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ECONOMIC GROWTH AND INNOVATION

Taxing Emissions, Not Income:

How to Moderate the Regional Impact of Federal Environment Policy

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In this issue...

If policymakers wish to reduce Canadian greenhouse gas emissions, they can do so using a suite of policy tools that mitigate regional impacts.

The Study in Brief

The Authors of This Issue

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If Canada is serious about reducing greenhouse gases (GHGs), then governments must put an economy-wide price on carbon dioxide and other GHG emissions. However, policymakers have yet to take such action because of concerns about the economic cost of GHG-reduction policies.

This *Commentary* shows that although policymakers do have reason to be concerned about the economic effect of GHG-reduction policies, both regionally and nationally, they have policy tools at their disposal to ameliorate the economic harm that taxing GHG emissions can cause.

For example, because provincial economies are very different from one another, a price on GHG emissions will affect them differently. If policymakers wanted to eliminate the inter-regional transfers that therefore would result from climate policy, one solution would be to return to the provinces the revenues collected through auctioned emissions permits, so that the provinces may offer personal and corporate income tax relief.

In addition to the regional economic effect, policymakers may also be concerned about the nationwide economic effect if Canada taxes emissions without the rest of the world also doing so. Indeed, if Canada acted alone to reduce GHGs, it would reduce the economic attractiveness of investing in Canada. However, reductions in personal and corporate income taxes or rebates to firms proportional to their GHG emissions would mostly offset the cost of reducing GHG emissions and would maintain the attractiveness of investing in Canada.

If a price on carbon emissions is to become a reality in Canada, a bargain must be struck that achieves some degree of regional equity while also supporting economic growth. Policymakers should carefully consider the regional impacts of climate policy as they pursue Canada's existing emissions reduction goals.

Efforts to reduce greenhouse gas (GHG) emissions in Canada are confronted by the significant difference in emissions intensity across the country, especially the high emissions intensity of Alberta and Saskatchewan.

While it is generally acknowledged that a considerable amount of the country's reductions must occur in these two provinces, there is little agreement on the allocation of costs between them and the rest of the country, or what this might mean for economic performance in different regions.

Relatively few studies have assessed the regional impacts of alternative climate policy approaches in Canada. Snodden and Wigle (2009) explored the regional impacts of climate policies proposed and/or implemented at the federal and provincial levels of government. This study focused on the interactive effects of policies implemented in different jurisdictions and concluded that a nationally "fragmented" climate policy was likely to be economically inefficient. Bataille et al. (2009) produced a study for the Pembina Institute and David Suzuki Foundation that analyzed the level of effort required to reach two targets for greenhouse gas emissions – the government of Canada's previous GHG target of a 20 percent reduction from 2005 levels by 2020, and a target that calls for a 25 percent reduction from 1990 levels by 2020. That study was intended to estimate the economic effects of achieving a deeper GHG target than proposed by the federal government, rather than to explore the implications of different designs for climate policy. However, some commentators expressed concerns that the design selected for the analysis showed a strong reduction in economic growth from Alberta and Saskatchewan relative to the rest of the country (Mintz 2009; Gibbons 2009).

This *Commentary* expands on the previous studies by analyzing how climate policies can be designed to achieve different regional outcomes. It illustrates that government has significant control over how the economic burden of climate policies will be distributed among provinces. Specifically, this *Commentary* analyzes three simplified cap-and-trade policies that achieve the same aggregate target for Canada's greenhouse gas emissions, but achieve drastically different regional distributions of economic cost. The first policy involves intensity-based standards, with federal regulations that cap the amount of emissions per unit of output and allow emission permit trading between emitters. In the second and third policies, government auctions emissions permits and allocates the revenues in the first instance via cuts in federal corporate and personal income taxes and in the second instance via transfers to provincial governments to cut provincial corporate and personal income taxes equal to the auction revenue collected from each province. The study further tests the sensitivity of the results to assumptions about investment mobility in the context of Canada enacting a climate policy that roughly corresponds in timing with policies in other countries.

Equity Definitions and Regional Impacts

The concept of equity can be interpreted in different ways when applied to distributing the burden of environmental policies (Cazorla and Toman 2000). The "polluter pays" approach suggests that it is equitable to make polluters pay the environmental harm caused by their polluting activity, such as emitting GHGs. This approach is similar to the "egalitarian" approach, where each person has an equal right to a certain level of emissions, meaning that those who emit more should be regulated or pay more. Under these

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approaches, GHG-intensive regions would pay for the damages caused by their emissions and/or pay to reduce their emissions.

The "sovereignty" approach to equity suggests that it is unfair to penalize regions for their current GHG-intensity, since this is the result of technology choices made prior to the global community, or an individual country such as Canada, deciding that GHG emissions are undesirable. This approach is similar to the "equal cost" approach, which suggests that each individual or region should bear similar costs for reducing GHG emissions, even though some have emitted more than others.

Finally, the "ability to pay" approach to equity suggests that it is fair to ask wealthier individuals, regions or countries to pay more to achieve a collective good like reducing the risk of climate change. In international climate change negotiations, for example, developing countries have argued that industrialized countries should bear a greater share of the costs of GHG reduction, partly because of their greater wealth.

Since people tend to intertwine their self-interests with their definitions of equity, it is no surprise – both internationally and within Canada – that the most vigorous and convinced proponents of each definition of equity are often those who do best under that definition.

In Canada, regional interests differ in part because of regional differences in GHG emissions intensity (CO_2 emissions per unit of GDP). The greenhouse gas intensities of Alberta and Saskatchewan are greater than the rest of the country (see Figure 1). Thus, the sovereignty and equal cost definitions of equity might be associated with the interests of provinces with high GHG intensity, namely Alberta and Saskatchewan, while the polluter pays and egalitarian approaches might be associated with provinces with low intensity. Finally, the results of taking the ability to pay approach are ambiguous. While Alberta and Saskatchewan have considerable wealth, thanks in part to exploitation of fossil fuels, other provinces, like Ontario and British Columbia, are also comparatively well off.

The challenge for achieving effective GHG emissions reduction policy in Canada is to find a political compromise between these conflicting definitions of equity. This would be similar to what Europe achieved in 1997 for allocating country shares of emissions permits under the Kyoto Protocol, which balanced sovereignty (historical emissions) with ability to pay and polluter pays. One might think that, as a single country, Canada should find it easier than Europe to reach an equitable arrangement for bearing the costs of GHG reduction. But that has not been the case. In fact, the issue has mostly been treated at a fairly superficial level, in which divergent interests seem to make little effort to find common ground.

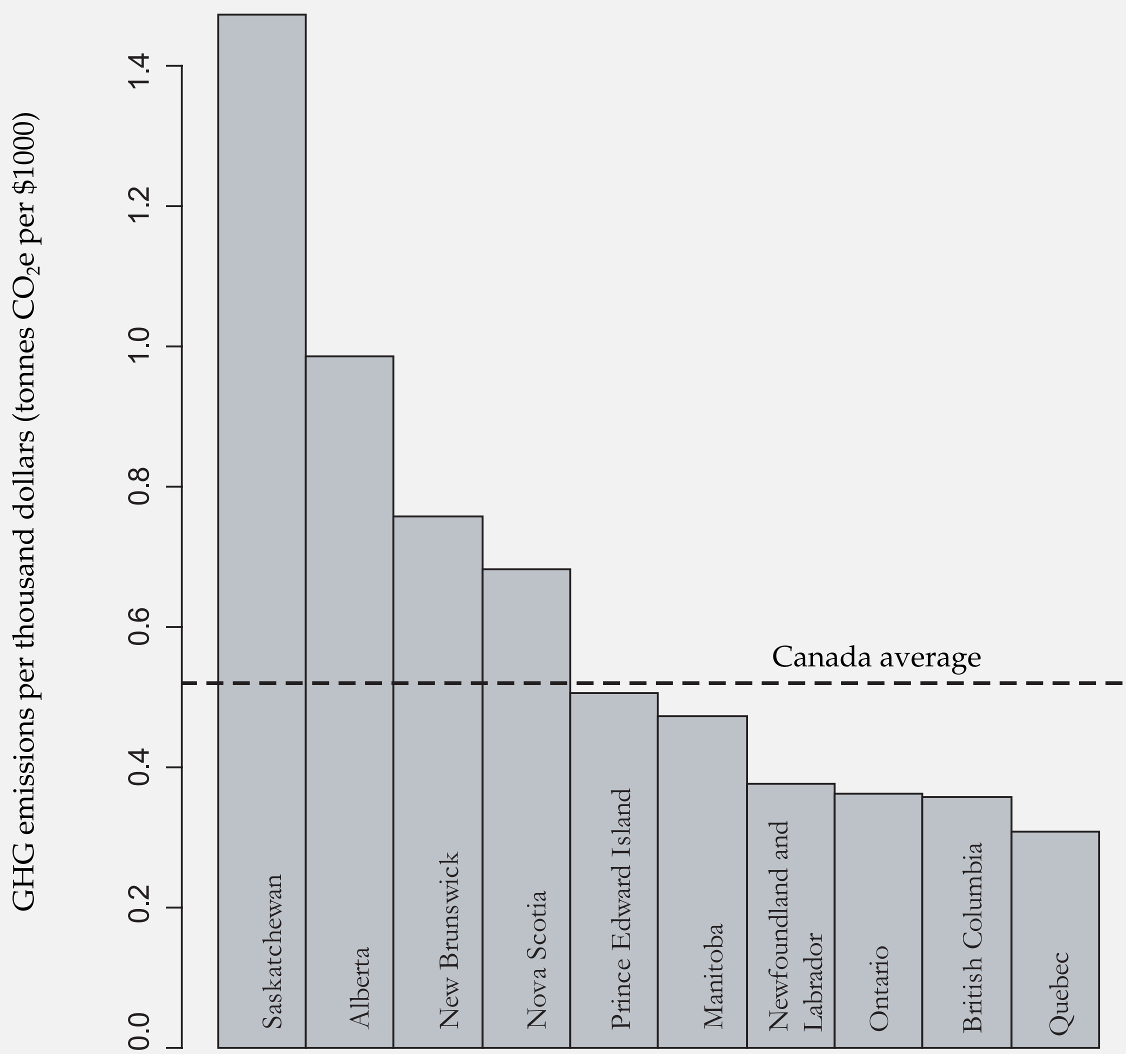
Approach in this Study

In this study, we take no position as to which is the most equitable approach for allocating the costs of GHG emissions abatement in Canada. Our goal is to bring greater clarity to the discussion of how different policy designs can lead to different regional effects. The design that Canada eventually settles on will be the outcome of negotiations that achieve a trade-off between these different definitions of equity and the interests they serve. Our hope is that studies such as ours can ensure that negotiations are not frustrated by confusion about the regional impacts of different policy designs.

While policymakers have many options for reducing GHG emissions, this study focuses on two approaches for cap-and-trade policies that achieve Canada's new target for GHG emissions – a 17 percent reduction from 2005 levels by 2020 (Environment Canada 2010).[1] While policy designs may also include several complementary policy measures (e.g., passenger vehicle emissions standards), we exclude them from our analysis. These approaches were selected because, if implemented at the federal level, they would provide a contrast in terms of regional impacts. The design details of the approaches are described below.

1 The government of Canada recently revised its target for greenhouse gas emissions from a 20 percent reduction from 2006 levels by 2020 to a 17 percent reduction from 2005 levels. The model used in the analysis currently excludes greenhouse gas emissions associated with agricultural soils, livestock, landfills and land-use changes, which account for about 10 percent of Canada's greenhouse gas emissions (Environment Canada 2008).

Figure 1: GHG Emissions per Gross Domestic Product in 2007



Source: Statistics Canada (2009); Environment Canada (2008).

1. The first approach is based on the federal government's proposed, but not implemented, *Regulatory Framework for Air Emissions* (Government of Canada 2008). Under the *Regulatory Framework for Air Emissions*, carbon pricing is applied using an intensity-based regulatory system, where large emitters are required to reduce their emission intensity by a specified amount per year. Trading among participants allows those with lower costs of abatement to achieve greater reductions and sell permits to those with higher costs. As initially conceived, the federal policy only applied to fossil-fuel based emissions from large industrial facilities. In this study, the policy is extended to GHG emissions from all sectors. Furthermore, parameters of the policy are set to ensure the intensity-based system attains its targeted 2020 emissions level.
2. The second approach employs an auction of permits by the federal government and the redistribution of auction revenue by reducing corporate and personal income taxes. This method of revenue recycling is based on British Columbia's carbon tax, which recycles approximately two thirds of carbon revenue by reducing personal income taxes and the remainder by reducing corporate income taxes. In our analysis, we consider two variants of this

Box 1: The Methodology

In our model, sectoral production is based on constant returns to scale technologies represented by nested constant elasticity of substitution functions. In resource extraction sectors, a sector-specific factor is required in production, which is used to capture resource payments (rents) and to calibrate the model to an exogenously specified elasticity of supply. The nesting structure adopted is identical to that used in the Emissions Prediction and Policy Analysis model applied by the Massachusetts Institute of Technology (Paltsev et al., 2005).

Economic output is divided between household consumption, investment, net exports, and government consumption. Government consumption is fixed in real terms. The treatment of investment and trade is described below. Household consumption is governed by a nested constant elasticity of substitution function representing the preferences of a representative consumer. At the top level of the nest, the household allocates its time between leisure and work. At the second and lower levels, the household chooses between non-energy commodities and between various energy commodities. Because this study is not focused on intertemporal or transitional dynamics, a static model is used. In this formulation, the rate of domestic savings is treated as exogenous, and does not respond to the policy. The treatment of foreign savings is discussed below. The total capital stock available to be used in production in each sector is endogenous, however, since investors are able to allocate capital in order to equalize rates of return between sectors.[2]

In a CGE model, important assumptions are required about model "closure" – how the model reaches a new equilibrium in response to a policy. These assumptions relate to whether or not government balances its budget (and over what time frame), the balance of trade with other countries and between regions, movement of labour between regions and countries, movement of investment capital between regions and countries, and the balance of leisure and work in the labour market. The closure assumptions chosen for this study reflect its objective of exploring regional distributional issues while maintaining model simplicity. (For more on the methodology see Appendix A.)

approach: in one, revenue is used to reduce federal corporate and personal income taxes; in the second, the revenue collected by the federal government from each province is returned to that province, where it is used to cut provincial corporate and personal income taxes. The latter variation ensures no net transfer of revenue between provinces.

Because the second approach has two variants – federal government uses permit auction revenue to cut taxes and federal government transfers auction revenue to provinces who cut taxes – we actually test three scenarios in total. Scenario one is the emissions intensity approach. Scenarios two and three are the two tax cut approaches.

Our Model Explained

The analysis in this paper relies on simulations using a computable general equilibrium (CGE) model of the Canadian economy. Such models are useful for this type of analysis because they connect all major activities in the economy (production, consumption, savings, investment, trade, public finances) to show how the structure and technological character of the economy changes in response to policies (See Box 1).

In the model, Canada is treated as a small open economy, meaning that policies implemented within Canada can affect domestic prices for commodities, but that Canada is a price taker on international export and import markets. Consistent with the objective of this study, the Canadian economy is disaggregated regionally, so that impacts of alternative policies on individual regions within the country can be discerned. The model is further disaggregated by sector and commodity, with 21 sectors and 18 commodities represented. Trade in the model occurs both between provinces and between Canada and other countries.[3]

2 In each sector, a proportion of capital is treated as sector-specific fixed capital, with this amount determined based on a initial stock of capital depreciated over the time period between the start of the policy (2010) and the reporting period (2020). This formulation is known as 'putty-clay' capital.

3 Like many CGE models, this one applies the so-called Armington formulation for representing international trade, in which goods produced in different regions are imperfect substitutes (Armington, 1969).

Table 1: Annual Growth in GDP between 2010 and 2020

	Business-as-usual	Intensity-based Cap-and-Trade System	Auction with Federal Personal and Corporate Income Tax Cuts	Auction with Provincial Personal and Corporate Income Tax Cuts
Alberta and Saskatchewan	2.30%	2.12%	1.88%	2.01%
Rest of Canada	2.16%	1.88%	2.06%	2.02%
Total	2.19%	1.93%	2.03%	2.02%

Source: Authors' calculations from GEEM (see appendix for details).

In the model, introducing an emissions cap-and-trade system increases the cost of using fuels and processes that produce GHG emissions and leads to shifts in: (1) the way households spend their income (i.e., usually favoring goods associated with fewer GHGs), (2) the inputs firms use to produce goods (i.e., using less GHG-intensive technologies and fuels), and (3) the allocation of investment capital and labour to different sectors of the economy to accommodate the choices of firms and households.

As described above, we assume the real government budget is fixed, that domestic saving is fixed, and households alter labour supply based on the real wage rate. We also assume that the labour market is free from rigidities, meaning that there is no long-term involuntary unemployment. We further assume labour is immobile internationally and interprovincially, but that workers can migrate between sectors in response to wage differentials (thereby equalizing the wages between sectors within a region).

Finally, we test two sets of assumptions regarding international capital mobility. In a first set of assumptions, we assume that net investment by foreigners in Canada is external to our model, meaning that policies in Canada can cause the domestic rate of return on capital to deviate from the international rate while the foreign investment stays constant. Because this amount of foreign investment in Canada is set externally to the model, so too is the balance of trade. In a second set of assumption, we assume that net foreign investment in Canada adjusts internally in the model so that the rate of return on capital is the same in Canada as elsewhere. This means that foreign investment can fall to reflect diminishing investment opportunities in Canada, perhaps because of domestic GHG-reducing policies that increase the cost of business.

It should be clear that both of these assumptions on capital mobility represent extremes. Empirical evidence suggests that investors do respond to differences between domestic and international rates of return, but with much less vigour than would be expected if capital markets were frictionless. By modeling extremes, we can assume that the response is likely to fall somewhere between.

Our own view is that for this exercise, the assumption that capital is not mobile internationally is more appropriate. Canada is unlikely to implement a strong climate policy unless other countries also do and, in this case, it is unlikely that the combined policies will cause a major shift of capital allocation between countries (although a re-allocation between sectors – which we model here – is more likely).

Results and Discussion

We model the growth of gross domestic product for each region under the three policy scenarios described above (Table 1 and Appendix Figure A5).[4] Every region experiences a slight reduction

4 All estimates of gross domestic product are measured at basic prices in real 2005 Canadian dollars.

Table 2: Financial Transfers Leaving Region Under Different Policy Scenarios due to Policy as a Percent of GDP in 2020

	Intensity-based Cap-and-Trade System	Auction with Federal Business and Personal Income Tax Cuts	Auction with Provincial Business and Personal Income Tax Cuts
Alberta and Saskatchewan	-1.0%	3.8%	0.0%
Rest of Canada	0.3%	-0.9%	0.0%

Note: Positive numbers indicate a transfer from the region. No transfers occur when the auction revenue is used to cut provincial income taxes.
Source: Authors' calculations from GEEM (see appendix for details).

in economic growth as a result of the climate policies, but the magnitude of the reduction depends on policy design.

- Policy scenario one – allocating permits based on the emissions intensity of firms (intensity-based cap-and-trade approach) – leads to stronger growth in Alberta and Saskatchewan relative to the rest of the country. Under this policy, annual GDP growth in these two provinces is 0.18 percent slower than in the absence of a policy, while growth in the rest of Canada slows by 0.28 percent.
- Policy scenario two, in which the federal government uses the revenue from a permit auction to reduce federal business and personal income tax rates, has a greater impact on the GDP growth rate for Alberta and Saskatchewan than for the rest of the country.
- Policy scenario three, in which the federal government returns the revenue from a permit auction to provinces in proportion to their contributions, via reductions in provincial income taxes, yields an outcome in between the other two policy designs. Alberta and Saskatchewan end up with an economic growth rate comparable to the average of the rest of Canada (about 2.02 percent), which would still mean that these two provinces had given up more than others in terms of retreating from their business-as-usual growth rate.

Each of these policy senarios achieves the same aggregate level of emissions, but allocates the economic burden of achieving that target to different regions. The intensity-based scenario goes beyond a sovereignty or equal cost definition of equity because regions with low GHG intensity actually see a greater reduction of their rate of economic growth than Alberta and Saskatchewan. In contrast, using the revenue from a permit auction to reduce the federal business and personal income tax rate yields an outcome closer to an egalitarian or polluter pays definition of equity. These scenarios attain greater aggregate economic output – the national economic growth rate declines only by 0.17 percent in these policies while the growth rate declines by 0.26 percent in the intensity-based policy – but, as noted, at the expense of greater reductions in output from Alberta and Saskatchewan.

Each policy senarios has different economic growth effects due to: (1) the level of inter-regional financial transfers caused by the policy (2) and the criteria by which permits are allocated or the method by which the revenue from a permit auction is redistributed (Table 2 and Appendix Figure A6). Inter-regional financial transfers support economic activity in the region that receives the transfer. In policies where permits are auctioned and the revenue is used to cut income taxes, this stimulates economic activity, and dampens growth in the region that supplies the transfer.

In the scenario where auction revenue is used to cut federal business and personal income taxes, Alberta and Saskatchewan transfer income to the rest of Canada. But no transfers occur when the auction revenue is used to cut provincial income taxes.

Table 3: Annual Growth in GDP between 2010 and 2020 under Perfect Capital Mobility

	Intensity-based Cap-and-Trade System	Auction with Federal Personal and Corporate Income Tax Cuts	Auction with Provincial Personal and Corporate Income Tax Cuts
Alberta and Saskatchewan	2.10% (-0.02%)	1.87% (-0.01%)	1.99% (-0.02%)
Rest of Canada	1.86% (-0.02%)	2.05% (-0.01%)	1.99% (-0.02%)
Total	1.91% (-0.02%)	2.01% (-0.01%)	1.99% (-0.02%)

Source: Authors' calculations from GEEM (see appendix for details).

Note: the changes from the assumption of no capital mobility are in parentheses.

The intensity-based cap-and-trade system, leads to a net transfer from the rest of Canada to Alberta and Saskatchewan, and shows the strongest economic growth in these two provinces. Alberta and Saskatchewan benefit from an intensity-based policy because they have cheaper options to reduce emissions intensity. For example, the electricity sector in Alberta and Saskatchewan can increase generation from renewable resources and natural gas, or adopt carbon capture and storage when using coal, to significantly reduce emissions intensity, while the electricity sectors in other provinces already have low emissions intensity (because of the large role of non-emitting hydropower and nuclear power) with fewer options for improvement. As a result, even though all firms receive permits equal to their emissions intensity targets, firms in Alberta and Saskatchewan would face lower costs to reduce emissions below their intensity targets and thus would reduce emissions in order to generate surplus permits to sell to firms in the rest of the country.

Sensitivity to Assumptions about Capital Mobility

The results thus far are based on the assumption that net foreign savings in Canada will not change because of Canada's climate policies.We now test the alternative n which capital moves freely across international boundaries such that there is a single global return on capital.[5] Here, we treat Canada as a small economy, meaning that policies implemented domestically do not affect the global return on capital.

However, it turns out that the aggregate results are not significantly changed by altering this assumption. Even when Canada imposes a carbon policy while its trading partners do not, and when international capital markets are frictionless, growth rates are not significantly altered (Table 3). Under the revised assumptions, the changes from the assumption of no capital mobility are in parentheses.

In each scenario, the rate of annual growth in GDP declines by 0.02 percent or less, implying that net capital flows are largely unaffected by the policies. This small decline is mostly explained by the type of policies we simulated, which provide either direct or indirect subsidies to industry via the free emissions associated with an intensity target or the revenue provided by income tax cuts. Cutting corporate income taxes improves the after-tax return to investment, while the intensity-based allocations in the cap-and-trade system maintain robust returns to capital by indirectly subsidizing industrial output.[6]

However, the impact of capital mobility on Canada's GDP growth remains sensitive to

5 In the model, we exogenously impose a return on capital, and endogenously adjust net foreign savings until the domestic rate of return on capital matches the exogenously specified return on capital.

6 To disaggregate the effect of carbon costs from income tax cuts on net capital flows and GDP we would have to simulate an additional policy where the rents from permits are not allocated to firms or households. However this is not possible in a CGE model as the rents from a permit auction or free allocation must be allocated back into the economy somewhere, making the disaggregation difficult.

policy design. This analysis has explored two specific policies that were designed to highlight differences in inter-regional equity. They do not show significant differences in capital movement. A comprehensive analysis of policy designs or the effect of policies implemented in other countries would show that some designs can lead to greater capital movement.

Final Comment

The purpose of this study is to present different options for climate policy within the framework of inter-regional equity. It shows that climate policy can be designed to achieve either a polluter pays/egalitarian approach or a sovereignty/equal cost approach to equity. Climate policy resulting in substantial GHG emissions reductions in Canada need not lead to relatively slower growth in GHG-intensive economies like Alberta and Saskatchewan. Emissions permits can be distributed, or the revenue from a permit auction allocated, to achieve a large array of regional outcomes.

We have explored three policy scenarios under two broad design approaches – the first which is similar to the federal government's 2008 proposal for an intensity-based, cap-and-trade system and the second which is based on an emissions cap-and-trade system with auctioned permits returned to the economy via tax cuts (the same approach British Columbia uses to redistribute the revenue from its carbon tax). The former leads to outcomes most consistent with a sovereignty or equal cost approach to equity, while the latter is more flexible and can achieve a polluter pays approach or a compromise between the two definitions.

The compromise can be achieved by having the federal government return permit auction (or carbon tax) revenues to provincial governments in proportion to the contribution they have made. This suggests, however, that the permit-auction process may need to be operated in a highly transparent manner by both provincial and federal governments – no federal government will want to be in a position of being solely responsible for raising energy costs to Canadians while provincial governments get the credit for returning auction revenues via cuts in provincial income taxes.

Finally, climate policy will not necessarily reduce corporate profitability or lead to a net outflow of investment capital from Canada. Carbon pricing policies can be designed to maintain corporate profitability by recycling carbon revenue via tax cuts (especially corporate income taxes) or by providing free allocations based on industrial production. In this analysis, neither of these policy scenarios results in a significant net outflow of investment capital.

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Appendix A - Description of GEEM model

The analysis employs a computable general equilibrium (CGE) model called GEEM. The GEEM model represents all economic activity in the economy and ensures equilibrium in all the markets (i.e., for commodities, services and factors of production) by adjusting prices until supply and demand reach an equilibrium. The version of GEEM used for this analysis represents British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec and Atlantic Canada, and each of these regions interacts through trade of commodities and services. Capital is assumed to be mobile among regions, while labour is assumed to be mobile within provinces or states. In the model, a representative household in each region is the owner of primary factors (labour, capital and natural resources) which they rent to producers who combine them with intermediate inputs to create commodities. Commodities can be sold to other producers (as intermediate inputs), to final consumers, or to other regions and the rest of the world as exports. Commodities can also be imported from other regions or the rest of the world. The key economic flows in GEEM are captured schematically in Figure A1.

The version of GEEM in this analysis is static – it solves for a single period in 2020; while the implicit time frame simulated in the model is from 2010 to 2020. Accordingly, in each sector a proportion of capital is treated as sector-specific fixed capital, with this amount determined based on an initial stock of capital depreciated over the time period between the start of the policy (2010) and the reporting period (2020). Any forecasted additions to the capital stock between 2010 and 2020 must be from new or malleable capital. Malleable capital is allocated to sectors until each sector offers the same rate of return to capital – therefore climate policy alters the allocation of capital among sectors. This formulation is known as 'putty-clay' capital.

The data underlying the model is derived primarily from the Statistics Canada System of National Accounts. We use the S-Level Input, Output, and Final Demand tables to populate the model, and aggregate and disaggregate these to focus on sectors of primary interest. One of the challenges with the S-Level data is its lack of disaggregation for energy and emissions intensive sectors. We disaggregate these sectors using the M- and L-Level data from Statistics Canada, Statistics Canada's Report on Energy Supply and Demand, the Canadian Association of Petroleum Producer's production data for oil and gas production, and the CIMS energy economy model, among other sources.

The following sections describe the representation of industry, consumers and trade between provinces and countries. Additionally, it discusses some of the key assumptions in modeling policies in each scenario.

Industry

The GEEM model represents 21 industries (see Table A1). The table also shows the data from Statistics Canada's input-output tables on which the sectors are based.

All industrial sectors in the GEEM model are represented by nested constant elasticity of substitution (CES) functions, which represent the technologies industry can use to produce goods and services. Central to this function are the elasticity-of-substitution parameters, which represent how easily a sector can substitute between different inputs while maintaining a given level of production. For example, the model simulates a tradeoff between energy consumption and value added (i.e., capital and labour) through the elasticity parameter labelled σ_{vae} in Figure A2. A low value for σ_{vae} indicates that the value-added bundle is not very substitutable for energy; and the energy intensity of the sector is largely unaffected by new economic conditions or policies. A high value for σ_{vae} indicates greater substitution possibilities; and economic conditions or policies that raise the price for energy relative to the price for the value-added bundle induce improvements in energy efficiency.

To model resource extraction sectors, we introduce the concept of "resource rent," which is profit earned by resource sectors that exceeds a normal rate of return on investment. Resource extraction sectors earn extra profits (some of which is collected by government in the form of royalties) because the resource they extract is scarce and resource plays have different costs of extraction. In other words, unlike manufactured commodities there is a finite amount resource to extract, such that buyers pay a premium that reflects the scarcity of the commodity. In addition, resource plays differ in their costs of extraction (quality), such that owners of easy to extract (high quality) resources earn additional profits relative to owners of resources that are more difficult to extract. For example, oil extraction from a conventional well would yield greater resource rent per unit of oil production than oil sands mining and upgrading (which has higher costs of extraction).

We use the concept of resource rent to characterize the supply curve for resources. As illustrated in Figure A2, we simulate the ability of a resource sector to substitute between the amount of a fixed resource and other inputs into production, which is represented by the elasticity value σ rr. If the price for the resource increases, the value of the resource rent (extra profits) for a given level of production increases. Assuming the price for other inputs into production stays constant, the model will simulate an increase in production by shifting away from the fixed resource towards greater inputs. This reflects industry moving towards more marginal resources. In an alternative scenario where the costs of extraction increase (due to the adoption of carbon capture and storage for example), the cost of inputs becomes more costly in comparison to the resource and the model simulates that the marginal resources will not be developed.

The values for all elasticity values used to parameterize the model are illustrated in Table A2.

An additional feature of the GEEM model is we include "alternative" methods of producing goods and services from sectors with specific abatement technologies (e.g., carbon capture and storage). These technologies are unprofitable in the reference case and only become active under certain economic or policy conditions (e.g., carbon pricing). Table A3 shows the key sectors and processes in which carbon capture and storage is available.

In the GEEM model, all industries maximize profits (i.e., revenue minus costs of production) subject to technology constraints. The projected growth rates for each industrial sector are based on projections provided to the authors by Informetrica.

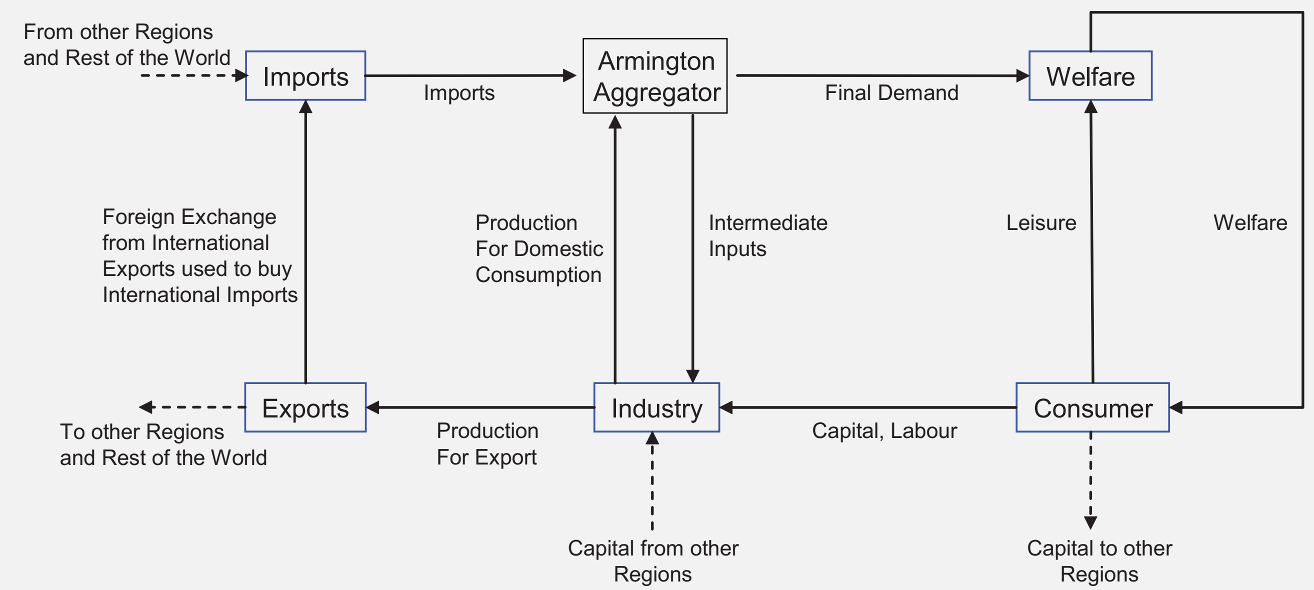
Consumers

GEEM uses a representative agent framework, where all households are represented by a single representative agent. In this framework, the representative agent maximizes his/her welfare, where welfare is a function of consumption of various commodities and leisure (see Figure A3 for the tree structure and Table A4 for the associated elasticity values). Note that the trees representing space heating, appliances and other goods are identical to the tree representing transportation, and therefore are not shown. Most of the elasticity values have been econometrically estimated from the CIMS energy-economy model, while the values representing the substitutability between an end-use and other goods (σ transit) are from Paltsev (2005).

Trade

The substitutability between domestically produced and imported goods is represented by an Armington formulation (see Figure A4 for the structure of imports and Table A5 for the corresponding elasticity values). An elasticity of infinity indicates that a commodity is homogeneous and Canada is a price taker. This is important to represent crude oil in international markets and natural gas in North American markets.

Figure A1: Overall structure of the GEEM model



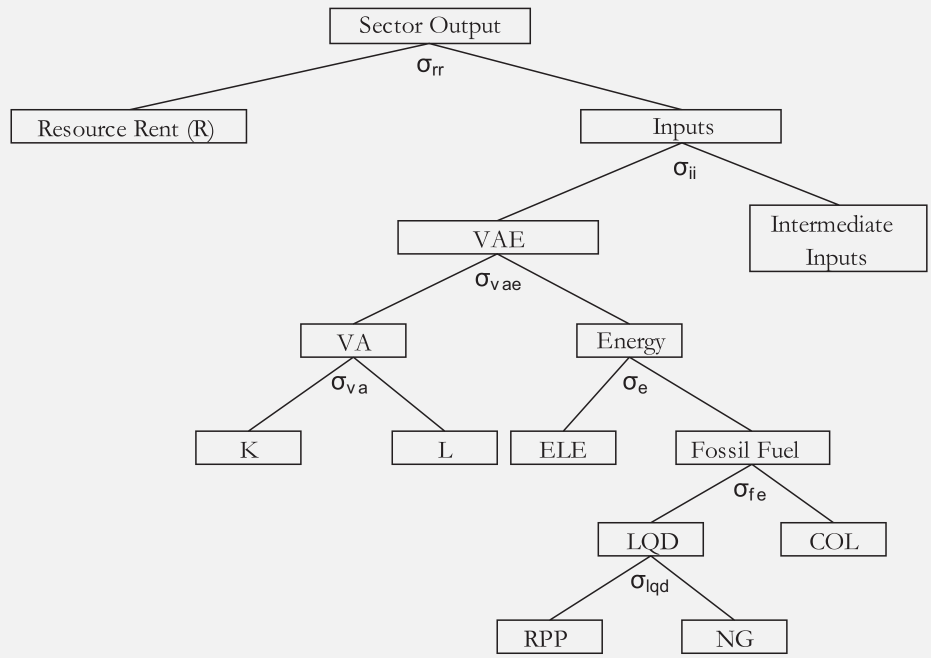
Source: Authors' calculations.

Table A1: Industries in GEEM

GEEM Sector	GEEM Sector Description	Data Available at the S-Level
PEXT	Crop and animal production Forestry and logging Fishing, hunting and trapping Support activities for agriculture and forestry	Crop and animal production Forestry and logging Fishing, hunting and trapping Support activities for agriculture and forestry
OSMU	Oil Sands Upgraded	Mining and oil and gas extraction
OSIS	Oil Sands In-situ	
OCLM	Oil Light Medium	
OCHY	Oil Heavy	
CNGAS	Conventional Natural Gas Extraction	
TNGAS	Tight Natural Gas Extraction	
SNGAS	Shale Natural Gas Extraction	
MINING	Coal and Mineral Mining Support activities for mining and oil and gas extraction	
CELEC	Conventional electric power generation	Utilities
RELEC	Hydroelectric and other renewable electric power generation	
PAPER	Paper manufacturing	Manufacturing
REFINE	Petroleum and coal products manufacturing	
CHEM	Chemical manufacturing	
INDMIN	Non-metallic mineral product manufacturing	
METAL	Primary metal manufacturing	
OMAN	Miscellaneous manufacturing	
TRANSIT	Transit and ground passenger transportation	Transportation and warehousing
TRANS	Other Transportation Transportation margins	Transportation and warehousing Transportation margins
SERV	Natural gas distribution, water and other systems Construction Wholesale trade Retail trade Information and cultural industries Finance, insurance, real estate and rental and leasing Professional, scientific and technical services Administrative and support, waste management and remediation services Educational services Health care and social assistance Arts, entertainment and recreation Accommodation and food services Other services (except public administration) Operating, office, cafeteria, and laboratory supplies Travel and entertainment, advertising and promotion Non-profit institutions serving households	Utilities Construction Wholesale trade Retail trade Information and cultural industries Finance, insurance, real estate and rental and leasing Professional, scientific and technical services Administrative and support, waste management and remediation services Educational services Health care and social assistance Arts, entertainment and recreation Accommodation and food services Other services (except public administration) Operating, office, cafeteria, and laboratory supplies Travel and entertainment, advertising and promotion Non-profit institutions serving households
GOVT	Government sector	Government sector

Source: Authors' calculations from GEEM (see appendix for details).

Figure A2: Structure of industrial sectors in GEEM



Source: Authors' calculations.

Table A2: Elasticities of Substitution by Sector

	σ_{rr}	σ_{ii}	σ_{vae}	σ_{va}	σ_{e}	σ_{fe}	σ_{lqd}
PEXT	0.6	0.2	0.5	0.55	1.08	0	1.17
OSMU	0.6	0.2	0.1	0.55	0.2	0.3	1.01
OSIS	0.6	0.2	0.1	0.55	0.2	0.3	1.01
OCLM	0.6	0.2	0.1	0.55	0.2	0.3	1.01
OCHY	0.6	0.2	0.1	0.55	0.2	0.3	1.01
CNGAS	0.6	0.2	0.1	0.55	0.2	0.3	1.01
TNGAS	0.6	0.2	0.1	0.55	0.2	0.3	1.01
SNGAS	0.6	0.2	0.1	0.55	0.2	0.3	1.01
MINING	0.6	0.2	0.1	0.55	0.2	0.3	1.01
CELEC	0	0.2	0.45	0.55	0.4	1	0.1
RELEC	0.6	0.2	0	0.55	0	0	0
PAPER	0	0.2	0.26	0.55	0.2	0.3	1.2
REFINE	0	0.2	0.26	0.55	0.2	0.3	1.2
CHEM	0	0.2	0.26	0.55	0.2	0.3	1.2
INDMIN	0	0.2	0.26	0.55	0.2	0.3	1.2
METAL	0	0.2	0.26	0.55	0.2	0.3	1.2
OMAN	0	0.2	0.45	1.1	0.4	0.8	1.2
TRANSIT	0	0.2	0.27	1.1	0.49	0.8	1
TRANS	0	0.2	0.27	1.1	0.49	0.8	1
SERV	0	0.2	0.35	1.1	0.2	0.5	1
GOVT	0	0.2	0.35	1.1	0.2	0.5	2.5

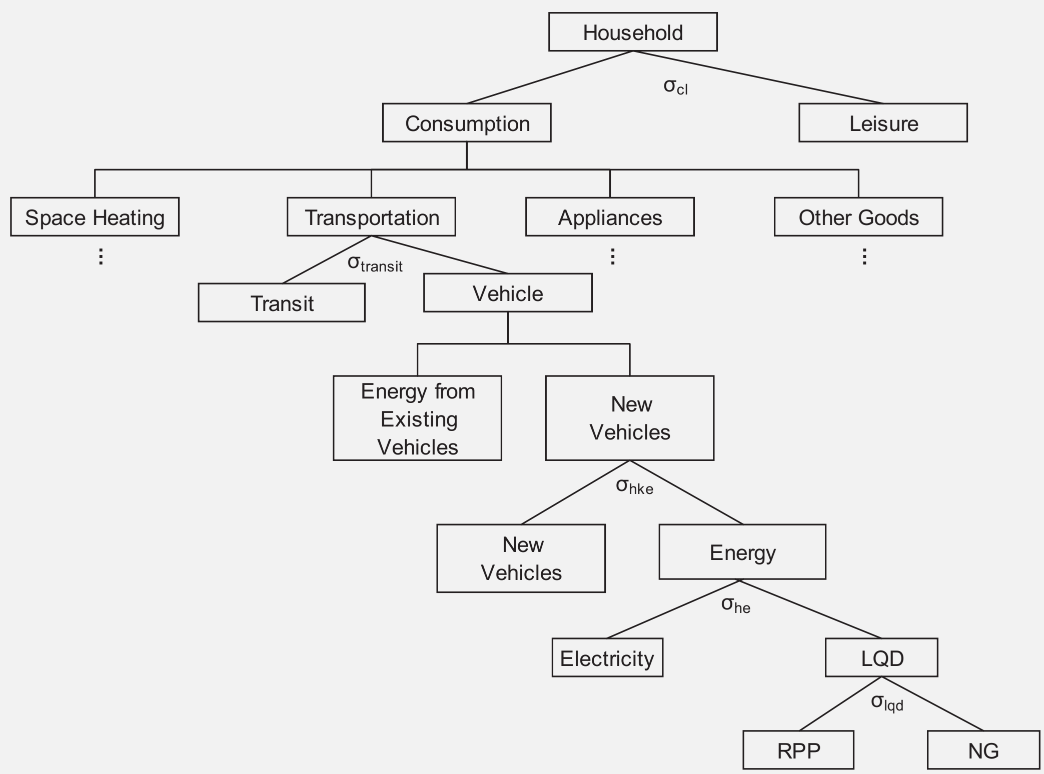
Source: CIMS, 2009 and Paltsev, 2005.

Table A3: Sector and Processes which Include a CCS option

Sector	Process
Oil Sands Mining and Upgrading	Hydrogen production
	Heat production
Oil Sands In-situ	Heat production
Natural Gas Processing	Formation CO_2 removal
	Heat production
Electricity Generation	Baseload coal
	Baseload NG
	Shoulderload coal
	Shoulderload NG
Non-metallic Minerals	Kiln operations
Petroleum Refining	Hydrogen production
	Heat production

Source: Authors' calculations from GEEM (see appendix for details).

Figure A3: Structure of Household Welfare



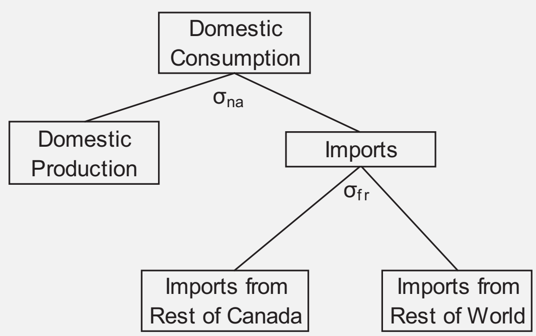
Source: Authors' calculations.

Table A4: Elasticities of substitution for households

	σ_{cl}	$\sigma_{transit}$	σ_{hke}	σ_{he}	σ_{lqd}
Space Heating	0.6	0	3.3	3.5	3.4
Transportation		0.2	0.6	7.5	0
Appliances		0	0.1	0	0
Other Goods		0.25	0	0	0

Source: CIMS, 2009 and Paltsev, 2005.

Figure A4: Structure of Imports



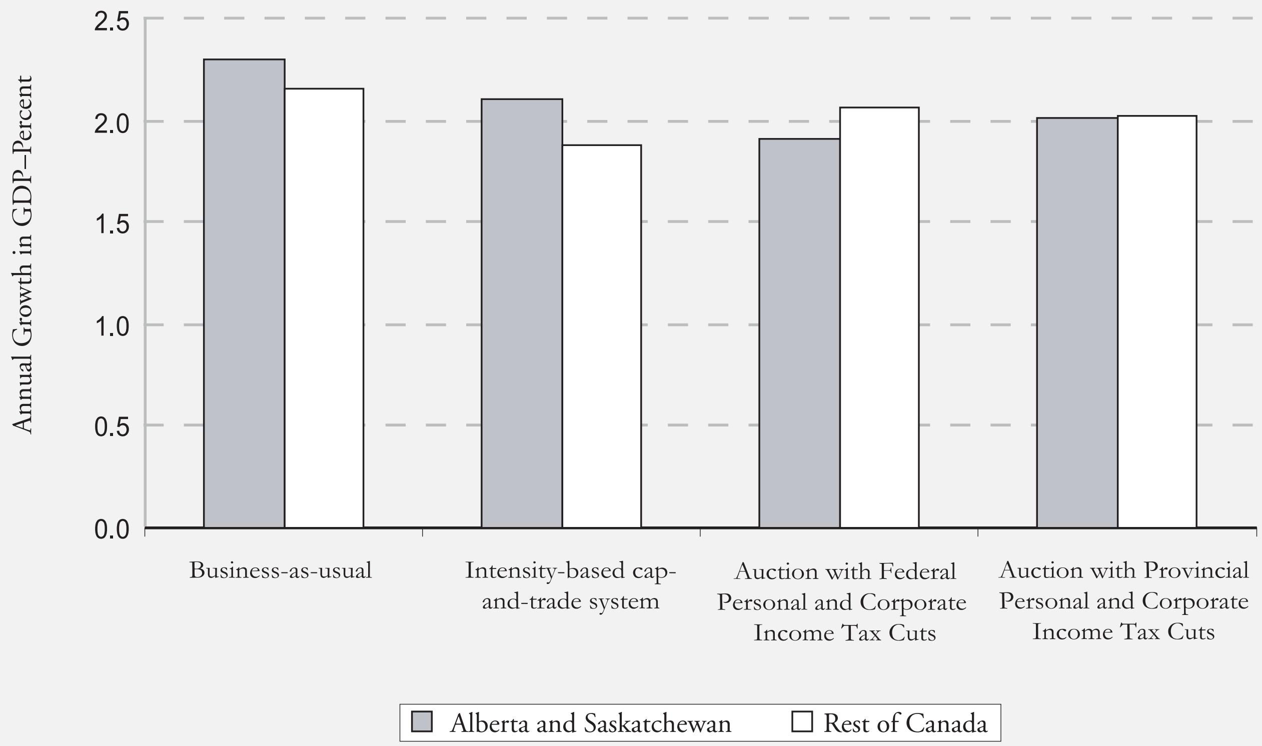
Source: Authors' calculations.

Table A5: Armington Elasticities

	σ_{na}	σ_{fr}
Crude Oil	∞	∞
Natural Gas	∞	4.0
Other Energy	4.0	4.0
Other Goods	2.5	2.5

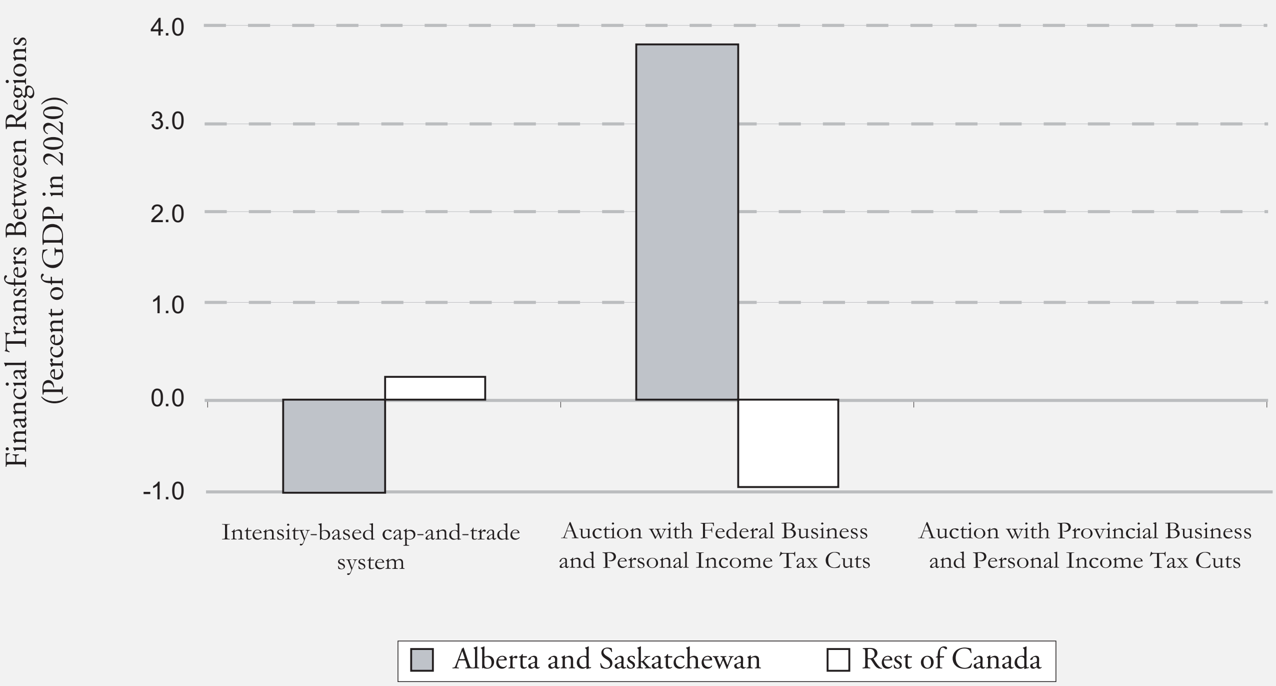
Source: Authors' calculations.

Figure A5: Annual Growth in GDP, between 2010 and 2020



Source: Statistics Canada (2009); Environment Canada (2008).

Figure A6: Financial Transfers Leaving Regions Under Different Policy Scenarios



Note: Positive numbers indicate a transfer from the region. No transfers occur when the auction revenue is used to cut provincial income taxes.
Source: Authors' calculations from GEEM (see appendix for details).

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