Implementing the Kyoto Accord in Canada: Abatement Costs and Policy Enforcement Mechanisms

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The anticipated abatement costs to be incurred by Canada and six of its provinces from the implementation of the Kyoto agreement (reduction of carbon dioxide (CO_2) emissions generated by fossil fuel burning by 6% from 1990 levels) are estimated using an emissions benefit function. Marginal abatement cost functions are estimated and used for the analysis of alternative policy enforcement mechanisms. The efficiency of a policy mechanism depends on the rule used to allocate the burden of the agreement among the provinces and on whether the provinces or the federal government implement the agreement at the provincial level. Under the rule of an equal emission reduction of 6% over 1990 levels in all provinces, Quebec bears no abatement costs while British Columbia and Saskatchewan incur the highest costs. An allocation rule based on the equimarginal principle achieves aggregate efficiency; it is, however, the rule that contains the risk of noncompliance by provinces that have already taken action toward emissions reduction.

Les auteurs estiment ce qu'il en coûtera au Canada et à six de ses provinces pour adopter les mesures antipollution qu'exigera la mise en œuvre du protocole de Kyoto (réduction de 6 % des rejets de CO_2 attribuables aux combustibles fossiles par rapport aux chiffres de 1990) au moyen d'une fonction faisant intervenir avantages et émissions. Ils estiment les fonctions du coût marginal des mesures antipollution et se servent des résultats pour étudier d'autres mécanismes visant à faire respecter les politiques. L'efficacité du mécanisme d'exécution dépendra, d'une part, de la règle qui servira à répartir le fardeau de la mise en œuvre entre les provinces et, d'autre part, de l'application de l'accord par le gouvernement fédéral ou provincial, au niveau des provinces. En supposant une réduction uniforme des rejets de 6 % par rapport aux relevés de 1990, dans toutes les provinces, l'exécution des mesures antipollution ne coûtera rien au Québec, tandis que la Colombie-Britannique et la Saskatchewan accuseront les frais les plus élevés. Une règle de répartition reposant sur le principe de l'équimarginalité s'avérera efficace globalement, mais on courra le risque que les provinces qui ont déjà pris des mesures pour combattre la pollution refusent de s'y plier.

INTRODUCTION

The increasing amount of greenhouse gases in the atmosphere is regarded as responsible for global warming, which is linked to potential climatic changes. The United Nations Convention on Climate Change, agreed to in Kyoto, Japan, in December 1997, reflects countries' concern and willingness to deal with the global warming problem. In the Convention, Canada, which emits 2.1% of the world's greenhouse gases but, with 0.5% of world's population, is one of the biggest per capita polluters of the planet, agreed to reduce its greenhouse gases emissions by 6% from 1990 levels during the period 2008–12.

The purpose of this paper is to investigate the implementation and the enforceability of the agreement in Canada. We focus on the provinces that contribute the most to the greenhouse gases generation. They are British Columbia, Alberta, Saskatchewan, Manitoba, Ontario and Quebec.[1] Energy policy in Canada has always been difficult because of the position energy has in the constitution. Both the federal and provincial governments have constitutional jurisdiction in the area of energy and the environment. Alberta and Saskatchewan produce most of the domestic supply of fossil fuels and thus are most affected by producer taxes. This difficulty was highlighted in 1980 when the Trudeau government capped fossil fuel prices with the National Energy Program (NEP). Any Canadian policy that attempts to reduce CO_2 emissions through a tax on fossil fuels will have a differential provincial impact. The Alberta and Saskatchewan governments have raised their opposition to such taxes and have stated they may not comply with a federal policy that places the financial burden of the Kyoto agreement on energy-producing provinces. Developing a consensus is going to require a great deal of federal–provincial consultation, which has already began as part of the National Climate Change Initiative. This process involving two federal Ministers and all of the provincial energy and environment Ministers, will become more challenging at the point when costly abatement choices have to be made. Therefore, in this paper, we examine alternative policy schemes that could address this federal–provincial conflict.

Two implementation issues are of interest: the estimation of abatement costs under an emission path that will achieve the agreed-upon emission reduction, and the choice of an allocation rule that could efficiently distribute the burden of the agreement among the provinces. An emission benefit function is used for the estimation of the agreement emission path. This function is estimated using the cointegration methodology as a long-run equilibrium relationship between the gross domestic product (GDP) and the CO_2 emissions. The allocation rule of an equal 6% emission reduction for all provinces will be the benchmark of comparison with the alternatives of the equimarginal principle and the emissions per capita allocation rules.

Costs associated with reducing emissions are termed abatement costs. The abatement costs incurred by Canada and by the provinces from implementing the Kyoto agreement are estimated only with respect to CO_2 emissions that are generated by fossil fuel burning. The focus is on CO_2 because it is the most important greenhouse gas, contributing about 80% to the global mean greenhouse forcing (Nordhaus 1991). As well it is closely connected to the combustion of fossil fuels, which in turn is connected to economic activity (Halvorsen et al 1989).

With respect to the enforceability of the agreement, the analysis focuses on a description of alternative policy instruments for achieving the desired emissions reduction. We show that the efficiency of the policy mechanisms changes when the provinces, rather than the federal government, are responsible for enforcing the agreement at the provincial level.

The structure of the paper is as follows. In the next section, a benefit function is estimated and is used to derive the total and marginal abatement cost functions under the agreement emission path. In the following section, the results of the estimations are used to conduct the economic analysis of alternative policy instruments using different rules to allocate the cost of the agreement among the provinces. The dependence of the suggested rules on whether it is the provinces or the federal government that have the legal authority to enforce the agreement at a provincial level is also examined. The final section briefly summarizes the main findings of the paper.

ABATEMENT COST ESTIMATION

The abatement costs from greenhouse gases reduction have traditionally been measured either by estimating an abatement cost function, which relates actual abatement costs to the amount of abated pollutants (Hartman et.al 1997), or by specifying and estimating applied general equilibrium simulation (AGE) models. The former method is used when actual abatement costs data are available, while the latter in the absence of data availability or/and when one needs to estimate the potential costs from reducing emissions under alternative emission scenarios. Some well-known global AGE models are the models of Edmonds and Reilly (1983), Manne and Richels (Global 2100) (1991), Rutherford (1992), Whalley and Wigle (1992), the IEA model (Vouyoukas 1992) and the OECD's GREEN model (Burniaux et al 1992). The above models have a medium- to long-term focus and their objective is to quantify the economic effects of policies aimed at reducing CO_2 emissions. Even though the above models have provided some useful insights on the costs of abating CO_2 emissions at a global level, large differences in the models' results have been detected (Hoeller, Dean and Hayafuji 1992). AGE modeling requires a lot of data and usually fixes the values of some key behavioral parameters on the basis of empirical evidence or on the modeler's priors. But even when key parameters and emission reduction targets were standardized for a model comparison project undertaken by OECD, the models' predictions of the economic costs of reducing CO_2 emissions still differed significantly. The baseline energy prices used, the substitution elasticities imposed, the introduction in the models of backstop technologies (use of alternative energy sources) at an arbitrary point in time and the differences in the prices of these technologies, are identified as some of the reasons of the observed differences.

The implementation of the Kyoto accord in Canada — reduction of CO_2 emissions by 6% from 1990 levels by the year 2012 — is a problem with a short time horizon. The short time horizon does not allow for any significant technological change, like the introduction of backstop technologies, apart from the introduction of energy efficiency improvements (IEA 1997). In addition, the emissions reduction path that should be followed is predetermined by the agreement (6% reduction from 1990 levels).

In the absence of abatement cost data and given the short time horizon of the problem that does not allow for significant substitutions between CO_2 generating and alternative energy sources, we follow a different approach from the above mentioned to estimate the anticipated abatement costs from implementing the Kyoto agreement in Canada. The theoretical framework used is as follows. First, a benefit function from CO_2 emissions is estimated. Analogous to the abatement cost function that relates abatement costs to the abated pollutant, the benefit function relates emission benefits measured by income to the pollutant, which is CO_2 emissions. This function is then used for estimating the discounted total benefits associated with different emission paths that prevail under two emission scenarios. These are the business as usual (BAU), which is the benchmark used for comparison, and the agreement scenario. The BAU scenario refers to the emission path that would be followed in the absence of the Kyoto agreement. Along this path, emissions continue to grow or decline at the average growth rates that prevailed during the period of study. The agreement scenario assumes that Canada's emissions are reduced by the required 6% below 1990 levels by 2012. The difference between the benefits associated with the BAU path and the path of the agreement scenario will reflect the abatement costs due to the agreement.

The Estimated Benefit Functions

An emission benefit function is used for the estimation of the benefits associated with CO_2 emissions, which are generated from the combustion of fossil fuels used in production activities. This function connects the Canadian and provincial gross domestic product (GDP) with the CO_2 emissions that are generated by fossil fuel burning as a by-product of production. In the environmental economics literature (Welsch 1993; Dockner and Van Long 1993; Hoel and Isaksen 1995; Kverndokk 1993, 1994; Petrakis and Xepapadeas 1996) the benefit function is defined as follows: $Y_t = (B(E(t))$ where Y_t denotes GDP and accounts for the benefits and E_t denotes CO_2 emissions. The benefit function of CO_2 emissions gives the maximum benefit (measured by income) that can be achieved under different CO_2 emission levels. The loss in income under a CO_2 emissions constraint relative to a no-constraint alternative (BAU) will reflect the abatement costs (Kverndokk 1993).

One should note that the benefit function is not a production function since it associates the output with a by-product of the production process (emissions) rather than with production inputs (energy). The AGE models make use of production functions (usually CES and Leontief) that assume low elasticity of output with respect to energy, mainly due to the small share of energy in GDP. The use of the benefit function allows us to capture the direct effect of a reduction in CO_2 emissions on GDP rather than inferring to their relationship indirectly through the relationship between energy and output. Our model allows for energy efficiency improvements, but it does not depict the potential substitutions between energy and nonenergy inputs nor does it allow for the introduction of backstop technologies. This omission is justified by the uncertainty pertinent to the development of noncarbon technologies which is intensified by the short-term nature of the problem considered. In other words, our model assumes that any reduction in emissions will be absorbed by changes in GDP and/or improvements in energy efficiency in the short run.[2] Given the above limitations of our model, our estimates should be viewed as representing upper bounds of anticipated abatement costs referring to a worse case agreement scenario under which the use of alternative energy sources is not feasible.

The functional form used to represent the benefit function in our model is the following:

$$Y_t = aE_t^b e^{cT+\frac{1}{2}dT^2} \qquad t, T = 1,\ldots,n \tag{1}$$

where the quadratic trend reflects exogenous technical change and accounts for energy efficiency improvements.[3] For estimation purposes, Eq. 1 is linearized using logarithms as follows:

$$y_t = \alpha + b\varepsilon_t + cT + \frac{1}{2}dT^2 + e_t \qquad t, T = 1,\ldots,n \tag{2}$$

where $y_t = \ln Y_t$, and $\varepsilon_t = \ln E_t$. The elasticity of CO_2 emissions is given by the parameter b in Eq. 2, while the rate of technical change for any given year t is given by $\partial y_t / \partial T = c + dT$. For the estimation of Eq. 2, the cointegration methodology is used (Phillips and Loretan 1991; Banerjee et al 1993), as we are trying to establish the existence of a long-run relationship between income and emissions. The analytical estimation of Eq. 2 and the standard errors of the estimated coefficients are given in Appendix A. The estimated benefit functions for Canada and the provinces are:

Canada: $Y_t = 649.086E_t^{0.501612}e^{0.024841T}$

British Columbia: $Y_t = 235.053E_t^{0.604216}e^{0.021731T}$

Alberta: $Y_t = 267.161E_t^{0.551917}e^{0.033971T}$

Saskatchewan: $Y_t = 63.620E_t^{0.682528}e^{0.012992T - 0.00062T^2}$

Manitoba: $Y_t = 81.173E_t^{0.656159}e^{0.04456T - 0.001257T^2}$

Ontario: $Y_t = 35.332E_t^{0.824815}e^{0.047804T - 0.001141T^2}$

Quebec: $Y_t = 3200.578E_t^{0.350939}e^{0.056149T - 0.00173T^2}$

The larger elasticity of CO_2 emissions observed in Ontario, Saskatchewan and Manitoba shows a higher dependence of GDP on CO_2 emissions in these provinces.[4] Canada's estimates can be viewed as representing the average of all provinces. Finally, the average rate of technical change for the period under study varies between provinces from 0.61% in Saskatchewan to 3.72% in Quebec.[5] The positive average rates of technical change indicate that for a given level of emissions, the GDP increases. The larger the rate of technical change, the greater the increase in GDP for the same level of emissions, indicating use of cleaner technology.

ABATEMENT COSTS UNDER DIFFERENT EMISSION SCENARIOS

The total benefits associated with alternative emission paths are calculated using the estimated benefit functions. The discount rate used to express total benefits in present value terms is approximated by the social time preference rate. This is defined as $r = \rho + \omega \cdot \gamma$, where ρ is the pure rate of time preference,[6] ω is the elasticity of the marginal utility of per capita consumption,[7] and γ is the growth rate of per capita consumption. The value of ω used in the present study is 1.5, which was estimated by Scott (1989) for the U.K. and is in line with the estimates of Cline (1991) for developed countries. A low value of 0.005 is chosen for ρ, which indicates that each generation is given 84% of the weight of the previous generation (assuming a 30-year period between generations). The value of γ is approximated by the growth rate of per capita GDP, which equals 2.5% for Canada. The value of r used in the current analysis is therefore 4.2%.

The total discounted benefits under a given path are $\int_{t=0}^{T} e^{-rt} Y_t dt$ where $t = 0$ refers to year 1998 (last year of available data) while T refers to year 2012 (year that the goals of the agreement should be met). The following emission paths are considered in the present study.

Path 1: refers to the BAU scenario. Along this path emissions are assumed to change (grow or decline) at the average rate that prevailed during the period of study (1978–98).

Path 2: refers to the agreement scenario where a constant rate of emissions reduction starts at time zero (1998) and continues up to year 2012.

The average emission growth rates, v, for each path are presented in Table 1.[8] The negative average emission growth rates observed in Manitoba, Ontario, and Quebec under path 1

Table 1. Average emissions growth rates, *v*, under alternative emission paths (%)

Region	Path 1	Path 2
Canada	0.72	–1.53
British Columbia	1.09	–1.47
Alberta	1.37	–1.46
Saskatchewan	1.08	–3.10
Manitoba	–0.21	–1.22
Ontario	–0.04	–1.61
Quebec	–1.49	–0.45

Source: Authors' estimation.

imply that in these provinces emission levels decline under the BAU scenario. In addition, under path 1 the decline in Quebec's emissions is greater than the reduction required by the agreement when path 2 is followed.[9] The low reduction rate required for Quebec under the agreement is partly due to the relatively high 1990 emission levels compared to subsequent years. The positive growth rates under path 1 observed in British Columbia, Alberta, and Saskatchewan imply that positive reductions in CO_2 emissions will be required for path 2. In Alberta this is due to the high emission growth rates under the BAU scenario, while in British Columbia it is due to both the high emission growth rates under the BAU scenario and the relatively low 1990 emission levels relative to the previous and subsequent years. The highest emissions reduction under path 2 is demanded in Saskatchewan because, apart from the relatively high current emission growth rates, the emission levels in 1990 were low relative to previous and subsequent years.

Using the estimated emission growth rates, total discounted benefits for the period 1998–2012 were estimated under the two emission paths. The results are presented in Table 2. The difference between the benefits under the BAU emission path (path 1) and the agreement emission path (path 2) represents the abatement costs, i.e., the value of GDP lost by implementing the agreement. The total abatement cost (TAC) incurred by Canada and the provinces under path 2 for the period 1998–2012 is presented in Table 3.[10] To illustrate the magnitude of the TAC values, the average abatement cost (AAC) for the period 1998–2012 were estimated and expressed as a percentage of annual GDP.[11] These results are also presented in Table 3.

The results in Table 3 indicate that if path 2 is followed, the average abatement cost that Canada will incur for the period 1998–2012 will represent 7% of its GDP if no significant backstop technology is introduced. British Columbia, Saskatchewan and Alberta are the provinces that will bear the largest total abatement costs. This result is not surprising, given that emissions per capita are large in these provinces (2.93, 5.19 and 5.57 t per capita, respectively). In addition, these provinces have the highest emission growth rates under the BAU scenario. The negative TAC observed in Quebec implies that the agreement path requires a smaller reduction in emissions than the reduction that takes place under the BAU scenario. Therefore, Quebec does not incur any abatement costs under path 2 and follows the BAU scenario, since by doing so it does not violate the agreement.[12]

Table 2. Total discounted benefits for the period 1998–2012 under emission paths 1 and 2 (billions of dollars)

Region	Path 1	Path 2
Canada	11,998.80	11,130.30
British Columbia	1,416.61	1,302.58
Alberta	926.69	845.15
Saskatchewan	258.52	227.35
Manitoba	250.38	242.66
Ontario	3,486.95	3,325.25
Quebec	1,247.73	1,278.51

Source: Authors' estimation.

Table 3. TAC and AAC as a percentage of GDP under emission path 2 for the period 1998–2012 (billions of dollars)

	Path 2	
Region	TAC in $ billions	AAC as a % of GDP
Canada	868.50	7.11%
British Columbia	114.03	7.58%
Alberta	81.55	5.87%
Saskatchewan	31.16	6.99%
Manitoba	7.72	1.92%
Ontario	161.70	3.39%
Quebec	–30.82	–1.21%

Source: Authors' estimation.

The estimated total abatement costs under the agreement emission path (path 2) are used for the estimation of marginal abatement costs (MAC), which give the additional costs required to reduce emissions by one more unit (thousand tonnes of carbon). The concept of MAC is very useful in designing environmental policies, as it shows the least cost way of reducing emissions. The MAC function is given by differentiating the total abatement cost function[13] with respect to CO_2 emissions. The MAC for any given year t is estimated by substituting the emissions of that year into Eq. 3:

$$MAC = a \cdot b \cdot \left(E_{1t}^{(b-1)} - E_{2t}^{(b-1)}\right) \cdot e^{\left(cT + \frac{1}{2}dT^2\right)} \qquad t, T = 1, \ldots, n \tag{3}$$

The average values of MAC for the period 1998–2012 are represented in Table 4.

The zero MAC value observed in Quebec reflects the fact that it does not have to abate CO_2 under the agreement scenario, since its emissions are being reduced in the BAU scenario at a rate higher than that required by the Kyoto agreement.[14] British Columbia, has the

Table 4. Average MAC for the period 1998–2012 (millions of dollars per thousand tonnes of carbon)

Region	MAC
Canada	0.298
British Columbia	0.436
Alberta	0.407
Saskatchewan	0.246
Manitoba	0.111
Ontario	0.148
Quebec	0.000

Source: Authors' estimation.

greatest MAC, followed by Alberta and Saskatchewan. Canada's MAC value should be viewed as the average of all provinces (including the ones that are not considered in the present analysis).

ECONOMIC ANALYSIS OF ALTERNATIVE ENVIRONMENTAL POLICIES

In environmental policy literature, the efficient level of emissions is determined by the intersection of the MAC curve and the marginal damage (MD) curve.[15] A policy can then be applied to achieve this efficient level of emissions. In this paper, we are not interested in estimating optimal emission levels (which can be achieved through optimal emission paths), since the desired emission levels are predetermined by the agreement. Given that we know the MAC functions under the agreement emission path (path 2) and the desired emission levels at the country level, we analyze the efficiency of different policies in achieving the desired levels.

One of the objectives for this paper is to examine the alternative policy options that Canada has when reducing the level of CO_2 emissions. So far, this analysis has considered only the case of an equal emission reduction in all provinces. Alternative allocation rules like the emissions per capita or the equalization of MAC now need to be considered. The provincial governments will likely reject any option that places too much of the burden on one or two provinces. Given the split constitutional authority in the areas of energy and the environment enforcement becomes problematic, if the two levels of government do not fully support all aspect of the chosen policy. Following, the environmental policies regarding emission standards, emission taxes and transferable emission permits are analyzed with respect to their efficiency in enforcing the Kyoto agreement within Canada.

Emission Standards

Emission standards are a popular policy mechanism in controlling pollution because they appear to be straightforward. Given that the emission standard is determined by the agreement at the country level — in our case a 6% reduction over the 1990 emission levels — those determined at the provincial level could be based on different cost allocation rules. In specific, a standard could be set based on a uniform 6% emission reduction in all provinces, on the provincial per capita emissions, or on a rule that would lead to equalization of their MAC functions.

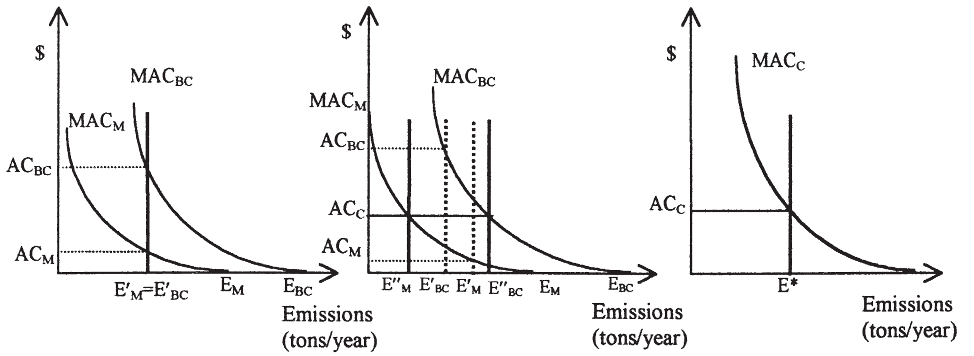


Figure 1a. Standard set based on emissions per capita (provincial level)

Figure 1b. Standards set based on a uniform 6% emission reduction and on the equalization of MAC (provincial level)

Figure 1c. Standard set based on a 6% emission reduction (country level)

Figure 1. Emission standards determination under different cost allocation rules

A uniform 6% emissions reduction or an emissions per capita standard setting may appear fair in the sense that, under the first, the provinces are treated equally while, under the second, they pay according to the damages they cause. These allocation rules though can be highly inefficient when the polluting sources have different marginal abatement costs. In fact, the greater the difference in marginal abatement costs, the less efficient these rules are (less emissions reduction for a given abatement cost). The most efficient (least cost) way to abate is to equalize marginal abatement costs of all sources (equimarginal principle) (Field 1997).[16]

What the equimarginal principle implies is that if the MAC functions of the different polluting sources are known, then different standards can be set for each source based on the aggregate (country level) MAC and the desired emission levels. Figure 1 demonstrates the emission outcomes of the above-mentioned allocation rules under the policy of emission standards, using the example of Manitoba and British Columbia.

Under the BAU scenario, Manitoba emits E_M while British Columbia emits E_{BC} (Figure 1a, 1b). Under a uniform 6% emission reduction in all provinces (Figure 1b), Manitoba incurs abatement costs equal AC_M and emits E'_M. British Columbia, on the other hand, incurs high abatement costs equal to AC_{BC} (see Table 4) and emits E'_{BC}. The standards set for British Columbia and Manitoba are represented by the dashed vertical lines. Under a standard set based on emissions per capita, the same standard would be imposed on both provinces, since their emissions per capita are almost the same (Figure 1a). In this case, Manitoba will incur abatement costs equal to AC_M and British Columbia equal to AC_{BC}. If the equalization of MAC is pursued, the standards will be set such as the costs will be the same for all provinces and equal to the country's abatement cost AC_C (Figure 1b, 1c). This would require British Columbia to reduce emission by less than 6% over its 1990 levels (E''_{BC} rather than E'_{BC}), while Manitoba would have to reduce its emissions by more than 6% over its 1990 levels (E''_M rather than E'_M).

Despite its aggregate efficiency, the equimarginal allocation rule discriminates against the provinces with the more elastic MAC curves, which are the ones that have either already taken action toward their emissions reduction, use cleaner more advanced technology, or whose economic sectors are less dependent on fossil fuel burning. In other words, the more efficient provinces are "penalized," since they subsidize the less efficient ones who under the equimarginal allocation rule face a smaller emission reduction.

The superiority of the equimarginal allocation rule over alternative rules in terms of achieving aggregate efficiency holds as long as it is the federal government that has the legal authority to enforce the agreement at the provincial level. If the provinces have the legal authority, or when it is not clear who is responsible for doing so, it is highly unlikely that the "efficient" provinces would agree to implement a policy based on the equimarginal principle. If the provinces, for which this allocation rule is not a Pareto improvement relative to the equal emissions reduction or the emissions per capita allocation rule, choose not to comply and use the legal system to resolve the dispute, this allocation rule may prove to be more costly. This would occur because of the high transaction costs involved with the use of the legal system and the fact that the emissions reduction may not take place until the dispute is resolved.

Emission Taxes

For a policy using emission taxes as a mechanism to reduce CO_2 emissions, a tax is set for every unit of emissions. Emissions will be reduced to the point where the MAC equals the imposed tax. Since the tax imposed is the same for all sources, the MAC will be equalized across all sources. The fact that efficiency is achieved without the requirement that the MAC functions be known for all polluting sources gives an advantage of using taxes rather than standards to control emissions.

When the federal government has the legal authority to implement the agreement and its goal is economic efficiency, a cost allocation rule based on the equimarginal principle should be used. The cost efficient tax would be set to equal the aggregate MAC (country level) that corresponds to the desired/agreed emission level of any given year (i.e., E^* in Figure 2b). That would lead to the equalization of MAC across all provinces achieving economic efficiency at the country level.

If the provinces are responsible for enforcing the agreement within their borders, the issue of provincial noncompliance could be resolved by an allocation rule based on an equal percentage reduction or on emissions per capita. In the first case, the per-unit tax should equal the provincial MAC for any year in path 2. That would mean that in Quebec no tax would be imposed, since the MAC is zero. When the cost allocation rule is emissions per capita, all provinces would incur a positive abatement cost, with Alberta and Saskatchewan facing the highest taxes and Quebec the lowest.

The difference between the provincial versus the federal government tax level is illustrated below in Figure 2 for Quebec and Alberta. When an equal emissions reduction is required for all provinces, Quebec would emit E_Q (which corresponds to the emission levels under the BAU scenario) and would have zero abatement cost, while Alberta would emit E_A and would have abatement cost equal to t_A. Polluting sources within Alberta will pay a tax equal to $t_{A,}$ thus the MAC of all polluting sources within the province will be equal. Under a tax based on emissions per capita, polluting sources in Quebec would pay a tax equal to t_Q

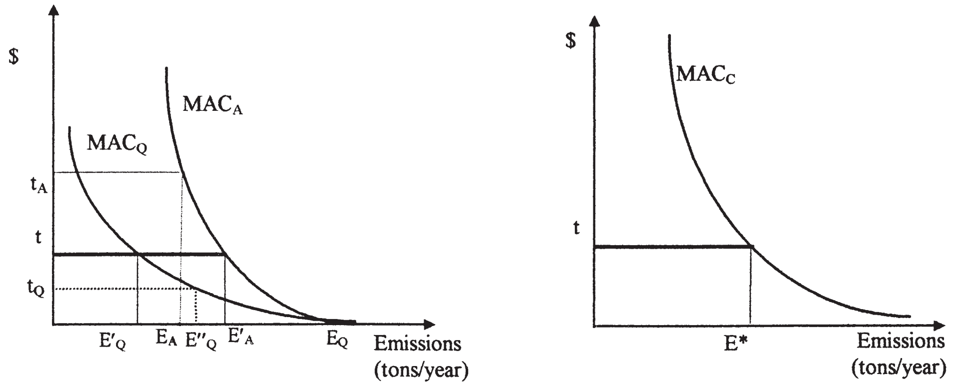


Figure 2a. Tax determination at the provincial level

Figure 2b. Federal tax determination at the country level

Figure 2. Emission tax determination under different cost allocation rules

and the provincial emissions would be reduced to E''_Q.[17] When national economic efficiency is pursued, a tax t will be imposed on all provinces. For this tax level, Quebec will incur a positive abatement cost equal to the tax and reduce its emissions levels to E'_Q, while Alberta could emit E'_A, with abatement cost t.

In addition to implementation procedures, the efficiency of this policy depends on the ability to measure, at a reasonable cost, the emitted pollutants that are subject to the tax. Taxes are a source of revenue for the government, and they could be invested in a cleaner technology. That could lead to a reduction of the effective abatement costs incurred by the provinces.

Transferable Emission Permits

Like a tax, transferable permits are another mechanism to provide firms a market-based incentive to reduce emissions. Once the total number of permits is set, which represents the maximum emission levels, the permits are distributed among the polluting sources. As permits are bought and sold by polluting sources, the equilibrium price of the permit will equal the marginal cost of abatement, thus satisfying the equimarginal principle.

A controversy related to this policy is how the permits will be initially distributed among the provinces. The issue of whether provinces will comply with an allocation rule other than an even 6% emissions reduction is of importance here as well. The 6% allocation rule does not take into account the provincial differences in their dependence on fossil fuel burning. Quebec and Manitoba, for instance, would be granted a larger quantity of permits than they need to be able to operate. On the other hand, if the distribution rule is based on emissions per capita, Alberta (5.57 t per capita) and Saskatchewan (5.19 t per capita) would be granted the higher number of permits, while Ontario (2.87 t per capita) and Quebec (2.05 t per capita) would have the least number of permits. This allocation rule results in rewarding the provinces that pollute the most.

The transferable emission permits mechanism is becoming very popular in dealing with environmental pollution problems. Its effectiveness depends in part on the initial number of permits that will be issued and on whether the provinces or the industrial sectors within them would be able to buy permits from the international permit market. If the latter case is possible, although global emissions would not be affected, emission levels within Canada cannot be controlled.

CONCLUSIONS

The abatement costs incurred by Canada and by six of the largest provinces from the implementation of the Kyoto agreement — reduction of CO_2 emissions generated by fossil fuel burning by 6% over 1990 levels by the year 2012 — are estimated with the use of an emission benefit function. The benefit function of CO_2 emissions gives the maximum income that can be generated under different CO_2 emission levels. The difference in income under an emission path that restricts emissions (agreement path) relative to an emission path that assumes no restriction in emissions (BAU path) represents the abatement costs of the agreement.

The choice of a policy mechanism that could be used to implement the Kyoto agreement is a formidable task. Either of the policies described in this paper could be used to achieve the agreed CO_2 emission reduction. Emission taxes and transferable emission permits are more efficient than emission standards since, once the level of the tax or the price of the permit is determined, efficiency is achieved automatically through the equalization of MAC of all sources. Emission taxes are probably preferred to transferable emission permits, given that there is uncertainty regarding the way that the permit market will be organized, whether permits should be given away or sold to the sources and whether everybody can enter the permit market or just the ones who emit.

The efficiency of the policy mechanisms also depends on the allocation rule used for distributing the cost of the agreement among the provinces. This depends on the federal–provincial agreement that can be reached over the enforcement of the agreement. Given that Canada has signed the accord, the federal government is responsible for distributing the burden of the agreement among the provinces. Different allocation rules result in different emission and cost outcomes at a provincial and/or at a country level. The institutional problems, created by the Canadian Constitution regarding the responsibility of different levels of government, cannot be over emphasized. Without an agreement on enforcement, any policy will likely be highly inefficient and ineffective in reducing CO_2 emissions.

Allocation of the burden of the agreement among provinces using the equal 6% emissions reduction or the emissions per capita rule may appear fair but are inefficient relative to an allocation rule based on the equimarginal principle. Even though the equalization of MAC of all sources gives the least cost way to achieve the agreed emissions reduction at the country level, it is also the rule that is expected to create the most controversy among the provinces. The efficiency of this latter allocation rule is questioned when the risk of noncompliance of the provinces with the more elastic MAC is taken into consideration. Noncompliance could result in high transaction costs associated with legal actions to enforce the agreement and, in the long run, the failure of Canada to honor the agreement.

APPENDIX A: BENEFIT FUNCTION ESTIMATION

According to standard economic theory assumptions, the benefit function should have the following properties:

$$\frac{\partial B}{\partial E} > 0, \frac{\partial^2 B}{\partial E^2} < 0, \frac{\partial B}{\partial E} \to \infty, \text{ as } E \to 0$$

The functional form of the benefit function is given by:

$$Y_t = aE_t^b e^{cT + \frac{1}{2}dT^2} \qquad t = 1, \ldots, n \tag{A-1}$$

Eq. A-1 is linearized for simplicity using logarithms as follows:

$$y_t = \alpha + b\varepsilon_t + cT + \frac{1}{2}dT^2 + e_t \qquad t = 1, \ldots, n \tag{A-2}$$

where $y_t = \ln Y_t$ and $\varepsilon_t = \ln E_t$.

The data series for GDP and CO_2 cover the period 1949–98 for Canada and the period 1978–98 for the provinces. The GDP time series are expressed in millions of Canadian dollars (base year 1990) (Cansim database), while the CO_2 time series are expressed in thousand tonnes of carbon. The CO_2 emission series are calculated by applying emission coefficients on the fossil fuel consumption data, which is expressed in thousand tonnes of coal equivalent (ktce) (Casim database). The emission coefficients for the three types of fossil fuels, solids, liquids and gas are given by Halvorsen et al (1989) and are the following:

	Solids	Liquids	Natural Gas
kt carbon/ktce	0.69653	0.57579	0.39934

Eq. A-2 is estimated using the cointegration methodology, as most economic series are not stationary but rather are integrated. But when dealing with integrated series, conventional test statistics are a poor guide on whether relationships exist among them. Only when integrated variables are cointegrated, the regression of one series on another will not be spurious. Thus using cointegration is crucial, since it will provide a proof of the long-run relationship between the variables GDP and CO_2 if they are found to be nonstationary.

Two conditions must hold for cointegration to exist. The first is that the series have to be integrated of the same order, and the second is that there must be some linear combination of them which is stationary; that is, integrated of order zero I(0). In examining whether the two conditions for cointegration are fulfilled, we start by testing for the order of integration of the two series. The Augmented Dickey Fuller (ADF) unit root test is used, which tests the null of the existence of unit roots against the alternative that the series are stationary. The application of the ADF test indicated that the null hypothesis could not be rejected in either series y_t and ε_t in all regions under consideration. We will thus treat these series as being integrated of order one, I(1). The results are presented in Table A-1.

The first condition for cointegration is fulfilled, so in testing for the existence of a cointegrating relationship of the form of Eq. A-2, the error term should be integrated of order zero. The standard methods test the null hypothesis of no cointegration against the alternative that the variables are cointegrated and are residual based. According to this analysis, though, the cointegrating vector that results by the

Table A-1. ADF test for unit roots on the levels and the first differences of series y_t and ε_t [a]

	y_t				ε_t			
Region	ADF statistic levels		ADF statistic first differences		ADF statistic levels		ADF statistic first differences	
Canada	–1.843251		4.145188		– 1.381636		–4.396353	
	(–3.5713)*	k = 1	(–3.5745)*	k = 1	(–3.5745)*	k = 2	(–3.5778)*	k = 2
British Columbia	–0.175088		–3.775532		–0.437465		–2.502787	
	(–3.0199)**	k = 0	(–3.0294)**	k = 0	(–1.9602)**	k = 1	(–1.9614)**	k = 1
Alberta	–1.276869		3.712557		–0.830205		–4.491163	
	(–3.8067)*	k = 0	(–3.0294)**	k = 0	(–3.8067)**	k = 0	(–3.8304)*	k = 0
Saskatchewan	–0.299742		–3.242671		–0.734504		–4.753736	
	(–3.0199)**	k = 0	(–3.0294)**	k = 0	(–4.5348)*	k = 1	(–4.5743)**	k = 1
Manitoba	–0.106022		–3.531075		–0.777949		–3.971062	
	(–3.0199)**	k = 1	(–3.0294)**	k = 1	(–3.0169)**	k = 0	(–3.8304)*	k = 0
Ontario	–0.157816		–3.215672		–1.883008		–3.417542	
	(–3.0294)**	k = 1	(–3.0400)**	k = 1	(–3.0294)**	k = 1	(–3.0400)**	k = 1
Quebec	–0.14265		–3.50612		–0.567509		–2.245609	
	(–3.0199)**	k = 0	(–3.0294)**	k = 0	(–1.9592)**	k = 0	(–1.9602)**	k = 0

[a]MacKinnon critical values for rejection of hypothesis of a unit root are given in parentheses.[18] k = the number of lags used.[19]
*refers to 1% critical level.
**refers to 5% critical level.

estimation of Eq. A-2 is assumed to be time-invariant. However, there is a probability that there is a structural break in the model, so we believe that a test for parameter stability would be useful. For this reason, the ADF* test of Gregory and Hansen (1996) is applied, which tests the null hypothesis of no cointegration against the alternative of cointegration and which allows for a one-time regime shift of unknown timing. This must be considered as a pre-test for cointegration that can contribute to a correct model specification, since rejection of the null hypothesis provides evidence in favor of the specification of the model with a regime shift.

We are considering the case where the structural break, if it takes place, can be incorporated in a model that allows for a change in the intercept, which is interpreted as the efficiency parameter of the benefit function. The slope coefficient indicating the elasticity of CO_2 emissions is held constant. This is a level shift model with a trend and it is given as follows:

$$y_t = \alpha + \alpha_1 D_{t\tau} + b\varepsilon_t + cT + ½\, dT^2 + \varepsilon_t \qquad t = 1, \ldots, n \tag{A-3}$$

where $D_{t\tau}$ is a dummy variable that takes the values zero and one depending on the timing of the break (t ″ n and $t > n$, respectively).

The cointegration test statistic is computed for every possible shift $\tau \in$ T, where T refers to the interval T = (0.15, 0.85). Large negative values of the test statistic tend to reject the null hypothesis and indicate the possible break point.[20] The results from the application of the ADF* test indicate that in Canada and in some of the provinces under consideration the null of no cointegration should be rejected in favor of the alternative, which allows for a shift in the cointegrating vector. Table A-2 presents the possible break points.

Table A-2. Timing of structural break

Region	Year
Canada	1975
British Columbia	1986
Alberta	1986
Saskatchewan	—
Manitoba	—
Ontario	1985
Quebec	—

Source: Authors' estimate.

Table A-3. Test for cointegration using ADF test on the residuals of Eqs. 3 and 4[a]

Region	ADF test statistic	
Canada	–2.409379	
	(–1.9476)**	k = 1
British Columbia	–5.381180	
	(–3.8067)*	k = 0
Alberta	–3.827243	
	(–3.0294)**	k = 1
Saskatchewan	–2.964584	
	(–2.6968)*	k = 1
Manitoba	–2.116814	
	(–1.9592)**	k = 0
Ontario	–3.273064	
	(–3.0199)**	k = 0
Quebec	–2.957780	
	(–2.6968)*	k = 1

[a]MacKinnon critical values for rejection of hypothesis of a unit root are given in parentheses. k = the number of lags used.
*refers to 1% critical level.
**refers to 5% critical level.

Given the above results and using model Eq. A-3 to describe the benefit function for Canada, British Columbia, Alberta and Ontario, and using model Eq. A-2 for Saskatchewan, Manitoba and Quebec, we apply the standard ADF unit root test on the errors obtained by ordinary least squares estimation of Eqs. A-2 and A-3. The results, which are presented in Table A-3, indicate that the null of no cointegration is rejected for all regions considered. The series are thus treated as being cointegrated. Given that the series are treated as being cointegrated, we can estimate the cointegrating vector using conventional test statistics. For this reason, the ordinary least squares estimators are used; the results are given in Table A-4.

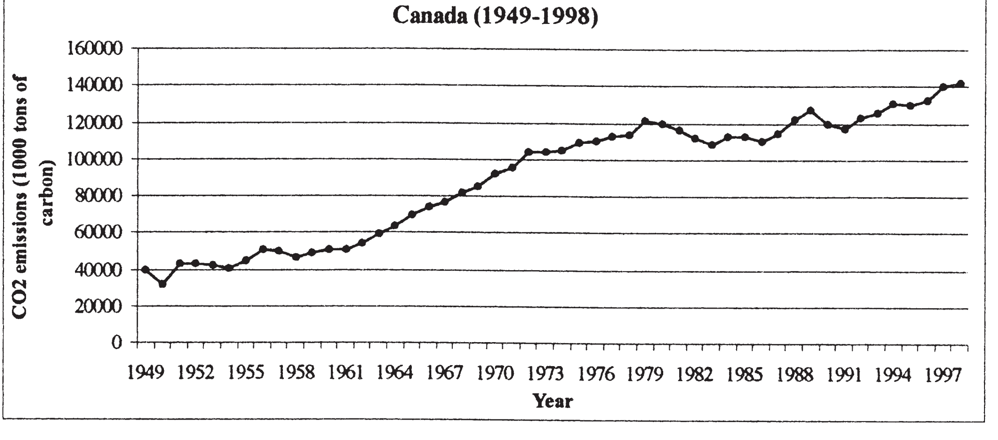
Table A-4. Estimates of the benefit functions using OLS estimators[a]

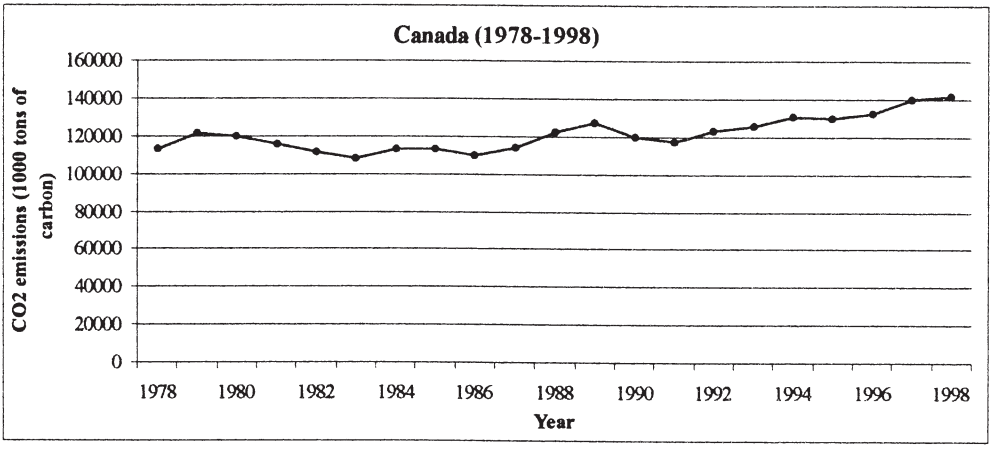
Region	a	a_1	b	c	d	adjusted R^2
Canada	6.431387	0.044179	0.501612	0.024841	–0.000401	0.853
	(19.12168)	(2.629802)	(15.95142)	(20.84974)	(–0.95378)	
British Columbia	5.435097	0.024715	0.604216	0.021731	–0.00015	0.975
	(7.576875)	(2.077713)	(7.678606)	(7.052839)	(–0.43937)	
Alberta	5.863608	–0.27576	0.551917	0.033971	–0.00105	0.859
	(2.909522)	(–6.32066)	(2.584379)	(2.995259)	(–1.0573)	
Saskatchewan	4.152943	—	0.682528	0.012992	–0.00124	0.699
	(1.850217)		(2.106235)	(1.895205)	(–1.991052)	
Manitoba	4.396583	—	0.656159	0.04456	–0.00252	0.925
	(1.746195)		(1.954732)	(3.986377)	(–2.30756)	
Ontario	3.468481	0.096314	0.824815	0.047804	–0.00228	0.898
	(2.246984)	(2.520757)	(5.60778)	(4.63731)	(–3.01806)	
Quebec	8.071087	—	0.350939	0.056149	–0.00346	0.944
	(5.411982)		(2.363172)	(4.317133)	(–2.77774)	

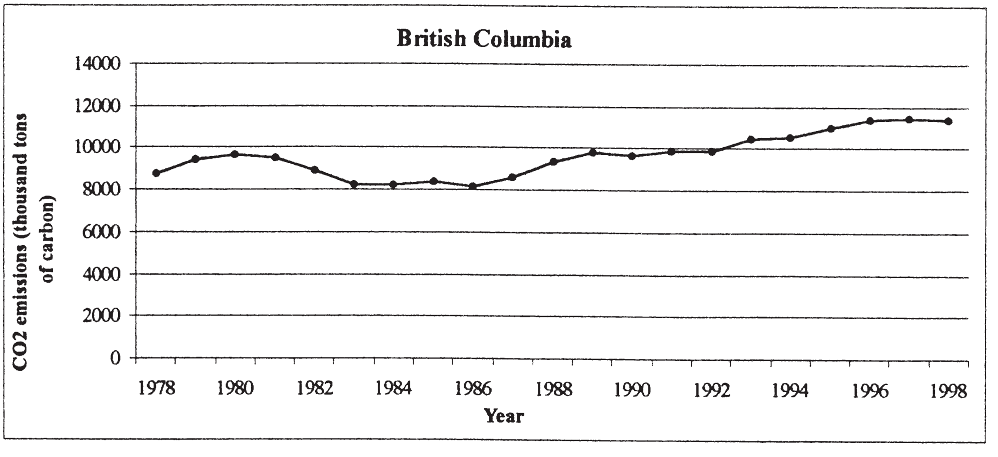
[a]*t*-statistics are given in parentheses.
Source: Authors' estimates.

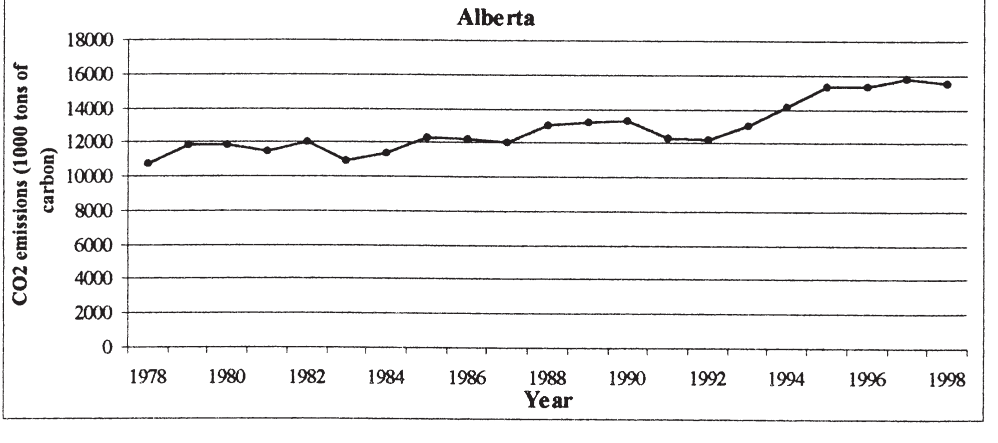
The results in Table A-4 support the existence of a structural break in Canada, British Columbia, Alberta and Ontario since the dummy variable is statistically significant. In addition, the results indicate that exogenous technical change has been significant in determining GDP. Moreover, the elasticity of CO_2 emissions, which reflects the degree of dependence of the GDP generation on fossil fuel burning, is less than one, indicating strictly concave benefit functions, which is in accordance with the theoretical models.

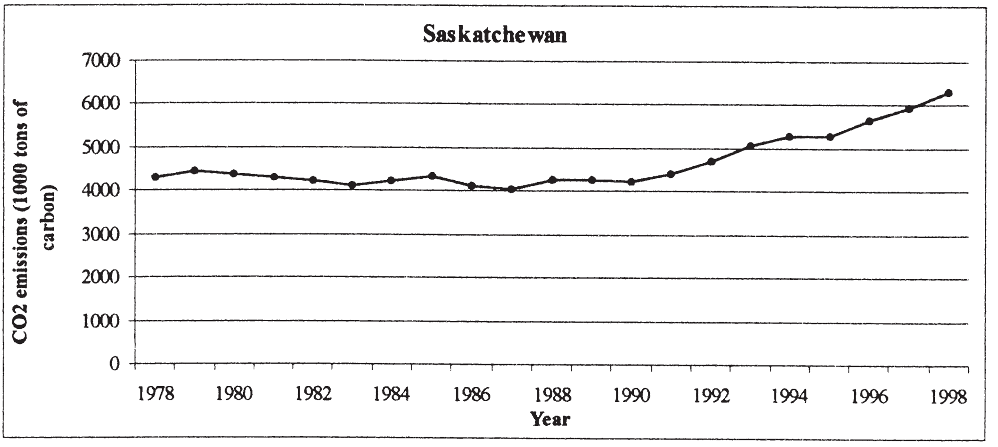
APPENDIX B: GRAPHICAL REPRESENTATION OF THE EVOLUTION OF CO_2 EMISSIONS

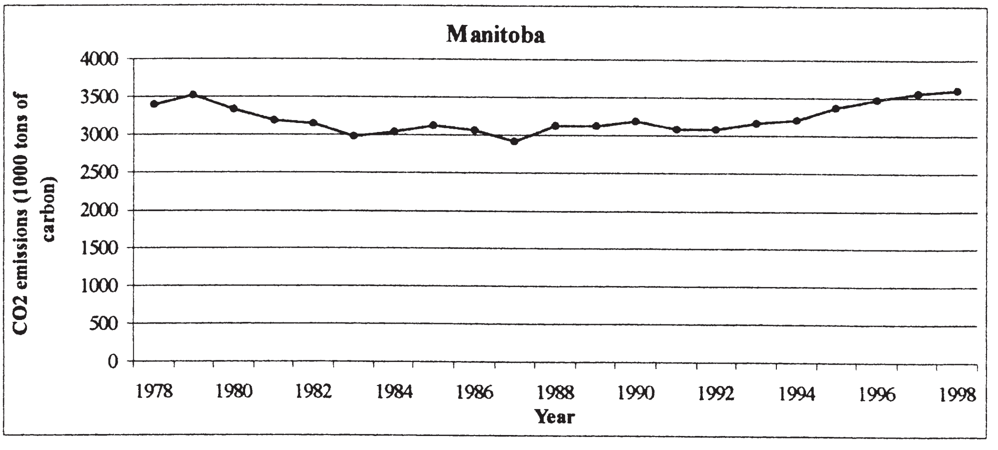


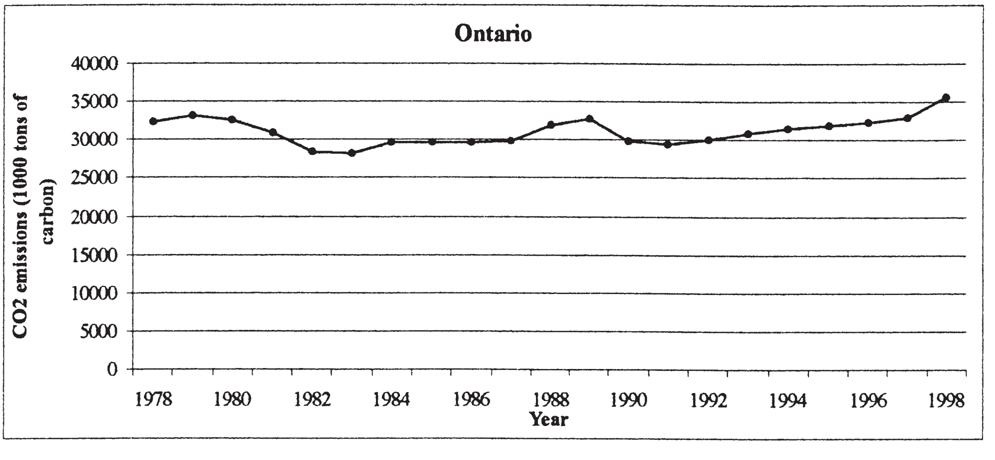

Canada (1978-1998)
CO2 emissions (1000 tons of carbon)
160000
140000
120000
100000
80000
60000
40000
20000
0
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
Year

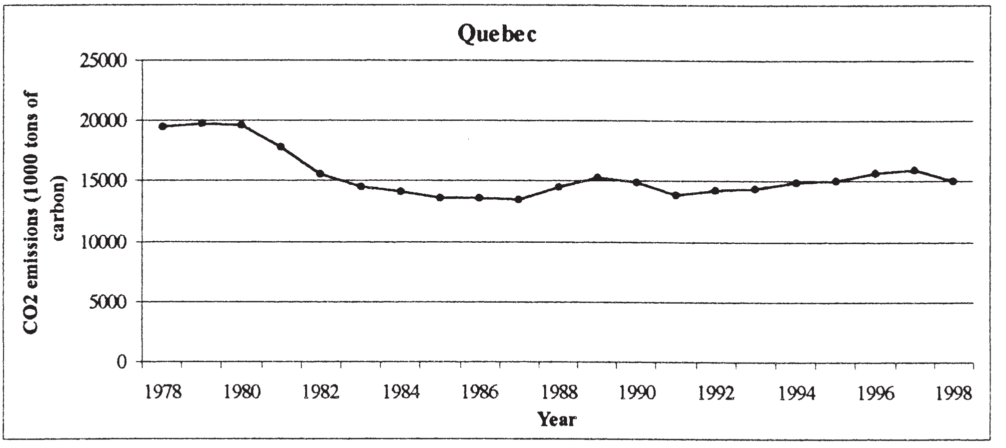

British Columbia
CO2 emissions (thousand tons of carbon)
14000
12000
10000
8000
6000
4000
2000
0
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
Year


Alberta
CO2 emissions (1000 tons of carbon)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
Year


Saskatchewan
CO2 emissions (1000 tons of carbon)
0
1000
2000
3000
4000
5000
6000
7000
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
Year


Manitoba
CO2 emissions (1000 tons of carbon)
0
500
1000
1500
2000
2500
3000
3500
4000
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
Year


Ontario
CO2 emissions (1000 tons of carbon)
0
5000
10000
15000
20000
25000
30000
35000
40000
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
Year



NOTES

[1]In terms of their per capita CO_2 emissions (generated by fossil fuel burning), the six provinces are ranked from highest to lowest as follows: Alberta (5.57 t per capita), Saskatchewan (5.19 t per capita), Manitoba (2.96 t per capita), British Columbia (2.93 t per capita), Ontario (2.87 t per capita), Quebec (2.05 t per capita).

[2]Note that our model specification is adequate for the analysis of a problem with a short-run horizon (of the kind considered here) where it is assumed that only energy efficiency improvements are possible and substitutions are not feasible. The above assumption in not realistic when a problem with a long-run horizon is considered. In the long run, where different kinds of substitutions are possible, other variables secondary to the current model may become important/relevant and a new model should be used to incorporate them.

[3]The introduction of quadratic terms in time allows for a smooth and slowly changing pattern of technical change (Diewert 1981).

[4]The elasticity values should be used with caution to draw conclusions about the dependence of the economic sector on fossil fuel burning or the efficiency of transforming energy to output. The reason is that different types of fossil fuels (solids, liquids, gas) have different carbon content (solids > liquids > gas) and thus different potential in generating CO_2 emissions, and provinces vary with respect to the intensity of the type of fossil fuel they use. In Quebec, for instance, only 2.7% of the emissions are due to solid fossil fuel burning while in Ontario emissions from solids are 8.4% of the total emissions of the province. Therefore, even in the case where two polluting sources have the same elasticity of CO_2 emissions but one is using gas fuels while the other is using solid fuels, a higher quantity of the former is necessary to generate the same amount of emissions as the latter. So the source that uses the gas fossil fuels appears to be "cleaner" but less efficient. For instance, in Manitoba and British Columbia, where the percentage use of the different types of fossil fuels is quite similar, one could argue that Manitoba's economy is more dependent on fossil fuel burning. The reason is the higher elasticity of CO_2 emissions in Manitoba, especially given the fact that two provinces have almost the same emissions per capita (2.96 t per capita versus 2.93 t per capita).

[5]The rate of technical change $\frac{\partial y_t}{\partial T} = c + dT$ is computed for every year t within the period 1978–98, and the average value for the above period is reported.

[6]The value of ρ reflects society's concern about future generations. The lower the value of ρ, the higher the premium on future generations. Values of ρ range from 0 to 5% (Squire and van der Tak 1975). Equal weight implies that $\rho = 0$.

[7]The value of ω reflects society's attitude toward distribution of income. The lower the value of ω, the less weight society gives to equity. Values of ω range from 0 to 3 (Brent 1990).

[8]Under path 1, the average emission growth rates, v, up to 1998 are estimated using the function $E_t = Ae^{vt}$, where E_t is CO_2 emissions at time t. Our assumption is that these emission growth rates would be followed in the absence of the Kyoto agreement. They thus represent the emission growth rates under the BAU scenario. Under path 2, where emission levels at the year 2012 are known (6% below the 1990 emission levels), v is estimated by $v = \ln(E_t/E_0)/t$, where E_0 are the emissions in 1998 and t refers to a 15-year time period.

[9]Figures N-1 and N-2 represent the way emissions evolve through time under the two emission paths in Canada and in Quebec, respectively.

[10]TAC at the country level should be given by the sum of the TAC of the 10 provinces. The difference observed between the estimated sum of the TAC of the six provinces considered and Canada could be explained by the fact that four provinces are not considered in the analysis. Even though their contribution to the aggregate CO_2 emissions is relatively small, a reduction in their emissions may be too costly given their already low emission levels. Nevertheless, the six provinces considered in the analysis are representative of the impact of the CO_2 emission reduction at the country level; this can be seen at Tables 4 and A-4. As mentioned in the subsections under Abatement Cost Estimation above, Canada's

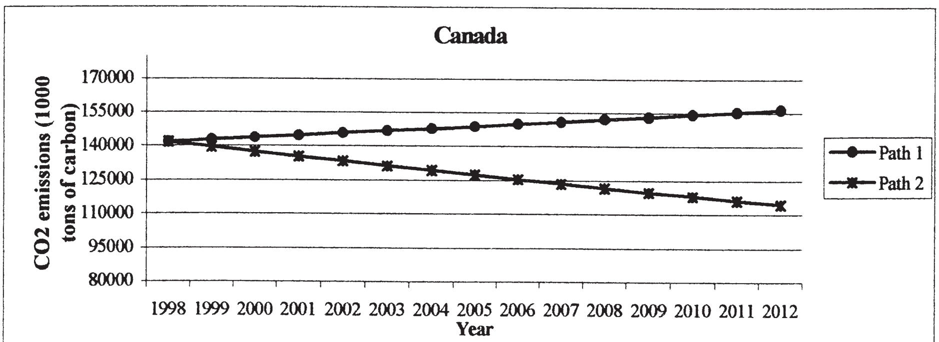


Figure N-1. Evolution of emissions under paths 1 and 2 in Canada

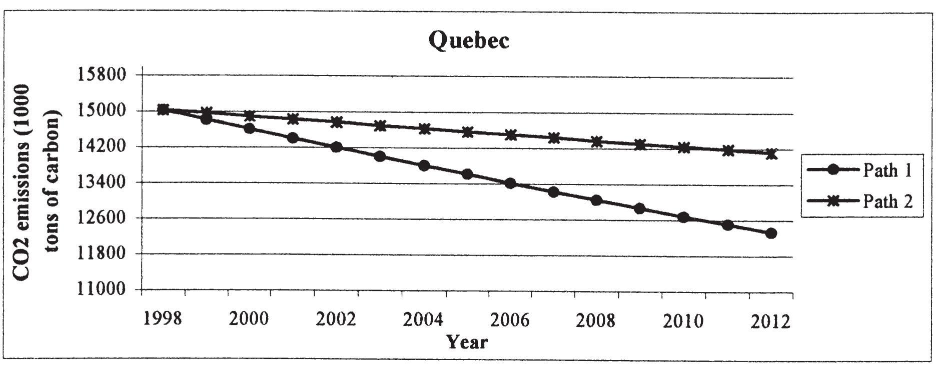


Figure N-2. Evolution of emissions under paths 1 and 2 in Quebec

estimates represent the average of all provinces. From the above tables, one can see that the average of the provincial estimates (of the six provinces considered) are close to Canada's estimates.
[11]The AAC = TAC/15. The value of GDP used is that of 1998 and refers to 1990 constant prices.
[12]Note that all results in the subsection on Abatement Costs under different Emission Scenarios hold under the assumption that the average emission growth rates of the period 1978–98 will prevail under the BAU scenario.
[13]The total abatement cost function is given by $Y_t = a\, e^{(cT+0.5*dT2)} (E_1t^b - E_2t^b)$ where E_1t refers to emissions at time t under path 1 while E_2t refers to emissions at time t under path 2.
[14]Note that we deal only with CO_2 emissions that are generated by fossil fuel burning.
[15]The marginal damage function shows the change in damages resulting from a unit change in emissions.
[16]An analytical illustration of the principal and its efficiency is given by Field (1997).
[17]For simplicity, we assume that the same tax t_A is imposed on Alberta.
[18]MacKinnon values for the Augmented Dickey Fuller tests are given in the Quantitative Micro Software Eviews, Version 3.1.
[19]The appropriate lag length is determined using the Akaike information criterion (minimum Akaike value).
[20]The critical values for the test are given by Gregory and Hansen (1996).

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