costs, assuming a perfectly competitive market structure, may be as high as 30 percent.

Still, we should mention that the cost estimates presented in this study should be considered an upper limit on the true costs of compliance to the Kyoto Protocol, for at least two reasons: first, we have not considered other greenhouse gases, and second, we have only envisaged implementation of the Protocol at the national level, while international co-ordination among Annex-B countries in the market for tradable permits may contribute to reduce the penalty associated with the use of fossil fuels by economic agents in Canada. Finally, it is important to note that the economic costs of compliance to the Protocol should be compared to the potential benefits resulting from a lower accumulation of carbon dioxide in the atmosphere.



## NOTES

- 1 Howaston and Campfens (1997) and Wigle (2001) provide interesting reviews of different studies focussing on the economic impact on Canada of greenhouse gas reductions.
- 2 See, for example, Ambler and Cardia (1998), Devereux, Head and Lapham (1996), Gali (1994) and Keuschnigg and Kohler (1996).
- 3 With free access to world capital markets, bonds and domestic equities have the same yield as international assets.
- 4 Because of the presence of increasing returns to scale in the technology of value added, labour and capital demands are indeed affected by firms' market power.
- 5  $\mu^i$  is the absolute value of the inverse of the perceived price elasticity of the composite output demand. In competitive sectors,  $\mu^i = 0$ . The share of value added in the composite output is  $sv^i$ .
- 6  $K_{t+1}^j$  is the level of the capital stock in sector  $j$ .
- 7 The assumption of homothetic technology, with the implication of no-rationalization effect at the firm level, has also been made by Keuschnigg and Kohler (1996) and Rotemberg and Woodford (1996). See Hertel (1994) and Brown (1991) for discussions of the non-homothetic technology case.
- 8  $\mu_d^i = 0$  for competitive firms.
- 9 When expressed per efficiency unit of labour.
- 10 Note that the latter includes capital installation costs.
- 11 Note that exports are not subject to this penalty.
- 12 The 14<sup>th</sup> commodity represents non-competitive imports (i.e. goods not produced in Canada) like tea, coffee, etc.
- 13 Rotemberg and Woodford (1995) use a mark-up of 20 percent in their study of the United States, while Keuschnigg and Kohler (1996) use a mark-up of 11 to 25 percent in their study of Austria.
- 14 This composite output is made up of the domestic and export goods.
- 15 See Gagnon (1990) for more details on this method.
- 16 We apply the same rate of 26.5 percent to CO<sub>2</sub> emissions and to total GHG emissions.
- 17 Carbon permit prices are expressed in \$CAN1995.
- 18 Since no limit is imposed on CO<sub>2</sub> emissions before 2010, these emissions are considered a free good whose price is zero.
- 19 Note that electricity is produced by using, among other inputs, fossil fuels.
- 20 See Dissou (2001) and Goulder and Eichengreen (1992) for details on the computation of this welfare measure.

- 21 We caution the reader not to be misled by the seemingly small magnitudes of the measures of welfare change used in this study.

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