Implementing the Kyoto Agreement Using Tradable Permits: The International Context for Canada

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ABSTRACT

This paper considers tradable emissions-permit schemes in four contexts. They are designed to uncover the advantages and disadvantages are of various permit-trading scenarios for Canada.

Using a framework that allows us to fully account for the financial transactions that accompany permit trading, we examine the effect that abatement and trading has on a number economic measures (both over the short and long term). Abatement, for example, leads to important direct effects on both consumers and firms while trading causes changes in interest rates and exchange rates. Both these phenomena will affect consumption and investment activity.

These repercussions lead to some important lessons that come from the scenarios analysed. These include: first, that summary measures of the effects of the Kyoto Protocol such as the impact on real GDP can be misleading in terms of providing information regarding the overall impact of the Protocol on the Canadian economy. Second, that some of the most important effects on the Canadian economy come from actions undertaken by our trading partners (most notably the United States); that is, if Annex B countries implement the Protocol, our economy will be adversely affect whether or not Canada implements. Third, that as a net exporter of fossil fuels, Canada will be disadvantaged relative to other economies in terms of the impact on GDP; however, the cheap sources of coal and natural gas imply that marginal abatement cost is likely to be lower than that in other economies. Fourth, that the terms of trade will move against Canada in response to GHG abatement policies in other countries. Finally, that a global permit-trading regime can mitigate the impact of the Protocol on Canadian GDP but on a broader scale it is not clear that emissions trading will have a large impact on the Canadian economy.

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RÉSUMÉ

Dans ce document, les régimes de permis d'émissions échangeables sont envisagés dans quatre cadres distincts, de façon à dégager les avantages et les inconvénients de différents scénarios en matière d'échange de droits d'émissions.

À l'aide d'un modèle permettant de prendre pleinement en compte les opérations financières rattachées aux échanges de droits d'émissions, nous examinons les effets de ces échanges et des réductions d'émissions connexes sur différentes mesures économiques (à court ainsi qu'à long termes). Ainsi, les réductions d'émissions auront des effets directs importants sur les consommateurs et sur les entreprises, tandis que les échanges auront une incidence sur les taux d'intérêt et les taux de change. Tous ces effets se feront sentir sur l'investissement et sur la consommation.

À la lumière de ces conséquences, il est possible de tirer des leçons importantes de l'analyse des différents scénarios envisagés. D'abord, les outils de mesure condensée des effets rattachés au Protocole de Kyoto, par exemple les effets sur le PIB réel, peuvent être trompeurs lorsqu'on veut savoir quelles seront les répercussions globales du Protocole sur l'économie canadienne. Ensuite, certains des principaux effets sur l'économie canadienne seront attribuables à des mesures prises par nos partenaires commerciaux (en particulier les États-Unis) – autrement dit, si les pays désignés à l'annexe B s'acquittent de leurs obligations aux termes du Protocole, notre économie s'en ressentira, peu importe que le Canada prenne lui-même des mesures conformément au Protocole. De plus, en tant qu'exportateur net de combustibles fossiles, le Canada sera en situation de désavantage par rapport à d'autres économies au plan de l'incidence de la mise en œuvre du Protocole sur le PIB; par contre, l'existence de sources peu coûteuses de charbon et de gaz naturel signifie que le coût marginal de réduction sera sans doute moins élevé que pour d'autres économies. Également, les termes de l'échange évolueront en défaveur du Canada par suite de la mise en œuvre de politiques de réduction des GES dans d'autres pays. Enfin, un régime d'échange de droits d'émissions à grande échelle pourrait atténuer l'incidence du Protocole sur le PIB canadien; toutefois, dans une perspective plus large, il n'est pas certain que les échanges de droits d'émissions auront de fortes répercussions sur l'économie canadienne.

Executive Summary

Since the signing of the Kyoto Protocol in 1997 much work has been done to study which implementation options would lead to an efficient implementation of the commitment undertaken by Canada. This paper considers tradable emissions permit schemes, which many observers believe are an efficient instrument that is likely to minimise the overall impact on industry and consumers.

The permits are examined in four contexts which are designed to uncover the advantages and disadvantages are of various permit-trading scenarios for Canada.

Since tradable permits establish a property right that must be paid for when they are transferred, it will be important to understand the consequences of financial flows. This will be especially true in a global trading system where the value of the permits might lead to very large capital transfers between countries. In the work reported in this paper we are able to fully account for the financial transactions that accompany permit trading and the effect that those transactions have on consumption and investment behaviour (both over the short and long term). As such, our results incorporate not only the effect of permits in changing the marginal cost of abatement to firms, but also indirectly in changing interest rates and exchange rates.

The scenarios examined in this paper consist of:

- a setting where all Annex B countries implement the Protocol but no permit-trading between countries occurs;
- a setting where Canada alone implements the Protocol;
- a setting where all Annex B except Canada implement (with globally tradable permits);
- a setting where all Annex B including Canada implement (with globally tradable permits).

As is evident from this list, we provide a complete accounting of the international context for Canada of GHG abatement. While some of these scenarios are purely pedagogic, they nonetheless provide valuable insight into the effect that Canadian policy will have on the Canadian economy, versus the effect of our trading partners' policies on our economy.

Each of the scenarios outlined above will involve complex inter-relationships that need to be sorted out in order to understand the impact of any policy. For this reason we have undertaken the analysis primarily through a general equilibrium global model. The model we use is G-cubed. It was developed at the Brookings Institution and has been expanded to include an explicit representation of the Canadian economy.

The important lessons that come from analysing the scenarios with this model are as follows:

- Summary measures of the effects of the Kyoto Protocol such as the impact on real GDP can be misleading in terms providing information regarding the overall impact of the Protocol on the Canadian economy.

- Some of the most important effects on the Canadian economy come from actions undertaken by our trading partners (most notably the United States). If Annex B countries implement the Protocol, our economy will be adversely affect whether or not we implement.

- As a net exporter of fossil fuels, Canada will be disadvantaged relative to other economies in terms of the impact on GDP. However, our cheap sources of coal and natural gas imply that our marginal abatement cost is likely to be lower than that in other economies.

- The terms of trade will move against Canada in response to GHG abatement policies in other countries.

- A global permit-trading regime can mitigate the impact of the Protocol on Canadian GDP. On a broader scale, however, it is not clear that emissions trading will have a large impact on the Canadian economy.

The remainder of this paper provides the analytical foundation for these comments.

I. Introduction

The international agreement on greenhouse gas emissions (GHGs) that was negotiated in Kyoto in December of 1997 (the Kyoto Protocol) called on countries to make very strong reductions in emissions between 2008 and 2012. The recognition by its signatories that a badly managed implementation of those reductions could have significant adverse impacts on their domestic economies led many to reinvigorate their analysis of potential options. Fortunately the Protocol left open – indeed, encouraged – the possibility of international cooperation in finding low-cost sources of abatement. As a result, the disruption to individual economies may be mitigated by transferring abatement requirements to regions of the world which have lower cost.

One mechanism for facilitating such an outcome is an internationally tradable permit for emitting GHGs into the atmosphere. Such a permit can be viewed as a restricted *right* to emit a predetermined quantity of GHGs[2]. This paper will look at the use of a permit scheme as a policy instrument for widespread implementation of GHG reductions. We will look at the effect it might have on the Canadian economy as well as that of our major trading partners. Our analysis will assume that the permits are auctioned annually by a central government who requires that they be surrendered at the end of the year. Full compliance is assumed so wherever emissions occur there will be a permit to account for the source. In cases where permits are exchanged, it is assumed that trading occurs on a firm-to-firm basis without transaction cost.

The concept of a tradable permit traces its roots back to Dales[3] who noted that once a property right (e.g., a permit) to pollute had been established, a competitive market would balance both harm and benefits from pollution in the price of the permit. That is, the price of a restricted number of permits – when available to all individuals – would reflect a balance between the social harm done by the pollution and the social benefit of the goods produced through that pollution. Such a permit was soon shown, under broad circumstances, to be similar in its effect to an equivalent Pigouvian levy on pollution. The reason for this was that with both instruments (a levy or a permit), a firm would face a given marginal cost for a specific activity – which would induce a behavioural change in a profit maximising firm.

The behavioural change comes about because the firm finds itself with a new vector of relative input prices (as a result of the permit requirement). In the case of permits to emit greenhouse

[2] The restrictions may be in many forms – from specifying the rate at which emissions occur to the place, time and transferability of emissions.

[3] Dales, J.H. (1968), *Pollution, Property and Prices*. Toronto: University of Toronto Press.

gases (GHGs) from the combustion of fossil fuels, those fuels would increase in price and any products made using fossil fuels would also become more expensive. Firms using such products must then decide whether to: (*a*) reorganise activities so as to use less fossil fuels with existing capital and labour inputs; (*b*) invest in technologies that require less fossil fuels; and/or (*c*) use some of their capital and labour to abate emissions. In other words, there will be a private optimisation process that will occur within the firm in response to the input-price change. The extent to which this reorganisation occurs will depend on the price at which the firm can purchase permits from other firms. A profit maximising firm will continue to make internal changes up to the point at which the cost of the last action is exactly equal to the cost of acquiring a permit from external sources. Since all firms are simultaneously undergoing the same process, a tradable permit has the feature that the cost of the last unit of carbon dioxide abated is equal across all firms – irrespective of their location or the products they produce (assuming an absence of market failures). With global trading this outcome is extended to all firms in all countries participating in the scheme.

When a firm purchases a permit to emit GHG's, the payments to other factors must be diminished – given that it can not simply pass along the cost. This has the effect of reducing the value of the firm's physical capital, as well as the human capital of its employees. The firm's owners will be affected since the value of their wealth will have changed with the value of firm's capital. A tradable permit scheme, therefore, has effects on: (1) the consumers of a firm's output (through increasing prices); (2) the firm's owners; and (3) the firm's employees. Within a country, this transfer of resources will lead to movements of capital and labour between industries.

Among countries, however, there will be a number of additional effects. First, the return to capital will be affected. In some of the scenarios examined below, foreign investors have an incentive to withdrawn from investments in Canada. This will lead to a fall in the exchange rate and ultimately to a change in trade patterns. Second, Canadians may save more in response to an initial loss of income. This can result in less borrowing from abroad and a lower level of long term indebtedness – domestic consumption may be higher than it otherwise would be in the long run. When a permit is tradable between countries, the transfer of resources between countries will *in and of itself* cause repercussions apart from the effect of a reorganisation of production and consumption; that is, the money that pays for the permits will generate changes in exchange rates since the sellers will use much of their additional income to purchase local goods (they will be selling the foreign currency they receive). This will, again, lead to changes in trading patterns. Moreover, if the sellers do not spend their income immediately but instead invest it for the long term, then the effect of the transfer may linger indefinitely in the form of income from increased foreign asset holdings.

When a permit is not tradable, differences in abatement costs between countries will nonetheless lead to important differential effects – each economy's "energy costs" will be affected by differing amounts. These differences again lead to changes in the relative price of imports and exports. In addition, the impact of the policy on aggregate demand in foreign economies will lead to changes in their demand for Canadian goods through a reduction in income: trading patterns will also be affected as a result of actions undertaken abroad.

To restate, the international context of a policy regime matters in a variety of important ways. This paper will attempt to elucidate some of the reasons why that might be so, as well as reporting on the relative magnitudes of those reasons. We will do so by examining domestic policy in the following contexts:

- a setting where all Annex B countries implement the Protocol but no permit-trading between countries occurs;
- a setting where Canada alone implements the Protocol
- a setting where all Annex B except Canada implement (with globally tradable permits);
- a setting where all Annex B including Canada implement (with globally tradable permits).

In the presentation of the results of these analyses we will focus on explaining the outcome for the Canadian economy and only tangentially outline their effects in other economies. To understand the relative impacts of climate change policy in Canada vis-à-vis that of trading partners, three factors weigh heavily on the results. These consist of:

- the cost of fossil fuels in Canada before the Protocol is implemented;
- the degree to which fossils fuels can be replaced as sources of energy (e.g. in electricity production);
- the contribution of fossil fuel extraction and processing to the Canadian economy.

The analysis illustrated in the remainder of this paper is undertaken with an economic model that was developed at the Brookings Institution primarily by Warwick McKibbin and Peter Wilcoxen, with contributions from a number of other researchers. Of relevance to the foregoing discussion is the fact that the models parameters (e.g., substitutability of fossil fuels) are estimated using data from 1961 to 1995. In other words the responsiveness of industrialised economies to the oil price shock of the early 1970's underpins the analysis we report regarding future changes in energy prices. Following some comments in the next section on the structure and empirical basis for the model, we will discuss the results in more detail.

The remainder of this study is organised as follows. In the next section (II) we provide a broad description of the economics underlying the model. We will also outline important features of the Canadian region of the model. Section III will then present and discuss the previously mentioned scenarios. These will be organised into a series of international cases which attempt to establish an international backdrop to domestic policies. The final section (IV) provides a brief overview of the implication of these results along with some concluding remarks.

II. The G-cubed Model[4,5]

The economics of the results that follow can be better understood by having some background into the model and its underlying principles. To provide that information we will now describe the theoretical structure of the model and present some estimated parameters that underpin that structure.

The model that will be used in this analysis is G-cubed. It has now been expanded to include an explicit representation of the Canadian economy. G-cubed is a dynamic general equilibrium model of the world economy that captures many of the inter-linkages that are important in examining the repercussions of policy between trading partners. It is particularly strong in representing capital flows between countries that result from differential policy initiatives. It is, therefore, ideally suited to looking at tradable permits on domestic and international scales.

G-cubed represents all economies to a 12-sector disaggregation. The energy producing part of each economy is modelled by 5 sectors and the carbon emission intensity of output for all 12 industries can be reported. By requiring all sectors that use fossil fuels to purchase a permit, the model can capture the effects of a tradable permit scheme on industries in the economy.

Table I shows the goods and services that are produced by firms in the model. We can see that there is more disaggregation in the energy sectors than there is in other parts of the model – evidence that the model was developed with the intention of examining climate change issues. The last sector (Services), for example, accounts for more than 50% of the economy.

Table I. Sectors of G-cubed

Energy	
	Electric Utilities
	Gas Utilities
	Coal Mining
	Oil&Gas Extraction
	Oil Refining
Non-energy	
	Agriculture
	Forestry and Wood Products
	Mining
	Durable Manufacturing
	Non-durable Manufacturing
	Transportation
	Services

[4] The description of G-Cubed given in this section is similar to that given in McKibbin, W. J. and P. J. Wilcoxen (1999), "The Theoretical and Empirical Structure of the G-Cubed Model", *Journal of Policy Modelling*.

[5] The version of G-cubed used in this analysis features a Canadian region that has been modified substantially to correct for peculiarities in the data. It also treats household durables in all countries differently from the original model.

G-cubed is also an international model that includes a specification of the economies of each of the world's regions. All countries that are represented in the model produce and consume the same number of goods and services, and each has similar macroeconomic institutions. In table II we outline the regions that are included in this version of the model.

Table II. Regions of G-cubed
Canada
United States
Japan
Australia
Other OECD
China
LDCs
Oil Exporting Developing Countries
Eastern Europe and the former Soviet Union

The model is flexible and more regions can be represented. However, the computing requirement grows non-linearly with additional regions: since each region has a similar structure and all regions potentially trade in all goods, the addition of another economy creates a non-linear increase in the number of inter-linkages that must be accounted for. Furthermore, each additional economy will require the same level of detail in the database and parameters as other economies, increasing the burden to collect meaningful data.

With this introduction to the sectors and regions of the model we now outline the components that are particularly relevant for this analysis.

Households

Households purchase goods and services annually from the firms that are represented in the model. They also demand labour and capital services. The capital services are derived from a service flow from consumer durables (including residential housing) while labour services are derived from unincorporated private agents (household maids, etc). Households receive income by providing labor services to firms and the government, and from their holdings of financial assets. They may also receive transfers from their government.

Within each region household behaviour is modeled by a representative agent with an intertemporal constant elasticity of substitution (CES) utility function. They derive pleasure from consuming the privately provided goods and services (those listed in table I) as well as from publicly provided ones. The representative consumer is assumed to have a slight preference for current consumption over future consumption[6]. The household maximises its

[6] The specification in the model imposes the restriction that household decisions on the allocation of expenditure

utility subject to an income constraint. Since the household has the ability to plan its consumption profile over time, the income constraint is based on current and future income. This implies that the present value of consumption must be equal to the value of human wealth plus initial financial assets. Human wealth is equal to the present value of the future stream of after-tax labor income and transfer payments received by households. Financial wealth in the model is represented by the sum of:

(1) real money balances,
(2) real government bonds in the hands of the public,
(3) net holdings of claims against foreign residents (including tradable permits),
(4) the value of capital in each sector.

The well-known result of this specification is that the value of each period's consumption is equal to the household's wealth times its rate of time preference.

Casual observation suggests that not all households can be represented in this manner because many individuals cannot borrow fully against their future income. Indeed, empirical evidence given by Campbell and Mankiw[7], and others, lends credence to that observation. It is, therefore, assumed that only a portion of consumption is determined through the foregoing specification. The remainder is determined by after-tax current income; i.e., some consumers are constrained to consume from current income rather than purely from wealth. Total consumption is thus a weighted average of the forward-looking based consumption and backward-looking based consumption.

The supply of household capital services is determined by consumers themselves who buy durables in order to generate a desired flow of services. It is assumed that the services provided by consumer durables are a constant proportion of the productive value of stock. As in the industry investment model (to be discussed below), investment in household capital is subject to adjustment costs.

Production

Each producing sector is represented by a single representative firm which uses inputs of capital (K), labour (L), energy (E) and materials (M) to produce one of the outputs listed earlier in table I. The firm is assumed to maximise profits which are defined as the return to invested capital (in the model this is analogous to choosing its level of investment in order to maximize its stock market value). The relationship between the firm's KLEM inputs and its output can be represented by a constant elasticity of substitution (CES) function. The energy and materials inputs are composites of 5 energy goods and seven material goods. A CES function also represents the relationship between the five energy goods that make up the energy composite and the seven material goods that make up the material composite.

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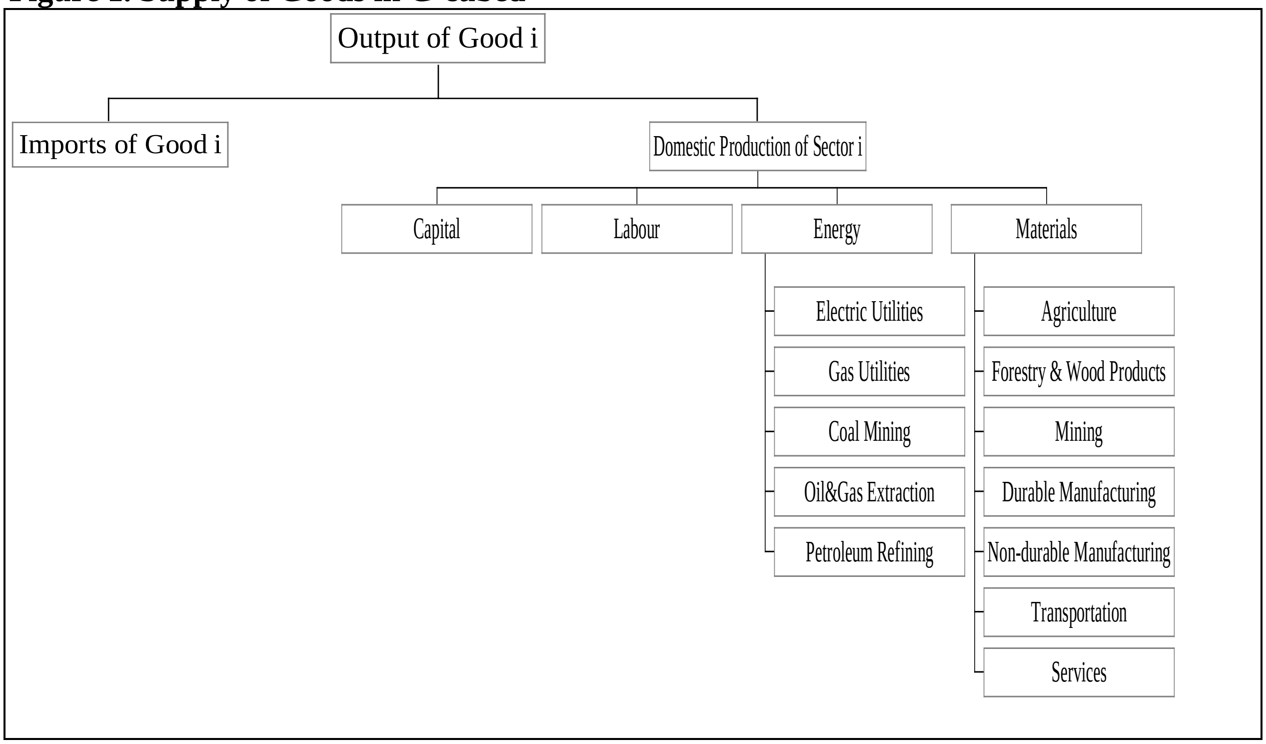
among different goods at different points in time be separable.

[7] Campbell, J. and N. G. Mankiw (1990), "Permanent Income, Current Income and Consumption." *Journal of Business and Economic Statistics*, Vol. 8, No. 2, pp. 265-79.

The solution to the firm's maximization problem gives demands by the firm for each of the twelve outputs produced in the economy, as well as capital and labour services. Since some of the inputs used by domestic firms may be coming from foreign sources, two additional levels of detail are included: domestic and imported inputs of a given commodity are imperfect substitutes, and imported products from different countries are imperfect substitutes for each other. Thus, the final decision the firm must make is the fraction of each of its inputs it will buy from each region in the model (including the firm's home country). This decision is represented using a two-tier CES function, although in this version of the model unitary substitution elasticity has been imposed for most sectors. The complete supply of a good or service in the model can be summarized as show in figure I.

Figure 1. Supply of Goods in G-cubed



All agents in the economy are assumed to have identical preferences over foreign and domestic varieties of each particular commodity.[8] This decision is parameterised using trade shares based on aggregations of 4-digit United Nations SITC data for 1996. The result is a system of demand equations for domestic output and imports from each region.

In addition to buying inputs and producing output, each sector must also choose its level of investment. Capital is assumed to be specific to each sector and investment is subject to

[8] Anything else would require time-series data on imports of products from each country of origin to each industry, which is not only unavailable but difficult to imagine collecting.

adjustment costs. The capital stock in each sector, therefore, changes by the amount of gross investment less depreciation of existing capital.

Following the cost of adjustment models of Lucas[9] and others, the investment process is subject to a rising marginal cost of installation. To formalise this it is assumed that in order to install *J* units of capital the firm must buy a quantity of investment goods that is proportional to the square of *J*.

The solution to the firm's investment problem gives an equation for investment that depends on taxes, the size of the existing capital stock and marginal *q* (the ratio of the marginal value of a unit of capital to its purchase price).

As with consumers in this model, casual observation suggests that this purely forward-looking specification of investment is not appropriate for all firms. Following Hayashi[10], the investment function is thus modified to improve its empirical properties by specifying investment as a convex combination of optimal investment and the firm's current profit (capital income). Investing from current profits is consistent with the notion that some firms are limited in their ability to borrow and, therefore, invest purely out of retained earnings.

In addition to the twelve industries discussed above, the model also includes a sector that produces capital goods. This sector supplies the new investment goods demanded by other industries. Like other industries, the investment sector demands labour and capital services as well as intermediate inputs. This is represented using a nested CES production function with the same structure as that used for the other sectors. The parameters of this function are estimated from price and quantity data for the final demand column for investment.

Government

Each region's real government spending on goods and services is assumed to be exogenously allocated among final goods, services and labor in fixed proportions (using 1996 values). Total government spending includes purchases of goods and services plus interest payments on government debt, investment tax credits and transfers to households. Government revenue comes from sales, corporate, and personal income taxes, and by issuing government debt. For the version of the model used in this analysis it was assumed that revenues from any increases in taxes are redistributed lump sum to consumers. In the simulations reported in subsequent sections, this assumption of an unchanged debt path has important implications. Since some consumers are assumed to be income-constrained, a general redistribution of income will have a stimulative effect on the economy. Therefore, a permit scheme in which disbursement occurs through an auction will, in the short run, imply a smaller loss of consumption and GDP than under a non-constant debt scenario.

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[9] Lucas, R.E. (1967), "Optimal Investment Policy and the Flexible Accelerator," *International Economic Review*, Vol. 8, No.1, pp. 78-85.

[10] Hayashi, F. (1979), "Tobin's Marginal q and Average q: A Neoclassical Interpretation." *Econometrica*, No. 50, pp. 213-224.

Government bonds in the model have value because the government commits to paying interest on outstanding debt (agents in the model are assumed not to hold the government's debt without this commitment). This is imposed in the model through a transversality condition on the accumulation of public debt. In principle, this condition has the effect of ensuring that the stock of debt at each point in time is equal to the present value of all future budget surpluses from that time forward. In practice it is implemented by requiring a change in lump sum taxes that is equal to the change in interest payments that must be made on the debt.

Trade and Capital Flows

The eight regions in the model are linked by flows of goods and assets. Flows of goods are determined by bilateral import demands (described above as an Armington specification between domestically produced goods and their foreign counterparts). These demands are summarized in a set of bilateral trade matrices which give the flows of each good between exporting and importing countries. There is one 9 by 9 trade matrix for each of the twelve sectors (for each country).

Trade imbalances are financed by flows of assets between countries. Since foreign assets are ultimately held by consumers in each country, trade imbalances imply a transfer of wealth between counties. Asset markets are, by assumption, perfectly integrated across the OECD regions. As such, expected returns on loans denominated in the currencies of the various regions are arbitraged to equality across regions in each period. More commonly, this is known as an uncovered interest parity condition. The model does, however, allow for risk premia to exist between various currencies but they are exogenously set and, therefore, do not factor into any outcomes of counterfactual analysis.

For the non-OECD countries the exchange rates are free to float at an annual frequency. Capital is also freely mobile within those regions, and between the non-OECD regions and the rest of the world. This may appear to be overly simplified especially when many developing countries have restrictions on short term flows of financial capital. The experience of some east-Asian countries during 1998, however, would suggest that the free-flow of capital is a reasonable approximation of capital flow outside the OECD. Moreover, the capital flows in the model are, by definition, equal to the change in the current account and so incorporate both flows of short term financial capital as well as foreign direct investment. In many countries with constraints on financial instruments there are nonetheless significant flows of direct foreign investment responding to changes in expected rates of return that need to be captured.

When international trade in permits is allowed, it figures prominently in the international flow of financial capital. They are, in effect, claims on the output of the countries that purchase the permits. In G-cubed permits are assumed to be acquired by domestic firms from foreign ones. Whether those permits are purchased from current profits or the stream of future profits, they ultimately affect the asset holdings of the owners of the firm. Since the country whose firms are buying permits will have to purchase them from foreigners, consumers in the purchasing country will experience a reduction in net foreign asset holdings (recall that foreign assets are ultimately held by consumers). For the country selling the permits, there will be an equivalent increase in foreign assets. Moreover, since foreign assets represent holdings of wealth, this change in net wealth will only affect current consumption in both countries by the change in the return on those assets. More succinctly, if Russia is allowed to sell permits for the difference between its emissions in 2008-12 and its Kyoto commitment (“hot air”), Russian consumers are not assumed to immediately spend all of that money on foreign or domestic goods.

Labour Markets

Labour is perfectly mobile among sectors within each region but is not mobile between regions. The result is that wages will be equal within regions across all sectors. The nominal wage is assumed to adjust slowly according to an overlapping contracts model where nominal wages are set based on current and expected inflation and on labour demand relative to labour supply. In the long run labour supply is given by the exogenous rate of population growth, but in the short run the hours worked can fluctuate depending on the demand for labour. For a given nominal wage, the demand for labour will determine short-run unemployment.

Canadian Region

The Canadian region was parameterised using data for 1960 to 1995. To accomplish this we begin by deriving estimable equations from the theoretical constructs in the model and then obtaining the data that matches the model’s conceptual underpinning.

As was outlined earlier, each industry in G-cubed is described by three production functions. At the top level in the nesting is a four-factor production function using capital, labour, energy and materials (KLEM). It can be represented by:

$$Q = A_O \left(\sum_{j=K,L,E,M} \delta_j^{1/\sigma_O} X_j^{(\sigma_O - 1)/\sigma_O} \right)^{\frac{\sigma_O}{(\sigma_O - 1)}} \tag{1}$$

Where Q is output, X is the factor input, σ is the elasticity of substitution, δ is a distribution parameter and A is a scale parameter.

The energy and material inputs in equation (1) are composites of five energy and seven material goods, respectively. For the energy composite we have:

$$X_E = A_E \left(\sum_{j=1}^{5} \delta_j^{1/\sigma_E} X_j^{(\sigma_E - 1)/\sigma_E} \right)^{\frac{\sigma_E}{(\sigma_E - 1)}} \tag{2}$$

And for the material composite we have:

$$X_M = A_M \left(\sum_{j=1}^{7} \delta_j^{1/\sigma_M} X_j^{(\sigma_M - 1)/\sigma_M} \right)^{\frac{\sigma_M}{(\sigma_M - 1)}} \qquad (3)$$

Estimable equations for the energy and material composites (i.e., equations (2) and (3)) take the form:

$$\ln(s_i) = \ln(\delta_i) + (\sigma - 1)\ln(A) + (1 - \sigma)(\ln p_i - \ln p_o) \qquad (4)$$

Where p_o is the price of the composite output and p_i is the price of the input whose share is represented by s_i . This equation shows that for estimating the elasticity of substitution we need only know input prices, output prices and factor shares.

For the output node we have to account for the short-term inflexibility of capital. Using Sheppard's Lemma we can derive an estimable form of equation (1) with a fixed factor as:

$$X_j = \delta_j p_j^{-\sigma} \delta_k^{\frac{1}{\sigma - 1}} X_k \left((p_o A)^{1-\sigma} - \sum \delta_i p_i^{1-\sigma} \right)^{\frac{\sigma}{1-\sigma}} \qquad (5)$$

Notice that we now also need to have a measure of capital in each sector. Equations (5) and (4) can give parameter estimates for all sectors in the supply side of the model.

The data for estimating equations (5) and (4) for each industry were compiled primarily from Statistics Canada's L-level IO tables[11]. These tables are available in a consistent form from 1960 to 1995. To obtain price data we divide nominal matrices by the constant dollar matrices. To obtain data on capital stocks we used both the Capital Stocks and Flows series from Statistics

Table III: Estimated Elasticities

	KLEM	Energy	Materials
Electric Utilities	0.56 (.09)	0.93 (.12)	0.55 (.15)
Gas Utilities	0.26 (.12)	0.12 (.10)	2.51 (.41)
Petroleum Refining	0.03 (.01)	0.05 (**)	0.61 (.08)
Coal Mining	0.05 (**)	0.05 (**)	0.64 (.14)
Oil&Gas Extraction	0.30 (.05)	0.36 (.13*)	0.10 (.33)
All Mining	0.52 (.09)	0.13 (.10)	0.90 (.13)
Agriculture	0.44 (.11)	0.46 (.14)	0.08 (.17)
Wood	0.61 (.07)	0.61 (.05)	0.53 (.07)
Non-durable Man.	0.75 (.01)	0.25 (.13)	1.15 (.09)
Durable Man.	0.06 (.03)	0.26 (.11)	0.18 (.06)
Transportation	0.36 (.06)	0.33 (.08)	1.06 (.21)
Services	0.31 (.05)	0.15 (.05)	1.37 (.30)

* Imposed value (estimated directly from natural gas use)
** Imposed value (estimation gave insignificant parameter)

[11] The mapping from the L-level tables to the sectors in the model is available from the author.

Canada as well as a procedure that allocated National Balance Sheets data to individual industries through investment expenditures in the IO tables. Both capital series gave similar results. The estimation procedure used non-linear maximum likelihood for both nodes. The results of the estimation are given in Table III with standard errors reported in brackets. The first column gives the elasticity estimated from equation (5) for each industry while the next two columns give the elasticity from equation (4) for the energy and materials nodes for each industry.

An adjustment was made for the Oil and Gas Extraction industries because the IO tables under-report their own use of natural gas (the IO tables report marketed transactions but much of the natural gas used in that industry is non-marketed). For Oil and Gas Extraction, we used a substitution elasticity estimated directly for natural gas (0.36) rather than the one obtained from the procedure of the preceding paragraphs (0.55)[12]. Moreover, using the lower value allows us to qualify our results as being pessimistic regarding the effects of those policies in Oil and Gas Extraction.

Background Information

In Appendix A we have included a discussion of issues of relevance to our main research results. These include: coverage of sources of GHG emissions; fugitive emissions; and Russian “Hot Air”. Before reporting model results we briefly summarise the discussion in Appendix A.

Coverage

Emissions in the model cover only those from fossil fuels. Non-combusted fossil fuels are covered but only to the extent they are used as inputs into the production of goods and services (i.e., carbon for metallurgical purposes). This implies that 81% of emissions GHG emissions are covered in terms of CO_2 equivalents (i.e., approx. 138 Mt of carbon in 1995). It also includes approx. 2% of emissions that are officially listed as 'fugitive' because they are used by upstream oil and gas extractors for production and distribution.

Fugitive Emissions

The treatment of fossil fuel production in G-cubed results in some fugitive emissions being accounted for within the model, while others are not. Environment Canada (1997) reports fugitive emissions from Upstream Oil and Gas as 58Mt of CO_2 equivalents in 1995. This figure is comprised 23% of stripped CO_2 from natural gas and 22% of combusted natural gas by the industry for production. The remaining 55% consist of methane emissions from oil and gas production (1.6Mt of methane by weight) – vented or leaked.

The fact that the model omits some fugitive emissions can affect the results in two ways. First, it means that the cost of implementing the agreement is underestimated. The extent of underestimation depends on how costly it would be to reduce fugitive emissions, or how much

[12] Both estimates are within two standard errors of each other so they are statistically indistinguishable.

emissions from fossil fuel combustion must be reduced to compensate for the lack of abatement of fugitive emissions.

The omission of some fugitive emissions will lead the model to underestimate the impact of a tradable permit scheme on the upstream oil and gas industry, but only if permits would be required for fugitive emissions. At the moment, it does not appear to be practical to impose a permit requirement on fugitive emissions from oil and gas extraction, so the results reported here should be unbiased. If a permit requirement was imposed on fugitive emissions from oil and gas extraction, the costs reported here for the upstream oil and gas industry would be underestimated by about 30%.

Russian "Hot Air"

To deal with issues in the availability of permits from the Former Soviet Union we have used a supply curve for Russian "Hot Air" developed by Jae Edmonds of the US Department of Energy's Pacific Northwest Laboratories. In many of the international scenarios reported below (with trading of emission rights) the supply of permits from Russia and other Eastern European countries reduces the combined abatement by Annex B countries by almost half in 2008.

III. Model Results

We now use the G-cubed model to present results for the cases listed earlier. The first set of results will attempt to identify international interactions by considering scenarios of similar coverage in a number of international settings.

Case I. *Canada Goes-it-Alone*

We begin by examining a case where Canada undertakes an abatement policy but no other country follows suit. While this case is intended to be purely pedagogic, it highlights a number of issues that are important for a small open economy.

The policy is announced in 2004 (in a fully credible manner) and reduction targets are implemented from 2008. Purchasers of petroleum products, including refineries and extractors, as well as purchasers of coal and natural gas are required to have a permit for the carbon content of the fuel they use. Overall, Canada is assumed to abate emissions by an average of 25% during the years 2008-2012 relative to business as usual (BAU)[13].

Since agents in the model are forward-looking, assumptions regarding policy in a post-Kyoto period must be made. For this scenario the analysis assumes that at the end of the Kyoto period carbon emissions will continue to be priced indefinitely at the permit value that resulted for 2012.

[13] Overall, Canada is assumed to abate emissions by an average of 25% during the years 2008-2012 relative to business as usual (BAU).

We assume that the permit for carbon emissions is imposed at the point where a fossil fuel is being used. In the case of natural gas and coal, this means that whoever purchases the output of the extracting industries will be required to have a permit. In the case of petroleum, the permit is required by the purchasers of refined petroleum products. Applying the permit at this level implies that the crude oil, natural gas and coal that are exported will escape the permit requirement but imports of all these products will be covered. Domestic oil and gas extractors, however, will also be required to have permits for their own use of oil and gas.

Table IV shows the permit value for each year of the Kyoto period and the resulting reduction in GDP, GNP and private consumption relative to BAU[14]. Recall that GDP accounts for the domestic production of goods and services while GNP reports GDP less the net income accruing to foreigners from their holdings of Canadian assets.

When the policy is put in place there is a desire by foreign investors to move money out of Canada (the return on capital will be adversely affected). This causes a depreciation in the Canadian dollar and leads to an improvement in the trade balance – offsetting some of the negative repercussions. This then leads to reduced payments to foreigners and higher domestic consumption relative to GDP – as we see in the results for GNP and private consumption. This is seen even more clearly in appendix B where we show the long run results. In sum, the observed difference between GDP, GNP and consumption is largely a result of international capital flows induced by the policy.

Table IV. Case I - General Results for 2008-12

	Permit value Carbon ($1996)	GDP (% Change)	GNP (% Change)	Private Consumption (% Change)
2008	$96	-0.39	-0.38	-0.64
2009	$97	-0.71	-0.68	-0.92
2010	$100	-0.76	-0.71	-0.91
2011	$101	-0.73	-0.66	-0.82
2012	$104	-0.69	-0.60	-0.72

We turn briefly to some of the details about how the abatement program affects energy prices and usage. As is evident in table V (next page), the bulk of abatement is undertaken through reduced coal use. The most obvious implication of this result is that electricity production will move away from coal-based technologies.

It is also interesting to note that refined petroleum plays a rather minor part in the abatement regime, its price rises by about 15% and its use falls by 9%. Since the results are for an average of all petroleum products, the price of gasoline will actually increase by less than the 15% indicated in the table.

[14] Private consumption is approximately 55% of GDP. Since Canadians also consume government provided services, this is not a precise measure of the reduction in total consumption.

Table V. Case I - Prices and Abatement in 2008.

	Price Change To Producer	Price Change To User	Change In Use	Reduction in Carbon (%)
Refined Petroleum	-2%	15%	-9%	-22.5
Coal	-40%	127%	-77%	
Natural Gas	-3%	29%	-15%	

The economics underlying these relative effects on coal and gasoline are that energy from coal is cheap in comparison to energy from gasoline (energy from coal is actually cheap in comparison to other oil products and natural gas as well). When a fixed price increase is imposed on energy from various sources, the cheapest source will see the largest percentage increase and therefore give the largest response (assuming a given demand elasticity). The current structure of energy supply in Canada is such that consumers of refined petroleum products are likely to be least affected by the Kyoto Protocol when the policy is economy-wide and based broadly on emissions from the fuel source. This is in part due to the fact that refined petroleum products already have significant taxes in the final product price. It is, however, also due to the fact that petroleum products have considerable value-added by the time they reach consumers. A given price increase for the carbon content of a fuel should imply a smaller percentage increase for a fuel with higher value-added.

It should be noted that the structure of the oil and gas extraction sector of the economy that is assumed in the baseline of the model is similar to that of 1996. This means that approximately 26% of oil production is from oil sands. Since current projections call for the output of that sector to be 50% by the year 2010, this industry appears to be misrepresented in the model. Two factors, however, mitigate this apparent misrepresentation. First, since the unit cost of production is in the range of $14 (Canadian) per barrel[15] for existing operators, a $29 per barrel base price that is assumed in the model still leaves considerable margin for covering fixed costs. For example, assuming that on average 25% of emissions[16] per barrel of non-conventional oil occur at extraction, the $96 per tonne of carbon permit-price given in table IV for 2008 implies a $2.74 increase in cost to the producer. Unit costs would (all else equal) increase to $16.74 whereas revenue would remain at roughly $29 per barrel. The second factor that mitigates the misrepresentation is that the technology for producing oil from oil sands is improving more rapidly than is assumed in the model. The baseline of the model assumes that emissions per barrel produced remain constant, but recently developed technological improvements will reduce emissions in planned expansions as well as in existing facilities. Syncrude, for example, projects that between 1997 and 2008 energy-saving technologies will allow them to reduce emissions by about 22% per barrel of oil produced. Since the conventional oil being displaced by oil sands also had emissions associated with its production, the increase in emissions from the shift to oil sands may not be as large as expected. Indeed, NRCan’s projection of emissions from oil and gas production only shows a 20% increase between 1995 and 2010 (only a little higher than what is in the baseline of the model).

[15]See Syncrude’s financial statement for 1997.

[16]*A Report on Crude Oil Life Cycle Analyses for Syncrude Canada*, T.J. McCann and Associates, 1998.

In the data given in appendix B (Table B.I) it is shown that private consumption recovers following the initial decline and eventually returns above baseline. By 2016 consumption is above baseline and remains there indefinitely. The explanation for this phenomenon is that when Canada undertakes this policy without its trading partners, the rate of return on capital begins to fall and foreigners invest less than they otherwise would. As a result, domestic savings is increased relative to domestic investment (both fall relative to baseline but *net foreign savings* rise) and in the long run Canadians consume more of the goods produced domestically. This occurs because service payments on foreign debt will be reduced (from baseline). It is important to note that this does not imply that the economy is better off as a result of this policy. People's preferences are such that they would rather consume more now instead of well into the future. The fact that the policy changed the time profile of consumption and production in the economy without reducing deadweight losses necessarily implies that consumers are worse off.

Case II. *Everyone but Canada*

In this scenario all countries except Canada are assumed to undertake an abatement policy. We have changed the baseline assumption to allow for trading of permits between all other Annex B countries. Since each country applies the abatement policy to imports and exports of coal, petroleum products and natural gas, as well as domestic consumption, the substantial effect that occurs in Canada arises from terms of trade and aggregate demand effects. Since Canada is a net exporter of fossil fuels and energy intensive products, the terms of trade move against us as a result of abatement policies imposed abroad. We see in table VI that the movements in the terms of trade are indeed large. The implications of this change are twofold: (1) relative to case I, consumption is only partially affected – it falls by about 10% less in the previous case – because the value of that physical output falls relative to the foreign goods that we consume; (2) the changes in GDP are only one third as large since there is a relatively small reduction in the physical output (real GDP) of the economy, caused by the small contraction of foreign demand for Canadian products. As a result, the real value of consumption contracts more than the physical output of the economy.

An improvement in the trade balance once again leads to weaker effect on GNP – though this time capital flows result from the trade effect rather than visa-versa.

The central message from this analysis is that, for Canada, movement by the industrialised countries to implement the Kyoto Protocol will be costly with or without our participation.

Table VI. Case II - General Results for 2008-12

	GDP (% Change)	GNP (% Change)	Consumption (% Change)	Terms of Trade (%Change)
2008	-0.16	-0.13	-0.54	-1.32
2009	-0.11	-0.07	-0.48	-1.40
2010	-0.13	-0.09	-0.51	-1.45
2011	-0.16	-0.13	-0.55	-1.51
2012	-0.19	-0.17	-0.60	-1.56

These results suggest that participating in the implementation of the Kyoto Protocol should be viewed not as "business-as-usual versus the effects implementing the Protocol", but rather as the results of table VI versus participating in the Protocol. The next cases will outline implementation scenarios for Canada and Annex B countries against which the results of table VI should be compared to help determine the incremental cost to Canada of implementing the Kyoto Protocol.

It is interesting to note from appendix B (Table B.II) that emissions in Canada actually increase in response to non-participation. This occurs because the cost of fossil fuels fall for firms and consumers (reduced demand elsewhere lowers the world price of oil and gas) which leads them to increase their use of these inputs. In other words, not participating in the Kyoto Protocol would nonetheless require Canada to undertake some abatement if it were to decide to at least avoid increasing emissions relative to BAU.

***Case III**. No Annex B Trading*

We now examine the case where all Annex B countries participate in implementing the Kyoto Protocol but they do so without the use of the Kyoto flexibility measures. Each country individually seeks to achieve its abatement target as specified in appendix A.

Table VII. Case III - General Results for 2008-12

	Permit value Carbon ($1996)	GDP (% Change)	GNP (% Change)	Consumption (% Change)	Terms of Trade (% Change)
2008	$115	-0.64	-0.59	-1.32	-1.78
2009	$113	-0.91	-0.84	-1.51	-1.59
2010	$113	-0.99	-0.91	-1.51	-1.43
2011	$113	-1.01	-0.92	-1.47	-1.31
2012	$115	-1.01	-0.91	-1.42	-1.21

As table VII illustrates, the burden on Canada of the abatement program is much larger than when none of the other Annex B countries participated. One reason for this, of course, is that there will be a general reduction in economic activity amongst trading partners concurrent with the domestic disruption caused by the abatement policy.

As in the earlier analyses, an important channel through which an abatement policy would work is in the terms of trade for Canada -- causing a significant impact on private consumption. The fact that GNP falls by less than GDP also implies that Canada's trade balance has improved. Underlying this improvement in the trade balance is a sharp reduction in imports that occurs when consumption decreases. In other words, international capital flows can be important even when there is no international trading of emission permits.

In table VIII we present some comparative results for other countries. Notice that the cost of abatement varies significantly from country to country. This suggests that the gains from trading in abatement opportunities are potentially large for most countries. Given that this is a dynamic model, the differences between consumption and output in 2010 should not be attributed solely to terms of trade effects.

Table VIII. Case III - Comparative Results for 2010

	GDP (% Change)	GNP (% Change)	Consumption (% Change)	Permit Prices (US$ 1996)
USA	-0.57	-0.55	-0.13	USA: $55
Japan	-0.20	-0.25	0.18	Japan: $139
Australia	-2.62	-2.46	-1.05	Australia: $175
Canada	-0.99	-0.91	-1.51	Canada: $79
ROECD	-1.44	-1.41	-1.40	ROECD: $242

One reason why permit prices vary so much across countries in this case is that each country has different energy prices before the Protocol is implemented. These differences are particularly important in the context of a general equilibrium analysis where consumption and production are represented by functional forms with smooth curvature. For example, if production technologies allow for moderate substitutability away from fossil fuels (e.g., an elasticity of substitution of 0.3), then a low baseline price for fossil fuels would imply that a relatively small *absolute* increase in price could induce a substantial movement away from fossil fuels. In the Canadian context this is best seen in the price of coal. The average cost of energy from coal is approximately $1.05 per petajoule. A price of $20 per tonne of CO_2 for tradable permits would imply a cost increase of approx. $1.70 per petajoule, representing an increase of 162%. With an elasticity of 0.3 we would expect the $20 per tonne permit to result in a 50% reduction in coal use[17].

To appreciate how variable energy prices are across countries we show in table IX the cost of energy relative to the United States. Notice that in Canada the relative cost of natural gas and coal are low.

Table IX. Relative Energy Costs

Relative to US	**Canada**	**France**	**Germany**	**Japan**
Gasoline[a]	1.3	3.1	3.2	3.0
Diesel[a]	1.4	2.3	2.1	2.0
Light Heating Oil[b]	--	1.5	1.1	1.7
Heavy Fuel Oil[b]	1.2	1.3	1.3	2.1
Natural Gas (to industry) [a]	0.6	1.3	1.6	3.3
Coal	0.5[c]	1.4[d]	--	2.5[d]

[a] 1996, Source: EIA (2000), http://www.eia.doe.gov/emeu/international/prices.html
[b] 1999, Source: EIA (2000), http://www.eia.doe.gov/emeu/international/prices.html
[c] 1995, Source: NRCan
[d] 1995, Source: IEA (1997), Coal Information.

[17] Notice that some studies have called for a price of $130 per tonne of CO_2 for Canada (implying a 1053% change in coal prices) to achieve overall reductions of 25% of CO_2 emissions: Charles River Associates, September 1999, *Analysis of the Impact on the Canadian Upstream Oil and Gas Industry of the global Implementation of the Kyoto Protocol*.

The substitutability of fossil fuels in different countries is more difficult to illustrate succinctly since a number of factors must be accounted for. In Canada, however, analyses such as those undertaken with the MARKAL model[18] suggest that in the long run there is considerable flexibility in switching between sources of energy. For other countries, surveys such as that by Hawdon[19] also suggest that energy should not be treated as fixed in proportion to the economy's output.

The terms of trade move substantially in Japan's favour and that country actually experiences an increase in consumption. For Canada and Australia the effects on GDP are disproportionately large given the permit price. This occurs because both countries are important producers of fossil fuels and so they can expect to experience both a reduction in aggregate demand from the policy as well as a reduction in their productive capacity.

Case IV*. Full Annex B Trading*

We now turn to the case where trading of permits amongst Annex B countries is allowed. The intention – and result – of this scenario is to equate marginal abatement costs across all firms in all countries. In the case just presented, the marginal abatement cost was sufficiently different between countries that we could expect large gains from trade. As well, total emissions of Annex B countries would be higher under full trading, because that part of Russia's allowable emissions that went "unused" in Case III is fully exploited in this case.

Table X. Case IV - General Results for 2008-2012.

	Permit value Carbon ($1996)	GDP (% Change)	GNP (% Change)	Consumption (% Change)	Financial Flows ($m,1996)
2008	$57	-0.51	-1.30	-1.15	-$771
2009	$63	-0.68	-1.61	-1.37	-$904
2010	$68	-0.76	-1.74	-1.49	-$944
2011	$74	-0.80	-1.80	-1.59	-$948
2012	$80	-0.83	-1.82	-1.66	-$927

Table X shows that in some respects the gains from a trading regime are surprisingly small for Canada as a whole despite the fact that marginal abatement costs are reduced almost in half during the first year (the amount of abatement undertaken domestically is approximately 14% – versus 23% in the non-trading case). The cost to Canada of purchasing the emission rights from other countries is almost a billion dollars annually. Most of the permits Canada purchases are from the former Soviet Union region which supplies Annex B countries with permits for 510 Mt

[18] See Loulou, R., and A. Kanudia, 1998, The Kyoto Protocol, Inter-Provincial Cooperation, and Energy Trading: A Systems Analysis with integrated MARKAL Models, GERAD discussion paper: G-98-42, University of Montreal.

[19] Hawdon, D. (1992), *Energy Demand: Evidence and Experience*, Surrey University Press, Toronto.

of carbon in the year 2008 – out of total emissions of 1013 Mt for that year. The net effect of purchasing permits rather than undertaking the abatement ourselves is that the loss of GDP is reduced – on the order of 20% in 2008. However, since the payment for the permits shows up in GNP, there is a substantial reduction in Canadian GNP – more than 120% larger in 2008.

As was mentioned earlier, the international trading scheme implemented in G-Cubed (and used in this scenario) is one where an auction is simultaneously held in all participating countries. Firms purchase permits and a process of arbitrage between countries ensures that one price holds for all permits. Those permits that were purchased from foreigners result in a transfer of funds between countries – changing their net foreign asset (NFA) holdings. This change in foreign asset holding is reflected in the discrepancy we see in table IV between GNP and GDP.

As was also mentioned earlier, foreign assets are ultimately held by consumers (the owners of the firms) so these transactions affect the wealth holdings of domestic individuals. For the country that is selling the permits the transaction increases their wealth holdings. Since consumers in both countries derive consumption from income (i.e., return on labour income and assets), the effect will be to increase consumption in the selling country and decrease it in the purchasing country. However, this increase/decrease will be equal to the rate of return on assets. In other words, the working assumption in implementing this scheme is that Russians who sell the permits invest the money and consume the interest.

We show in figure 2 the effect on consumption of a trading scheme versus a non-trading one to highlight the importance of international linkages. Notice that the consumption profile is improved somewhat in the short run and clearly so in the long run in the case where no emissions trading occurs. This is the result of two separate effects: one short term and another long term. In the short run there is a stimulative effect on the economy from the redistribution of permit-auction revenues to income-constrained consumers. Recall that the fiscal policy assumption used in the model is that debts and deficits remain unchanged. As a result, additional revenues are redistributed to consumers, some of whom have a high marginal propensity to consume. In the case where there is no trading, the revenues that are redistributed in this way are larger than

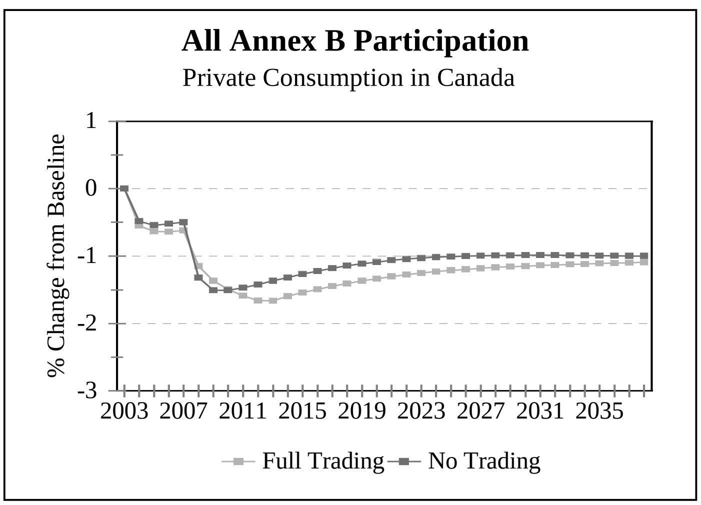

Figure 2

when trading occurs. As it turns out, the stimulative effect on consumption of this redistribution is large in comparison to the additional cost imposed on the economy by having domestic agents undertake all abatement (this was confirmed by looking at alternative fiscal policy scenarios).

In the long run, even though the GDP loss is smaller in the case where emission trading occurs, more than $4.5 billion dollars have gone to purchasing emission permits from abroad. That additional debt has to be serviced and the result is that domestic consumption is lower. This is aggravated by the fact that the increase in foreign indebtedness has to be paid at a rate of interest higher than the growth rate of the economy.

The upshot of a permit trading scheme is that it allows the domestic economy to avoid having to make deep reductions in GHG emissions in exchange for a long term outflow of capital (in the form of debt servicing payments). For domestic output, the effects of permit trading are clearly beneficial since output suffers less in both the long and short run. For domestic consumption, however, the comparison is not as clear. Some of the gain in output from purchasing permits will have to be given to foreigners in exchange for their permits. In the long run, therefore, it is not clear whether consumption should be higher or lower under trading versus non-trading (in our results it was lower under trading). In the short run, since the economy is experiencing a sharper reduction in economic activity under non-trading, one would expect that consumption would be higher under trading. However, when other factors such as the stance of fiscal policy are thrown into the mix, we can get the alternative result that non-trading in permits is less costly for consumption as a result of a stimulative stance in fiscal policy.

Terms of Trade

These scenarios have laid out some basic comparative results for understanding the impact of achieving the Kyoto Protocol in Canada. While we have reported results from the model to a considerable degree of accuracy, we are nonetheless conscious of the fact that all modelling exercises carry considerable degrees of uncertainty in the results. This is due in part to their necessarily oversimplified view of the economy but, as well, also to the potential for errors in the parameterisation of the economic inter-relationship being modelled. Given this, it is perhaps best to consider these results as ranking policies and highlighting important factors in the consideration of means by which the government may achieve its objectives in the Kyoto Protocol. To this end, it is worth highlighting that an important factor in their ranking is the impact they have on Canada's terms of trade. Since Canada's is a fossil-fuel exporting economy, we can expect that the terms of trade will be adversely affected by a policy that seeks to raise the price of fossil fuels to consumers. Figure 3 (next page) summarises the comparative effect each of the foregoing cases has on Canada's terms of trade.

As expected, in the long run the case where other Annex B countries achieve their targets but Canada does not gives the least favourable results for our terms of trade. Note, however, that there is an improvement in the terms of trade when Canada alone undertakes the policy. This rests on an assumption that goods produced in Canada with fossil fuel inputs are not perfectly

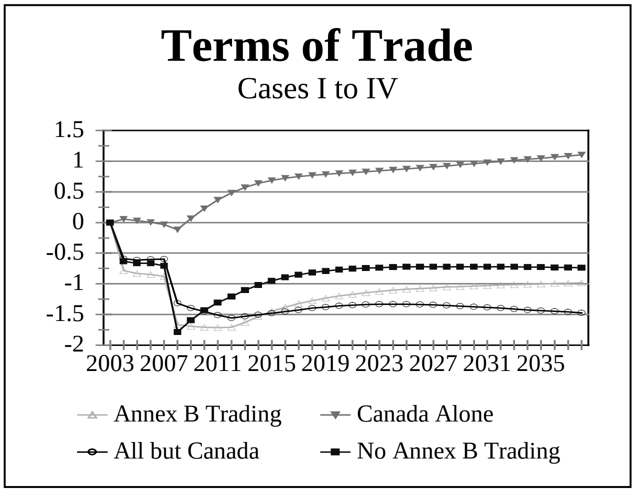

Figure 3

substitutable with goods from other countries. In other words, we obtain a result that is analogous to the *optimal tariff* literature: a producing country which is able to influence the price of its output can improve its terms of trade by raising the price of its exports.

It is also important to note the strong dynamic induced in both the case where we have full Annex B trading and the case where there is no trading. This overshooting in the terms of trade is, in large measure, responsible for the dynamic that is observed in consumption in figure 2. Its source can be found in the potential international capital flows that result from the policy initiative. When the policy is put in place real interest rates in Canada fall with the slowdown in the economy. Real interest rate parity with the rest of the world, combined with the previously outlined forward-looking behaviour and economic rigidities, imply that the real exchange rate must overshoot its long-term decline in order to avoid large capital outflows. These movements in the real exchange rate are reflected in the terms of trade and result in the dynamic observed in figure 3.

In sum, international capital flows (or their potential in an economy with forward-looking agents) are crucially important for the dynamic outcome of climate change policies.

IV. Concluding Remarks

This paper has presented a number of results for using tradable permits in domestic and international contexts. In doing so it highlighted important issues not only in the inter-linkages that are likely to be important in climate change policy but also in the reporting of results from such analyses. One of the lessons we derive from that observation is that summary measures (particularly concerning model comparisons) that reduce an analysis to a single (or even a few) indicators are inadequate when examining a complex policy that will affect many facets of the economy.

The results reported earlier highlight, in a number of ways, the role that international repercussions have on Canadian policy. For example, we saw that even in the case where

Canada does not participate in an abatement regime, the cost to our economy can still be substantial. Participating in an abatement regime, therefore, should not be compared to a business-as-usual baseline but rather to an already changed path.

We also saw that the flow of financial capital, or its potential, can affect the long term equilibrium path the economy will attain after the policy has been put in place. In scenarios such as the one where Canada alone undertakes the policy, capital flows actually result in consumption returning above baseline in the long run because a reduced international debt allows us to consume more of the goods we produce. Even in the cases where all countries undertook to abate emissions, the potential for capital flows resulted in an inter-temporal dynamic in the terms of trade which had significant effects on the economy as a whole.

Finally, it is worth highlighting the observation that Canada has some advantages in implementing the Protocol since we are starting from a position of relatively cheap energy in comparison to some of our trading partners. Unfortunately, since we are also an important producer of fossil fuels, we will have some important adjustments to make.

Appendix A: Coverage, Fugitive Emissions and Russian "Hot Air"

Coverage

Emissions in G-cubed cover only those from fossil fuels. They are accounted for by tracking the use of refined petroleum, coal mining output, and natural gas. Wherever these fuels are used as inputs they are assumed to cause carbon emissions at a fixed rate per unit of fuel (in this model a unit of fuel is defined in terms of a constant-dollar level of output from the producing industry).

Any policy that affects the price of fuel inputs (i.e., a requirement to hold a permit for the carbon content of the fuel) will cause a substitution to non-carbon fuels, followed by a substitution into non-energy inputs. The degree of substitutability is given by the parameters of Table IV so the responsiveness of the model to a permit requirement is, in principle, given by historical experience.

Non-combusted fossil fuels are also covered but only to the extent they are used as inputs into the production of goods and services (i.e., carbon for metallurgical purposes). This implies that 81% of emissions GHG emissions are covered in terms of CO_2 equivalents (i.e., approx. 138 Mt of carbon in 1995). It also includes approximately 2% of emissions that are officially listed as 'fugitive' because they are used by upstream oil and gas extractors for production and distribution.

For the other sources of emissions not covered in the model, we make the implicit assumption that non-fossil fuel sources of GHG emissions will also be abated by 25% during the Kyoto period (at no cost). However, if fossil fuels were required to achieve all of the abatement for the Protocol, the reduction in fossil fuel emissions would have to be approximately 31%. A linear approximation of the repercussions of such a requirement would involve scaling up most results reported in the next section by 24%.

Fugitive Emissions

The treatment of fossil fuel production in G-cubed results in some fugitive emissions being accounted for within the model, while others are not. Environment Canada (1997) reports fugitive emissions from Upstream Oil and Gas as 58Mt of CO_2 equivalents in 1995. This figure is comprised 23% of stripped CO_2 from natural gas and 22% of combusted natural gas by the industry for production. The remaining 55% consist of methane emissions from oil and gas production (1.6Mt of methane by weight) – vented or leaked.

Since all these emissions must be accounted for under the Kyoto Protocol, we can choose to exclude these sources of emissions – and require other sources to make up the difference – or include them in a permit trading program. The fugitive emissions not already covered in G-cubed account for 6% of all emissions, thus the burden on the included industries may increase if these emissions are excluded.

The result of not including these emissions in the trading regime (and also not accounting for them in the abatement program) is that we have potentially underestimated the impact on the economy of a 25% abatement of GHGs. In particular we have underestimated the impact of the program on the upstream oil and gas extraction industries. An important question becomes: How much is this underestimation?

Consider the 23% of fugitive emissions that are stripped CO_2. If permits were required for fugitive emission, the 13.4Mt of emissions in 1995 would have required the industry to purchase 3.6 million carbon permits (3.67Mt of CO_2 represents 1Mt of carbon). In the most expensive scenario we look at in this paper, those permits would have cost the industry approximately $400 million (ceteris paribus).

Now consider the 55% of fugitive emissions in the form of methane. The industry would have required 8.7 million permits for carbon equivalent emissions to cover that source in 1995. Those permits would have cost approx. $965 million, again in the most expensive case we examine (ceteris paribus).

For emissions that are not fugitive, the industry would have been buying 10.7 million permits – already accounted for in the model through the purchase of permits for fossil-fuel use. The omission of methane and stripped CO_2, therefore, in the model's reporting of upstream oil and gas requirements of emissions permits is indeed large. On the basis of a requirement to hold 12.3 million permits for fugitive emission, our calculation of the industry's expenditure to buy permits would be wrong by a factor of 2.15 (or 115%). On the other hand, if the natural gas being emitted as methane were burned, the permit requirement for fugitive emissions would fall to 1.1 million carbon equivalents[20]. In that case our calculation of the industry's expenditure to buy permits would be off by a factor of 1.3 (or 30%). Since the permit requirement for fugitive emissions could be reduced by a factor of 8 when the natural gas is burned rather than leaked or vented, there will be a large incentive to fix leaks and flare unwanted gas (where capturing is infeasible). Indeed, with the cost differential just cited it is difficult to imagine that any emissions would remain as methane from upstream oil and gas. Moreover, as a consultant's study of the leakage of methane from gas processing plants suggests, there are significant opportunities for abatement even at relatively low cost[21].

This discussion suggests that fugitive emissions in upstream oil and gas may cause us to underestimate the cost to the industry by 30% (since we assumed ceteris paribus, this is an upper-bound estimate) if fugitive emissions were subject to a permit requirement.

Russian "Hot Air"

In principle, the emission of CO_2 from any industry in the economy is related to its use of fossil fuels. Since an economy's Input-Output tables account for purchases of all inputs by firms and

[20] This decision to burn rather than vent methane could be modelled endogenously but the scarcity of data on which to parameterise would make the relationship tenuous at best.

[21] *Measurement Of Natural Gas Leak Rates At The Paramount Kettle River Gas Processing Plant,* Indaco Air Quality Services, Inc., October, 1999.

consumers, it should be possible to report emissions through those tables. In the G-cubed model, emissions from various sectors are accounted for in exactly this way. Purchases of coal, natural gas and refined petroleum products are identified for each sector and emissions are calculated from that data. For most OECD countries this produces fairly accurate emissions data; however, for some economies an adjustment may be needed for fugitive emissions – as we saw above.

Of particular concern in using Input-Output tables for reporting economic activity – and for reporting emissions – is the Former Soviet Union countries. This is due to a number of factors, but perhaps the most important is the fact that since 1990 the economies of that region have changed dramatically, and are likely to continue changing over the coming decade. Projections of economic activity in the Former Soviet Union for the year 2010 that are based on existing Input-Output tables will carry more than the usual qualifications. Since those economies are also required to reduce GHG emissions under the Protocol – but they appear likely to be well under their cap – there is a potential for those countries to sell unused emission rights. This difference between their Kyoto commitments and their projected emissions has come to be termed "Hot Air". This is an important issue for climate change analysis because the availability of those emissions rights in a tradable permit scheme would imply a considerably reduced abatement requirement of other Annex B countries.

To deal with issues in the availability of permits from the Former Soviet Union we have used a supply curve for Russian "Hot Air" developed by Jae Edmonds of the US Department of Energy's Pacific Northwest Laboratories. In many of the international scenarios reported here, where there is trading of emission rights, the supply of permits from Russia and other Eastern European countries reduces the combined abatement by Annex B countries by almost half. Finally, note that the supply of permits from that region diminishes over time; i.e., a fixed international permit price would imply a reduction in the number of permits supplied.

Appendix C

Table AI. Baseline Data

Target Reductions	Mt of Carbon Canada	USA	Japan	Australia	ROECD
2008	35 (22.5%)	469	56	43	406
2009	36 (23.7%)	497	62	45	433
2010	38 (25.0%)	526	67	48	461
2011	40 (26.2%)	559	73	51	489
2012	43 (27.4%)	592	79	54	518

Aggregate Data (% of Baseline GDP)	Private Consumption	Imports	Exports
2008	53%	30%	36.5%

Sectoral Data (% of Baseline GDP)

	Output	VA	Investment	Exports	Imports	Profits	Capital
Electric Utilities	4.07%	3.04%	0.59%	0.19%	0.01%	2.0%	12.7%
Gas Utilities	0.46%	0.37%	0.10%	0.30%	0.01%	0.2%	2.8%
Petroleum Refining	3.13%	0.81%	0.04%	0.53%	0.20%	0.0%	1.8%
Coal Mining	0.35%	0.24%	0.03%	0.16%	0.06%	0.1%	0.8%
Oil&Gas Extraction	4.31%	3.26%	0.28%	2.41%	0.70%	1.8%	5.9%
All Mining	2.75%	1.76%	0.02%	0.74%	0.36%	0.6%	1.0%
Agriculture	5.36%	2.51%	0.24%	1.50%	0.66%	0.9%	5.9%
Wood	8.13%	3.55%	0.03%	2.14%	0.24%	0.5%	0.6%
Non-durable Man.	45.84%	30.19%	0.88%	18.43%	17.71%	2.8%	14.5%
Durable Man.	21.09%	9.03%	0.66%	9.06%	6.21%	1.7%	10.7%
Transportation	10.60%	4.31%	0.29%	0.00%	0.00%	0.8%	8.1%
Services	91.13%	56.42%	5.17%	2.87%	3.78%	12.2%	90.1%