Modeling Climate Change Policies in the U. S. and Canada: Preliminary Results

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ABSTRACT

Pacific Northwest National Laboratory and the Energy and Materials Research Group of Simon Fraser University are jointly working on an integrated version of CIMS[1] for Canada and the United States that will allow climate change policy modeling jointly in both countries. This paper provides preliminary results on that joint development and explains how some of the more energy-intensive trade flows are handled. Our operating hypothesis is that divergent climate change policies will fundamentally alter the relative price structure of energy intensive goods and thus have profound effects on the balance of trade between these two countries.

CIMS is a technology explicit and economically realistic method of modeling a generic economy, which includes the four major end-use sectors – industry, transportation, residential and commercial buildings – plus an energy supply sector which provides electricity, coal, natural gas, and petroleum products to the end-use sectors. The model simulates the evolution of the capital stock, and hence fuel use and emissions, for each of these sectors using behaviorally realistic technology competition algorithms over a 35 year period.[2] It also equilibrates supply and demand for energy based on the cost of production and goods and services based on price elasticities and macroeconomic algorithms. When the two countries are simulated together, the major interaction is in energy and non-energy trade flows. Of major interest to climate change modeling is the trade of energy-intensive goods between the U. S. and Canada: energy, lumber, pulp and paper, chemicals, and primary metals.

Introduction

For the last two years, staff at the Energy and Materials Group at Simon Fraser University in Vancouver, Canada, have been working with staff at Pacific Northwest National Laboratory on the joint development of two CIMS models, one of Canada, one of the US, which could be simulated simultaneously. The major interaction between the two country models is trade: between the two countries and with the rest of the world (ROW). This paper will explain how CIMS works, identify the major interactions between the two country models, and report preliminary results. More about CIMS can be found at: http://www.emrg.sfu.ca/

CIMS is an engineering-economic model of the economy with detailed energy end-use, conversion and supply sectors. The supply and demand for energy are balanced through price adjustments, subject to internationally set commodity prices. While CIMS allows a link to the

[1] CIMS originally stood for Canadian Integrated Modeling System; it was introduced in the US as the Consolidated Impacts Modeling System. Both of these have been abandoned for the generic CIMS. This paper has been given the designation: PNNL-SA-55463

[2] The latest version of CIMS Canada is calibrated and paramterized to 2050 and has the potential to run to 2100.

macroeconomic structure of each country, we have not exploited this option in the current study in the interest of simplicity.

The major trade flows between Canada and the US are energy, metals, wood products including pulp and paper, chemicals, and fabricated goods (especially transportation equipment). Canada is the largest trading partner of the US and *vice versa*. All other trading partners of both countries are lumped into a ROW account for the purposes of this paper. As policies within the separate countries affect the production costs of energy within each country, the incremental costs of these policies translate into higher (lower) prices for goods traded between the countries, so adjustments in trade occur. Since much of the trade between Canada and the US is in the form of highly energy-intensive goods, policy impacts are likely to have a major impact on trade between the two countries. Under regimes where, say, Canada pursues stringent climate change policies and the US does not, there could be major impacts on the trade patterns between these two countries. This concern motivates the research.

Three additional sections and a conclusion provide further discussion of these issues. The first section provides some detail about CIMS for both Canada and the US, with some discussion about the differences between the two models. The second section explains how trade between the two countries and ROW is handled. The third section reports results from simulation of the two models. Our final section concludes the paper.

Two CIMS Models

Overview[3]

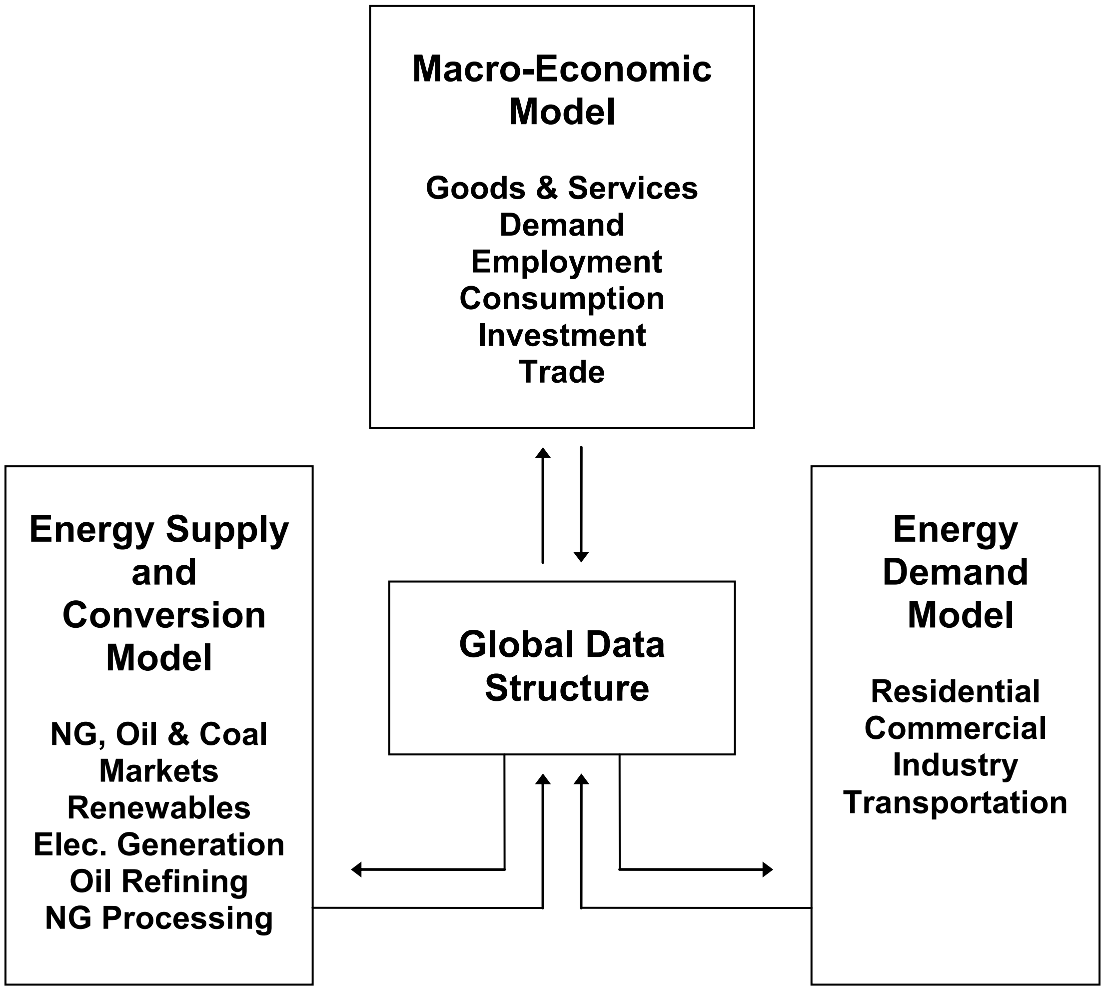
Energy flows are at the heart of CIMS. It tracks the flow of energy, beginning with production processes, through to eventual end-use by individual technologies. Unlike partial equilibrium models, which compete technologies against each other to serve pre-specified demands for end-uses, CIMS, with all dynamics running, is a nearly full equilibrium system that incorporates macroeconomic demand feedbacks, and energy trade.

CIMS focus on detailed energy flows through technologies makes it ideal for modeling air quality and greenhouse gas emissions. Emission levels of all pollutants are technology specific; unless a model operates on an individual technology basis, as CIMS does, the emission estimates can only be approximated by economic activity. Furthermore, this technological detail allows the modeling of policies that target specific technologies, such as vehicle emissions standards and renewable generation portfolios.

The following diagram (Figure 1) describes CIMS.

[3] This overview material is drawn from the description of CIMS provided at: http://www.emrg.sfu.ca/

Figure 1. The Structure of CIMS



On the right side of the diagram is the energy demand module. The four models in the demand module comprise the industrial, residential, commercial and transportation sectors. The industrial model is by far the most complex due to its heterogeneous processes and technologies. The data for the model was originally derived from the ISTUM model developed during the mid-1980s (Jaccard and Roop, 1990), and has since been extensively updated, expanded and improved. The residential, commercial (institutional), and transportation models were added in the 1990s using disaggregated data from government and independent agencies. These sector models benefit from behaviorally realistic models of consumer decision-making that reflect how market shares for new technologies evolve in the real world. CIMS Canada is maintained by the Energy and Materials Research group at Simon Fraser University and is used extensively for climate change policy analysis in Canada.

On the left side of the diagram is the energy supply module. This includes both energy supply and major energy conversion processes for coal, crude oil, natural gas, refined petroleum products and electricity. These processes are also represented by energy flow models that have been extensively updated and improved to include advanced, new and nascent technologies.

At the top of the diagram is the macro-economic module. In the past, CIMS simulations were driven by one or several macro-economic scenarios about structural change, economic growth, and other key assumptions (regulations, technologies, international prices, trade, etc.). However, this approach does not allow for feedbacks as changes in the costs of industrial inputs and consumer goods and services may lead to structural shifts (one major sector or industrial branch grows relative to another) and changes in overall economic activity (the key indirect effects of GHG reduction policies). In the standard version of CIMS, we use estimated energy service price elasticities and a few key macro-economic linkages to simulate the structural and total output feedbacks from changes in costs of energy services (resulting from policies that affect energy prices and/or the choice of technologies by firms and households).

CIMS Canada

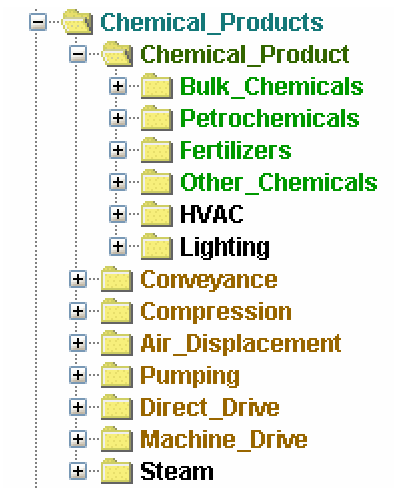
A CIMS-CA model was constructed by aggregating the existing seven-region model of CIMS into a single, aggregate Canadian model. For both the Canadian and US models, there are eleven industrial sectors, of which four sectors are part of the energy supply sector. In addition to the industrial sector, energy demand arises from commercial, residential, and transportation sectors. The energy supply sectors consist of coal mining, natural gas extraction, crude petroleum extraction, petroleum refining, and electricity production. In addition to the extraction and refining, the industrial sector consists of chemicals, non-metallic minerals, iron and steel, other primary metals, pulp and paper, non-coal mining, and other manufacturing (which represents the large and diverse number of sectors with lower energy intensity and significant cumulative value added).

CIMS United States

The US version of CIMS was constructed using the aggregated Canadian model as a starting point. Then, model structure, energy prices and technology costs were modified to match US data. Most data for the US model was published by the EIA or adapted from input data to the NEMS model. In specific areas, such as transportation, additional data from other government agencies and other models was used. Each of the 16 sectors was then calibrated to US consumption, energy use and emissions data.

A major modification of the Chemical sector was necessitated by the fact that the Canadian chemical sector relies much more on electricity and heavy fuel oil than the US industry. A more "generic" version of the chemical industry was constructed along the lines shown in Figure 2, where only four categories of chemical products are explicitly modeled (four items below "Chemical Product"), along with HVAC and Lighting. The remaining items (auxiliary services) and steam are used by each of the four major industries.

Figure 2. CIMS-US Chemical Industry



Integrating the Two Models

Since the objective of simulating the two models together is to explore how alternative climate change policies might affect economic performance of the two countries, our first issue was how to handle trade between the two countries. Much of the trade is in energy-intensive goods, so we would expect that if climate change policies were very different, then energy costs would be quite different between the two countries and therefore the costs of these traded goods would change. In turn, there would be an effect on how much of these goods was imported from Canada, in the case of the US, and *vice versa*, rather than the rest of the world (ROW).

We focused on modeling trade flows that we believe are most likely to be influenced by climate change policies and that could have a significant economic impact on either country.

Energy Trade

The US imports about one third of its energy requirements[4] and about one third of these imports are provided by Canada. Although conventional oil and gas production in the US is in decline, coal reserves remain large and unconventional oil and gas resources could play a more significant role than they have so far. How the US meets its growing demand for energy depends on how production costs evolve in the various exporting countries and how the country develops its own resources. Political considerations and concerns about supply security will no doubt also play a key role. We use different supply scenarios to simulate security imperatives. Imports of crude oil, natural gas, electricity and refined petroleum products to the US are therefore important trade flows that we include in the model.

Canada does not currently import large amounts of energy. Some regions of Canada import crude oil from various exporters, typically Norway or Venezuela, but we assume that domestic production is a poor substitute for these imports because of transportation costs within Canada; partly because of geography, it is more economic to sell western Canadian crude to the

[4] Based on year 2000 data from EIA.

US, and import crude from other nations by tanker to the industrial centers in eastern Canada. This may change as Canada develops its offshore resources.

Production costs of electricity, natural gas, refined petroleum products and crude oil are sensitive to emission taxes and energy prices and therefore we adjust the supply curves in each country to reflect the local production costs in our model. Coal production costs are less sensitive to these factors so we do not adjust supply curves for coal production endogenously.

Other Traded Goods

Because the CIMS model tracks energy use by technologies we can simulate changes in the prices of goods as a result of changes in energy costs and taxes on emissions. Table 1 shows the energy costs in CIMS as a proportion of total output in selected industrial sectors. Also shown, is the greenhouse gas emission intensity of production. Based on this data, we originally planned to model trade flows for the following groups of goods; however, to simplify the computation for this paper, only four energy flows are modeled.

- Iron and steel
- Chemicals
- Industrial minerals (includes cement and lime)
- Non-ferrous metals (aluminum, zinc, copper)
- Pulp and paper products (pulp, newsprint)
- Other manufacturing (vehicles and automotive parts, machinery, …)

Trade between Canada and the US in these product categories is significant, as are imports and exports from and to the rest of the world.

Table 1. Emissions- and Energy-Intensive Production Sectors

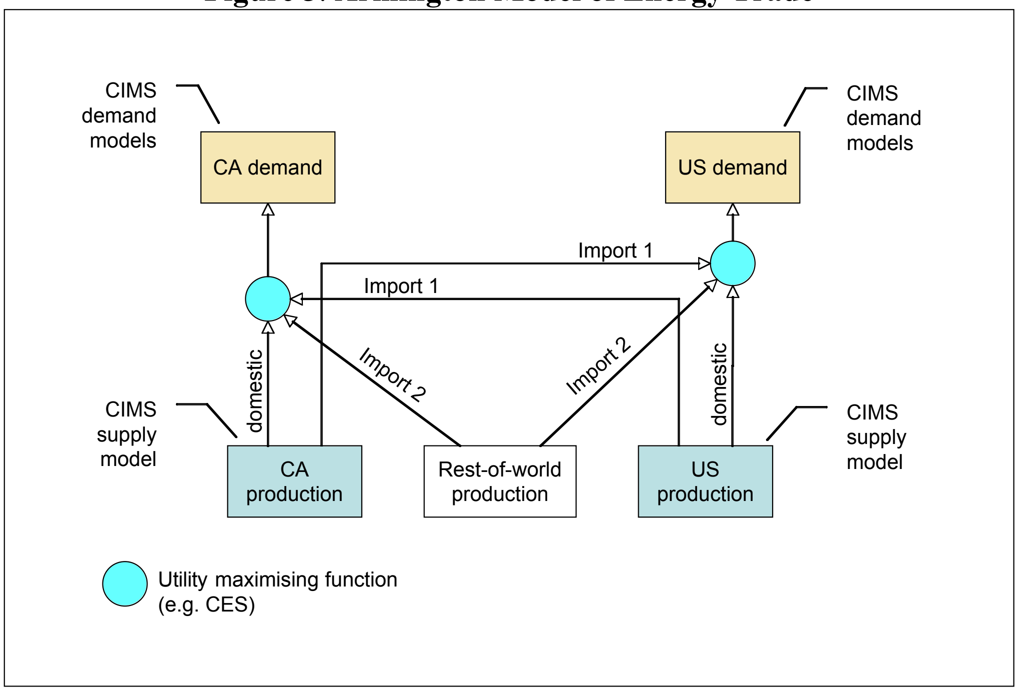
Sector	Units of output	Energy intensity of production (GJ/unit output)		GHG emission intensity of production* (tonnes CO_2 equiv. / unit output)	
		US	Canada	US	Canada
Chemicals	Tonnes	66	12	5.2	1.0
Metals	Tonnes	40	52	7.1	4.9
Pulp & Paper	Tonnes	29	27	1.7	1.1
Iron & Steel	Tonnes	15	8	1.9	0.6
Industrial Minerals	Tonnes	7	4	0.8	0.9
Other Manufacturing	$1,000 GDP	4	4	0.4	0.2

* Emission intensity includes emissions from electricity generation.

Modeling Trade

To model international trade we adopted Armington's assumption that domestic production and imports from other countries are imperfect substitutes and can be represented by a constant elasticity of substitution (CES) function. This approach is common in CGE modeling (Zhang, 2006). We use a simple Armington model where one CES function determines how domestic production and imports from each exporting country satisfy demand. As there are only three countries in our model this structure is quite simple. Figure 3 shows the Armington model structure for energy supply. Note that the trade models for any traded goods involve imports to Canada (exports from the rest-of-world (ROW) and from the US) and imports to the US (again from ROW and Canada). We do not model imports from Canada and the US to ROW, so each traded good requires seven equations: one each for the supply of the good (from Canada, the US and ROW), two equations for the demand for the good (one for the US, one for Canada), and two equations to establish the price of the composite traded good (one Canadian, one US). CIMS is used to estimate the production (costs) of the traded goods from the US and Canada, as well as the (initial) demand for the goods. Thus the non-linear solution to these 7 equations requires some data from CIMS, some response surface information to construct the partial derivatives to know what direction to move to solve the set of equations, plus the CES structure for the equilibrating prices. We use an iterative numerical root finder to converge towards a solution in demand, trade, supply and prices.

Figure 3. **Armington Model of Energy Trade**



To construct the model we required elasticities of substitution of imports to each country. Some researchers have estimated Armington elasticities for specific commodities using trade data (Wirjanto, 1999). Where appropriate we use published values. In most cases we make assumptions about the elasticities of substitution.

The CIMS natural gas and crude supply models are not equipped to provide realistic responses in the cost of production to changes in demand. The models are good at reflecting how capital, energy and operating costs change in response to energy prices, emission taxes and technological change, but not so good at reflecting increases in the marginal cost of production due to absolute factors such as resource quality. These (and other) factors are important determinants of the long run supply curve in the production sectors. Instead of using the CIMS sector models directly we use constant elasticities of supply to determine the shape of the production cost curve, and base these on published data. We then shift the cost curve up or down according to the relative changes in production costs in the CIMS sector models. This method ensures that the influence of energy costs and emissions taxes is reflected in the trade flows.

Results

Figures 4, 5, 6 and 7 report some of the results from simulating the two models. At this point, we have not yet solved the two models for energy trade flows; but expect to report on these at the conference.

As an example of what the impacts of energy price increases on US crude oil supply might be, see Figure 4. This figure shows the quantities of crude supplied by domestic production and imports from Canada and the rest of the world (ROW). The first scenario is a reflection of year 2000 actual supply. The other two scenarios show how the Armington model responds to a 15% price increase in first Canadian production costs, and then both Canadian and US production costs. The extent to which supply shifts to the low price source depends on the price difference, the elasticities of substitution, and the overall demand response to the price increases. With just a Canadian tax, US production would increase only slightly, with reduced imports from Canada being made up by higher imports from ROW; Canadian crude oil supply would decline. If both countries applied the tax, both US and Canadian domestic production would decline, with a very slight increase in imports from ROW.

Figure 4. Effect of Canadian and US Production Costs on Crude Oil Supply

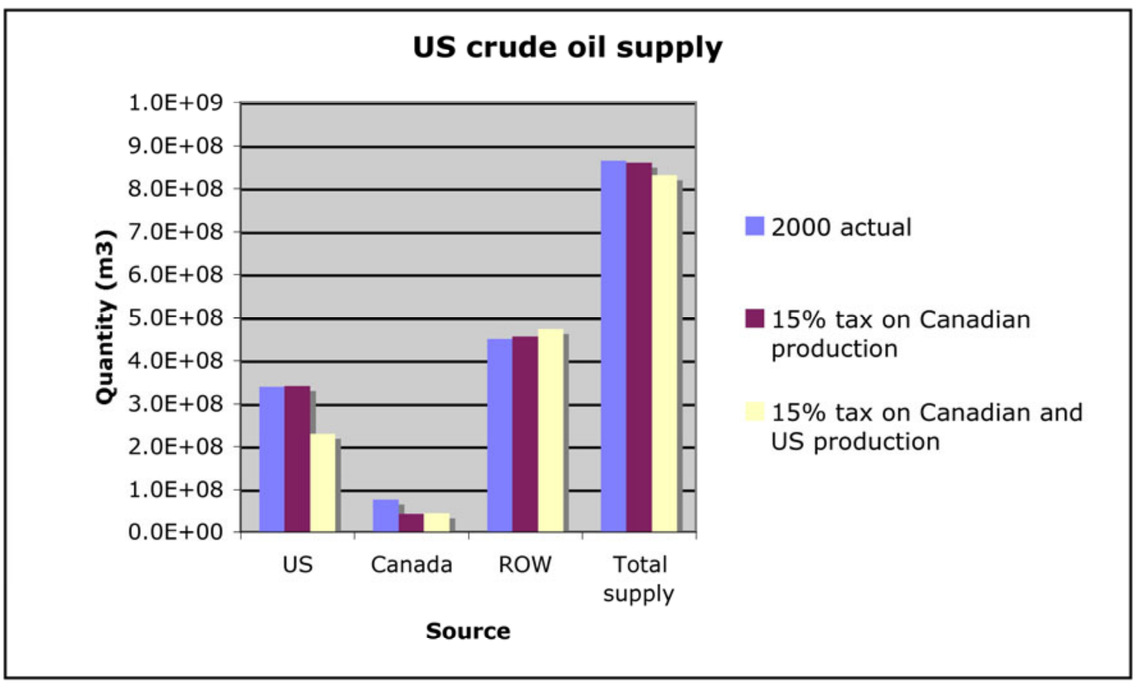


Figure 5 plots out the demand curves for energy commodities when the refined petroleum products price varies from half its baseline price to twice its baseline price in the year 2020. These price changes would have very little effect on electricity prices but there would be significant declines in both the consumption of crude oil and refined petroleum products, with the latter falling about 20%. Natural gas consumption would increase, by about 20%, while coal consumption would increase only slightly.

Figures 6 and 7 show the response curves of the various sections to a tax on carbon emissions.

Figure 5. Effect on Energy Demand of RPP Price Changes

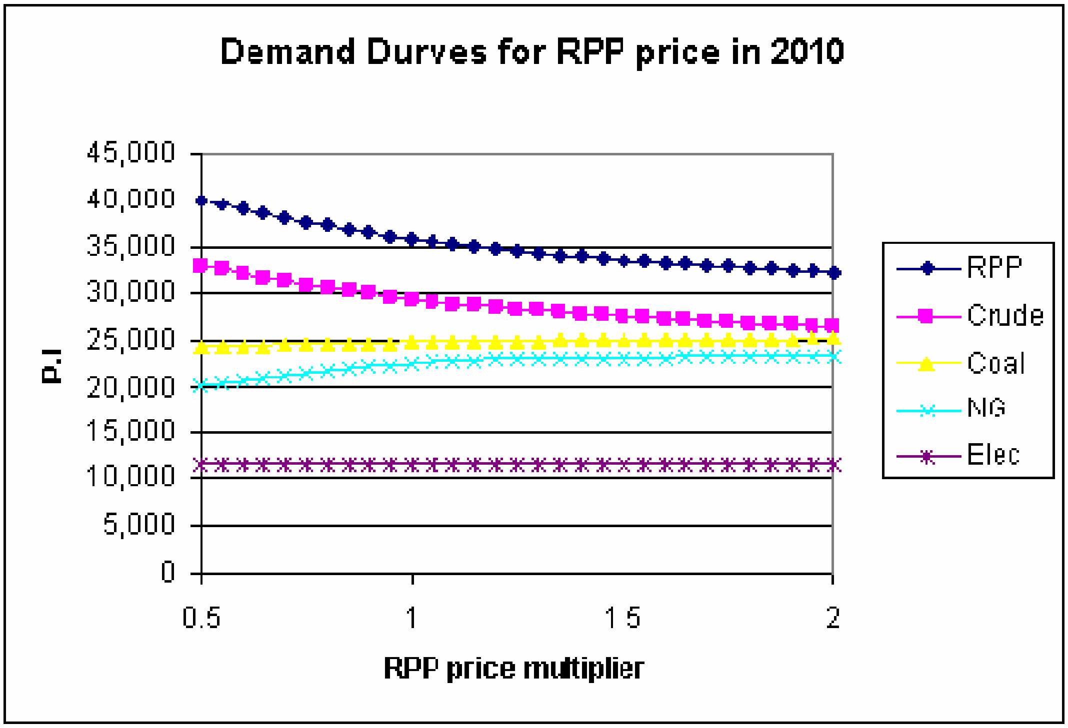
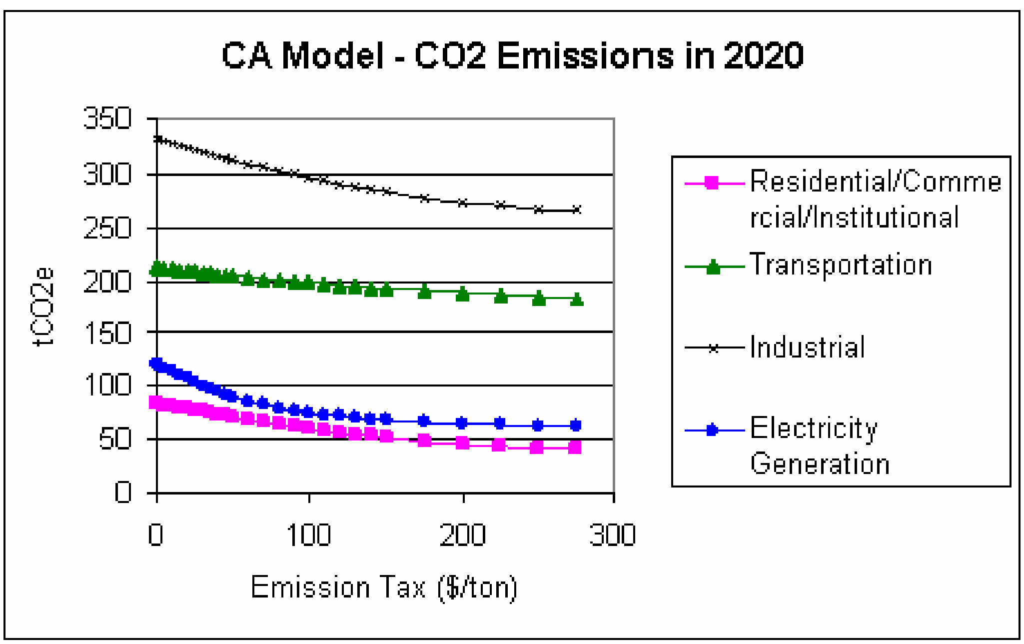


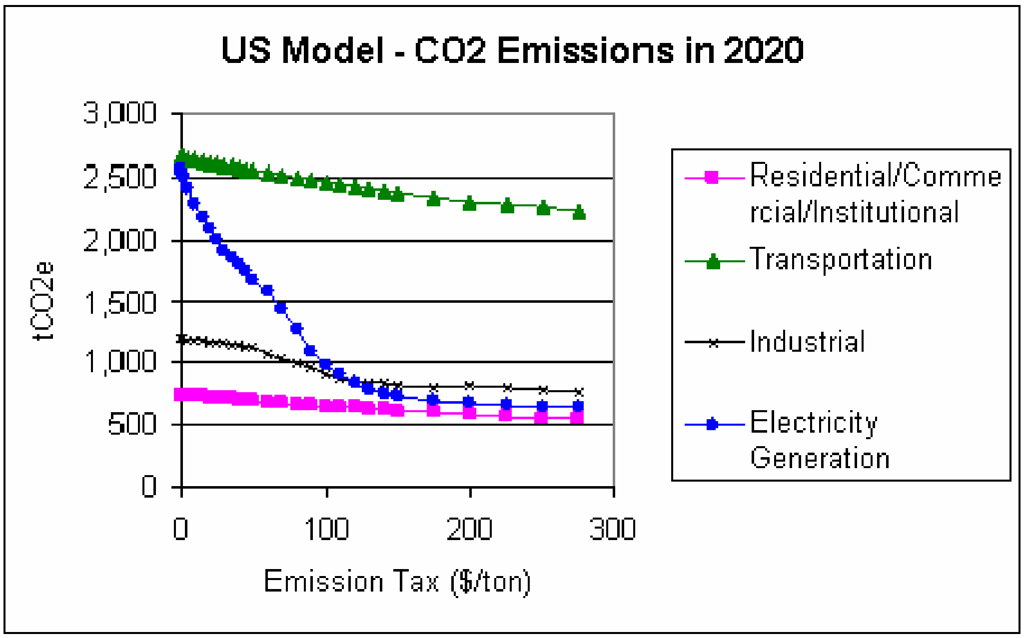
Figure 6. Effect of Carbon Tax on Canadian Energy Demand



For Canada, shown in Figure 6, the carbon tax rate affects industry the most, with electricity production also falling substantially. Energy use by both buildings and transportation would decline, but more modestly. After about $150 per tonne (i.e., metric ton) tax, the decline in all the sectors tapers off, with very little reduction in carbon emissions for the electricity sector, especially. This may be due to a saturation in the penetration of alternative technologies explicit in the model.

The response in the US is substantially different. Carbon taxes reduce emission in the electricity sector the most, with a decline in total emissions of about 60% with taxes up to $100 per tonne. Industrial emissions are also substantial, with transport emissions declining somewhat less and building emissions declining even less. With the US dependence of nearly 50% on coal to produce electricity, these rapid declines in emissions for this sector contrast sharply with Canada which is far more dependent on hydro for its electricity.

Figure 7. Effect of Carbon Tax on US Energy Demand



Conclusions

Our preliminary findings suggest the following:

- GHG emissions in Canada can be reduced with similar results in all of the major sectors, but with the strongest impact on industry (including oil and gas supply) and the electricity sectors.
- The US, in contrast, would see the electricity sector bear a major portion of the emissions reductions as a result of carbon emissions taxes. Industry in the US would also be affected as a result of carbon emissions taxes, responding to emissions taxes with reductions in emissions much as Canadian industry does.
- We surmise (with results to be reported in July) that one-sided environmental policies, as with crude oil supply, would disproportionately affect Canada more than the United

States, mostly because of the basic energy intensity of the Canadian economy and partly because of size discrepancies (much more of the Canadian economy is engaged in energy supply due to export requirements) .

- To determine whether environmental policies in Canada could have negative (or positive) effects on Canada's economy is not possible with a simple model of trade that does not take account of complex trade flows in energy intensive goods and services.

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