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ESTIMATED IMPACTS OF A $170 CARBON TAX IN CANADA

Revised Edition

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Executive Summary

As part of its Healthy Environment and Healthy Economy (HEHE) plan to address climate change the Canadian government intends to increase the carbon tax from its current level of $30 per tonne to $170 per tonne over the next nine years. Although it claims to have done a comprehensive macroeconomic analysis of the effects, no information has been released to the public about the economic impacts, except for the claim that there will be no effect on Gross Domestic Product.

By contrast, we find that the federal carbon tax will cause a 1.8% drop in Gross Domestic Product (GDP), which works out to about $1,540 in current dollars per employed person, and the loss of about 184,000 jobs nationwide. This estimate is in line with numerous analyses done 20 years ago of the costs of meeting the Kyoto Protocol target. Those studies, which were made by multiple independent groups inside and outside the government all concluded that significant greenhouse-gas reductions would impose large costs on the Canadian economy.

The economic costs vary by province. Alberta will experience a 2.4% reduction in GDP while Quebec and British Columbia will face drops of 1.5% and 1.6%. The largest proportionate burdens of job losses will fall on Ontario and Alberta, with Quebec and British Columbia close behind.

The federal government maintains that, because they plan to rebate most of the carbon-tax revenue, the majority of Canadians will get back more than they pay, and that Canadians will “most likely” find themselves better off as a result of the policy. It is noteworthy that increases in energy costs fall disproportionately more heavily on lower-income households. We find that, even after taking account of the rebates and the stimulative effect of new spending, average real household consumption falls in every province by between 0.4% and 1.4%. While it is possible that the government’s goal is feasible, depending on the distribution of impacts it may be difficult to achieve in practice.

Furthermore, it will not be feasible for the government to rebate the majority of carbon-tax revenues without increasing the federal deficit. The increased carbon tax will cause the rest of the tax base to shrink, offsetting much of the new tax revenues. If the government rebates 90% of the carbon tax revenues to households, spends the remainder, and keeps all other tax rates constant, it will permanently increase government deficits by about $22 billion annually.

1 Introduction

1.1 The Canadian carbon tax

As part of the Pan-Canadian Framework on Clean Growth and Climate Change the federal government has implemented a carbon tax, or a charge on use of fossil fuels in proportion to the carbon content of the fuel. The tax was assessed at a rate of $20 per tonne of CO_2-equivalent in 2019. Under the Healthy Environment and Healthy Economy (HEHE) plan, the tax is scheduled to rise in steps until 2030, at which point it will reach $170 per tonne (Government of Canada, 2020). The government proposes to reimburse households by providing lump-sum rebate cheques funded by the proceeds of the carbon charge. Their assertion is that most households will be better off since they will receive greater reimbursements than they pay in carbon charges.

> Bottom line: if you live in a province where the federal carbon price applies, you'll most likely find yourself better off, saving money and better able to invest in affordable solutions that reduce pollution. (Government of Canada, 2020: 26)

However, this claim is rendered doubtful by the fact that the carbon charge will cause reductions in the rest of the tax base that will offset the revenues available for households. These include the following.

- The increased cost of using fuel will reduce the tax base for other sales taxes, especially by reducing the base on which fuel excise taxes are charged, and will propagate throughout other consumer prices, causing reductions in demand and thus reduced revenues from other provincial and federal sales taxes. Indeed, one of the main channels by which the carbon tax reduces emissions is by cutting the use fossil fuels, which by implication reduces other parts of the tax base. The more effective it is at reducing fuel use the more it will affect the rest of the sales tax base.

- The increased cost of living will reduce real wages and cause the labour supply to shrink. Also, firms will have lower revenues and will reduce their demand for labour and capital. Both of these changes will reduce federal income-tax revenues.

Consequently, if the federal government aims to refund most of the proceeds of carbon charges to households while keeping other spending and tax rates unchanged, the net effect will be an increase in the government deficit.

Extended Non-technical Summary

The federal government's Healthy Environment and Healthy Economy (HEHE) plan includes a $170-per-tonne carbon tax to be phased in over 9 years. Unlike previous cases when the government proposed major policy changes, it has not released any quantitative economic analyses of the impacts of the plan, except to claim that the policy will have no effect on GDP. This claim is at odds with numerous previous analyses of the costs of greenhouse-gas emission controls that were made inside and outside the federal government during discussions of the Kyoto Protocol.

In this study, we present an analysis using a large empirical model of the Canadian economy that indicates that the tax will have substantial negative impacts, including a 1.8% decline in Gross Domestic Product and the net loss of about 184,000 jobs, even after taking account of jobs created by new government spending and household rebates of the carbon charges. The drop in GDP works out to about $1,540 in current dollars per employed person.

The analytic method we use here is called Computable General Equilibrium (CGE) modeling and is one of the standard approaches for assessing this type of policy. In previous policy debates, the federal government provided multiple independent analyses using several CGE models developed within federal ministries or in the academic sector and, for comparison, provided estimates using other analytical methods that were again developed internally or in the private sector. We compare our findings and show that our macroeconomic cost estimate is almost identical to the average of six previous studies when scaled to an equivalent reduction in carbon-dioxide emissions.

In our analysis of the policy, we account for the effects of the Output-Based Pricing System for energy-intensive and trade-exposed sectors and we take partial account of the effects of the Clean Fuels Standard, on the assumption that compliance will be aided by a credits-trading system that will limit the actual effect on fuel carbon intensity.

CGE models do not attempt to estimate temporary unemployment arising from a policy shock. Instead they compute "before and after" snapshots assuming that the labour market clears each time. In order for labour supply and demand to balance after introducing the carbon tax it is necessary that real wages decline. We find that real household incomes in the model decline by 2.5% nationally, but the carbon tax rebates offset much of that loss so real household consumption only declines by 1.0%. We also observe that real consumption goes down in every province. The federal government intends for the majority of Canadians to be made better off by the policy, but this may end up being difficult to achieve in practice.

We deflate the nominal value of the carbon tax to $140 to account for inflation. We estimate that a carbon tax of this magnitude will result in a 26% reduction in carbon-dioxide emissions. This will not be sufficient to reach the Paris target. We estimate that a constant-dollar carbon tax of $243 per tonne would be required to get 2030 emissions down to the Paris target, and it would need to increase continually thereafter to keep emissions constant in the context of a growing population.

A key finding of this analysis is that introducing the carbon tax will cause rather pronounced reductions in revenues elsewhere in the tax system, such that the government will not be able to refund household carbon-tax payments to the extent it has promised without going into deficit. The net increase in government revenue will only cover about 28% of the carbon taxes on final demand. If the government intends to rebate 90% of the revenue and use 10% to increase spending elsewhere, it will add about $22 billion annually to the consolidated government deficit.

1.2 Comparisons to previous cost estimates

Another claim that government has made is that the HEHE plan will not affect Canada's gross domestic product (GDP).

> The [Environment and Climate Change Canada] modelling projects that the measures in the plan will to lead to a very small reduction in annual real GDP growth of about 0.05%, an amount that is considerably less than the average annual revision to GDP year-over-year. (Government of Canada, 2020: 6, Modeling and Analysis).

This statement is the entirety of the federal government's disclosure of quantitative estimates of the economic consequences of its plan. [1] It is, furthermore, ambiguous so we clarified via e-mail with the staff of Environment and Climate Change Canada (ECCC) that the estimated change is essentially zero. If, for example, under the base case the economy were to grow by 2% annually, under the HEHE Plan it would grow by 0.05% less, or 1.999% annually. Over ten years this implies the economy grows by 21.89% rather than 21.90%.

The claim that the policy is costless stands in sharp contrast to past estimates by government and the private sector of the costs of reducing greenhouse-gas (GHG) emissions in Canada. Table 1 presents a summary of six assessments of the costs of reducing greenhouse-gas emissions that were published over the interval between 1991 and 2001. All but one originated within the federal government, and the models used were drawn from both inside the government and from the private and academic sectors. To aid in comparison with the HEHE Plan the final column rescales the loss in GDP linearly to correspond to a 25% emission cut.

The numbers shown in table 1 are selected from an even larger suite of estimates in order to confine attention to policy experiments that broadly correspond to the HEHE Plan. For a 25% cut in greenhouse-gas emissions the scaled cost estimates range from 0.8% to 2.9% of GDP. Note that the lowest estimate (from the old Finance Canada Canadian Sectoral General Equilibrium Model (CaSGEM) model) was computed after imposing an assumption—which was disputed by Finance Canada at the time—that a large number of costless behavioural adjustments would take place in society as a result of moral suasion, such as widespread switching to public transit. They cautioned that the policy would be "noticeably more costly" if these changes did not turn out

[1] The on-line material referenced at Government of Canada, 2020 consists mainly of qualitative and aspirational claims. We confirmed with staff of Environment and Climate Change Canada (ECCC) that no other quantitative or modeling information is scheduled for release.

Table 1: Estimates of Kyoto compliance costs in terms of lost Canadian real GDP

Study	Origin	GHG reduction	GDP loss	Scaled GDP loss
Beauséjour, Lenjosek, and Smart, 1992	Dep't of Finance	12.5%	0.8%	1.6%
McKitrick, 1997	Academic	12.5%	0.8%	1.6%
Gov't of Canada, 2001	Federal government	15.0%	1.6%	2.7%
Analysis and Modeling Group, 2000	Natural Resources Canada	26.0%	2.0%–3.0%	1.9%–2.9%
Wigle, 2001	Industry Canada	25.0%	1.5%	1.5%
Canada, Dep't of Finance, Economic Studies and Policy Analysis Division, 2000	Dep't of Finance	26.0%	0.8%	0.8%
Average of above				1.9%
This study (2021)	Private sector	25.6%	1.8%	1.8%

to be costless. The CaSGEM analysis also assumed that carbon capture and storage would be available for coal-fired power plants at a cost of $38 per tonne (in 2010 dollars), which sharply reduced the costs of compliance for the electricity sector. The next lowest estimate, from Wigle, 2001, was from a model that assumed there were no other taxes in the economy and fixed employment, which would tend to dampen the estimated costs of a new carbon tax.

Our analysis finds that use of a carbon tax to achieve a 25% reduction in GHG emissions would cause Canada's real GDP to shrink by about 1.8%. This is almost identical to the average estimate from the suite of previous studies.

1.3 Interactions between carbon charges and the rest of the tax base

Environmental economists have put a lot of effort over the past few decades into understanding the interactions between emission taxes and the rest of the tax system (*e.g.*, Sandmo, 1975; Bovenberg and Goulder, 1996; Goulder, 1998; Parry, Williams, and Goulder, 1999; Fullerton and Metcalf, 2001; Goulder, 2013; Böhringer, Rivers, and Yonezawa, 2016). All tax systems give rise to "excess burdens" or dead-weight losses, when it costs more than one dollar in lost economic welfare to yield one additional dollar in public funds. The excess burdens arise because taxes drive a wedge between prices for buyers and sellers, which cause market quantities to fall below the levels that would be optimal in the absence of the requirement to fund the government. The marginal cost of public funds, or MCPF, measures the dead-weight losses associated with further increases in government revenues. An MCPF of, say, 1.5, means that the economy has to give up $1.50 worth of economic activity to yield one additional dollar for the government.

Emission taxes are like any other tax in that they have an MCPF greater than 1, and their introduction imposes costs that propagate throughout the economy. Using the revenues from emission taxes to fund reductions in other tax rates yields a so-called "Double Dividend", namely, a reduction in the excess burden of other taxes. However, research since the 1970s has shown that the excess burdens of new emission taxes exceed the potential Double Dividend, and the higher the MCPF in an economy, the worse the net effect will be.

The costs associated with tax interactions are made worse if the revenues from emission taxes are used for purposes other than reducing other tax rates. If, for example, the revenues are given out as lump-sum transfers to households, as Canada does, no offsetting Double Dividend is created, which makes the economic impacts of the tax worse than would have been the case if, for example, the emission-tax revenue had been used to reduce personal income taxes.

Canada's MCPFs are variable and in some cases quite large, which means tax-interaction effects can be expected to be large in the Canadian context. Dahlby and Ferede (2018) estimate MCPFs from general sales taxes range from 1.3 to 2.4 across Canadian provinces, [2] while Personal Income Tax MCPFs range from 1.4 to 6.8, and Corporate Income Tax MCPF's range from 2.9 to 5.2. MCPFs of this magnitude also imply that increases in taxes in one market have relatively large negative effects on the rest of the tax base, the so-called "fiscal externality" problem.

Böhringer, Rivers, and Yonezawa (2016) examine fiscal externalities between a carbon tax and other tax instruments in a model of the Canadian economy. Their analysis primarily examines how unilateral climate policy in one province can result in costs to other provinces by shifting part of the federal tax burden outwards. Many of their simulations assume the labour supply is fixed within each province but, when they relax that assumption and allow the labour supply to drop in response to higher taxes and consumer prices, the fiscal externalities get very large and exceed the magnitude

[2] This range omits Alberta since it has no provincial sales tax.

of the carbon tax measure. Since the model we use here also allows endogenous adjustment of the labour supply, this is the relevant case to compare. We will likewise find strong fiscal externalities between new carbon taxes and the rest of the tax base that extinguish much of the expected revenue from the carbon tax.

1.4 Costs and benefits

This analysis looks only at the costs of implementing the carbon tax policy. We do not attempt to quantify the benefits. Doing so properly would require a global analysis that takes account of, among other things, "leakage" effects: offsetting increases in other countries' emissions that result from policies that reduce Canadian emissions by sending the emitting activity elsewhere as opposed to eliminating it altogether.

Furthermore, it is incorrect to ascribe benefits to greenhouse-gas policy using the so-called "costs of inaction" approach, which entails listing the economic costs of all adverse weather events in recent years. Even if all such costs could be ascribed to greenhouse-gas emissions, which is not the position of the Intergovernmental Panel on Climate Change in its past assessments of the issue (*e.g.*, IPCC, 2013), the appropriate measure of the benefits of the policy would be only those costs that would be averted by adoption of the policy. In principle, this amounts to a very small fraction. The effects of CO_2 emissions are not local but are based on changes in the global average atmospheric concentration. Canada's CO_2 emissions are only about 1.5% of the global total [3] and the HEHE plan would only reduce this by about one quarter, which means global emissions would not fall by much, especially after taking account of leakage effects. Even full compliance by all parties to the Paris Accord would have barely noticeable effects on total global CO_2 concentrations and future climate projections over the coming century (Lomborg, 2016), something that was also true of the Kyoto Protocol (Wigley, 1998). Consequently, Canada's actions alone will not materially affect the path of future CO_2 concentrations, and by implication climate-induced adverse weather events, and even multilateral action by all our climate-policy partners will likewise have minimal effect, at least for the next century. So it would be misleading to suggest that adopting the carbon tax will prevent adverse weather events from happening in the future and then to use the costs of recent events as a measure of the policy's benefit.

[3] Data available at US Dep't of Energy, Carbon Dioxide Information Analysis Center (CDIAC), *Fossil-Fuel CO2 Emissions*: <https://cdiac.ess-dive.lbl.gov/trends/emis/meth_reg.html>, as of March 2, 2021.

2 Analytical Method

2.1 The LFX model

Appendix A (p. 22) provides a detailed technical description of the LFX model (version 3.0) used for this study. The model comprises a computable general equilibrium treatment of ten Canadian provinces plus the far North, resolving factor markets for labour and capital as well as intermediate input-output tables and final-demand categories, broken down into 26 sectors and commodities. The input-output tables are initialized using the 2016 Canadian Input-Output (Use) tables from Statistics Canada, but the equilibrium input-output coefficients are computed endogenously to be consistent with market-clearing prices. Governments are treated as a single consolidated layer, and the Canadian tax system is represented in some detail, with province-specific rates of sales tax computed based on indirect tax payments recorded in the Input-Output tables and income-tax payments as reported in Statistics Canada's *Consolidated Government Financial Statistics* (table 36-10-0450-01). Domestic and international trade flows are modeled using parameters estimated on Canadian historical data.

The computational sequence begins by applying all combined federal and provincial intermediate tax rates including the carbon tax to intermediate prices, then computing a first-order propagation to domestic output prices in each sector using the initial input-output coefficients. These prices are then used to compute final input-output coefficients, including labour and capital demands per unit of output, which yield seller-price indexes for each sector. The seller-price indexes are then passed to final demand sectors with addition of other sales taxes and other levies on final demands as appropriate. The household model yields labour supplies and final consumption demands. Other sub-models yield government final demands, Gross Fixed Capital Formation, and domestic and international trade flows. All goods and service markets in each province clear by application of the Leontief equation, which implicitly assumes constant returns to scale.

The labour market clears by iteratively adjusting the national wage rate until national supply equals national demand, hence there is no national unemployment in equilibrium, but individual provinces may experience labour shortages or surpluses. The capital market clears in each province by allowing the Capital Utilization Rate to vary based on comparison of demand for capital services and the fixed capital stock. The national exchange rate varies until nominal exports plus nominal foreign borrowing equals nominal imports. Foreign borrowing is determined by domestic investment needs to fund government deficits and gross fixed capital formation over and above that funded by domestic savings, although the model allows a disequilibrium in the external account to take account of other countries accumulating or decumulating Canadian dollar reserves within each period.

A policy experiment entails running the model twice, first computing a base-case solution with no carbon tax, then computing a new general equilibrium at the proposed carbon tax rate.

2.2 Representing the federal carbon pricing policy

Fuels charge and Clean Fuel Standard

The Canadian carbon tax is implemented in the model as a set of unit taxes on coal, petroleum, and natural gas. These fuel types are not broken down further (for instance into gasoline and diesel).

We assume that a uniform carbon price is imposed across the country. The nominal amount of the tax as of 2030 is $170 per tonne of carbon-dioxide equivalent. To take account of price changes over the coming decade we deflate this to $140 per tonne. The charge is implemented in the model in such a way that the HST/GST is not charged on the carbon-tax payment. This is different from the current implementation in some provinces, but the overall effect is likely to be small.

We assume that the government sets aside 90% of the carbon-tax revenues on final demand categories for rebating to households via a lump-sum transfer, and spends the remaining 10% on goods and services.

We also assume that a Clean Fuel Standard (CFS) is in place that reduces the carbon intensity of gasoline by 5% (see Lee and McKitrick, 2020). While the goal of the CFS is to achieve a 13% reduction in liquid-fuel carbon intensity, the government has also proposed a credits trading system with a price cap of $300 per tonne (Hosseini, Romaniuk, and Millington, 2019) that will limit the stringency of the policy. The CFS will affect not only the costs of fuel production but also consumer spending since ethanol has less energy per unit than gasoline. We estimate that the mandate for a 5% reduction in carbon intensity will add 17% to the cost of using motor fuels in Canada. Appendix B (p. 31) sets out the calculations behind this number. The increased cost is applied both in the base case and carbon-tax experiment. [4]

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[4] The results herein are not sensitive to the specific CFS cost assumption. For example, we re-ran the simulations assuming the CFS only adds 10% to the cost of fuels. None of our findings were affected.

We assume herein that the carbon tax is applied to all provinces equally. At present, the government is allowing some provinces to enact a lower-cost alternative policy. Quebec, for example, is not currently paying the fuels charge for this reason. However, in keeping with the intention of the government to have a pan-Canadian pricing system in place we assume that by 2030 every province will face the same carbon price.

We model the Output-Based Price System (OBPS) as follows. OBPS adjustments act as output subsidies so as to attenuate the potential loss of competitiveness for Energy Intensive/Trade Exposed (EITE) sectors. McKitrick and Aliakbari (2019) provided an analysis of the sectors at risk of competitiveness effects as a result of a $50 per tonne carbon tax and provided a theoretical examination of the incentives created by the OBPS mechanism. For an individual firm, the OBPS system functions as a price subsidy coupled with the carbon tax on energy inputs. As shown in that analysis, the carbon tax raises the marginal cost of production and the OBPS payment partially reverses the effect, which we term the competitiveness adjustment factor. Even though the system is set up to rebate 90% of a sector's carbon-tax revenue, for individual firms and for the sector as a whole, since marginal emissions are usually greater than average emissions, the overall effect is only a partial offsetting of the increased marginal production costs. [5]

In the current version of the LFX model, the export sector is insulated from the direct effects of the carbon tax by construction. Export volumes respond only to changes in the exchange rate according to an econometrically estimated sub-model, not in response to marginal costs of industrial outputs. While unrealistic, this assumption effectively applies an OBPS-type adjustment to all exporting sectors, not just those deemed EITE. In the domestic market, the model includes an OBPS adjustment on production costs in EITE sectors by applying a subsidy based on the sector-specific change in marginal production costs associated with the carbon tax. Since the OBPS program focuses on sectors with large trade exposure, this implies limited impacts on primarily domestically focused sectors.

The LFX model uses internally defined quantity units that are computed using nominal market volumes deflated by internally computed tax-inclusive prices. Consequently, the energy quantity units in the model do not correspond to measures in energy market data such as Terajoules or barrels of oil-equivalent. Coefficients to relate CO_2 emissions to the model index units are computed so that in a 2018 vintage base-case

[5] The previous version of this report erroneously claimed that the OBPS would be phased out in 2030. This applies only to the electricity sector: the government has no plans at present to phase out the OBPS for other sectors. Since the LFX model already insulates exporters from the price effects of the carbon tax no change was needed to accommodate that aspect of the OBPS. The treatment for domestic production was introduced as outlined.

solution, 2018-level national CO_2 emissions associated with each fuel type are reproduced. Carbon-tax revenues for each fuel type are then computed by applying the price per tonne to the estimated emissions, and these are subsequently converted to tax rates per model index unit.

Base case calibration

The LFX model is initialized using the 2016 provincial Input-Output tables although, as noted above, the input-output coefficients are recomputed during the mode run to reflect adjustments in response to price changes. Other inputs are tuned to an estimate of the 2030 state of the Canadian economy as follows.

The labour-supply functions were calibrated by taking 2019 employment levels by province, then increasing each by 20% to take account of population growth over the coming decade.

The government is treated on a consolidated basis, combining all three levels into one entity for each province. Debt and interest payments are taken from Statistics Canada's *Consolidated Government Financial Statistics* (table 36-10-0450-01) for the year 2019, and we assume that government debt will grow over the ensuing decade by $600 billion, with a corresponding increase in the debt-servicing costs assuming no change in the average interest rate on government debt. The debt load is shared across provinces in proportion to employment share.

Carbon-dioxide emissions by fuel type are not available in Canada's GHG emissions inventory. Emissions by fuel type for 2016 were therefore estimated using the methodology outlined in Appendix A (p. 22), and emission-intensity coefficients for each fuel were computed using the model solution on a 2016 base. The model base case for 2030 was then used to estimate changes in fuel use and cement production, subject to a number of ad-hoc caps on coal use, yielding the estimated business-as-usual increase in CO_2 emissions.

2.3 Strengths and weaknesses of the analytic method

Economic modeling frameworks

All economic modeling frameworks have inherent strengths and weaknesses that need to be understood by users of the analysis. Models that focus on energy policies tend to fall into three categories: top-down, bottom-up, and dynamic macro.

Top-down models, including the Computable General Equilibrium (CGE) model used herein, represent the economy through regional sectoral aggregates in which full macroeconomic closure is imposed, which means all agents are subject to budget constraints and all financial flows balance. They yield before-and-after representations of equilibrium outcomes, whereby all markets clear and all temporarily unemployed workers have been re-hired. They also assume that the private sector engages in optimizing behaviour. This means there are no "free lunches": it is not possible to make households or firms better off by restricting their behaviour, since they already had the option of imposing the restriction on themselves. The fact that they chose not to means it makes them worse off. In this way, such models accord with economic theory and impose all relevant macroeconomic restrictions but, because of their top-down perspective, they may leave important details of policy structures and specific markets or technologies unresolved.

Bottom-up models are built on detailed representations of specific technologies of interest, such as those that govern energy production, distribution, and use, and may leave the general macroeconomy unresolved or subject only to partial closure. Their advantage lies in their ability to represent granular details of current market and industrial structures, but their disadvantage is the absence of macroeconomic constraints and the absence of the optimization assumption, which may make "free lunches" possible.

Dynamic models are more commonly used for fiscal or monetary policy and try to achieve realistic representations of savings and investment decisions as well as transition paths between before-and-after states, including changes in unemployment. Like top-down models they may have limited representation of specific energy markets and technologies, and like bottom-up models they do not necessarily impose optimizing behaviour.

Note that the changes to labour markets reported herein are not estimates of short-term unemployment. Instead, they represent an estimate of the permanent change in the size of the labour market. Short-term unemployment may be much larger. In a policy experiment that yields a reduction in total employment, the model works on the assumption that wages will adjust downwards until all workers who want jobs are back in employment. The model also does not attempt to estimate how long this process will take, and it should not be assumed that it will be complete in one calendar year, even though the model units are expressed on a per-year basis.

An important difference between the LFX model and some of the CGE models referred to in the Introduction is that, because the Leontief equation is used to clear markets, most sectors exhibit constant returns to scale. This implies that the supply curve is horizontal, so output can scale up or down without the average production cost changing. Production costs change in the model as a result of policy changes and pass-through of cost changes from other sectors and from changes in labour and capital costs. This means that in response to the carbon tax more of the adjustment occurs on the quantity axis than the price axis. If the supply curve were assumed to be upward sloping, firms would absorb more of the costs themselves in the form of lower unit earnings rather than reduced output. In the short run, this would yield smaller changes in market quantities but larger long-run changes in capital and employment. The constant returns assumption means the adjustments herein are more indicative of long-run changes.

Emission-control frameworks

Carbon-dioxide emissions are not controllable through end-of-pipe technologies like catalytic converters or flue-gas scrubbers. Under existing technology as represented in the LFX model they can only be controlled by switching among fuels or reducing energy consumption. This is a reasonable assumption in the short run but may not represent the available abatement options in the long run.

In practice, it might be possible to implement other emission-control options such as carbon capture in which, for a fixed investment cost and with a resulting change in the facility marginal costs, the emissions intensity of a fuel type may be reduced. These types of technological changes can be represented in the LFX model on an ad-hoc basis but we do not attempt to do so herein. Similarly, it would be possible for an electricity system to replace coal- or natural-gas-fired generators with, say, nuclear generators. Again, this would involve a long time line, large fixed costs, and a change in the marginal operating costs of the electricity system, but would be difficult to represent properly, in part because nuclear is a base-load generating source whereas generators burning fossil fuels provide peaking power and these generator types cannot simply be traded off one-for-one. The reader should bear in mind that there may be, in some circumstances, abatement options that impose lower costs than those represented herein, but that are not currently represented in the LFX model framework.

3 Results

3.1 Overall macroeconomic impacts

The base-case experiment simulates the 2030 state of the economy with no carbon tax in place. The experimental run computes the equilibrium response of the economy to a $170-per-tonne nominal carbon tax ($140 per tonne real) using the assumptions as outlined in Section 2.2.

Tables 2–4 summarize the effects nationally and by province. As shown in **table 2**, GDP losses by province range from 1.4% to 2.4% and average 1.8% nationally. A drop in GDP of this magnitude works out to about $1,540 in current dollars per employed person. The policy reduces CO_2 emissions by 25.6%. This may be an overestimate, however, since the base case does not impose a prior phase-out of coal for electricity generation on those provinces where it is still in use. The percentage reductions in emissions vary by province from 17.0% to 47.5%, reflecting the variations in base-case emissions intensity across regions.

Table 2: Main macroeconomic effects (percentage change) of the carbon tax nationally and by province

Region	Real GDP	GHG emissions	Employment	Real income per worker	Real consumption per capita
Canada	−1.8	−25.6	−0.8	−2.5	−1.0
British Columbia	−1.6	−17.0	−0.8	−1.2	−0.4
Alberta	−2.4	−15.9	−1.1	−2.4	−1.4
Saskatchewan	−2.1	−37.1	−0.2	−3.2	−1.0
Manitoba	−1.2	−21.4	−0.2	−2.3	−0.5
Ontario	−1.9	−32.3	−0.9	−2.2	−1.2
Quebec	−1.5	−17.2	−0.8	−1.6	−0.9
New Brunswick	−2.2	−25.9	−0.4	−3.0	−0.9
Nova Scotia	−2.4	−47.5	−0.2	−3.6	−1.8
Prince Edward Island	−1.7	−19.7	−0.5	−3.0	−1.5
Newfoundland & Labrador	−1.2	−17.3	−0.4	−1.8	−0.5
Far North	−1.4	−25.5	+0.2	−3.2	−0.6

The tax/rebate policy leads to a 0.9% reduction in equilibrium employment, which is just over 184,000 jobs nationally, of which, as shown in **table 3**, nearly half are in Ontario, with Quebec experiencing the second-largest job losses. Ontario and Alberta bear the largest proportionate burdens of job losses, with Quebec and British Columbia close behind. As explained in section 2.1, the change in employment shown here refers to the outcome after the labour market has cleared; in other words, this is not a measure of temporary unemployment, it is a measure of permanent job losses. Temporary transitional unemployment would be greater but it is not computed in a CGE model. Also, the employment losses reported here are net of gains resulting from the use of some of the carbon-tax revenue to increase government spending on goods and services. In order for the labour market to clear it is necessary for the wage rate to adjust downward slightly while the cost of living rises as a result of the new tax, and the result is a 2.5% decline in real household income. This is partly offset by the increased transfer payments financed by the carbon tax, yielding a net reduction in real consumption of 1.0%. Nova Scotia and Prince Edward Island experience the largest reductions in real consumption, followed by Ontario and Alberta.

Table 3: Job losses and changes (%) in capital utilization, exports, and imports

Region	Job losses	Capital utilization	Real exports	Real imports
Canada	184,377	−1.1	−2.8	+1.2
British Columbia	21,538	−1.2	−2.9	+1.5
Alberta	30,139	−1.0	−1.9	+1.1
Saskatchewan	1,295	0.0	−1.9	+1.5
Manitoba	1,244	−0.8	−2.9	+1.4
Ontario	86,863	−1.3	−3.0	+1.2
Quebec	39,052	−1.3	−3.2	+1.4
New Brunswick	2,189	−0.4	−1.9	+0.4
Nova Scotia	987	−0.8	−2.7	−0.1
Prince Edward Island	345	−1.2	−3.9	+1.3
Newfoundland & Labrador	913	−0.7	−1.9	+1.5
Far North	−192	−0.3	−1.8	+0.8

Table 3 shows that capital utilization drops by 1.1% nationally. The LFX model assumes that the capital stock in each province is fixed in supply but may not be fully utilized depending on demand. The drop in capital utilization indicates that in a dynamic framework the policy would trigger a decline in investment. Exports drop by 2.8% nationally and imports rise by 1.2%. Note that the carbon tax is charged on imported fuels.

Table 4 shows that the tax, on its own, causes about 164 million tonnes of emission reductions, which is not sufficient to achieve the reduction of 227 million tonnes consistent with the Paris target. Other emission-control policies may be envisioned to reduce emissions further, although in general they will be more costly at the margin than a carbon tax. Achieving a reduction of 227 million tonnes in the LFX model would require a nominal carbon tax of $295, which would be about $243 in current dollars. It would impose very high economic costs: a 3.6% cut in GDP and a loss of over 370,000 jobs. Note also that this is the rate required to get 2030 emissions down to the Paris target on a one-time basis. If population continues to grow thereafter, so will emissions, and the tax will need to be raised continually if the intent is for emissions to remain flat.

Table 4: Greenhouse-gas effects (million tonnes) and changes ($ billions) to consolidated government accounts

Region	Change in GHG (million tonnes)	Change ($ billions) in:				
		Income tax revenue	Indirect tax revenue	Net total government revenue	Carbon tax revenue on final demand	Budget deficit
Canada	−164	−10.1	18.5	8.4	30.5	22.1
British Columbia	−9	−1.1	1.3	0.2	2.7	2.6
Alberta	−20	−1.4	3.0	1.4	4.9	3.3
Saskatchewan	−16	−0.2	0.8	0.5	1.7	1.1
Manitoba	−5	−0.3	0.7	0.3	1.5	1.1
Ontario	−78	−4.3	8.2	3.9	12.7	8.8
Quebec	−16	−2.0	2.6	0.6	4.0	3.4
New Brunswick	−7	−0.1	0.7	0.5	0.9	0.3
Nova Scotia	−10	−0.3	0.7	0.4	1.0	0.7
Prince Edward Island	−0	0.0	0.1	0.0	0.2	0.1
Newfoundland & Labrador	−1	−0.1	0.3	0.1	0.5	0.3
Far North	−2	0.0	0.2	0.2	0.5	0.3

3.2 Fiscal effects and the feasibility of rebating revenues

Table 4 also shows that, while the government's total revenue rises after implementing the carbon tax, most of the new revenue will be offset by losses in income and other indirect taxes. Detailed tabulations (not shown) show that total CO_2 emissions after implementing the tax are 475 million tonnes, which, at $140 per tonne, implies just over $66 billion in gross revenue. Of this, $30.5 billion is collected at the final demand stage, yielding $27.4 billion (90%) in refunds owing to households. However, the economic contraction reduces income-tax revenues by $10.1 billion while total indirect tax revenues only rise by $18.5 billion, leaving the government with a net gain of only $8.4 billion. [6] If the rebate is paid to households as planned and the remainder is spent on goods and services, the government will run a deficit of $22.1 billion annually on the policy. If the government wants to avoid running a deficit, it can only afford to rebate a maximum of $8.4 billion to households, which is only 28% of the carbon tax revenue collected at the final demand stage, or $5.4 billion if it also intends to fund $3 billion in new spending.

It is important to note that we are modeling the government as consolidated across federal and provincial levels. It is not necessarily the case that the level of government receiving the carbon-tax revenue will be the same as the level losing the income or sales tax revenue. In other words, the policy may indeed be fiscally neutral for the federal government, but that would imply all the revenue losses are at the provincial level. It is important that the provinces examine the implications for their budgets of the loss of tax revenue as a result of the federal carbon tax.

The analysis thus implies strong fiscal externalities across different components of the tax system. This implies the economy is high up on the "Laffer curve": increases in tax rates do not necessarily yield much additional revenue. The size of the loss in indirect tax revenue reflects, in part, the magnitude of pre-existing taxes on fuels, which include excise taxes and the PST/HST. If the carbon tax could generate revenue without shrinking the indirect tax base this would mean it was not forcing down fuel use, in which case it would be ineffective at reducing emissions, and vice versa.

3.3 Sensitivity analysis to the labour supply elasticity

The labour market response is sensitive to the assumed labour supply elasticity. The policy change causes the labour demand to decline. If the labour supply is relatively unresponsive, households will accept a lower real wage rate and will continue to offer the same amount of work as before. If the elasticity of the labour supply is higher, households will instead reduce the hours they work. The aggregate labour-supply measure used herein embeds both the employment-to-population ratio and the hours worked per person. Following Juksic (2020) [7] and Gottlieb, Onken, and Vallardes-Esteban (2020), we use a labour-supply elasticity of 0.7. Wagner (2018) by contrast uses a value of 0.5 while other studies use values closer to 0.3. Table 5 summarizes the effects on the results from applying these three values.

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[6] Note that totals may not correspond because of rounding.

[7] Juksic (2020) replicates an estimate of 0.7 from earlier work by Prescott and others on a sample of G7 countries including Canada. However, he then examines how the labour-participation elasticity estimate may be affected by taking account of a range of public-policy instruments that affect labour force participation decisions.

Table 5: Sensitivity analysis to labour supply elasticity parameter (% change)

	Labour Supply Elasticity		
	0.7	0.5	0.3
Real GDP	−1.8	−1.8	−1.7
Employment	−0.8	−0.7	−0.4
Real income per worker	−2.5	−2.9	−3.4
Real consumption per capita	−1.0	−1.0	−0.9
GHG emissions	−25.6	−25.6	−25.6
Government deficit	+22.1	+22.8	+23.8

Most of the results are robust to this parameter choice and changes are not reported. The major difference is the split between the change in employment compared to the drop in real income. The lower elasticity values lead to a smaller drop in employment (0.4%–0.7% versus 0.8%) and a larger decline in income (2.9%–3.4% versus 2.5%). The 0.4% employment change implies about 95,000 job losses. Also the deficit is slightly larger in the low-elasticity case. GDP and CO_2 emissions change by about the same amount.

4 Conclusions

The federal government's HEHE plan includes a proposed $170-per-tonne carbon tax to be phased in over the next 9 years. In contrast to its analysis of the Kyoto Protocol 20 years ago, the government has released no economic assessment of the impacts of such a tax, except for a brief claim that the policy will have no effect on national GDP. This is not consistent with previous studies, including those conducted by the federal government and others, of the costs for Canada of large-scale reductions in greenhouse-gas emissions.

The analysis in this publication suggests that the proposed carbon-tax plan, even with most of the revenues being refunded to households, will impose substantial costs on the Canadian economy. Real GDP could decline by about 1.8% compared to the case without the tax, and the economy will lose approximately 184,000 jobs. Also real household consumption will decline in every province even after taking account of the rebates, which highlights the challenge the federal government will face in achieving their goal that most Canadians will be made better off by the plan. The macroeconomic estimates herein are consistent with those of studies done for Kyoto compliance, when scaled to comparable emission reduction levels.

Furthermore, the analysis shows that, if the government intends to refund the revenues as planned, it will go into deficit since there will be revenue losses elsewhere in the tax system. We estimate that the current rebate plan could lead to about $22 billion in annual net losses for governments in Canada, which will ultimately require either spending reductions or new tax increases.

This analysis does not imply that regulatory measures would be less costly for the economy. If we take as given the goal of reducing CO_2 emissions by, in this case, 26%, the carbon tax as implemented herein is among the more efficient options, although the reliance on lump-sum rebates and new spending to recycle the revenue inflates the costs over what they could have been if, for example, the carbon tax proceeds were used to reduce income taxes.

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Appendix A: Technical Description of LFX Model, Version 3.0

Introduction

LFXCM is a hybrid Input Output/Computable General Equilibrium (IO/CGE) model of the Canadian economy maintained by LFX Associates (https://www.lfxassociates.ca). It resolves private-sector activity into 26 sectors with associated outputs in each of ten provinces plus the far north territories. Within each province, it identifies inputs and outputs for the following sectors:

1 Agriculture Fishing and Trapping
2 Forestry and Logging
3 Oil Sands
4 Conventional Crude Oil
5 Natural Gas
6 Oil and Gas Support Activities
7 Coal
8 Other Mining
9 Electricity
10 Other Utilities incl. Gas Distribution
11 Construction
12 Food Production
13 Semi-durables
14 Refined Fuels
15 Other Petrochemicals
16 Cement and Concrete
17 Automotive Parts and Assembly
18 Other Manufacturing
19 Wholesale and Retail Sales
20 Air, Rail, and Bus Transportation
21 Gas Pipelines
22 Crude Pipelines
23 Trucking Courier and Storage
24 Media, Banking, Finance, Information, and related Professional Services
25 Education and Health
26 Entertainment, Travel, Restaurants, and Miscellaneous Services.

The list of commodities is the same and all outputs are assigned to the corresponding sector. Petroleum products are divided into fuels and those used for non-combustion applications. The model resolves output, capital demand, labour demand, and intermediate-input demand for every commodity in every sector for each province, calibrated so as to reproduce the 2016 provincial input-output supply and use tables (Statistics Canada, 36-10-0478-01).

Final demand categories include households, government, gross fixed capital formation (GFCF), domestic (inter-provincial) exports, and foreign exports. Output includes net supply by domestic sectors, domestic imports and international imports.

Nesting structure

Households and firms are represented using Nested Constant-Elasticity-of-Substitution (CES) share functions. The nest structure for households is as follows:

Savings			
Leisure			
Consumption	Energy and Transport	Utilities	Electricity
			Other Utilities
			Gas Pipeline Services
		Fuels	Natural Gas
			Coal
			Gasoline
			Petrochemicals
		Transport	Oil Pipeline Services
			Air, Rail, and Bus
			Trucking and Storage
	Goods	Basic Goods	Conventional Crude
			Oil Sands
			Agriculture
			Forest Products
			Mining
		Produced Goods	Cement
			Semi-durables
			Automotive Parts and Assembly
			Other Manufacturing
			Food
	Services	Professional Services	Entertainment
			Construction
			Media, Finance, etc.
			Sales & Retail
		Other Services	Oil and Gas Support
			Education and Health

The nesting structure for firms is essentially the same except the top level combines intermediate inputs with labour and capital demand to yield output.

LFXCM can accommodate a unique elasticity value for each nest for each province. Initial values have been selected based on literature search and trial-and-error, but are subject to adjustment as more information is acquired and to ensure model stability. CES function scaling parameters are calibrated to reproduce budget shares based on the 2016 provincial input-output supply and use tables (Statistics Canada, 36-10-0478-01).

All program components and functions are written in R.

Calibration

The LFXCM software assimilates the entire 2016 Provincial Input-Output Supply and Use tables (36-10-0478-01), which resolves about 500 sectors and 500 commodities. These are aggregated into the 26 categories listed above. The condensed tables are then used to calibrate all share parameters and tax parameters.

Factors of production

Factors of production include employment (by sector and province) and capital. Capital stock valuations by sector and province are developed as scalar multiples of the operating surplus reported in the input-output tables, averaged over 2014 to 2016. The model also generates real and nominal capital demand in each solution, yielding an endogenous capital utilization rate.

Tax detail

Separate intermediate tax rates by industry and province are computed using the 2016 provincial I/O tables (Statistics Canada, 36-10-0478-01) values of output and input taxes net of subsidies on outputs and inputs, with the federal carbon tax added in the policy base case. Households also pay consumption taxes computed at the provincial level to take into account PST and HST rates across the province as well as the federal carbon tax levy. Households also pay income taxes, which are computed using the national total income-tax revenues as recorded by Statistics Canada in the Government Finances table 36-10-0450-01. The same average income-tax rate applies equally to labour and capital income.

Share functions

These functional forms are drawn from Shoven and Whalley (1992), *Applying General Equilibrium* and Berck and Sydsaeter (1992), *Economists' Mathematical Manual*.

Given a set of intermediate input prices the model determines input-output coefficients for each sector in each province. The input-output coefficients vary as relative prices change. The IO coefficients begin with the assumption that, within a nest consisting of (for example) two inputs (x_1, x_2) the firm chooses them to maximize

$$y = \left((a_1 x_1)^{\frac{\sigma-1}{\sigma}} + (a_2 x_2)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \text{ subject to } p_1 x_1 + p_2 x_2 = C$$

where σ = the elasticity of substitution. Note $a_i = w_i^{\frac{1}{\sigma-1}}$, where w_i are the base case real shares (= nominal shares assuming base case prices = 1).

The input-output coefficients consistent with the optimal solution are:

$$\frac{x_i}{y} = p_i^{-\sigma} a_i^{\sigma-1} \left(\left(\frac{p_1}{a_1}\right)^{1-\sigma} + \left(\frac{p_2}{a_2}\right)^{1-\sigma}\right)^{\frac{\sigma}{1-\sigma}}$$

The zero-profit condition implies $p_y y = p_1 x_1 + p_2 x_2$, therefore the nest price is

$$p_y = p_1 \frac{x_1}{y} + p_2 \frac{x_2}{y}$$

The household model uses nominal shares. Given prices and total income, the consumer maximizes a utility function. Standard CES forms are:

Shoven-Whalley: $U = \left(\Sigma_i\, \alpha_i^{\frac{1}{\sigma}} x_i^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$ where α_i are budget shares;

Berck-Sydsaeter: $U = \left(\Sigma_i\, a_i^{\frac{\sigma-1}{\sigma}} x_i^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$ where $a_i = \alpha_i^{\frac{1}{\sigma-1}}$ and α_i are budget shares.

Note: $a_i^{\frac{\sigma-1}{\sigma}} = \alpha_i^{\frac{1}{\sigma}} \Rightarrow a_i = \alpha_i^{\frac{1}{\sigma-1}} \Rightarrow a_i^{\sigma-1} = \alpha_i$.

The optimal nominal shares according to Shoven-Whalley are:

$$x_i = \frac{\alpha_i I}{p_i^{\sigma} \Sigma_j \alpha_j p_j^{1-\sigma}}$$

$$\Rightarrow \frac{p_i x_i}{I} = \frac{\alpha_i p_i}{p_i^{\sigma} \Sigma_j \alpha_j p_j^{1-\sigma}} = \frac{\alpha_i p_i^{1-\sigma}}{\Sigma_j\, \alpha_j p_j^{1-\sigma}}$$

$$= \frac{a_i^{-(1-\sigma)} p_i^{1-\sigma}}{\Sigma_j\, a_i^{-(1-\sigma)} p_j^{1-\sigma}}$$

$$= \frac{\left(\frac{p_i}{a_i}\right)^{1-\sigma}}{\Sigma_j \left(\frac{p_j}{a_j}\right)^{1-\sigma}}$$

Consumer model—top level

The utility function combines demand for leisure H and consumption C with associated prices w and p, time endowment T (which equals leisure H plus labour L) and exogenous income Y. The utility function is:

$$U = \frac{\gamma}{\alpha} H^{\alpha} + C$$

where γ is a scaling parameter. This is optimized against the budget constraint $wH + pC = Tw + Y$ using a Lagrangian function:

$$\ell = U - \lambda(wH + pC - Tw - Y)$$

The first-order conditions are:

$$\ell_C = 1 - \lambda p = 0 \Rightarrow \lambda = \frac{1}{p}$$

$$\ell_H = \gamma H^{\alpha-1} - \lambda w = 0 \Rightarrow H = \left(\frac{1}{\gamma}\right)^{\frac{1}{\alpha-1}} \left(\frac{w}{p}\right)^{\frac{1}{\alpha-1}}$$

These can be solved to yield a labour supply function:

$$L = T - \theta \left(\frac{w}{p}\right)^{\sigma}$$

where $\theta = \gamma^{\frac{1}{1-\alpha}}$ is a scaling parameter and $\sigma = \frac{1}{\alpha - 1}$ is the elasticity of leisure demand with respect to the real wage rate. Values from −0.3 to −0.7 are typically used and results are examined for sensitivity to this parameter choice.

Regulatory rents and policy experiments

The cost of certain regulations is akin to a tax-induced "Harberger triangle" or deadweight loss, except that the revenue portion does not accrue to the government; instead, it is dissipated and is unavailable to the economy. For example, suppose a regulation is introduced requiring construction firms to change procedures in such a way that the cost of building a house rises by 20% but, at the end of the process, the extra cost does not yield a 20% bigger house but instead a house of the same size. In this case, the production cost is scaled up by 20% but the increased selling price does not accrue as revenue to the builder; instead it is offset by decreased productivity of the inputs. The LFXCM builds a number of such regulatory inefficiencies into the base case of the model, including in the electricity and refining sectors, based on relative changes over time among provinces in the marginal cost of producing equivalent outputs. The LFXCM then tracks the national costs of compliance with these regulations. No attempt is made within the LFXCM to quantify the intended benefits associated with these regulations, although such estimates can be made using the model outputs.

Policy experiments can be run in the LFXCM in which a new policy is represented in the form of changes to the pre-existing regulatory constraint structure, changes to factor supplies, changes in any of the provincial or federal tax and subsidy rates, and so forth. Numerous metrics are available for determining the costs and benefits of the policy, including provincial utility, real GDP, real consumption, employment, changes in the equity value of the capital stock, and so on.

Model solution

The model computes an initial cost-propagation matrix for each province's economy using the weights from the nominal input (use) tables. If a policy experiment takes the form of, for example, a tax increase, the price change is first transmitted as a linear pass-through using the initial propagation matrix. This yields intermediate prices that are then used by all sectors in the nested CES optimization process described above to generate an endogenous input-output coefficient matrix *A* and unit costs of outputs. Prices of oil and natural gas are handled separately to ensure they are anchored to world prices.

Households take prices, government policy parameters (including transfers), and the wage rage as given. They determine the labour supply, savings, and final demands based on utility maximization. Savings is assumed to be a fixed fraction of income.

International exports and imports are calibrated using the 2016 provincial I/O tables (Statistics Canada, 36-10-0478-01). Real export demands are then adjusted using econometrically estimated functions that estimate annual changes in export volumes by province and commodity as functions of the exchange rate, the US GDP growth rate, and world prices of certain key commodities, including oil and gas. Real imports are adjusted using the change in the size of the provincial employed labour force and a demand factor based on import prices and the exchange rate.

Initial domestic export and import levels are taken from the 2016 provincial I/O tables (Statistics Canada, 36-10-0478-01), which balance to zero at the national level. They are rescaled endogenously based on income levels that may change during a policy experiment.

Government revenue is determined endogenously based on tax rates as described above. Transfers to households and labour demand are fixed at 2016 levels in the policy base case, and government purchases of goods and services are based on 2016 levels rescaled to match growth or decline in the labour market. The government budget surplus or deficit is thus endogenous.

Gross fixed capital formation (GFCF) is driven by a demand equation in which 2016 investments by sector and province are scaled up or down based on current rates of return to investment in a sector. The rate of return is determined using the endogenous capital demand less regulatory rents (explained below) relative to the base-case implicit capital stock. The nominal level of investment determines provincial investment needs. The funds available for investment by province are determined as the sum of household savings and the government surplus. The difference between investment needs and investment funds determines the foreign borrowing requirements within the province, or the capital account.

Within a province, given prices, tax rates, government spending, and trade parameters the model yields the input-output coefficient matrix A, and final demands for consumption C, government purchases G, investment or gross fixed capital formation I, exports X and imports M. Denote $C + I + G + X = F$. If real output is denoted Q, the Leontief market-clearing condition is $AQ + F = Q$. The model solves for Q using the matrix equation:

$$Q = (I - A)^{-1}F.$$

Then input-output coefficients for labour and capital are used to determine labour and capital demands by sector and province. Exogenous restrictions are imposed on the Education and Health sector in some provinces to limit its expansion since it is primarily governed by government policy and cannot respond freely to market conditions.

Since the Leontief equation is solved for each province, and some provinces are net importers of some goods (for example, Ontario imports crude oil for refining), the equilibrium output level can be negative. If the labour IO coefficient were applied it would yield a negative demand for labour. This is also an implication of the "cross-hauling" phenomenon in which provinces can both import and export the same commodity, such as food for instance. The relevant labour-demand level is therefore based on final demand before subtracting imports, which equals ($C + I + G + X$). This yields, for example, an employment level of zero for oil sands production in Ontario, which is the appropriate estimate. The model uses the pre-import final demand amount as the basis for analyzing changes in labour demand in each sector and province.

The model adjusts the national wage rate to clear the national labour market and the international exchange rate to balance the current and capital accounts. Capital demand determines the capital utilization rate. The provincial labour markets do not necessarily clear: there can be surpluses or shortage of labour within a province but they add up to zero nationally. The program verifies that Walras' Law holds at every iteration.

Policy parameters

Separate tax rates for each commodity in each province are tracked, as are labour, capital, and carbon taxes. Regulations are modeled as exogenous shifts to input costs or sectoral supply curves. Regulatory details can be specified down to the sectoral level within each province. A regulatory measure is quantified as a scarcity rent as described above.

Greenhouse-gas emissions are computed using coefficients calibrated on consumption of coal, natural gas, refined fuels, and cement production so as to reproduce the 2016 national carbon dioxide emissions inventory.

The costs and benefits of policy changes can be computed in numerous ways depending on the needs of the application, including changes in indirect utility, equivalent variations, real GDP, household consumption, employment, marginal regulatory rents, and so forth.

Model calibration of greenhouse gases

Emission coefficients for coal, petroleum liquids, and natural gas are derived as follows. BP (2020) reports that in 2016 Canada consumed 2,503 thousand barrels per day of oil, 3.82 exajoules of natural gas, and 0.78 exajoules of coal. Marland and Rotty (1984) estimate carbon emission coefficients for natural gas as 13.7 tC /TJ; for oil 0.85 tC/tonne oil, and for coal 0.75 tC/tonne coal.

For oil, 620.5 million barrels of oil annually at 0.136 tonnes per barrel implies 84.4 Mt oil and 71.7 MtC. Using a conversion factor of 11/3 implies 263.0 Mt CO_2.

For natural gas, 3,820,000 TJ implies 52.3 Mt Carbon and, using a conversion factor of 11/3, this implies 191.9 Mt CO_2.

For coal, 780,000 TJ converts to mass using 29.31 × 109 J/t (Marland and Rotty), yielding 26.6 Mt coal, 20.0 MtC, and 73.2 Mt CO_2.

These can be scaled up based on observed growth in fuel consumption over time.

Canada's IPCC Emission Inventory (https://unfccc.int/documents/65715) lists 6 Mt CO_2 emissions associated with cement production, although we do not apply a carbon tax to it in current experiments.

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Appendix B: Fuel Adjustment Cost Factor for Clean Fuel Standard and Ethanol Blending

Following Hosseini, Romaniuk, and Millington (2019: 35), we assume that the wholesale price of petroleum fuel (P_f) is $0.59 per litre and for ethanol (P_e)it is $0.90 per litre. In the base case, Canadians are assumed to use a blend in which the fuel fraction (θ_f) is 95% and the ethanol fraction ($1 - \theta_f$) is 5%. The per-litre blend cost is

$$P_b = \theta_f P_f + (1 - \theta_f) P_e \,.$$

In the base case this works out to $0.6055.

We assume that the P_f is fixed by the world supply price, but the price of ethanol follows an upward-sloping supply curve with an elasticity of $\sigma = 0.237$ based on Luchansky and Monks (2009).

The percentage change in the ethanol fraction compared to the base case is $(0.95 - \theta_f)/0.05$. A 1% change in the blend requirement may represent substantially more than a 1% increase in the Canadian supply requirement but we will assume the percentage change in required supply corresponds to the percentage change in the blend requirement. The new cost of ethanol production as a result of a new content requirement is therefore:

$$P_e = 0.9 \times \left(1 + \sigma \frac{(0.95 - \theta_f)}{0.05}\right).$$

The price adjustment factor resulting from the new blending requirement is therefore:

$$A_p = \frac{P_b}{0.6055} = \frac{\left(\theta_f \times 0.59 + (1 - \theta_f) \times 0.9 \times \left(1 + \sigma \frac{(0.95 - \theta_f)}{0.05}\right)\right).}{0.6055}$$

Ethanol contains only 67% of the energy in petroleum fuel. Therefore, the energy output of the blend is $E_b = (\theta_f + 0.67 \times (1 - \theta_f))$. In the base case, $E_b = 0.95 + 0.67 \times 0.05 = 0.9835$.

Therefore, the adjustment factor for the energy output of the blend will be:

$$A_b = \frac{E_b}{0.9835} = \frac{\left(\theta_f + 0.67 \times (1 - \theta_f)\right)}{0.9835}.$$

The combined adjustment factor for the cost of fuel will therefore be

$$AF = \frac{A_p}{A_b}.$$

Following Hosseini, Romaniuk, and Millington (2019), we assume gasoline has a carbon intensity (CI) of 88.14 g/MJ and ethanol has a CI of 41.0 g/MJ. The carbon intensity of the blend is therefore:

$$CI_b = \theta_f \times 88.14 + (1 - \theta_f) \times 41.0.$$

In the base case, this is 85.783. The CI target T_{CI} is expressed as a fraction of the base case. For instance, a 5% reduction in CI would be written $T_{CI} = CI_b/85.783$. Therefore, $CI_b = \theta_f \times 1.027 + (1 - \theta_f) \times 0.478$. This rearranges to:

$$\theta_f = \frac{T_{CI} - 0.478}{0.549}.$$

which yields the required fuel blend fraction to achieve a given CI target. This can be substituted into the formula for AF to get the resulting fuel-cost adjustment factor. **Table B1** presents sequential numbers based on the above parameters.

A_f and AF are plotted in **figure B1** (p. 34):

A CI reduction of 5% against the base case results in a 17% increase in the energy-equivalent cost to consumers.

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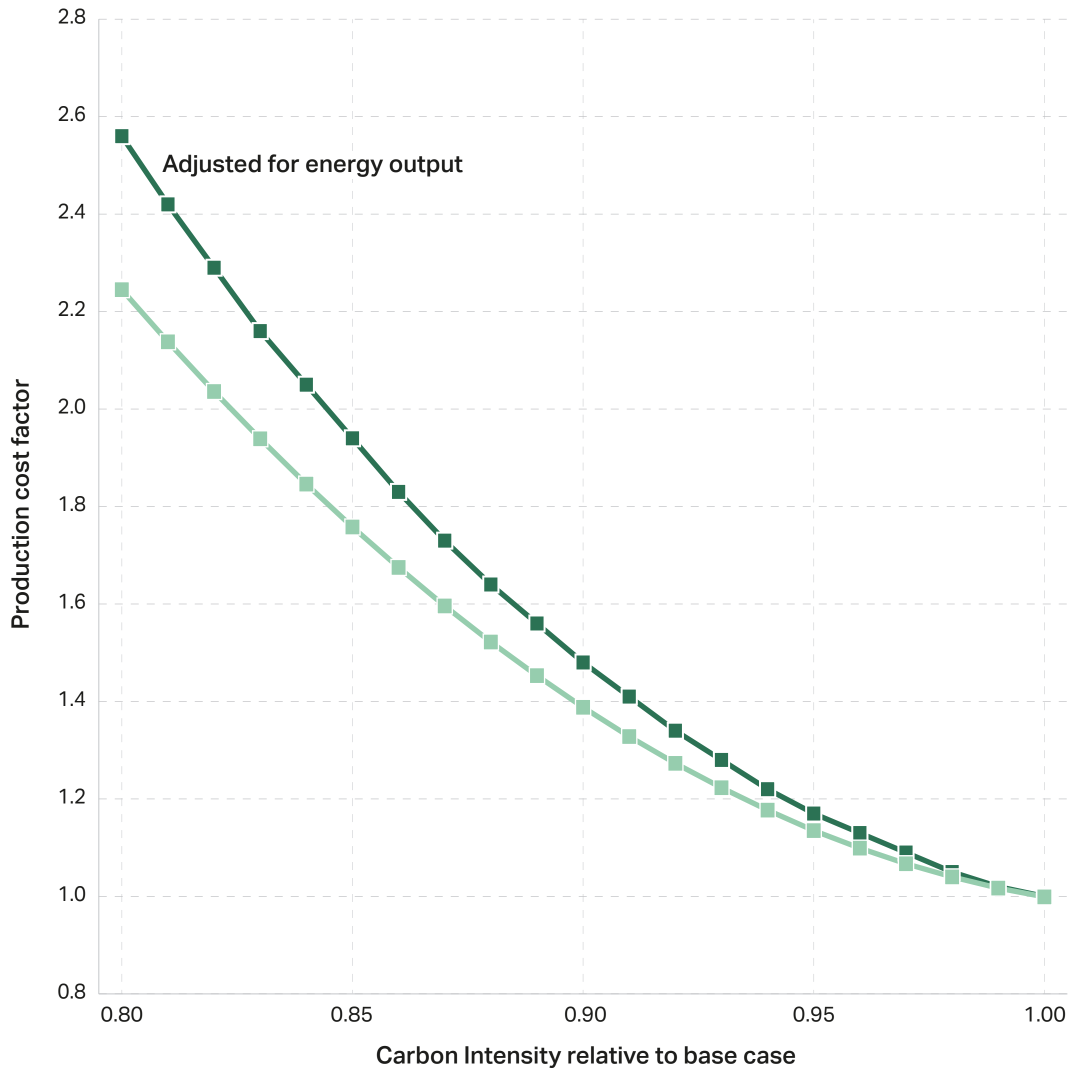
Table B1: Costs of Achieving Relative Carbon Intensity Level

- First column: carbon intensity relative to base case.
- Columns 2–5: intermediate parameters.
- Last column: consumer cost adjustment factor.

CI level	θ_f	P_e	A_p	A_b	AF
1.00	0.951	0.90	0.999	1.000	1.00
0.99	0.933	0.97	1.017	0.994	1.02
0.98	0.914	1.05	1.040	0.988	1.05
0.97	0.896	1.13	1.067	0.982	1.09
0.96	0.878	1.21	1.099	0.976	1.13
0.95	0.860	1.29	1.135	0.970	1.17
0.94	0.842	1.36	1.177	0.964	1.22
0.93	0.823	1.44	1.223	0.957	1.28
0.92	0.805	1.52	1.273	0.951	1.34
0.91	0.787	1.60	1.328	0.945	1.41
0.90	0.769	1.67	1.388	0.939	1.48
0.89	0.750	1.75	1.453	0.933	1.56
0.88	0.732	1.83	1.522	0.927	1.64
0.87	0.714	1.91	1.596	0.921	1.73
0.86	0.696	1.98	1.675	0.915	1.83
0.85	0.678	2.06	1.758	0.909	1.94
0.84	0.659	2.14	1.846	0.902	2.05
0.83	0.641	2.22	1.939	0.896	2.16
0.82	0.623	2.30	2.036	0.890	2.29
0.81	0.605	2.37	2.138	0.884	2.42
0.80	0.587	2.45	2.245	0.878	2.56

Figure B1: Production cost factor with and without adjustment for energy output



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