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SECTORAL IMPACTS OF KYOTO COMPLIANCE

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SECTORAL IMPACTS OF KYOTO COMPLIANCE

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TABLE OF CONTENTS

1. INTRODUCTION AND OUTLINE[1]

This paper looks at Canada's compliance with its Kyoto Protocol obligations, focusing on two questions:

1. What sectors are likely to be the hardest hit (and, conversely, which might benefit) from various modalities of compliance with the Kyoto Protocol?

2. How do the costs of compliance change when the domestic implementation plan exempts some sectors?

The analysis is conducted using a simulation model of the world economy. Specifically, a static CGE (Computable General Equilibrium) model based on the GTAP (Global Trade Analysis Project) data[2] is used. A distinguishing feature of this analysis is the relatively detailed sectoral breakdown: 31 sectors and 11 regions are identified.

The study first looks at two "core" cost-effective policy approaches (national and global carbon permit trading) by way of placing the model's results in the context of other existing CGE carbon models. The central case welfare effects and carbon taxes presented have a very similar flavour to results surveyed in the May, 1999 special issue of the *Energy Journal* on the costs of the Kyoto Protocol in most respects.

Given the plethora of models available for the analysis of these issues, the focus of this paper is on sectoral effects and the *relative* compliance costs associated with different domestic implementation schemes, rather than the specific welfare effects or carbon taxes generated. It also looks at how the sector-by-sector impacts of compliance are affected by various modalities of domestic implementation. This allows us to see how compliance costs and carbon prices respond to the same issues in policy configuration.

Part of the analysis focuses on domestic implementation against the backdrop of a given international framework. In particular, we consider domestic implementation plans that only apply to some sectors of the economy. The key findings are as follows:

1. If the Kyoto Protocol is implemented by reducing Canadian emissions by roughly 25 percent relative to *business-as-usual* (BAU) at 2010[3], Canada's most energy-intensive sectors can expect to decline markedly, though only dramatically for the energy sectors themselves. The energy-intensive sectors that don't decline will be those that enjoy energy or carbon-intensity advantages over their Annex B competitors (usually in the United States). This may reduce or reverse the decline of the sector. Canada's least energy-intensive sectors are likely to experience much more limited impacts and several may expand modestly.

   These conclusions assume a cost-effective domestic implementation scheme in Canada, such as an across-the-board carbon tax or a comprehensive carbon permits scheme. If such a domestic implementation scheme is adopted, the cost of compliance for Canada is estimated to be modest (less than 1.5 percent of GNP).

2. If the Kyoto Protocol is implemented with significant international trading, the important negative sectoral impacts largely disappear. In some cases, energy-intensive industries may *expand* modestly even if their energy intensities exceed those of Annex B competitors. This is most likely to be the case when their energy intensities are still less than those of their non-Annex B competitors. In such sectors, exports may rise and imports may fall.

3. Without sectoral exemptions, the broad conclusion is that, with or without global permit trading, Kyoto compliance is moderately costly. Extending broad sectoral exemptions or departing from cost-effective instruments of domestic implementation can alter that basic conclusion.

4. If any carbon restrictions are focused narrowly, the resulting plans can be extremely costly when all abatement occurs within Canada. The narrower the focus of implementation plans, the higher the cost to Canada. In one extreme case where the energy-intensive sectors are all exempted, the welfare cost can be 4–6 times as high as under a comprehensive scheme.[4] In the case where the most energy-intensive sectors alone are targeted, the welfare cost roughly doubles, but this result relies on the availability of a backstop technology which could provide added abatement at constant cost. Whether such a technology will be available at a feasible cost is an open question.

5. Such sectoral exemptions can also radically alter the pattern of sectoral effects in the absence of international trading. Indeed, the sectoral impacts come to reflect the pattern of exemptions rather than energy intensities.

6. In the presence of global trading, sectoral exemptions in the domestic implementation plan among buyer regions are typically more costly than cost-effective plans, but the consequences of the exemptions are dramatically less acute than without trading, even when these distortions are extended to all buyer regions. The narrower the focus of implementation plans, the higher the cost. One effect of such exemptions is to reduce the proportion of abatement achieved within Annex B regions with the exemptions.

7. When sectoral exemptions are used without trading, the effect is to enforce higher proportions of emissions reductions on those sectors that do need to comply. This raises the marginal cost of abatement (carbon taxes). In some cases, these tax rates are astronomical. Note that these high tax rates can emerge even when there is a carbon-free backstop, if the electricity sector is exempted from compliance. These extreme carbon taxes are indicative of a very serious flaw in the logic of extreme exemptions. By contrast, with global trading of emissions permits, one of the main impact is to reduce domestic abatement.

8. An exemption for final users appears to have significantly less welfare impact than sectoral exemptions, but does cause the required carbon tax for a given target to rise. This result is independent of the presence or absence of international trading. Further, when there is global trading of permits, it does not dramatically reduce the extent of the Kyoto commitment achieved through emissions reductions in Canada.

9. If international trading of permits between Annex B and non-Annex B regions is pursued on a project-by-project basis, many opportunities for inexpensive abatement are likely to be missed. Such divergences from cost-effectiveness in seller regions are likely to increase the world carbon price and increase compliance costs.

1.1 Outline

The structure of the report is as follows. First, the policy context of the Kyoto Protocol is very briefly reviewed in section 1.2. Some earlier research is then reviewed in section 2. The model used (MRT-C) and the accompanying data are briefly described in section 3.

Section 4 presents the main results for two "core" experiments plus some departures from the standard experiments. The core experiments are unilateral compliance by all Annex B countries and full global trading. In either case, the targets are achieved either by carbon taxes or tradeable permits. As implemented in this model, the two are entirely equivalent. With the appropriate assignment of revenues, our results can be used to represent a uniform global carbon tax system such as that suggested by Schneider and Goulder (1997) as well as a system of tradeable permits.[5] Once the results of these standard experiments are presented, we look at alternative cases where domestic implementation in Canada and/or abroad departs from a cost-effective approach.

The main findings are briefly summarized in section 5.

1.2 The Kyoto Protocol

The Kyoto Protocol binds a large number of high- and middle-income countries to reducing their greenhouse emissions by 2008–2012. Under the Protocol, Annex B countries committed to the emissions targets listed in Table 1.1. The Protocol includes the possibility of emissions trading under some circumstances. This trading could take place in a yet-to-be negotiated way between Annex B nations, but this will include exchanges on a project-by-project basis, called Joint Implementation (JI). Trading between Annex B and non-Annex B countries is allowed to take place using the Clean Development Mechanism (CDM).

Table 1.1
Kyoto Commitments (% of 1990 Emissions)

Canada	94
Australia	108
New Zealand	100
Japan	94
United States	93
European Union	92
Former Soviet Union	100
Central European Associates	92–95

The exact nature and regulation of emissions trading is yet to be completely resolved, but it seems clear that the intent is to make sure that trading results in real emissions reductions (presumably interpreted against BAU emissions) in the non-Annex B countries, which would effectively provide "abatement services" to Annex B countries.

1.3 Emissions Trading Schemes

Under an emissions trading or tradeable discharge permits scheme, a fixed quantity of emissions permits are either auctioned or allocated to polluters. Polluters are then free to emit a quantity of pollution no greater than the number of permits they have obtained.[6] In its purest form, an emissions trading scheme represents a cost-effective policy approach that provides incentives to abate to all polluters. If the permits were auctioned by the government, their market price per tonne of carbon would equal the exact carbon tax required to achieve the same emissions target. As such, the marginal cost of emissions would be the same for all emitters under the tax or permit scheme. Further, the tax revenue of the carbon tax would exactly equal the revenue returned to the government from the sale of permits under a permit scheme. A permit scheme has two key advantages over carbon taxes (emissions taxes or effluent fees).

The first advantage of an emissions trading scheme is that it allows the compliance costs of polluters to be lower. As long as some of the permits are allocated to polluters free of charge, the compliance costs will be cheaper than an effluent fee scheme attaining the same emissions target. While polluters must pay abatement costs under both schemes, the polluters are not required to disburse as much to obtain permits as they would pay in fees.

The second key advantage is that it allows flexibility in the allocation of the total burden of compliance. In the case of national permit schemes, particular sectors may be helped financially by being provided with large allocations of permits while still having a strong incentive to abate. If governments decide to use "grandfathered" permits, they would give some share of the permits away for free to firms based on some allocation rule. Typically, the permits are given away to firms based on their historical share of emissions or employment. Although the permits are given to firms, they are still worth something if the firm can abate its emissions for less than the market price of the permits. In the MRT-C model, permits are identical to carbon taxes because the market for permits is assumed to be perfectly competitive and because all revenues accrue to one consumer in each region.

In the case of international trading as foreseen for the Kyoto Protocol, poorer nations can be given incentives to abate, without requiring them to bear the full cost of compliance. Indeed, a permit scheme could be designed where the poor nations need to bear no net burden of abatement.

In practice, the performance of emissions trading schemes has varied widely. The sulfur dioxide trading scheme operated by the Environmental Protection Agency in the United States is thought to have been quite successful,[7] whereas numerous other trading schemes have been plagued with various problems that restricted the attractiveness or feasibility of trading, thereby reducing the cost-saving potential of the approach.[8]

In recent months, the European Union has formalized its proposals to limit the emissions permit purchases on a nation-by-nation basis to some formula-determined proportion of reference emissions. The intent is to ensure that all nations meet at least a certain proportion of their emissions reductions domestically. It could be expected that such limitations would increase the global cost of compliance, perhaps seriously, depending on the severity of the trading restrictions.

Even if international trading is not restricted, schemes with international trading are unlikely to be cost-effective for a range of reasons related to the domestic compliance plans adopted by individual nations. Previous experience with project-by-project trading, for example, suggests that the overhead costs of identifying possible trading opportunities and verifying their parameters has dramatically restricted the volume of trades (and hence cost savings). Further, if domestic schemes (whether permits or carbon taxes) are only applied to specific sectors such as the most pollution-intensive ones, some cost-saving trades will be prevented.

Confining compliance to the most pollution-intensive sectors may seek to reduce administrative costs of monitoring large numbers of small emitters. In this case, industries with low energy intensities might be exempted, with the idea of focusing abatement efforts on the biggest emitters. The opposite logic (exempting the most pollution-intensive sectors) have been motivated by the argument that such restrictions are "too" costly for firms in such sectors.[9] Taken to the logical extreme of exempting all but the least pollution-intensive sectors, this can dramatically increase the cost of attaining a given emissions target.

In all of these cases, domestic restrictions will raise compliance costs by eliminating incentives for some class of emitters. A recent working paper highlights some of the analytical and implementation issues arising when different nations adopt different domestic policy approaches.[10]

2. PREVIOUS RESEARCH

We begin by very briefly summarizing some key points from the literature on reduction of greenhouse emissions by OECD and/or Annex B countries.

2.1 GDP Impacts

A recent survey[11] gives an overview of the GDP consequences for Canada of stabilization of energy-related greenhouse gas emissions at 1990 levels, a somewhat smaller reduction commitment than Canada's Kyoto target.[12] Three types of models have been used to evaluate the costs of reducing energy-related emissions of greenhouse gases. Computable General Equilibrium (CGE) models are micro-based simulation models that (among other things) take account of the sectoral reallocation of resources in response to a given policy initiative. They stress the way in which policies are likely to affect the economy's medium- to long-run equilibrium. They are sometimes referred to as Top Down Models (TDM) since their representation of energy technologies are more schematic than others, especially Bottom-up (BU) models. BU models typically begin with a very detailed treatment of energy technologies and have somewhat schematic representations of the economy as whole. They trace out the consequences of various policies by determining the mix of technologies that is viable given the policy. Finally, macroeconomic models focus on the disequilibrium or cyclical movements in the economy, and as such stress how policy is likely to impact on the economy's movement towards or away from equilibrium.

The range of estimates from the three types of models is represented in Table 2.1. These GDP losses are as of 2010 in most cases.

Table 2.1
Range of Model Results

1990 Stabilization			
	Range		
Variable	**CGE**	**BU**	**Macro**
GDP loss in 2010 (%)	0.5–1.8	0*–0.5	0.4–2.3

* Some suggest GDP gains.

With one exception, these studies ignore the possibility of global trading of permits. In most cases, these are GDP effects versus welfare effects, since many of the models are incapable of calculating welfare effects. The DRI (1997) model is a macroeconomic model.[13] It reports GDP losses in lieu of welfare losses, and the GDP loss ranges from 1.5–1.7 percent of GDP for stabilizing emissions at 1990 levels by 2010. McKitrick (1997) uses a CGE model and finds that GNP can rise or fall as a result of stabilizing emissions at their 1990 levels by 2000.

An environmental tax is said to imply a double dividend when it not only gives incentives to reduce emissions (thereby correcting a pre-existing distortion), but even does so at a negative cost by allowing other taxes to be reduced. For example, if payroll taxes in an economy were high, they could discourage employment, imposing an economic cost. If an environmental tax generated sufficient revenue to allow these payroll taxes to be reduced, the economy could, in principle, expand as a result. McKitrick's finding of a welfare gain hinges on a sizeable double dividend driven by a somewhat high labour supply elasticity.

Table 2.2
Selected Model Results: Kyoto Protocol at 2010

		Carbon Tax ($/tonne)		Welfare/GDP (percent)	
Model	**Region**	**No Trade**	**Global Trade**	**No Trade**	**Global Trade**
SGM	Canada	$\$US_{92}$ 350	$\$US_{92}$ 26	n.a.	–0.5
AIM	Canada	$\$US_{95}$ 180	$\$US_{95}$ 40	n.a.	n.a.
MS-MRT	Other OECD	$\$US_{95}$ 249	$\$US_{95}$ 31	–0.9	–0.3
GTEM	Canada	$\$US_{92}$ 835	$\$US_{92}$ 114	–2.2	–0.2
G-Cubed	Other OECD	$\$US_{95}$ 261	$\$US_{95}$ 61	–1.2	–0.6

Other studies which look at permits normally find that international trading of permits can reduce compliance (GDP/welfare) costs. This reduction is very significant if global trading is permitted, and more modest if trading is limited to Annex B countries. An exception to this is the DRI (1997) study which finds losses significantly higher with internationally traded permits, even given a very modest assumed carbon permit price.

A recent special volume of the *Energy Journal* includes several revised model estimates of the impact of Kyoto Protocol Compliance on Canadian welfare and/or GNP. In one case to be discussed, a similar model gives results for a region composed of the OECD, Australia and New Zealand. Selected results are shown in Table 2.2. The results of unilateral abatement (no trading) range from a –0.9 percent reduction in the case of MS-MRT (for "Other OECD") to a 2.2 percent reduction in the case of the GTEM model.[14] With full global trading, the range is from –0.2 percent (GTEM) to –0.6 percent (G-Cubed) (for other OECD). Crucially, all studies find that global trading dramatically reduces the welfare or GNP costs of compliance.

2.2 Permit Prices

Studies of unilateral carbon dioxide emissions reductions look at the size of the carbon tax required to achieve a given emissions target independently in each country. Countries are assumed to do all abatement within their own borders. As discussed above, in many studies carbon taxes are equivalent to the permit price.

Such studies rank Canadian carbon taxes for a given experiment from among the very lowest to among the very highest in the world. More recent studies tend to place Canadian permit prices somewhat higher than those of the United States, but lower than those of Japan or Western Europe. A partial listing is presented in Table 2.3. Wherever possible the taxes correspond to those expected to prevail in 2010.

Most studies find that Canada will face one of the higher marginal costs of reducing CO_2 emissions. This is often attributed to the following key factors:

1. Canada already has relatively little reliance on coal. Typically, one of the lowest cost ways of reducing CO_2 emissions is by switching from coal to natural gas, notably in electricity generation. Because of its modest reliance on coal, Canada can only achieve modest emissions reductions even by dramatically cutting coal consumption. About 20 percent of Canada's CO_2 emissions in 1995 came from coal. This compares with an average for Western European countries of over 30 percent, and nearly 40 percent for the United States.

Table 2.3
Selected Model Results: Carbon "Taxes"

Canadian Carbon Tax with No International Trading ($/tonne)			
Study	**Case**	**Tax**	**Rank**
McKitrick, 1997	1990	$\$C_{95}$ 20	(at 2000)
DRI, 1997	1990	$\$C_{90}$ 325	Low
Kainuma et al., 1998	Kyoto	$\$US_{92}$ 150	High
Rutherford, 1998	Kyoto	$\$US_{95}$ 225	High
McKibbin et al., 1998	1990	$\$US_{95}$ 213	High
Tulpulé et al., 1999	Kyoto	$\$US_{92}$ 835	High
International Permit Trading ($/tonne)			
Study	**Case**	**Tax**	**Trading**
Nordhaus and Boyer, 1998	Kyoto	$\$US_{90}$ 11	Global
Edmonds et al., 1997	Kyoto	$\$US_{9?}$ 26	Global
Kainuma et al., 1998	Kyoto	$\$US_{92}$ 50	Global
McKibbin et al., 1998	1990	$\$US_{95}$ 91	OECD
Tulpulé et al., 1999	Kyoto	$\$US_{92}$ 114	OECD

2. Canada already relies heavily on hydroelectric power. Further, Canada's ratio of non-carbon electricity (nuclear plus hydro plus renewable) is projected to be among the highest in the world by 2010 at nearly 70 percent in the absence of any Kyoto-related actions.[15] If one further believes that there is limited scope for further expansion of hydroelectric or nuclear power, this restricts the ability to reduce emissions.

ABARE's GTEM model yields the highest Canadian carbon tax at $835 per tonne of carbon. This model assumes that no additional nuclear or hydro capacity is feasible. The next highest Canadian carbon tax is from the DRI (1997) study and it effectively makes the same assumption.

2.3 Sectoral Impacts

There is relatively little detailed analysis of the sectoral impacts in Canada of reducing greenhouse emissions. Table 2.4 shows the percentage changes in sectoral output from three of DRI (1997)'s relevant scenarios. The sectors denoted † correspond to those with the highest value share of energy products in their costs. Those denoted ‡ are those with the lowest value share of energy products in their costs.[16]

The labels for the experiments are as follows:

1990 Reduction of emissions to 1990 levels by 2010.

–10% Reduction of emissions of 10 percent below 1990 levels by 2010.

IPT Reduction of emissions to 1990 levels by 2010 with international trading of permits among Annex B nations.

Table 2.4
Sectoral Effects from the DRI Study (% change)

	1990	–10%	IPT
Agriculture †	–0.6	–1.3	–0.9
Forestry	–0.1	–0.5	–0.6
Fishing and Trapping	0.0	0.0	0.0
Metal Mining	1.2	1.4	–0.2
Non-metal Mining †	–1.6	–2.9	–1.1
Mineral Fuels	–7.0	–8.2	–1.5
Mining Services †	–1.9	–4.8	–1.0
Food, Beverage and Tobacco ‡	–0.2	–0.8	–0.9
Rubber and Plastics †	–1.6	–3.6	–1.8
Leather, Textile and Apparel ‡	0.8	1.8	–0.3
Paper and Allied	–0.4	–1.1	–0.9
Printing and Publishing	–1.2	–3.0	–2.1
Chemicals †	–1.1	–1.9	–0.4
Petroleum and Coal Products †	–15.3	–19.7	–6.3
Wood	–2.7	–5.1	–2.6
Furniture and Fixtures	–3.7	–7.3	–4.1
Primary Metals †	–0.5	–1.2	–0.7
Fabricated Metals	–1.8	–3.7	–1.9
Machinery ‡	–3.1	–5.2	–2.3
Transportation Equipment ‡	–0.5	–2.9	–2.1
Electrical Products ‡	–3.6	–7.8	–3.6
Minerals except Metals †	–1.8	–5.2	–5.0
Miscellaneous Manufacturing ‡	–0.1	–0.5	–0.5
Construction ‡	–2.4	–5.8	–3.5
Transportation and Storage	–0.1	–0.5	–0.5
Communications	–2.3	–3.6	–1.3
Electrical Power †	–3.0	–2.7	–1.5
Other Utilities	–13.1	–17.5	–4.8
Retail Trade	–2.4	–5.0	–2.4
Wholesale Trade	–4.2	–7.7	–3.3
Finance, Insurance and Real Estate	–1.5	–2.8	–1.4
Other Services ‡	–0.6	–1.6	–0.9
Economy Aggregate	–1.7	–3.2	–1.5

† Sectors with the highest value share of energy products in their costs.
‡ Sectors with the lowest value share of energy products in their costs.

It seems clear that the sectoral effects reflect much more than just the initial energy value shares. An important influence on these sectoral impacts is the disposition of revenues earned by industries which receive permits free of charge in the 1990 and –10 percent scenarios. In these cases, output of an energy intensive sector may not fall as much (or indeed may rise) as a result of a share of permit revenues being spent on new investment.[17]

Some discussion of the sectoral impacts on the OECD countries of Kyoto compliance appears in Manne (1998). This work is preliminary, but indicates that the United States and Japan (initially significant net exporters of energy-intensive manufactures) might experience increased export competition from non-Annex B countries.

2.4 Overview

This overview of studies suggests a range of both carbon taxes and welfare losses associated with Kyoto compliance. Many of the studies suggest that the problem of reducing carbon dioxide emissions will be relatively difficult for Canada. Among OECD countries, Canada is relatively energy-intensive, but not quite as carbon-intensive because of low reliance on coal and very heavy reliance on hydroelectricity. Unfortunately, both of these factors may make the challenge of reducing emissions that much greater. One of the lowest-cost ways to reduce CO_2 emissions is to reduce the amount of coal used in generating electricity. Half of the electricity in the United States is generated using coal. The corresponding figure for Canada is roughly 7.5 percent. As a result, there is limited scope for low-cost "abatement."

Because Canada already derives such a high share of energy from hydroelectric power, Canada has low initial input shares of "carbon" in the electricity sector. To reduce emissions from electricity generation would require an expansion of non-fossil generating capacity. Unfortunately, it seems unlikely that Canada can realize a net expansion of non-fossil generating capacity at rates comparable to today's.

3. THE MODEL AND DATA

3.1 Non-technical Sketch of the Model

This section provides a very brief non-technical look at the model. More details can be found in the following section and in the model documentation.[18]

MRT-C is a conventional static CGE model based on Tom Rutherford's GTAPinGAMS model.[19] CGE models represent the world economy in terms of interrelated supply and demand relations for goods and primary factors of production like labour and capital.

The model is first used to construct a 2010 business-as-usual (BAU) equilibrium. The endowments of capital, labour and resources of the regions in the model are increased in line with available forecasts of economic growth to 2010. Carbon emissions in the BAU scenario also hit available forecasts of 2010 emissions. The BAU "equilibrium" is then perturbed by introducing a given Kyoto experiment. The various effects are reported *relative* to the BAU scenario. More details on the BAU scenario are available in Appendix C.

When carbon taxes are introduced into such a model, the taxes drive up the consumer costs of goods depending on their carbon content. As a result, relative prices of goods from different sectors change within a country based on their carbon content. Relative prices of goods between countries depend on the relative energy and carbon content of goods between countries *and* on whether or not the goods in question are subject to some type of carbon tax or a similar instrument.

Depending on the type of carbon policy instrument used, government revenue may also rise. This will affect household incomes because tax revenues are normally passed on to consumers in this study.

The CGE model uses existing data about the patterns of inputs used by different sectors and the resulting cost shares to simulate the impacts of a given policy change within one country and between countries. Goods are traded internationally, initially reflecting observed data on international trade by commodity.

The combination of these relative price and revenue effects will also affect the markets for primary factors (labour, capital and resources). Typically, the value of resources usable only in the production of a heavily-taxed good is likely to fall as a result of the tax. This is likely to be the case, for example, for resources used only in the coal sector of a country complying with the Kyoto Protocol. For factors (like labour) that are assumed to be mobile between sectors, the effects of these relative price and revenue effects is often hard to anticipate.

Finally, these impacts on factor markets have feedback effects on goods markets. This further complicates the task of predicting the direction of change of a given sector's output caused by a given policy. The G in CGE corresponds to General equilibrium, the process by which these myriad influences are resolved to find a new equilibrium.

MRT-C is a static model, which means that it does not model the process of capital accumulation, investment or depreciation. Dynamic models, which explicitly account for intertemporal decisions about investment, are normally preferred for looking at policy questions like global warming where a long time horizon is relevant. Regrettably, it is difficult to reliably solve intertemporal models with the level of sectoral detail desired in this study.

3.1.1 Energy Use

Within the model, energy use in production and final demand is described in some detail. In production, there can be substitution between energy and primary factors or other goods as input. There is also significant possibilities to substitute between energy sources. Energy users pick the mix of energy sources they will use depending on relative prices.

The final and intermediate users of energy substitute between fossil fuels and electricity based on their relative prices. In turn, they choose between the various types of fossil fuel. Once again, the input proportions they employ depend on relative prices. Because coal is almost pure carbon, carbon taxes tend to be highest (per BTU) on coal and lower on refined petroleum products. The proportionate tax on natural gas depends on its original cost per BTU. Since natural gas may be cheaper per BTU than coal or oil, it may end up having a high carbon tax (as a proportion of value) even though natural gas has relatively low carbon emissions per BTU.

3.1.2 Electricity Generation

There are three electricity generating sectors in each region in the model. One generates electricity using fossil fuels. A second sector includes hydro, nuclear and other types of non-fossil electricity generation in use at present or likely to be adopted in the BAU case. There is a third "backstop" electricity sector which produces electricity completely free of greenhouse emissions. This sector is not profitable in the BAU scenario, but comes available once carbon taxes are high enough.

In the Kyoto experiments, the non-fossil electricity sector is assumed to be constrained by either hydro capacity or public resistance to the expansion of nuclear energy. Since one easy way of reducing carbon dioxide emissions is to switch between fossil and non-fossil electricity generation, the capacity constraints limit the ability of a region to reduce emissions by expanding non-fossil generating capacity.

The capacity constraints assumed for non-fossil electricity generation are shown in Table 3.1. They are expressed as proportions of the model's 1995 non-fossil electricity generating capacity. They are based on projections from the International Energy Agency (IEA) (1998) except for Canada, where a value of 1.0 has been used based on the analysis presented in Energy Forecasting Division (1998) and informal discussions. For several regions, the projected expansion of non-fossil capacity will not be enough to outstrip likely retirements of nuclear generating capacity.

By contrast, the backstop electricity sector has no capacity constraint, but has significantly higher costs than the fossil or non-fossil electricity sectors. The input shares of the backstop sector are the same as the non-fossil electricity sector, but the costs per unit of output are 67 percent higher.[20]

3.2 Technical Overview of the Model

1. All produced goods except three services are tradeable.[21] Cross-hauling (the simultaneous import and export of a given good by a country) is accommodated by the Armington specification. Substitution between domestic and imported goods occurs at two levels. There is, first, substitution between imports from alternative foreign sources. Subsequently, there is substitution between the composite of imports and domestic goods.

2. Benefits from reductions of either greenhouse gases or conventional air pollutants are not modelled. In other words, neither clean air nor an unchanged climate is valued *per se* by households. The analysis only captures the indirect welfare impact of the Kyoto Protocol via its effects on costs of production and real incomes. As a result, Kyoto compliance would always be expected to generate a welfare loss in this model. A loss must be compared to the value of benefits likely to accrue from reduced climate change.

3. The specification of energy use is relatively simple. Energy is produced as a constant elasticity of substitution (CES) composite of the fossil fuels composite and electricity. The fossil fuels composite is a CES composite of fossil fuel types (coal, refined petroleum products and natural gas).

4. Production involves energy intermediate inputs, non-energy intermediate inputs and primary factors (capital and labour). There are fixed input proportions of primary inputs and an energy-primary factors composite. Intermediate energy is substitutable for capital and sector-specific factors in a CES composite. This composite is in turn substitutable with labour. The elasticity of substitution between energy and capital (reported below) is referred to as SUBEV. The elasticity of substitution among this energy-capital composite and labour is referred to as SUBVA.

5. There is no possibility for a significant double dividend. There are no factor taxes in the GTAP data and, at this time, there is no labour supply decision in the model. The GTAP data incorporates detailed information on commodity taxes and border measures, but not on factor taxes.

6. All policies are implemented as permit schemes, with initial endowments of permits assigned to each region's representative consumer. Permits are in no sense captive to an industry. In other words, revenues from selling permits allocated to an industry are not added to a sector's revenue. Instead, they accrue to the region's representative consumer (as owner of the permits).

7. While the electricity generated is identical, electricity generation from fossil fuels (denoted ELY) is distinct from the process of generating electricity without fossil fuels (denoted NFE) which is in turn distinct from the backstop technology (denoted BST).

8. The model has a carbon-free backstop technology for generating electricity without any carbon. This carbon-free electricity generating technology is not used in the business-as-usual case because it is too expensive. In some of the experiments considered, the backstop technology comes into production.

9. The model does not assume any explicit autonomous energy improvement, although this is implicit in the interpretation of the BAU scenario. The BAU scenario generates carbon emissions increases close to the growth rate of GDP. The emissions play no role in determining the BAU, so they are rescaled to hit the IEA/NRCan targets. The central case Kyoto Protocol experiments thus correspond to eliminating a percentage gap in emissions, based on the IEA and NRCan projections. The central case emission gaps are listed below in Table 3.2. The disadvantage of this approach is that it precludes us from doing sensitivity analysis of differential economic growth, unless we use an exogenously specified linkage between economic and emissions growth.

Table 3.1
Non-fossil Electricity Capacity Constraints*

CAN	1.00
USA	1.00
JPN	1.05
EUR	1.05
OOE	1.05
CHN	3.16
FSU	1.17
CEA	1.05
ASI	1.85
MPC	1.85
ROW	1.85

* Ratio of maximum capacity to BAU production of non-fossil electricity. See Appendix A for a description of the regional and commodity aggregations.

Table 3.2
Kyoto Protocol "Gaps"*

Japan	27.285
Canada	24.725
USA	29.450
CEA	18.136
FSU	–14.284
EUR	27.051
OOE	27.119

* Required percentage reduction in emissions relative to BAU. For FSU, the Kyoto commitment *exceeds* BAU emissions. See Appendix A for a description of the regional and commodity aggregations.

3.3 Sectoral Analysis: Background

The pattern of sectoral impacts of Kyoto compliance depends on a large number of factors, but a few are obvious determinants:

1. *Carbon (and energy) intensity relative to other industries in Canada*[22] — This is most important if compliance requires all abatement to take place in Canada.[23] In this case, a main avenue for compliance will come from shifting production from more energy-intensive sectors to less energy-intensive ones.

2. *Carbon (and energy) intensity relative to same industry in our major import suppliers and export markets* — This may be as important or more important when abatement is global in scale and particularly when traded goods are close substitutes for domestic goods. In most cases, Canada's primary export market and import supplier is the United States. If a given Canadian industry has a higher energy cost share than the corresponding U.S. industry, then when both countries are reducing carbon emissions imports will tend to rise and exports will tend to fall, both leading Canadian output to fall.

3. *Compliance status of trading partners* — If compliance causes export markets to experience reduced real incomes, this will tend to cause Canadian exports to fall. Reduced incomes abroad may also contribute to lower supply prices of imports to Canada.

As carbon restrictions are applied (either through permits or taxes) the user cost of both carbon-based and carbon-free energy are expected to rise. Canada tends to have relatively high energy intensities but (because of high shares of hydroelectricity) relatively low initial carbon intensities. It seems that carbon taxes would cause Canada to become more competitive relative to the United States because the Canadian economy initially has a low carbon intensity. This impact can easily be offset by our higher energy intensity which comes to the fore as a result of carbon and non-carbon energy cost increases caused by Kyoto restrictions.

While these factors are important in understanding the pattern of sectoral impacts, it must be remembered that a key feature of the model and data is that large shares of produced goods are consumed as intermediate inputs. The most energy-intensive sectors (iron and steel, plastics, mining, etc.) produce goods which are primarily intermediate inputs. As a result, the pattern of sectoral effects may also depend significantly on a complex web of interdependency. A sector which might be expected to decline because of a high energy intensity, for example, might expand if the sectors which buy its production expand because of compliance. CGE models are used because they can, in principle, take into account all of these linkages. Unfortunately, the inherent complexity of the linkages may make some specific sectoral results difficult to explain.

Table 3.3 presents selected information relevant to the energy intensity and “openness” of each of the sectors considered in this analysis. Note that (as all subsequent “sectoral” tables) the non-energy sectors are ordered from those with the highest value share of energy in total cost (OMN or other minerals mining) to the lowest (WAP or wearing apparel). The energy sectors conclude the table.

Sectoral tables will normally include results for the fossil fuel electricity sector (ELY), the non-fossil electricity industry (NFE) and the backstop electricity sector (BKS). There are no trade effects listed for the NFE or BKS sector, since the changes in trade listed in the ELY row will include trade changes for the homogeneous good electricity.

Table 3.3
Energy Costs for Canada and its Competitors

Sector*	Share	X/Q	X-Diff	M/Q	M-Diff
OMN	7.2	40.5	–	17.1	–
CRP	5.9	34.4	+	39.9	+
I-S	5.3	25.1	–	25.2	–
AGR	4.8	49.0	+	25.4	+
NMM	4.1	20.7	+	27.4	+
LAP	3.7	17.3	+	4.0	+
NFM	3.3	69.1	–	20.9	–
PPP	3.2	42.4	+	10.9	+
T-T	3.2	5.5	+	7.3	+
GDT	3.0	n.a.	–	n.a.	n.a.
WTR	2.9	n.a.	–	n.a.	n.a.
TEX	2.3	21.4	+	43.1	+
OSP	1.9	4.0	+	6.8	+
LUM	1.7	51.9	+	11.7	+
FRS	1.6	1.6	+	3.4	+
FMP	1.4	20.0	+	28.0	+
OMF	1.2	32.9	+	89.4	+
CNS	1.2	n.a.	=	n.a.	n.a.
PFD	1.1	16.3	+	14.1	+
OTN	1.0	45.9	+	33.9	+
OSG	1.0	3.4	+	2.5	+
OME	0.9	64.3	=	122.3	=
ELE	0.8	47.6	=	60.8	=
LEA	0.7	28.0	=	157.7	–
MVH	0.7	74.9	=	50.0	=
WAP	0.6	14.3	=	35.3	=
COL	6.9	75.8	–	16.3	–
CRU	1.8	49.9	=	21.0	–
GAS	1.5	53.7	–	1.3	–
P-C	4.5	13.0	–	6.9	–
ELY	7.6	4.1	–	0.0	n.a.

* See Appendix A for a description of the regional and commodity aggregations.
Share: Energy share of total cost
X/Q, M/Q: Exports (Imports) as a percentage of total production
X-Diff, M-Diff : Energy cost share advantage or disadvantage versus major export market (X) or import competitor (M)
+ Canada's energy cost share is higher
– Canada's energy cost share is lower
= Energy cost shares are within 20 percent

4. ANALYSIS OF KYOTO COMPLIANCE

In this section, we look at variants of two core experiments aimed at reducing emissions of carbon dioxide from fossil fuel burning in line with Canada's Kyoto commitments. These commitments require that Canada reduce fossil fuel-related carbon dioxide emissions to 94 percent of their 1990 value from BAU values for 2010, either by emissions abatement within Canada or by supporting abatement elsewhere. This reduction amounts to almost 25 percent of Canada's 2010 BAU emissions. Unless otherwise stated, all results are presented relative to the business-as-usual reference case described briefly in Appendix C.

Two core experiments are considered:

NCP *National Carbon Permits* — In this experiment, each Annex B country or region of the model is bound to reduce its emissions of carbon dioxide from fossil fuel burning in line with its Kyoto commitments. This is achieved through a system of carbon emissions permits. The permits are all sold at auctions and apply to all burning of fossil fuels within the country. Intermediate, final and government uses of fuels are all subject to permits.

GCP *Global Carbon Permits* — In this experiment, each Annex B country or region of the model is bound to reduce emissions of carbon dioxide from fossil fuel burning in line with its Kyoto commitments. It can do so through any combination of domestic emissions reductions and purchases of permits. In turn, non-Annex B countries which reduce their emissions can sell permits equal to the difference between their allowance and their actual emissions.

Each Annex B country is given an allowance of permits corresponding to its Kyoto target emissions. Each non-Annex B country is given an allowance (effectively an endowment) of permits equal to its projected BAU emissions. Each nation's allowance (or endowment) of permits is sold at auctions and permits apply to all burning of fossil fuels. Intermediate, final and government uses of fuels everywhere are subject to permits.

In these core cases, the presumption is that the domestic implementation (through a universal carbon tax or universal carbon permits) is cost-effective given their national scope. National carbon taxes or national permit schemes will give incentives to equalize the marginal abatement cost of each abating polluter within the country.

We then turn to some scenarios where various aspects of the scheme are *not* cost-effective. In one case, we consider sectoral exemptions and in another we consider the departures from cost-effectiveness resulting from various imperfections in the international trading regime.

4.1 National Permit Schemes

If nations were required to meet their Kyoto abatement target purely by reducing domestic emissions, this could be achieved by an emissions trading scheme. Each user of fossil fuels would require permits proportional to the carbon (and hence CO_2) content of fossil fuels to be burned. As mentioned above, in this model the policy is formally modeled as a tradeable permits scheme, but it can be viewed as a carbon tax scheme as long as the revenue from carbon taxes, the proceeds from the sale of permits, and the rents from selling excess permits all accrue to the same consumer.

Table 4.1
Summary Table for NCP

	Welfare Cost ($B)	Welfare Cost (%)	Carbon Emissions (%)	Carbon Price ($)
CAN	–7.02	–1.13	–24.73	255.12
USA	–52.01	–0.60	–29.45	231.16
JPN	–48.03	–1.09	–27.28	1,238.60
EUR	–126.02	–1.21	–27.05	930.96
OOE	–3.21	–0.72	–27.12	147.69
CHN	–6.28	–0.39	1.64	0.00
FSU	2.78	0.60	3.39	0.00
CEA	–1.10	–0.30	–18.14	96.13
ASI	–3.70	–0.24	1.92	0.00
MPC	–10.68	–0.72	1.81	0.00
ROW	–1.92	–0.06	1.57	0.00
WLD	–257.17	–0.78	–11.54	0.00

A summary of the effects of a cost-effective scheme of "national" carbon taxes or carbon permits is presented in Table 4.1. In this table, dollar figures denoted $B are in billions of 1995 US dollars. Carbon prices are all quoted in 1995 US dollars per tonne of carbon.

The welfare losses to Canada are among the highest of all regions in percentage terms but are still rather modest. Canada loses roughly 1.1 percent of its GDP. As mentioned above, it could be expected that Canada's welfare effect might be high (somewhat like Japan's) because Canada has relatively little opportunity to abate cheaply. An added factor affecting Canada is the change in the producer's price of fossil fuels.

As already indicated, two inexpensive ways of reducing emissions are substituting away from coal in energy use, or expanding hydroelectric capacity. Canada already uses very little coal (notably in electricity generation) and has very limited opportunities to substitute away from coal. Similarly, the assumption underlying this analysis is that there is no net addition of hydroelectric capacity possible, removing another low-cost option for abatement.

Terms of trade effects also contribute to high welfare costs for Canada (in percentage terms) relative to other regions. Other regions with higher carbon taxes (Japan and Europe) are large net importers of fossil fuels, whereas Canada is a small net exporter. As a result of abatement in Annex B regions, the world price of fossil fuels is reduced. This cuts the losses of regions which are large net importers of energy (including the United States) but increases the losses of Mexico and OPEC and, to a much lesser extent, Canada. U.S. losses are modest in percentage terms because that country initially burns a lot of coal and may also benefit from the terms of trade effects resulting from cheaper world prices of fossil fuels.

The required carbon tax is over $250. This places Canada's carbon tax higher than all others except those in Japan and Europe. The Canadian carbon tax is slightly higher than that of the United States. This relative ranking of carbon prices is due to the factors described above.

Compliance with these Kyoto emissions targets leads to a reduction in global emissions of over 11 percent. Non-Annex B regions increase their emissions. This "leakage" comes via a number of avenues. Among the causes are that fossil fuel products fall in price on world markets, and that production of energy-intensive goods rises outside of Annex B countries as their prices rise. The Rest of World (ROW) region's emissions rise by about 2 percent.

A number of features of this model distinguish it from some others used to analyze Canadian Kyoto compliance. A short discussion of how our results differ from three key studies follows.

McKitrick When MRT-C is used to model 1990 stabilization, the welfare loss is about 0.5 percent, similar to McKitrick's finding of 0.8 percent if a carbon tax is not used to reduce factor taxes. This is probably the closest experiment to the assumptions used in this study.

MS-MRT Published results for "Other OECD" in Bernstein et al. (1999) are quite similar to the results presented in this study. Private communications suggest that the welfare losses and carbon taxes from the version of the MS-MRT model which identifies Canada are somewhat higher.[24]

DRI The Standard and Poor's DRI study has GDP losses for Canada of a similar magnitude to those presented here, but that study looks only at 1990 stabilization. It is difficult to compare the results of the models since the DRI model is macroeconometric in nature. In the DRI model, patterns of investment are endogenous and driven by (among other things) sectoral cash flows. As a result, the most heavily restricted sectors often expand in that analysis, potentially increasing GNP losses. Also, as pointed out in Bernstein et al. (1999), GNP and welfare estimates need not correspond.

Some limited sensitivity analysis of our core results is presented in Appendix D.

While the welfare and carbon tax results are sensitive to a number of parameters, a key parameter is the costliness of the carbon-free electric technology. A short summary is presented in Table 4.2. In the central case results, the backstop technology is assumed to have a 66 percent cost disadvantage over fossil fuels. If one could argue that such backstop technologies could come online for very close to the projected cost of fossil electricity, the costs of Kyoto would be even lower than 1 percent of GNP.

Table 4.2
Sensitivity to Backstop Technology

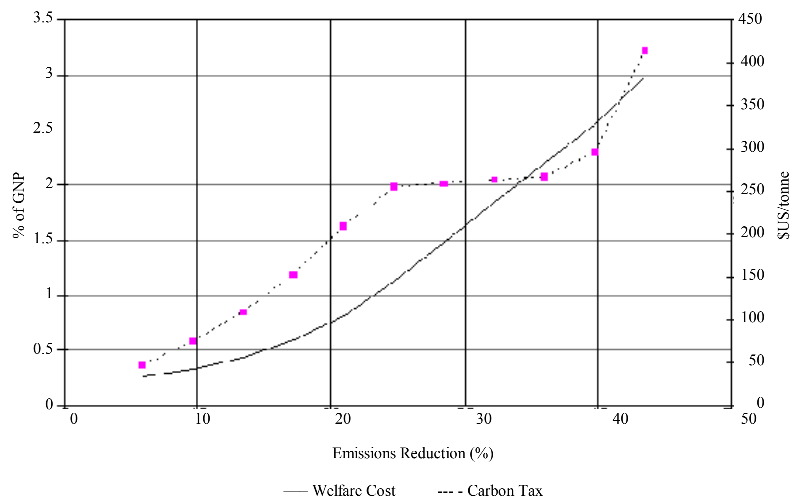
	Cost Disadvantage (%)		
	33.3	66.6	86.0
Canadian Welfare (%)	–1.01	–1.13	–1.13
Carbon Tax ($US)	186	255	279
Backstop Sector Share (%)	73.3	4.1	0

Other key parameters include the ease of substitution between fossil fuels, the ease of substitution of primary inputs for energy, and the trade elasticities. These trade elasticities determine the degree of competitiveness between domestic and foreign products.

4.1.1 Depth of Emissions Reduction

To give some sense of the relationship between the depth of emissions reduction, and the welfare costs and carbon taxes required, the model was used to evaluate alternative depths of emissions cuts in Canada. A curve relating emissions reductions to welfare costs and carbon taxes is described in Figure 4.1. In these experiments, all other Annex B nations are assumed to reduce emissions in line with the central case.

Figure 4.1
Welfare Cost and Carbon Tax



The figure shows that the welfare cost increases (at an increasing rate) as the percentage reduction from BAU emissions rises. The welfare cost hits 2 percent of GNP at a reduction of roughly 35 percent from BAU. Recall that the Kyoto target for Canada is to reduce emissions by roughly 25 percent.

Figure 4.1 also illustrates the important role of the backstop technology. Carbon prices reach $250 at roughly 25 percent emissions reduction and remain close to that level until the emissions reduction reaches 35 percent, after which the carbon price begins to rise quickly. It would seem that once carbon prices are high enough to bring the backstop technology on-line, subsequent abatement takes place through progressively replacing fossil fuel electric capacity with backstop capacity. Once there is no electricity generated using fossil fuels, further abatement must take place in other sectors at a progressively increasing marginal cost. Note also that the horizontal section in the carbon “price” curve corresponds to a linear section of the welfare cost curve.

4.1.2 Sectoral Effects

The sectoral effects of a "national" scheme are summarized in Table 4.3.[25] High-carbon energy products suffer the most significant reductions in output relative to BAU. Output of energy products and the most energy-intensive products typically fall about 5 percent.

The non-ferrous metals sector (NFM) expands slightly even though it is energy-intensive. The reason is that it is one of the sectors which has an energy-intensity advantage over both our major import competitor and export market. Even so, its output expands very modestly (0.07 percent).

Table 4.3
Canadian Sectoral Table for NCP
(percentage)

	Production	Employment	Energy	Exports	Imports
OMN	–3.89	–1.89	–14.45	–7.34	0.44
CRP	–7.40	–3.87	–21.03	–9.46	–0.26
I-S	–4.15	0.44	–19.61	–9.36	3.28
AGR	–5.20	–3.70	–20.89	–7.90	1.03
NMM	–0.67	1.41	–15.23	–0.25	0.21
LAP	–1.05	0.36	–12.90	–3.71	0.89
NFM	0.07	1.64	–12.76	0.05	–0.60
PPP	–1.28	0.00	–13.52	–1.16	–1.80
T-T	–1.10	–0.16	–14.25	–1.98	–0.88
GDT	–1.98	–0.65	–22.47	0.00	0.00
WTR	–1.27	–0.41	–16.40	0.00	0.00
TEX	–0.69	0.50	–13.56	–1.59	0.25
OSP	–0.63	–0.12	–13.06	0.39	–2.17
LUM	–0.20	0.64	–12.41	–0.06	–1.41
FRS	–0.56	0.43	–15.45	–0.23	–1.51
FMP	–0.95	–0.32	–14.80	–1.68	–0.50
OMF	0.17	0.69	–13.46	2.30	–1.63
CNS	–0.31	0.28	–14.97	0.00	0.00
PFD	–0.23	0.35	–14.26	1.95	–2.38
OTN	1.53	1.93	–11.46	3.10	–0.47
OSG	0.82	1.00	–13.69	7.12	–2.29
OME	0.83	1.23	–12.23	1.08	–0.81
ELE	2.26	2.58	–11.29	3.16	–0.94
LEA	2.65	2.97	–10.28	5.19	–1.26
MVH	0.05	0.74	–13.20	0.37	0.06
WAP	3.55	3.75	–8.99	13.94	–4.76
COL	–6.95	–7.20	–20.23	7.31	–54.44
CRU	–3.57	–3.87	–16.01	–5.76	–23.71
GAS	–7.62	–8.69	–22.44	8.85	–51.90
P-C	–9.53	0.41	–17.31	8.97	–25.01
ELY	–20.51	–11.23	–33.89	–55.38	0.00
NFE	0.00	–0.22	n.a.	n.a.	n.a.
BKS	7.35	n.a.	n.a.	n.a.	n.a.

The other private services sector (OSP) declines by about 0.6 percent. It is somewhat more energy intensive than the government services sector (OSG) which grows by roughly the same percentage. The least energy-intensive industrial sectors expand by 2–3.5 percent in the case of electrical and electronic equipment (ELE), other transportation equipment (OTN), and leather and apparel (LEA and WAP).

It is difficult to explain the exact size of all the sectoral impacts because of complex linkages between the sectors within a country and within a sector internationally. The pattern of sectoral impacts is in line with the intuition that energy-intensive sectors are likely to decline most in response to compliance without trading. Indeed, for each 1 percent increase in the cost share of energy in total cost, the reduction in sectoral output is likely to be higher by more than 1 percent.[26]

In some cases, energy-intensive sectors may not decline or may decline less if they have an energy-cost advantage over the corresponding sector in our major trading partners for that good. Often the major trading partner is the United States. Finally, non-energy intensive sectors will face two important influences. Some of the capital and labour freed up by declining energy-intensive sectors will become available to other sectors. At the same time, total demand for all goods is likely to decline as a result of falling incomes in Canada and most of our major trading partners.

These results differ from the results of the DRI model in that the energy-intensive sectors do not expand. In contrast to the DRI model, permit revenues in this model are returned in a lump-sum fashion to the region's representative consumer. As a result, there is no incentive to increase investment or expand productive capacity of the energy-intensive sectors that might receive a large amount of permits.

Exports of most energy-intensive goods fall, notably electricity, whose exports are reduced by over 50 percent. Imports of all fossil fuels also fall markedly. Exports of coal and natural gas rise. In the case of coal, the increase in exports is driven by declining demand at home. In the case of natural gas, the increase in exports is driven by expanded U.S. demand for gas (likely as a substitute for coal).

The sectoral effects in the electricity sector show that the output of fossil electricity falls by about 20 percent. Of that reduction in output, roughly one third (7 percent) is replaced by "backstop" electricity. The remainder (roughly 13 percent) is a decrease in the total production of electricity. Much of this decrease shows up as reduced exports.

4.1.3 Sectoral Exemptions

In this section, we restrict the domestic coverage of the carbon tax or permit scheme in a number of ways in line with our earlier discussion. In the context of greenhouse gas abatement, policy makers might want to focus efforts on the most energy-intensive sectors to reduce administrative costs of a permit scheme. On the other hand, energy sector interests might argue that it is unfair to burden energy-intensive sectors with "crippling taxes." A number of considerations might lead to domestic policies that depart from cost-effectiveness in a number of respects.

Four experiments are considered:

NPA Final demand in Canada is exempt from permits or carbon taxes. Policy measures apply only to intermediate use of energy in Canada. All other Annex B nations use cost-effective domestic policies.

NPB Restrictions (permits or carbon taxes) are imposed only on intermediate use of energy in energy-intensive industrial sectors. The sectors covered are:

I-S	Iron and Steel
CRP	Chemicals, Resins and Plastics
OMN	Other Minerals
ELY	(Fossil) Electricity
T-T	Trade and Transportation
PPP	Pulp, Paper and Publishing
NFM	Non-ferrous Metals
LAP	Livestock and other Products

Final demand (consumption and government) as well as all other intermediate uses are exempt in Canada. All other Annex B nations use cost-effective domestic policies.

NPC Restrictions (permits or carbon taxes) are imposed only on intermediate use of energy in the *most* energy-intensive industrial sectors. The sectors covered are:

I-S	Iron and Steel
CRP	Chemicals, Resins and Plastics
OMN	Other Minerals
ELY	(Fossil) Electricity

Final demand (consumption and government) as well as all other intermediate uses are exempt in Canada. All other Annex B nations use cost-effective domestic policies.

NPD Restrictions (permits or carbon taxes) are imposed only on intermediate uses of energy in *non*-energy-intensive sectors. The sectors covered are those not covered in the NPB case. Final demand (consumption and government) is not restricted in Canada. All other Annex B nations use cost-effective domestic policies.

The welfare and carbon tax impacts of these various cases are considered in Table 4.4. A number of observations emerge from comparing these alternative schemes. First of all, the welfare cost tends to rise with the degree to which emissions reductions are narrowly focused on a subset of sectors. The NPA, NPB and NPC cases could be seen as progressions on the same theme, namely, focusing abatement where emissions are concentrated. Initially (exempting final demand) this is not too expensive, but eventually costs get very high. It is worth noting that the costliness of these three restrictive cases would be much higher if the backstop technology was unavailable. In the current results, as non-energy-intensive sectors are progressively exempted, the backstop sector can expand, effectively providing additional abatement at constant cost to make up for the abatement no longer required in exempted sectors. If the backstop technology was unavailable, these costs are likely to be substantially higher.

Experiment NPD involves exempting the most energy-intensive sectors. In this case, a significant amount of abatement is required from non-energy-intensive sectors. The welfare cost is quite staggering. While few people would take carbon prices over $8,000 a tonne very seriously, the results flag the difficulties likely to be experienced when focusing very narrowly abatement efforts.[27] More likely, such restrictions would make the Kyoto targets unachievable.

Table 4.4
National Schemes with Sectoral Exemptions

Experiment	Welfare	Carbon Tax
	(%)	($US95/tonne C)
NCP	–1.1	255
NPA	–1.3	259
NPB	–1.7	271
NPC	–2.0	388
NPD	–7.5	8,192

Sectoral Impacts: Sectoral Exemptions

The pattern of sectoral impacts is dramatically altered as sectors are included or excluded from coverage. The sectoral impacts associated with various policy alternatives are presented in Table 4.5. As abatement efforts are progressively focused on the most energy-intensive sectors (NPA → NPC), we note that output of the most energy-intensive sectors eventually fall by up to 16 percent. The output of the least energy-intensive industrial sectors (which tended to rise in the standard NCP experiment) tend to rise less as abatement is progressively focused on the most energy-intensive sectors.

There is some experience with *exempting* pollution-intensive sectors from restrictions when it is felt that compliance would cripple the industry. This case is illustrated in experiment NPD, where all energy-intensive sectors are exempted from compliance. In that case the welfare cost of over 7 percent is quite a bit higher than the opposite extreme policy (NPC, where *only* the most energy-intensive sectors are subject to the policy). This is due, in part, to the presence of the backstop energy technology. If the most energy-intensive sectors are subject to restrictions, the adoption of the carbon-free electricity generating technology allows a significant amount of abatement to occur at around $US 250 per tonne of carbon.

If energy-intensive sectors are exempt, as in experiment NPD abatement available by using the backstop technology remains untapped. In that case, the most energy-intensive sectors are predicted to expand significantly. Recall that in this experiment we are assuming that our trading partners retain cost-effective regimes, so the cost of their energy-intensive goods is rising.

Finally, permit costs also rise as abatement efforts are focused more selectively. In the extreme case where all abatement is required of the non energy-intensive sectors of the economy, the carbon taxes are astronomical. This is true in spite of the fact that the model does have a backstop technology for generating electricity. The availability of backstop technologies will only contain carbon taxes if users have an incentive to adopt them. With the wrong pattern of exemptions, some available technologies will not be used.

A final observation is that exempting "final" uses of energy (Case A) from restrictions seems to have very little impact on welfare and the carbon price. The defining feature of final demand is that there is a lower degree of substitution possible between energy and other goods than in intermediate use. As a result, the abatement done in final demand in the NCP case is not extensive.

In the case where final demand is exempted (NPA), the pattern of sectoral impacts seems like a slightly amplified version of those under the cost-effective scheme (NCP). The sectors that decline most tend to decline even more and the sectors that expand most expand even more.

Table 4.5
Sectoral Reallocation Effects for Canada

	Sectoral Output Level (% Change)				
	NCP	**NPA**	**NPB**	**NPC**	**NPD**
OMN	–3.89	–4.75	–6.69	–8.09	14.97
CRP	–7.40	–8.35	–10.00	–16.08	12.09
I-S	–4.15	–4.46	–5.37	–11.93	15.37
AGR	–5.20	–5.82	0.43	0.02	–74.27
NMM	–0.67	–1.24	5.15	4.38	–56.34
LAP	–1.05	–1.60	–1.83	–0.32	–14.59
NFM	0.07	–1.08	–4.60	1.03	47.24
PPP	–1.28	–1.70	–2.91	0.31	11.91
T-T	–1.10	–1.36	–1.80	–0.77	0.00
GDT	–1.98	–2.37	–1.44	–2.04	–16.67
WTR	–1.27	–1.68	–1.59	–1.73	–10.36
TEX	–0.69	–1.08	0.78	0.04	–29.97
OSP	–0.63	–0.90	–0.85	–1.01	–7.98
LUM	–0.20	–0.05	2.21	2.49	–29.51
FRS	–0.56	–0.61	0.90	1.69	–23.40
FMP	–0.95	–1.13	–0.30	–1.67	–14.49
OMF	0.17	0.09	0.85	0.10	–13.71
CNS	–0.31	–0.32	–0.19	–0.22	–3.02
PFD	–0.23	–0.85	–0.85	–0.58	–15.59
OTN	1.53	1.43	1.37	0.16	1.36
OSG	0.82	0.54	0.20	–0.17	–3.56
OME	0.83	0.77	0.74	0.08	1.60
ELE	2.26	1.86	1.18	0.86	6.64
LEA	2.65	2.75	1.91	1.54	12.28
MVH	0.05	–0.40	0.73	–0.96	–22.60
WAP	3.55	3.33	2.83	2.53	4.03
COL	–6.95	–8.55	–6.67	–7.40	–62.08
CRU	–3.57	–3.74	–3.20	–3.11	–13.98
GAS	–7.62	–6.01	–4.98	–4.61	–7.04
P-C	–9.53	–7.91	–2.08	0.00	–51.49
ELY	–20.51	–53.17	–83.56	–100.00	7.58
NFE	0.00	0.00	0.00	0.00	0.00
BKS	6.75	36.93	66.93	82.85	0.00

The changes to the pattern of sectoral impacts associated with various schemes of sectoral exemptions are fairly closely linked with the nature of the exemptions. When carbon restrictions apply only to energy-intensive sectors (NPB), the sectors covered decline dramatically more than in the cost-effective case or the case where final demand is exempted. With very few exceptions, the other sectors either decline less or expand more than under the no-exemption (NCP) experiment.

When all abatement efforts are concentrated on the most energy-intensive sectors (NPC case), those sectors decline at least by 8 percent. Exempted sectors tend to decline less or expand more, in some cases dramatically. The most dramatic change is in the fossil electricity sector, which shuts down completely. Electricity is all generated by hydro or backstop technology. The backstop technology replaces over 80 percent of the fossil fuel sector's production.

In the final case of sectoral exemptions considered, the exemptions are reversed relative to the previous cases. Here the energy-intensive sectors are all exempted with predictable results. Most of the energy-intensive sectors now expand, with many non-energy intensive sectors declining. This, of course, complicates the task of reducing emissions.

4.1.4 Summary: National Schemes

This section considers the impact of a national carbon tax or permit scheme adopted simultaneously by all Annex B regions. The key findings are:

- The predicted welfare costs are modest when a cost-effective strategy (broad-based carbon tax or permit scheme) is adopted.

- The sectoral shifts implied by a cost-effective carbon tax scheme involve energy-intensive sectors declining most and those that are least energy intensive expanding somewhat. In some cases, sectors which are energy-intensive expand when they have a lower energy intensity than the corresponding sector in our major import or export market.

- Restricting application to a subset of sectors can raise compliance costs, in some cases markedly. At the same time, limiting abatement efforts to carbon emissions associated with intermediate use (versus also imposing restrictions on final demand) seems to have relatively modest effects.

- In the case where the energy-intensive sectors are exempt from carbon taxes or the requirement to obtain permits, these sectors expand for a number of reasons.

    - The user cost of fuels has been driven down by the taxes imposed on non-exempted sectors.
    - Since only Canada engages in this folly, Canadian exports of energy-intensive goods (primarily to Annex B markets) expand and imports fall.

The welfare costs are very high and estimated domestic carbon taxes stretch the imagination. Indeed, they probably signal that the Kyoto target would be unachievable with such restrictions.

- While the welfare costs rise less dramatically when carbon policies apply only to the most energy-intensive sectors, the result depends on the availability of a non-carbon backstop technology. Without it, the costs of achieving the Kyoto target are likely to be very high.

4.2 Global Permit Schemes

Moving to global trading of permits dramatically reduces the "carbon tax" that Canadians face, and the welfare costs fall to less than one half what they would be under a national scheme.[28] With global trading, the same global emissions reduction is achieved, but a greater share of the abatement takes place in non-Annex B countries, where the abatement cost is initially lower.

For Canada, the welfare loss from compliance is reduced from about 1.1 percent to about 0.5 percent (see table 4.6). Canada buys emission permits from countries that can reduce their emissions at a lower cost than Canada. Canadian emissions now fall only 7.5 percent rather than 25 percent in the case where all Canadian abatement was done in Canada. The welfare loss for the United States also falls to about half the cost with no permit trading. Japan's welfare gain is very small in percentage terms. This is because Japan is a significant net importer of energy, and while it is very costly to reduce domestic emissions, Japan is paying much less for its imports of fossil fuels. Note that with global trading, Japan and Europe do very little domestic abatement. Their emissions both fall by about 3 percent relative to the BAU scenario. The welfare losses experienced by the oil exporters (Mexico and OPEC) fall from $10 billion to under $4 billion with global trading. In their case, terms of trade losses figure prominently in their welfare effects, and these are reduced significantly under the global permits scenario.

Table 4.6
Summary Results for GCP

	Welfare Cost ($B)	Welfare Cost (%)	Carbon Emissions (%)	Carbon Price ($)
CAN	–3.05	–0.49	–7.51	45.79
USA	–25.00	–0.29	–10.29	45.79
JPN	–2.14	–0.05	–3.20	45.79
EUR	–13.90	–0.13	–2.75	45.79
OOE	–2.84	–0.64	–12.67	45.79
CHN	4.09	0.26	–15.95	45.79
FSU	9.86	2.15	–17.06	45.79
CEA	–1.37	–0.38	–11.50	45.79
ASI	2.32	0.15	–14.87	45.79
MPC	–3.92	–0.27	–10.33	45.79
ROW	0.41	0.01	–12.87	45.79
WLD	–35.55	–0.11	–11.25	45.79

The other aspect of some interest is the size and nature of trading that would occur. These results are summarized in Table 4.7. All OECD regions end up purchasing emissions permits. Canada buys about 35 MT of carbon permits. The volume of permit purchases by Canada and the United States is very similar to the Second Generation Model (SGM) estimates (MacCracken et al., 1999). China and the Former Soviet Union (FSU) each provide a large number of permits. Trading is in megatonnes of carbon (MT), prices are in $US per tonne, and value is merely the product of the first two in billions of $US.

Several regions that sell emissions permits (China, Former Soviet Union and Asia) experience a welfare gain with global trading. In the case of the Former Soviet Union, the gain is roughly 2 percent of GNP. This is partially explained by the fact that the FSU's emissions allowance is expected to exceed its 2010 BAU emissions. As a result, the FSU can sell significant permits without doing any abatement. This favourable emissions allowance is often described as "hot air."

Table 4.7
Carbon Policy Summary for GCP

	Trading MT	Value $B	Price $/TC
CAN	–35.15	–1.61	45.79
USA	–345.89	–15.84	45.79
JPN	–96.09	–4.40	45.79
EUR	–288.73	–13.22	45.79
OOE	–15.80	–0.72	45.79
CHN	251.16	11.50	45.79
FSU	261.59	11.98	45.79
CEA	–16.19	–0.74	45.79
ASI	113.70	5.21	45.79
MPC	75.08	3.44	45.79
ROW	96.32	4.41	45.79

4.2.1 Sectoral Effects

With global trading of carbon permits, Canadian energy-intensive sectors tend to contract, but the contraction is normally much more modest than in the previous case where all abatement was achieved in Canada. Compared to the case with no international trading of permits, sectoral energy intensity is much less correlated with sectoral performance.[29] With no international permit trading, each 1 percent increase in the cost share of energy is associated with a reduction in sectoral output that, on average, is more than 1.5 percent higher. With trading, the impact of a 1 percent higher energy share falls to less than 1/3 percent. The sectoral results for Canada under GCP are presented in table 4.8.

This change in the pattern of sectoral impacts is related to trading. As carbon restrictions are entered under a global permits scheme, nations can reduce emissions by shifting from carbon-intensive sectors to less carbon-intensive sectors, as well as by substituting other factors for energy in all productive activities.

From the Canadian perspective, producers of energy-intensive goods in non-Annex B regions experience an improved competitive position when only Annex B regions reduce emissions, as in the earlier experiment (NCP). In that case, the cost of Canadian carbon-intensive goods is rising and the “world” price of fossil fuels is falling. This leads to a reduced export market for Canadian goods and fiercer import competition, especially for carbon-intensive goods. Under a global scheme, both of these effects are dampened as non-Annex B producers also face higher energy input prices. Further, although Canadian energy-intensive goods tend to be more energy-intensive than U.S. goods, they are often less energy-intensive than goods produced in non-Annex B regions, leading to some possibility of expanding exports or reducing imports relative to the “national” implementation case.

Table 4.8
Canadian Sectoral Results for GCP
(percentages)

	Production	Employment	Energy	Exports	Imports
OMN	0.73	1.21	–1.78	–0.30	1.98
CRP	–0.91	–0.30	–4.92	–0.81	–0.14
I-S	0.65	1.54	–4.14	1.36	0.75
AGR	–1.07	–0.90	–5.57	–1.62	–0.05
NMM	0.87	1.19	–3.02	2.95	–1.12
LAP	–0.26	–0.11	–3.18	–0.79	–0.18
NFM	2.99	3.19	–0.33	3.61	0.71
PPP	–0.10	0.07	–3.11	0.11	–0.51
T-T	–0.31	–0.20	–3.53	0.20	–0.41
GDT	–0.35	–0.24	–6.58	0.00	0.00
WTR	–0.31	–0.25	–4.32	0.00	0.00
TEX	0.07	0.23	–3.10	0.55	–0.18
OSP	–0.21	–0.19	–3.18	0.89	–0.69
LUM	0.09	0.21	–2.81	0.25	–0.32
FRS	–0.06	0.07	–3.80	–0.78	0.02
FMP	0.60	0.67	–2.86	1.78	–0.43
OMF	0.92	0.97	–2.40	2.31	–0.57
CNS	–0.11	–0.04	–3.69	0.00	0.00
PFD	–0.10	–0.08	–3.59	0.90	–0.83
OTN	1.15	1.16	–1.94	2.38	0.04
OSG	–0.10	–0.15	–3.65	1.86	–0.86
OME	1.22	1.23	–1.92	1.66	–0.10
ELE	0.99	0.97	–2.23	1.46	–0.19
LEA	–0.05	–0.04	–3.01	0.29	–0.37
MVH	0.06	0.11	–3.17	0.14	–0.05
WAP	0.26	0.25	–2.56	1.90	–1.06
COL	–6.15	–7.08	–13.43	–4.74	–22.88
CRU	–1.35	–1.56	–4.81	–2.03	–3.83
GAS	–2.74	–3.29	–7.59	1.97	–17.58
P-C	–1.81	0.31	–4.25	3.76	–7.07
ELY	–2.67	–0.40	–8.61	–9.58	0.00
NFE	0.00	–0.17	n.a.	n.a.	n.a.
BKS	0.00	n.a.	n.a.	n.a.	n.a.

It is important to note that the change in the nature of the sectoral effects does not come from permit revenues being spent on investment in sectors that receive permits, as in the DRI (1997) results. Here, permit revenues are returned to the consumer in a lump-sum fashion, so that there is no incentive to increase investment expenditures in sectors with high entitlements to permits. While this treatment of revenues sounds strange, it could be consistent with "grandfathering," wherein firms in a sector are given an allowance of permits to use or sell. In that case, one could imagine the shareholders of the firm being the true recipients of the permits. The firm's managers, acting on the shareholders' behalf, should abate until the firm's marginal abatement cost equals the market price for permits. Thereafter, the managers should sell permits if they have any left over or purchase additional permits to cover their emissions in excess of their permit allowance. In the end, of course, the value of the permits given away effectively increases the consumer's income for that period.

4.2.2 Sectoral Exemptions

In this section, we consider similar exemptions but in tandem with unrestricted international trading of carbon permits. In the following experiments, sectoral exemptions are assumed to apply to all permit-*buying* regions. One experiment looks at divergences from cost-effectiveness on the part of seller regions.

Five cases are considered:

GPA Restrictions (permits or carbon taxes) are imposed only on intermediate use of energy and not on final demand (consumption and government) in all regions buying permits.

GPB Restrictions (permits or carbon taxes) are imposed only on intermediate use of energy in energy-intensive sectors. The sectors covered are:

I-S	Iron and Steel
CRP	Chemicals, Resins and Plastics
OMN	Other Minerals
ELY	(Fossil) Electricity
T-T	Trade and Transportation
PPP	Pulp, Paper and Publishing
NFM	Non-ferrous Metals
LAP	Livestock and other Products

Final demand (consumption and government) is not restricted. All Annex B nations comply using the same type of domestic scheme.

GPC Restrictions (permits or carbon taxes) are imposed only on intermediate use of energy in the *most* energy-intensive sectors. The sectors covered are:

I-S	Iron and Steel
CRP	Chemicals, Resins and Plastics
OMN	Other Minerals
ELY	(Fossil) Electricity

Final demand (consumption and government) is not restricted. This applies to all Annex B nations who buy permits.

GPD Restrictions (permits or carbon taxes) are imposed only on intermediate use of energy in *non*-energy-intensive sectors. The sectors covered are those not covered in the GPB case. Final demand (consumption and government) is not restricted. This scheme is adopted by all Annex B nations.

GPE Buyer regions do not exempt any of their sectors from compliance, but all seller regions exempt final demand. Further, to reflect problems associated with the case-by-case approach to project verification and other practicalities of implementation, seller regions "subsidize" purchases of carbon permits for intermediate use by 50 percent. This will have the effect of making some cost-effective abatement unattractive.[30]

Most notably, the sectoral restrictions seem to have very modest welfare effects in the presence of unrestricted global trading. The welfare effects of compliance with exemptions are, in most cases, very similar to those with no exemptions. The largest welfare effects are in permit-selling regions, which benefit from higher permit prices. The results for Canada under these various scenarios are presented in table 4.9.

It is also noteworthy, that, because the carbon taxes are so modest, they do not activate the backstop electricity technology in any of the global scenarios considered. Unlike several of the national experiments, the backstop technology is too expensive to be used.

Table 4.9
Overview: Restricted Domestic Policies with Global Trading

	GCP	GPA	GPB	GPC	GPD	GPE
Canadian Welfare (%)	–0.49	–0.46	–0.50	–0.52	–0.60	–0.67
Carbon Price ($)	45.79	52.51	55.05	56.70	57.57	69.75
Canadian Emissions (%)	–7.37	–6.35	–5.53	–4.46	–1.40	–10.49

Experiment GPE deals with a departure from cost-effectiveness by permit-selling regions. The idea is that the process of identifying appropriate "projects" for emissions trading is likely to be rather inefficient and that some projects that get approved are likely to be less cost-effective than others that are not approved. The 50 percent distortion introduced in the model might be considered small if CDM trading takes the form of project-by-project trading as some foresee. This problem was highlighted in Hahn and Stavins (1999). Nonetheless, the impact on welfare, carbon prices and sectoral effects are all relatively modest. Note that Canadian emissions reductions are higher under GPE because of the increased cost of permits.

Sectoral Effects: Sectoral Exemptions

The sectoral reallocation effects in Canada are presented in table 4.10. If exemptions are limited to the final users of energy, as in the GPA case, the sectoral effects are virtually identical to those of the cost-effective plan (GCP). When all non-energy-intensive sectors and final demand are exempted (case GPB), abatement is focused on the energy-intensive industrial sectors. In this case, the covered sectors decline more or expand less than under the cost-effective scheme (GCP). Every exempted sector (except Coal) experiences a smaller decline, or a larger increase in output. In processed foods, a small decline in output under GCP becomes a small increase under GPB. These changes relate directly to the change in coverage of the policy.

In experiments GPA to GPC, the electricity sector declines more than without sectoral exemptions. It appears that as abatement is progressively focused on the most energy-intensive sectors, output reductions get larger in the electricity sector and smaller in the primary fuels sectors (coal, natural gas and petroleum).

Table 4.10
Sectoral Reallocation Effects: Canada

	Sectoral Output Level (% change)					
	GCP	**GPA**	**GPB**	**GPC**	**GPD**	**GPE**
OMN	0.73	0.80	0.72	0.87	2.50	0.35
CRP	–0.91	–0.99	–1.58	–1.73	1.79	–1.89
I-S	0.65	0.64	0.34	0.21	3.70	–0.28
AGR	–1.07	–1.10	0.17	0.12	–1.63	–1.31
NMM	0.87	0.86	1.60	1.52	0.99	0.61
LAP	–0.26	–0.27	–0.24	0.03	–0.27	–0.22
NFM	2.99	3.11	2.93	4.12	5.24	2.99
PPP	–0.10	–0.13	–0.33	0.13	0.25	–0.14
T-T	–0.31	–0.32	–0.38	–0.19	–0.26	–0.41
GDT	–0.35	–0.35	–0.11	–0.12	–0.30	–0.59
WTR	–0.31	–0.31	–0.24	–0.21	–0.30	–0.46
TEX	0.07	0.06	0.52	0.39	–0.10	0.08
OSP	–0.21	–0.20	–0.13	–0.16	–0.37	–0.25
LUM	0.09	0.07	0.49	0.43	–0.33	0.16
FRS	–0.06	–0.09	0.20	0.24	–0.36	–0.05
FMP	0.60	0.59	0.89	0.79	0.91	0.47
OMF	0.92	0.95	1.33	1.24	1.06	0.90
CNS	–0.11	–0.11	–0.09	–0.09	–0.12	–0.15
PFD	–0.10	–0.11	–0.02	0.04	–0.37	–0.05
OTN	1.15	1.13	1.52	1.16	0.28	1.65
OSG	–0.10	–0.05	0.00	–0.08	–0.48	–0.03
OME	1.22	1.24	1.60	1.46	1.02	1.50
ELE	0.99	1.02	1.23	1.10	0.36	1.58
LEA	–0.05	–0.03	0.01	–0.12	–0.46	0.80
MVH	0.06	0.04	0.32	0.21	0.36	–0.04
WAP	0.26	0.29	0.41	0.23	–0.47	0.87
COL	–6.15	–6.37	–7.69	–7.65	–2.33	–6.87
CRU	–1.35	–0.88	–0.24	0.03	–0.87	–1.75
GAS	–2.74	–1.95	–1.13	–0.72	–0.97	–3.79
P-C	–1.81	–0.79	–0.42	0.60	–0.21	–2.72
ELY	–2.67	–4.02	–5.22	–5.81	0.91	–4.09
NFE	0.00	0.00	0.00	0.00	0.00	0.00
BKS	0.00	0.00	0.00	0.00	0.00	0.00

It is notable that exemptions have dramatically less impact on the sectoral adjustments that occur in the presence of global trading than in the national permit scenarios. In the GPD case, carbon restrictions only apply to non-energy-intensive intermediate use. In this case, all of the energy-intensive sectors except agriculture and livestock expand! Trading influences are contributing to these effects, since these sectors are subject to carbon restrictions in non-Annex B regions.

While sectoral exemptions alter the pattern of sectoral effects, these are still less dramatic with trading (cases GPA–GPD) than without trading (NPA–NPD). The world price of carbon tends to rise as restrictions are progressively imposed. The exemptions cause a further increase in demand for permits and a corresponding increase in the price of carbon. Abatement in Annex B countries is lower and abatement in non-Annex B regions is higher in experiments GPA–GPD than the unrestricted trading GCP case.

A key aspect of experiments GPA–GPD is that all Annex B regions are assumed to pursue the same policies. This reduces the likelihood that distortions will cause dramatic shifts in intra-Annex B trade and the resulting sectoral shifts.

4.2.3 Global Trading: Summary

In this section, we looked at the cost and consequences of Kyoto compliance with the possibility of global trading in emissions permits. A number of assumptions about Canadian (and Annex B countries) implementation were explored. The key conclusions are:

- International permit trading dramatically lowers the welfare cost of compliance and the permit cost or carbon taxes associated with it.
- The pattern and severity of sectoral impacts in Canada are quite different from those observed without permit trading, as energy-intensive sectors in non-Annex B cut back output (instead of expanding when compliance is restricted to Annex B countries).
- Sectoral exemptions to intermediate use in buyer regions have much less absolute impact on the cost of compliance with global trading. To some extent, this seems to suggest that one of the benefits of trading is to mitigate the cost of domestic policy errors.[31]
- Modest divergences of policies from cost-effectiveness by permit-selling regions are associated with relatively small welfare consequences. Seller regions benefit from higher permit prices.
- When sectoral exemptions are used without trading, the effect is to impose higher proportions of emissions reduction on those sectors that do need to comply. This raises the marginal cost of abatement (carbon taxes). By contrast, with global trading of emissions permits, a main impact is to reduce domestic abatement. In that case, the result is increased purchases of emissions permits.

5. SUMMARY AND CONCLUSIONS

This study has focused on the sectoral effects of Kyoto compliance and the impacts of various forms of sectoral exemptions.

If Canada's compliance must take place without international permit trading, the costs of compliance are only likely to be modest if domestic implementation is achieved through a cost-effective scheme. That is to say, a scheme with limited sectoral exemptions. If exemptions are too broad, or poorly designed, the welfare cost of complying with the Kyoto commitments is likely to be dramatically higher.

Global emissions trading reduces the expected welfare cost if the implementation is cost-effective. If, however, domestic implementation is *not* cost-effective, international emissions trading may reduce the *cost* consequences of non-cost-effective domestic implementation in Annex B regions. The contrast between the impacts of various domestic "exemptions" with and without trading is quite stark.
The drawback of sectoral exemptions with international emissions trading is not so much their increased cost, but the significant decrease in Canadian abatement that results.

In terms of sectoral effects, one of the important conclusions is that while the most energy-intensive sectors in Canada tend to decline with cost-effective domestic policies (with or without international emissions trading), the consequences are dramatically reduced (and in some cases reversed) with unrestricted global trading. When abatement is done without emissions trading, marked decreases in the activity level and emissions of Canadian energy-intensive sectors are required to reduce emissions in Canada. With global trading, the most serious output and emissions reductions take place in energy-intensive sectors abroad, leading to significant reductions in the production of these goods on the world market. With global trading, the effect of increased energy costs is often largely offset by reduced supply of foreign energy-intensive goods.

The research reported here suggests two main avenues for future research:

Asymmetric Sectoral Exemptions — When sectoral exemptions were considered under a national permits scheme, only Canada was assumed to grant exemptions. The exemption cases with global trading considered imply a symmetric pattern of divergences from cost-effectiveness by all Annex B regions. In other words, all Annex B regions adopted the same pattern of exemptions. It would be useful to analyse selected cases of interaction in the presence of different patterns of domestic exemptions in different buyer regions.

Departures from Cost-effectiveness — It would also be useful to consider cases where departures from cost-effectiveness occur in *both* buyer and seller regions. It seems unlikely that implementation in *buyer* regions will be perfectly cost-effective. It seems absolutely certain that implementation in seller regions *will not* be cost-effective.

APPENDIX A
DATA

Table A.1
Kyoto Regional Aggregation

CAN	Canada
USA	United States
JPN	Japan
EUR	Europe
OOE	Other OECD
CHN	China
FSU	Former Soviet Union
CEA	Central European Associates
ASI	Other Asia
MPC	Mexico plus OPEC
ROW	Other Countries
WLD	World

Table A.2
Kyoto Commodity Aggregation

AGR	Primary Crops and Fibres
LAP	Live Animal Products (includes Livestock, Wool and Fishing)
PFD	Processed Food
COL	Coal
CRU	Oil
GAS	Natural Gas
OMN	Other Minerals
FRS	Forestry
TEX	Textiles
WAP	Wearing Apparel
LEA	Leather Goods
LUM	Lumber and Wood
PPP	Pulp and Paper
P-C	Petroleum and Coal Products
CRP	Chemicals Rubber and Plastics
NMM	Non-metallic Mineral Products
I-S	Primary Ferrous Metals
NFM	Non-ferrous Metals
FMP	Fabricated Metal Products
MVH	Motor Vehicles
OTN	Other Transportation Equipment
ELE	Electronic Equipment
OME	Machinery and Equipment
OMF	Other Manufacturing Products
ELY	Electricity
GDT	Gas Manufacturing and Distribution
WTR	Water
CNS	Construction
T-T	Trade and Transportation
OSP	Other Services (private)
OSG	Other Services (public)

APPENDIX B
CENTRAL CASE PARAMETERS

This section reviews the central case elasticity configuration. The energy-substitution parameters are common across all regions.

Table B.1
Energy Substitution Parameters

	V
Substitution between fossil fuel types	0.50
Substitution between electricity and fossil fuels	0.30
Substitution between energy and primary factors	0.50
Substitution between energy and goods (final demand)	0.24

There are two "Armington" elasticities. ESUBDM is the elasticity of substitution between domestic goods and a composite of imports. ESUBMM is the elasticity of substitution between imports from different foreign sources. These elasticities of substitution are common across countries for a given sector.

ESUBVA is the elasticity of substitution between factors in the value-added nest. It is set at 0.2 for the sectors other than the primary fossil fuel sectors, and at 0.05 for the primary fossil fuel sectors. In the latter case, this elasticity is chosen to give an elasticity of supply of fossil fuels in the range of 0.6–1.0 in line with other studies. Table B.2 lists the standard values used in GTAP for trade elasticities and the GTAP standard elasticities of substitution between primary factors.[32]

In the central case presented here, all GTAP trade elasticities except those for Coal are used. In the case of coal, lower elasticities are used (1.2 and 2.4) to reflect the limitations imposed by distance on substituting between coal from different sources.

Table B.2
Sector-specific Parameters

	ESUBDM	ESUBMM	ESUBVA
AGR	2.20	4.40	0.20
LAP	2.79	5.45	0.20
PFD	2.38	4.69	0.20
COL	2.80	5.60	0.05
CRU	2.80	5.60	0.05
GAS	2.80	5.60	0.05
OMN	2.80	5.60	0.20
FRS	2.80	5.60	0.20
TEX	2.20	4.40	0.20
WAP	4.40	8.80	0.20
LEA	4.40	8.80	0.20
LUM	2.80	5.60	0.20
PPP	1.80	3.60	0.20
P-C	1.90	3.80	0.20
CRP	1.90	3.80	0.20
NMM	2.80	5.60	0.20
I-S	2.80	5.60	0.20
NFM	2.80	5.60	0.20
FMP	2.80	5.60	0.20
MVH	5.20	10.40	0.20
OTN	5.20	10.40	0.20
ELE	2.80	5.60	0.20
OME	2.80	5.60	0.20
OMF	2.80	5.60	0.20
ELY	2.80	5.60	0.20
GDT	2.80	5.60	0.20
WTR	2.80	5.60	0.20
CNS	1.90	3.80	0.20
T-T	1.90	3.80	0.20
OSP	1.90	3.80	0.20
OSG	1.90	3.80	0.20

Some limited sensitivity analysis of core results is presented below. SUBEV is the elasticity of substitution between the energy composite and the value-added composite. EVASHR is the share of energy that is allocated to the value-added nest rather than the intermediate inputs nest. CAPTY is the ratio of hydroelectric generating capacity in the 2010 BAU scenario to the benchmark hydroelectric generating capacity.

Table B.3
Region-specific Parameters

	SUBEV	**EVASHR**	**CAPTY**
CAN	0.20	0.99	0.92
USA	0.40	0.99	0.92
JPN	0.10	0.99	1.05
EUR	0.20	0.99	1.05
OOE	0.40	0.99	1.05
CHN	0.40	0.99	3.16
FSU	0.40	0.99	1.17
CEA	0.40	0.99	1.05
ASI	0.40	0.99	1.85
MPC	0.40	0.99	1.85
ROW	0.40	0.99	1.85

APPENDIX C
BAU SCENARIO

The BAU (business-as-usual) scenario is assembled in a relatively straightforward fashion. A region-specific growth factor reflecting 1995 (benchmark) to 2010 growth in the absence of carbon policy is applied to all primary factors in each region. The BAU growth factors between the benchmark data (1995) and 2010 are shown in Table C.1.

Table C.1
BAU Growth Factors

CAN	1.386
USA	1.427
JPN	1.228
EUR	1.504
OOE	1.370
CHN	2.390
CEA	1.450
FSU	1.200
ASI	1.740
MPC	1.740
ROW	1.740

These growth rates are applied in a neutral fashion: all endowments of primary factors are assumed to grow at this common rate. A quick summary of the BAU scenario which results follows. Done this way, the growth applies to sector-specific factors (resources and land) as well as those that are mobile between sectors.

Table C.2
Summary Table for BAU (BCH)

	Welfare ($B)	Welfare (%)
CAN	173.48	38.92
USA	2,611.76	43.29
JPN	855.24	24.03
EUR	3,495.43	50.70
OOE	122.94	38.05
CHN	897.37	127.10
FSU	81.44	21.54
CEA	112.93	45.57
ASI	653.32	71.87
MPC	608.24	70.18
ROW	1,307.69	73.02
WLD	10,919.83	49.29

C.1 Emissions

Once the new equilibrium has been achieved with these new factor endowments, CO_2 emissions are significantly higher than the IEA/NRCan (International Energy Agency/Natural Resources Canada) forecasts. As a result, the emissions are rescaled to exactly hit these targets by region and fossil fuel.[33]

The target emissions percentage growth between the benchmark and BAU case is presented in Table C.3.

Table C.3
Target Emissions Growth 1995-2010 (%) (IEA/NRCan)

	CAN	USA	JPN	EUR	OOE	CHN
COL	25.250	30.230	14.421	12.938	22.808	63.764
GAS	17.699	22.379	57.820	68.633	39.936	241.666
P-C	14.216	18.758	15.006	21.955	19.275	122.799
TOT	17.610	23.494	19.484	28.289	24.063	77.113

	FSU	CEA	ASI	MPC	ROW
COL	19.186	19.186	70.458	70.458	70.458
GAS	29.652	29.652	99.370	99.370	99.370
P-C	18.566	18.566	56.978	56.978	56.978
TOT	23.535	20.854	66.617	70.166	66.923

All figures are with respect to the 1995 benchmark. Values are in billions of 1995 U.S. dollars.

APPENDIX D
PARAMETER SENSITIVITY

D.1 Limited Sensitivity Analysis of NCP

A number of sensitivity cases were specified to investigate parameter sensitivity of the welfare and carbon price effects of Kyoto compliance. A brief description of the difference between the various sensitivity cases and the central case is presented in Table D.1.

Table D.1
Parameter Configurations

C-C	Central case
MRT	MRT values when known, otherwise C-C
GTP	Suggested values distributed with GTAP (otherwise C-C)
LEV	Elasticity of substitution between energy composite and value-added reduced to 0.1 from 0.4
LFF	Elasticity of substitution between fossil fuel types reduced to 0.1
LEF	Elasticity of substitution between the fossil fuel aggregate and electricity reduced to 0.1 from 0.3
LVA	Elasticity of substitution within value-added nest reduced to 30% of GTAP (high) values
LTR	Trade elasticities (import-domestic and between import sources) reduced to 50% of their initial value
HTR	Trade elasticities (import-domestic and between import sources) raised to 160% of their initial value
CBS	Cheaper backstop technologies are available: the backstop is only 33% more costly at benchmark prices than fossil electricity
HNF	Higher non-fossil generating capacity: non-fossil generating capacity (hydro plus nuclear plus wind, solar, etc.) is assumed to be 10% higher than the reference assumptions

Limited sensitivity results are presented in Table D.2. In the sensitivity cases LEV–HTR, the relevant parameters were altered from their central case values in the same way for all regions. It appears that key elasticities for these results are the elasticity of substitution between energy and value added plus the elasticity of substitution between fossil fuel types. Lowering the trade elasticities increases the Canadian welfare loss by almost 50 percent. Finally, reducing the cost disadvantage of the backstop technology (CBS) reduces the welfare cost of compliance noticeably.

Table D.2
Welfare Sensitivity Summary for NCP

	C-C	MRT	GTP	LEV	LFF	LEF	LVA	LTR	HTR	CBS	HNF
Canada	–1.13	–1.21	–1.05	–1.26	–1.24	–1.14	–1.20	–1.46	–1.01	–1.01	–1.10
United States	–0.60	–0.61	–0.47	–1.43	–0.64	–0.65	–0.64	–0.52	–0.62	–0.56	–0.60
Japan	–1.09	–1.09	–0.58	–1.12	–1.43	–2.31	–1.38	–0.80	–1.16	–1.04	–1.09
Europe	–1.21	–1.23	–0.71	–1.81	–1.37	–1.42	–1.44	–1.13	–1.23	–0.94	–1.21
Other OECD	–0.72	–0.99	–0.89	–1.41	–0.80	–0.71	–0.52	–1.07	–0.57	–0.99	–0.72
China	–0.39	–0.38	–0.18	–0.51	–0.45	–0.44	–0.61	–0.78	–0.27	–0.32	–0.39
Former Soviet Union	0.60	0.64	0.01	1.08	0.70	0.92	1.00	0.20	0.94	0.13	0.61
Central European Associates	–0.30	–0.41	–0.37	–1.10	–0.37	–0.32	–0.32	–0.33	–0.29	–0.48	–0.31
Other Asia	–0.24	–0.22	–0.08	–0.40	–0.25	–0.33	–0.30	–0.44	–0.19	–0.10	–0.24
Mexico plus OPEC	–0.72	–0.72	–1.09	0.08	–0.82	–0.44	–0.28	–1.94	–0.37	–0.99	–0.72
Other Countries	–0.06	–0.07	–0.17	0.04	–0.06	0.00	0.11	–0.27	0.02	–0.11	–0.06
World Total	–0.78	–0.79	–0.54	–1.17	–0.89	–1.01	–0.87	–0.81	–0.76	–0.69	–0.78

D.2 Limited Sensitivity Analysis of GCP

Some limited sensitivity results are also presented in Table D.3. The sensitivity cases considered are those described above in Table D.1. There are two key parameter changes for the Canadian welfare effects. Reducing the elasticity of substitution between energy and value added and the elasticity of substitution between fossil fuels increases the welfare loss to almost 1 percent of GNP even with trading.

Table D.3
Welfare Sensitivity Summary for GCP

	C-C	MRT	GTP	LEV	LFF	LEF	LVA	LTR	HTR	CBS	HNF
Canada	–0.49	–0.52	–0.47	–0.87	–0.59	–0.50	–0.50	–0.61	–0.44	–0.49	–0.49
United States	–0.29	–0.29	–0.24	–0.67	–0.34	–0.31	–0.31	–0.34	–0.27	–0.29	–0.29
Japan	–0.05	–0.04	–0.03	–0.11	–0.07	–0.07	–0.08	–0.05	–0.04	–0.05	–0.05
Europe	–0.13	–0.13	–0.11	–0.28	–0.17	–0.14	–0.15	–0.17	–0.12	–0.13	–0.13
Other OECD	–0.64	–0.72	–0.60	–1.15	–0.63	–0.64	–0.63	–0.81	–0.58	–0.64	–0.63
China	0.26	0.27	0.22	0.79	0.31	0.25	0.25	0.69	0.16	0.26	0.25
Former Soviet Union	2.15	2.14	1.69	5.51	2.60	2.35	2.42	2.55	1.94	2.15	2.14
Central European Associates	–0.38	–0.39	–0.30	–0.81	–0.42	–0.41	–0.44	–0.41	–0.37	–0.38	–0.38
Other Asia	0.15	0.15	0.15	0.46	0.12	0.14	0.12	0.34	0.09	0.15	0.15
Mexico plus OPEC	–0.27	–0.27	–0.40	–0.11	–0.48	–0.16	–0.09	–0.36	–0.24	–0.27	–0.27
Other Countries	0.01	0.01	–0.01	0.21	–0.03	0.02	0.05	0.03	0.01	0.01	0.01
World Total	–0.11	–0.11	–0.10	–0.17	–0.14	–0.11	–0.11	–0.11	–0.10	–0.11	–0.11

Increasing the trade elasticities makes it easier to substitute between domestic and imported goods. This causes the Canadian welfare loss to fall.

It is notable that the world total welfare loss is not very sensitive to these parameter variations, but that the distribution of the loss between regions is.

The most influential parameter for the carbon price is the elasticity of substitution between the energy composite and the value-added composite.

NOTES

1 The structure of the model used here (MRT-C) is similar to that of a static model developed by Glenn Harrison and Tom Rutherford for the analysis of the Uruguay Round. It also employs Tom Rutherford's GTAPinGAMS modelling system. To that extent, it has some similarities to, but should not be confused with the dynamic MS-MRT model used by Tom Rutherford and Charles River Associates. See Wigle, 1999.

2 See Center for Global Trade Analysis, 1998.

3 In other words, if there are no opportunities to purchase emission permits from other nations.

4 This is summarized in section 4.1.3.

5 See a summary of William Nordhaus' comments at http.//www.weathervane.rff.org/features/feature055.html.

6 In the U.S. Environmental Protection Agency's language, the "permits" are called Emission Reduction Credits or ERC's.

7 See Joskow et al., 1998.

8 See Tietenberg, 1985 or even the relevant sections of Tietenberg's current environmental policy text (Tietenberg, 1998).

9 See Bohringer and Rutherford, 1996.

10 See Hahn and Stavins, 1999.

11 See Howatson and Campfens, 1997.

12 Canada's Kyoto commitment is to reduce emissions by 6 percent from 1990 levels.

13 It should be noted that the DRI (Data Resources International) policy instrument is not cost-effective because of the way revenues end up being assigned.

14 The GTEM model is housed at the Australian Bureau of Agricultural and Resource Economics (ABARE). See Tulpulé et al., 1999.

15 Compare this with about 25 percent for the United States. See Tulpulé et al., 1999, Table 5, and Natural Resources Canada, 1997.

16 The cost shares were computed from the most corresponding GTAP sector.

17 The DRI specification assumes that the added profits generated by permit sales are split between dividends and retained earnings. The retained earnings are invested in the same sector.

18 See Wigle, 1999. The model documentation is available at: http:/www.kw.igs.net/~rwiglw/model.pdf

19 http://nash.colorado.edu/~tomruth/gtapingams/html/gtapgams.html

20 This means that the backstop electricity sector becomes profitable at about $US 250 per tonne of carbon.

21 The GTAP data has three untraded service sectors where the trade flows are zero by construction. These are WTR (water and utilities), GDT (gas pipelines and distribution) and CNS (construction).

22 By carbon intensity we mean the amount of carbon emissions produced per dollar of output. Similarly, the energy intensity is the value of energy inputs per unit of output.

23 A sector that consumes very little fuel could still have high effective energy input if it uses a lot of energy-intensive intermediate inputs.

24 The results compare with MS-MRT estimates of welfare losses for Canada closer to 2.5 percent and a carbon tax over $350.

25 In all the sectoral tables that follow, non-fossil electricity (NFE) is distinguished from electricity generated using fossil fuels (ELY) and electricity generated using the backstop technology (BKS). Since these three goods are assumed to be perfect substitutes, the exports and imports are reported in the ELY row. The changes in production reported correspond to that sector only. In the case of the backstop electricity sector, the change in production is expressed as a percentage of the initial production of fossil energy.

26 A least-square curve fitted to the observed sectoral output effects and the sectoral energy shares explains about half of the variation of the sectoral effects around their mean.

27 If we extended the ill logic far enough, it's easy to understand infinite carbon taxes for the no-trading case. This would result if we required all of Canada's abatement target to be achieved by the Canadian feather duster industry.

28 The size of the welfare losses under domestic compliance relative to those under global trading depends on the parameter specifications.

29 A least-square curve fitted to the observed sectoral output effects and the sectoral energy shares in this case explains less than 20 percent of the variation of the sectoral effects around their mean.

30 The intention of this formulation is to model divergences from cost-effectiveness in the seller region's responses, rather than restricted international trading as foreseen in recent European proposals.

31 These experiments differ from the corresponding "National" experiments in that it is assumed that all Annex B regions adopt similarly distorting policies. One possibility that warrants attention is if different Annex B regions adopt different sets of exemptions in the presence of global trading.

32 Capital, labour, skilled labour, resources and land.

33 In terms of the precise modelling, the benchmark and BAU carbon emissions play no role. There are enough permits available so that their value is zero. As a result, it is possible to rescale them at that point to hit an arbitrary target. Further, it is possible to rescale them by fuel type and region to hit emissions forecasts by fuel source and region.

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