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Cross-Border Impacts of Climate Policy Packages in North America

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Cross-Border Impacts of Climate Policy Packages in North America

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ABSTRACT: We quantify cross-border effects of the recent climate mitigation policies introduced in Canada and the U.S., using the global general equilibrium model IMF-ENV. Notably, with the substantial emission reductions from Canada's carbon tax-led mitigation policies and the U.S.' Inflation Reduction Act, these two countries would bridge two-thirds of the gap toward their Nationally Determined Contribution (NDC) goals. While the broadly divergent policies are believed to elicit competitiveness concerns, we find the aggregate cross-border effects within North America to be very limited and restricted to the energy intensive and trade exposed industries. Potential carbon leakages are also found to be negligible. A more meaningful difference triggered by policy heterogeneity is rather domestic, especially with U.S. subsidies increasing energy output while the Canada model with a carbon tax would marginally decrease it. This analysis is complemented by a stylized model illustrating how such divergence can affect the terms of trade, but also how these effects can be countered by exchange rate flexibility, border adjustments or domestic taxation.

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I.   Introduction

The ramp-up of climate policies in the United States and Canada in recent years illustrates how divergent climate policies may elicit competitiveness concerns. Canada adopted a carbon pricing strategy in 2019 (adding a more ambitious pricing path along with an emission reduction roadmap in 2022) and complemented carbon pricing with investment tax credits for green energy and clean manufacturing in the 2023 budget. Differently, in the United States, the 2022 Inflation Reduction Act (IRA) is largely centered around green subsidies for clean electricity and investment subsidies for clean manufacturing, with no carbon-pricing scheme in sight. U.S. trading partners, notably Canada and the euro area, have voiced concerns that this policy could affect relative prices, and in turn their output and market shares. Such a loss in competitiveness may also be accompanied by production relocation towards countries with laxer environmental regulations which could lead to potential "carbon leakages", i.e., increases in GHG emissions abroad that partly offset the emission mitigation in countries with green policies.

However, the economic relevance of these concerns about competitiveness remains an open issue. Previous IMF work (Chateau et al. 2022a and Chateau et al. 2022b) has shown that effects of different climate policy options could vary along macroeconomic outcomes, energy prices and trade competitiveness. Sectoral divergence in costs depends on sectoral characteristics like emission and trade intensity, available clean technologies and choice of instrument. The domestic policy could also lead to cross-border spillovers through carbon leakage, changes in trade shares and international fossil fuel markets. But competitiveness concerns may well be overblown. First, Canada's carbon pricing system includes elements of tradeable performance standards (TPS) for large industries to address the competitiveness concerns of the domestic tradable sector. Second, carbon taxes generate revenues that can be deployed in different useful ways (including to offset effects on the worse-off through cash transfers or to offset efficiency losses by decreasing distortionary taxes such as labor income taxes), while green subsidies require higher (distortionary) taxes elsewhere, which might offset some of their positive effect on competitiveness. Finally, exchange rates would be expected to adjust in response to policies, possibly offsetting part of the effect as well.

In this paper, we investigate the legislated climate policy packages of Canada, Mexico, and the U.S. as of 2023 through a new lens, namely cross-border spillovers. More specifically, the paper's objective is to quantify competitiveness effects (namely, price effects, trade losses and reallocation of production by sector) of climate packages, for home and neighboring countries within North America, as well as the GHG emission carbon leakage effects resulting from these policies. As such, it is the first attempt to quantify effects of both the Inflation Reduction Act's climate-related measures and of Canada's climate mitigation policies especially with a focus on the North American countries. The global computable general equilibrium (CGE) model IMF-ENV developed in the IMF's Research Department used here is well-

Figure 1. Trade Coverage

(Pecent of total trade, North American trade partners)
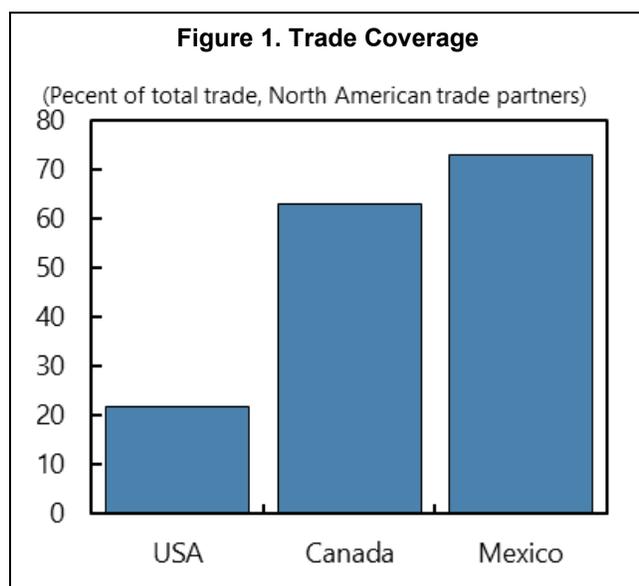
fitted for such analysis: (i) it has global coverage and therefore can assess cross-border impacts; (ii) it provides sectoral granularity (especially in the energy sector but also for energy-intensive and trade-exposed industries) to model sector-specific shocks and quantify cross-sector reallocation effects; (iii) it maintains fiscal consistency; (iv) it establishes an explicit link between economic activity and GHG emissions; and finally (v) it is a recursive dynamic model and therefore can provide an assessment up to 2030. To set the stage for the quantitative model and assessment, the paper also discusses the intuition behind a few key cross-border channels drawn from a simple, yet distinct, theoretical model.

Firstly, we present the domestic impacts of climate policies in North American countries. Our paper first shows that Canada's carbon tax-centered mitigation policies and the U.S.' Inflation Reduction Act measures provide a significant push towards reaching the NDCs' emission goals for these countries and could unlock a large increase in the share of green electricity by 2030. In combination with existing policies, Canada's carbon tax and green subsidies, on the one hand, and the U.S.' IRA, on the other hand, would in total reduce GHG emissions by around 29 percent and 35 percent respectively (relative to 2005 levels) by 2030, compared to goals of a 40-45 percent and 50-52 percent decline, respectively. This means that existing policies and these two packages are expected to bridge around two thirds of the gap towards NDCs. This is accompanied by a significant increase in the share of green electricity from around 81 to 89 percent in Canada, and from around 52 to 73 percent in the U.S. relative to the business-as-usual scenario baseline by 2030. Because the relative price effects of the different green strategies diverge significantly, their effects on energy demand differ. The IRA increases the supply of total electricity, leads to greater reliance on clean energy and lower demand for fossil fuels in the U.S., and stimulates production and jobs in the electricity sector through lower electricity prices and stronger demand for electricity. In contrast, Canada's climate mitigation policies make fossil fuel prices more expensive. While they significantly boost employment and production in the renewables' sectors and reduce them in the fossil fuel sectors, the overall demand for energy declines, largely driven by the higher fossil fuel prices. On net, though, employment in electricity nevertheless increases.

Next, we discuss the cross-border macroeconomic implications of the national mitigation policies in North America. The inclusion of the domestic sourcing requirements for production of electric vehicles and for critical minerals within the IRA was highly debated globally, and most of the cross-border spillover concerns were raised in this context. Canada and Mexico's trade within North America is 60 percent and 70 percent of their total trade (see Figure 1), respectively and therefore, changes in trade restrictions in the U.S are important to them. However, for these two countries, the sourcing requirements were not of great concern since sourcing from them qualified firms to receive tax credits within the IRA. As a result, in our assessment, the main driver of cross-border impacts of domestic actions of countries is rather through the changes in energy markets and energy prices because of the heterogeneous mitigation policy instruments adopted by Canada and the U.S. (carbon tax versus green subsidies, respectively). The domestic electricity price increases in Canada because of the carbon tax while it decreases in the U.S. because of the IRA subsidies[1]. The competitiveness effect (proxied by export market shares), which arises because of different impacts on producer prices stemming from changes in energy prices, is found to be small and restricted to energy and energy-intensive and trade-exposed (EITE) sectors[2] for neighbor countries within North America. However, trade flows are impacted driven by

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[1] Based on COMTRADE database, in 2021 about 83 percent of U.S. exports of electricity were to Canada (USD 498mn) with the rest 17 percent to Mexico (USD102mn), all of Canada's exports of electricity were to the U.S. (amounting to USD 2.63bn). Mexico's electricity exports were 67 percent (USD 151mn) to the U.S. and 33 percent (USD 72mn) to Guatemala.

[2] The Energy Intensive & Trade Exposed (EITE) sectors consists of five sectors- Paper & Paper Products, Non-Ferrous Metals (includes copper, aluminum, zinc, lead, gold, and silver), Non-metallic mineral products (includes cement production), Iron & Steel, and Chemical Products.

changes in relative input prices of the energy commodity across North America. Specifically, the IRA is found to trigger only limited effects in the outputs of fossil fuel extraction and electricity sectors in Canada and Mexico, mainly driven by the reduction in demand for fossil fuels in the U.S. Similarly, the Canada climate mitigation policies would have a very marginal impact on the outputs of these two sectors in Mexico and in the U.S. The U.S. is found to gain some market share in the electricity generation sector as a result of the IRA (and, to a marginal extent, the Canada carbon tax), while Canada is shown to lose some market share in electricity generation as a result of both the Canada carbon tax and the IRA. Changes in market shares of overall EITE sectors is marginal though heterogeneity exists within EITE sectors. The U.S. gains market share in iron and steel and non-ferrous metals while it loses market share in the chemicals sector with negligible impacts in the other EITE sectors. Differently, Canada faces losses in market share in chemical and iron and steel sectors with very small changes in the other EITE sectors. Despite considerable impacts in some sectors, on aggregate almost no cross-border effects are expected on economy-wide variables (total output, employment and consumption).

Estimates suggest that the Canadian carbon tax and subsidies and the U.S.' IRA incentives would result in a very marginal carbon leakage to the rest of the world. Changes in competitiveness of EITE products and lower fossil fuel prices resulting from lower demand by Canada and the U.S. do not substantially increase the consumption of fossil fuels in the rest of the world, and therefore, the carbon leakage rate from the Canadian and the U.S. policies is almost nil. Carbon leakage rate, calculated as the increase in emissions triggered by these policies outside Canada and the U.S., as a ratio of the emission declines enabled by the policies in Canada and the U.S., is estimated to amount to around 0.02 percent.

The remainder of this paper proceeds as follows. The next section details the legislated climate packages in the U.S., Canada, and Mexico. The third section discusses the literature on the effects of climate mitigation measures on emissions and the macroeconomy, both within country and across borders. The fourth section presents the results of a theoretical model comparing terms-of-trade implications of green subsidies and carbon taxation. The fifth section outlines the global CGE model used in the paper and how it integrates the measures legislated in both the U.S. and Canada. The sixth section discusses modeling results under different scenarios assuming the sequential introduction of Canada's carbon tax, the U.S. Inflation Reduction Act measures, and the Canadian green subsidies. The sensitivity of the results is tested against two assumptions on the pace of decarbonization in the rest of the world – firstly, when countries outside North America continue only with their current policies and secondly, when countries outside North America ramp-up their domestic policies to reach their NDC commitments. Section VII concludes.

II.   Description of Legislated Climate Packages

A. Climate and Energy security related provisions in the U.S. Inflation Reduction Act

When introduced, the Inflation Reduction Act, signed into law in August 2022, was expected to direct almost USD 400 billion federal funding to Energy Security and Climate Change measures, according to initial estimates by the Congressional Budget Office (CBO) and the Joint Committee on Taxation (JCT), published in 2022. More recently, the JCT updated its scores, leading to a significantly higher cost estimate of $660 billion (CRFB, 2023). With the aim of fighting inflation, this act encourages investment in clean domestic energy production and manufacturing, which is expected to substantially lower U.S. GHG emissions. Measures mainly comprise tax credits, and to a lesser extent grants and loans (see Figure 2). They are designed to increase the investment in, production of and usage of clean or non-carbon-based energy, including through lower cost of clean technologies, higher efficiency of power producing technologies, and higher production capacity to enable accelerated deployment of and shift to cleaner energy. The IRA also contains other non-climate related spending measures, which are not described here.

While IRA cost estimates have been updated by the CBO/JCT in 2023, and are also subject to discussion (see Voigts and Paret, 2024 for details), the Congressional Budget Office (CBO, 2022) initial estimates (which were the ones initially presented to the public (see Figure 3), when the IRA was approved) suggest:

Figure 42. IRA Climate Related Measures, by Type (based on initial CBO estimates)
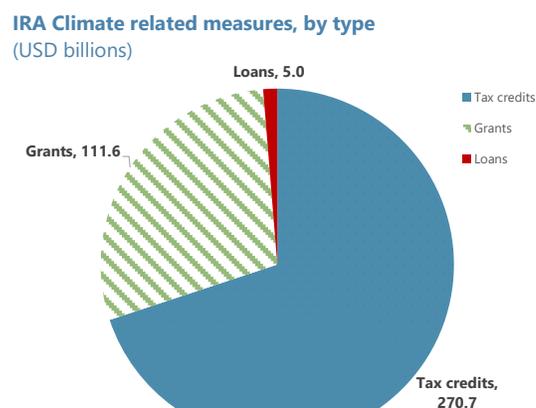
IRA Climate related measures, by type
(USD billions)

Note: This breakdown is based on staff's analysis of the IRA and cost estimates by the Congressional Budget Office, as per the table presented in Annex.

Figure 57. IRA Climate-Related Measures, by Sector

(USD billions)

Note: This breakdown is based on staff's analysis of the IRA and cost estimates by the Congressional Budget Office, as per the table presented in Annex.

- Most of the measures are directed to the energy sector to boost non fossil fuel energy through investment and production incentives, tax disincentives for oil and gas use, methane emission penalties, and different types of financing to repurpose energy infrastructure and improve energy efficiency.
- A second set of measures promotes energy-efficient buildings and home production of green energies.
- Almost the same amount is spent in measures devoted to the agriculture sector and to environment preservation. This includes assistance for rural energy and electricity and support to undeserved farmers, as well as programs for environmental quality, conservation, forest and parks restoration, farm loans, and resilience and mitigation measures, partly offset by the Methane emission penalties.

- The fourth set of measures is devoted to greener transportation and a wider production and use of electric vehicles (EVs), including through tax credits for the purchase of clean vehicles, and the installation of EV chargers.

- Another set of measures of around the same amount aims to support the reduction of air pollution, including through the Greenhouse Gas Reduction Fund.

- Finally, the rest of the measures is linked to the industry sector, to support innovation or infrastructure, for example, as well as carbon removal.

Available studies estimate that these measures, on top of a pre-IRA baseline, could cut U.S. emissions by about 40 percent by 2030, relative to 2005 levels—to be compared to the U.S. overall objective of halving 2005 emission levels by 2030. The emission reduction is expected to be driven mainly by the incentives in the power and transportation sectors.

B. Canada's Carbon Pricing Led Mitigation Strategy

Canada aims to cut GHG emissions to 40-45 percent below 2005 levels by 2030 on the path to net zero emissions by 2050. From a challenging starting point as one of the world's top 10 largest GHG emitter, and with among the highest per-capita emissions of any major economy, Canada has laid out an ambitious and comprehensive mitigation strategy centered around carbon pricing, and supported by sectoral, fiscal and regulatory measures.

Carbon Pricing is at the center of Canada's mitigation strategy. First introduced in 2019 at Can$20 per ton, carbon price stands at Can$65 in 2023 and is planned to increase gradually by Can$15 every year until it reaches Can$170 in 2030. Provinces and territories are required to have carbon prices (either through an explicit tax, a tradeable performance system, or an equivalent emissions cap-and-trade system) at these levels, and if they fall short, a federal carbon pricing backstop comes into effect, including a fuel charge and an output-based performance standard (OBPS) for EITE industries.

Building on earlier climate measures, the 2030 Emissions Reduction Plan introduced in March 2022 sketches the roadmap for

Figure 4. Canada-Announced Climate Measures, by Sector
(CAD Billion, cumulative between 2023-2035)

- Transportation and Infrastructure 11.38
- Housing 5.21
- Labor market 0.25
- Energy 46.10
- Technology and Manufacturing 46.00
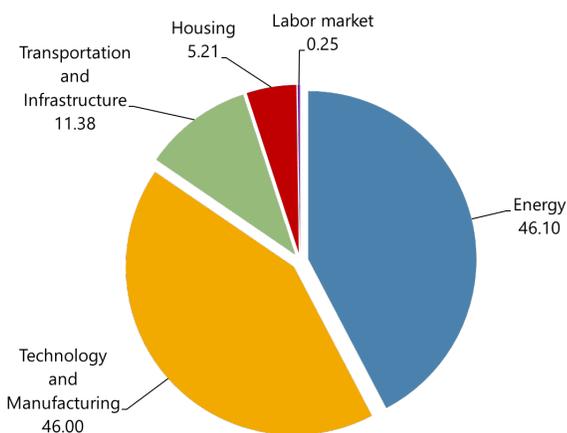
Note: This breakdown is based on staff's analysis of Canadian climate policies announced in the Federal Budget 2022 and Federal Budget 2023 as well as the VW/PowerCo SE Battery Factory Subsidies.

mitigation policies in the remainder of the decade. The Plan confirms the carbon pricing regime and lays out

other measures yet to be finalized and enacted. These include (i) carbon contracts for differences[3] and/or legislative approaches to ensure policy certainty around carbon pricing; (ii) a complementary cap on emissions or differentiated carbon pricing to address the oil and gas industry; (iii) more stringent regulations to achieve a 75 percent reduction in methane emissions from the oil and gas sector by 2030; (iv) the development of a Clean Electricity Standard (CES) to support a net-zero electricity grid by 2035; and (v) the electrification of Canada's transportation sector including setting targets for shares of zero-emission vehicles (ZEVs) sales.

Federal Budget 2023 delivered a sizable ramp-up in green fiscal incentives (see Figure 4), partly in response to the U.S.' IRA. The Fall Economic Statement in November 2022 and notably the latest budget in March 2023 committed more than Can$60 billion in new investment tax credits (ITCs) for clean electricity, clean hydrogen, and clean technology and manufacturing over around 10 years. This is much larger than the ITCs for carbon capture, utilization, and storage (CCUS) introduced in the 2022 budget for less than Can$10 billion (0.3 percent of GDP). These were also followed in April 2023 by a package of incentives—to secure a Volkswagen's electric battery plant in Ontario—including production tax credits (PTCs) expected to cost Can$8 to Can$13 billion over 10 years. Other smaller scale green fiscal incentives include subsidies for the purchase of ZEVs up to Can$5 billion until 2025 and reduced corporate and small business income tax rates for zero-emission technology manufacturers with a cost just below Can$1.5 billion over 10 years.

Canada's climate strategy is also supported by regulatory measures, as well as financing and investment programs. Regulatory measures include emission rate standards for vehicles and power generators, regulations for ZEV trucks, and a reformed Buildings Code. Financing programs include building retrofit programs, Greener Homes Loan program, Canada Growth Fund, Strategic Innovation Fund, CIB financing for electricity. Investment projects aim at supporting the green electrification by expanding and modernizing power generation and transmission and developing the ZEV infrastructure.

C. Mexico's Multi-Pronged Strategy

Mexico has committed to reduce greenhouse gas emissions by 30 percent by 2030 relative to its baseline forecast for the same year. Ambition increased during the COP27 with this target revised up from 22 percent. As for policies to meet this target, the government has been an early adopter of the carbon tax and is setting up an ETS, but carbon prices remain modest. The federal carbon tax level is stable at about MXN 60 per ton and is levied on fossil fuels in proportion to their emissions in excess of the emission rate of natural gas, while the ETS is at a pilot phase and is not expected to generate revenues before 2027. A rising number of states are complementing the federal policies with local carbon taxes but only with a modest effective overall taxation rate so far. Priorities rather include combating deforestation and raising the share of electric vehicle sales (to 50 percent by 2030), with an exemption of the new vehicle sales tax, a progressive levy of 2 to 17 percent of the vehicle value. The authorities have launched a plan to foster green finance and issued sustainable bonds to support green public spending projects. Their plan also includes carbon emission restraints by Pemex with reduction of gas flaring and scaling up cogeneration. By contrast, the authorities have also taken actions to favor Pemex, the state-owned oil producer, and CFE, the state-owned electricity at the expense of greener plans of their competitors, such as easing revocation of licenses to the private sector, imposing onerous

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[3] Carbon Contracts for differences (CCfDs) offer a market solution to hedge against carbon price uncertainty (Chiappinelli et al., 2021). These contracts involve an agreement between a government and an agent structured as a two-sided option with a strike price. If the market price is lower than this strike price, the agent receives the shortfall. Conversely, if the market price exceeds this strike price, the agent must return the surplus revenue to the government.

storage capacity constraints on competitors, and declaring Pemex the operator of an oil field that spanned private and public claims.

This paper will focus on Mexico from a "receiving" point of view. For modelling purposes, this paper focuses on the carbon price of USD 3.3 USD per ton—incorporated in the baseline in this paper.[4] The overall net effect of other policies is likely modest and could therefore not be embedded given data limitations. However, this paper will look at the effects of Canada and U.S.' policies on Mexico, as the country is also part of the North American Free Trade Agreement and, as an emerging market, represents a different type of recipient country, compared to the U.S. and Canada.

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[4] This price is considering the average exchange rate over the first half of 2023. It would be marginally higher (3.4) with the average exchange rate of the whole year, and results would be similar.

III. Literature Review

A. Within Country Effects of Climate Change Mitigation Measures

Theoretical Effects Expected from the Literature

Economic costs of policy instruments could be different even if they deliver the same environmental outcome. Viable policy alternatives to carbon pricing exist, particularly in sectors where technology can replace current methods. Although carbon pricing is typically the optimal policy, previous IMF work (*IMF 2019, Chateau et al. (2022a), Chateau et al. (2022a and 2023)*) indicates that regulations and feebates could also be effective in the industry, power and vehicle sectors, as they have similar GDP costs to carbon pricing and a more controlled impact on energy prices. A feed-in subsidy to non-carbon electricity generation sources could lower energy prices, but if implemented alone, could be more expensive as it encourages energy use, doesn't restrict fossil fuel usage, and in addition requires higher taxes for funding. It would be more effective to pair such instruments with policies that directly decrease fossil fuel use, such as carbon pricing or regulation.

United States

When it comes to the U.S. specifically, the literature finds the IRA to have a marginal impact on GDP and inflation over 10 years, however, to significantly shift the electricity mix towards more renewables. Though the literature largely agrees that the GDP impacts of the IRA in the U.S. would be limited, there is no agreement on the direction of impacts. Small positive impacts on real GDP, ranging from 0.01 to 0.3 percent by 2030 have been found by some studies (*Mahajan et al.*, 2022, *Moody's*, 2022, *Penn University*, 2022, *Barrios et al., 2023 and Rusch et al., 2023*) while others (*Diamond*, 2022, *Fajeau et al. 2023 and Rusch et al., 2023)* find a small negative impact on real GDP ranging from -0.008 to -0.2 percent due to the IRA Climate and Energy Security measures (relative to pre-IRA by 2031). Rusch et al. (2023) find a mild increase in U.S. GDP (about 0.01 percent by 2028) if the IRA measures are financed by issuing debt while the impact becomes mildly negative (-0.2 percent by 2028) if the IRA measures are financed by increasing corporate income taxes.

Studies broadly differ on the scope of the IRA measures that are captured and on the assumption on financing. On the one hand, some studies do not incorporate any financing measure (*Mahajan et al.*, 2022 and Attinasi et al. 2023, for example) while the rest make different assumptions such as increasing corporate taxation or lumpsum taxes and issuing debt (for example *Fajeau et al. 2023 and Rusch et al., 2023*). On the other hand, the scope of the measures also varies with some studies assessing the effect of the whole IRA package (*Penn University*, for example), while others studying different subsets of the measures. Besides, the IRA is not expected to have a significant impact on inflation, with either a nonsignificant (*Penn University, 2022*) or a 0.33 percent impact on the CPI index by 2030 (*Moody's*, 2022). The only study estimating the IRA fiscal costs (*Crédit Suisse,* 2022) finds that tax credits (which make up around 70 percent of the IRA Climate and Energy Security measures) are likely to cost more than three times as much as initially estimated by the *Congressional Budget Office* (2022) over the next ten years, mainly due to the tax credits being uncapped, to the crowding in of private sector investment that is usually not taken into account in projections, and to financing programs in the IRA that are likely to catalyze further investments. However, as discussed above, the CBO/JCT updated its estimates recently, leading to a significantly higher cost estimate of $660 billion (CRFB, 2023). *Voigts and Paret* (2024) find total fiscal costs that could be moderately above that (US$820 bn in total until 2030, vs. US$590 bn estimated by the CBO/JCT in their recent update, over the same period). In any case, fiscal costs

will depend on the uptake of the measures, with most of the tax credits uncapped (and based, for example, on investment or production levels) and EV subsidies subject to various requirements. The ultimate effects of the IRA will also depend on the extent to which real world hurdles (such as permitting delays, for example) are overcome (see *Voigts and Paret*, 2024). The latter two aspects therefore add uncertainty in terms of the effects of the IRA measures. Studies generally find the IRA to increase the share of electricity generation from non-fossil fuels by around 21 percentage points, to around 75 percent (see *Mahajan et al.*, 2022, *Princeton University*, 2022, *Rhodium Group*, 2022 and *Annual Energy Outlook*, 2023). See *Voigts and Paret* (2024) for details. Finally, the IRA is also found to have societal implications, notably through improved public health outcomes from lower emissions (see *Bistline et al.*, 2023 for a survey of such assessments).

Beyond the macroeconomic impact, the IRA is expected to reduce emissions substantially but to fall short of allowing to reach the country's NDCs. *Mahajan et al. (*2022), *Princeton University* (2022), and *Rhodium Group* (2022) expect the IRA to reduce emissions by 14 to 20 percent by 2030, relative to baseline, which would leave a gap of around 10 percent before reaching the U.S. Climate goal of a 50-52 percent reduction in emissions by 2030 relative to 2005 levels. Measures in the electricity power sector (including clean energy tax credits) are expected to contribute the most, followed by measures in the industry and transportation sectors (including tax credits for the purchase of electric vehicles or to support the expansion of chargers).

Canada

The literature finds that Canadian climate policies will be associated with moderate economic costs, which could be mitigated or reversed through global cooperation (*Böhringer et al*., 2021). *Chateau, Jaumotte and Schwerhoff* (2022a) find that planned climate policies as of 2022 in Canada will be associated with limited economic costs—estimated at around -0.5 percent of 2030 GDP, and a limited loss (of around 0.1 percent) in terms of the trade share in EITE industries due to the divergence of climate policies with trading partners. Additionally, in a study of the New Brunswick province under the federal requirement to increase carbon pricing from Can$20 in 2019 to Can$170 in 2030, *Withey et al.* (2022) show a linear decrease in GDP growth from 2019 to 2023 with a cumulative present value of -0.6 to -0.63 percent of GDP. *Rivers* (2010) finds that carbon pricing in Canada leads to increased relative prices in export markets for energy-intensive commodities, decreasing energy-intensive firms' competitiveness. He also finds labor-intensive firms' competitiveness mildly improve due to decreased wage rates, change in commodity demand, and exchange rate effects under carbon pricing. *Konradt and Weder di Mauro* (2023) analysis of Canada provincial-level carbon taxes in British Columbia, Quebec, and Alberta indicates that the introduction of a carbon tax has had an only marginally positive effects on headline inflation through the elevated food and fuel inflation while having no initial effect on core inflation and a disinflationary effect in medium term. The July 2023 Monetary policy report from the *Bank of Canada* (2023) finds that the national carbon price is expected to only add 0.1 percentage points to year-over-year headline inflation between 2023 and 2025.

The literature finds that the aggregate economic impact of carbon pricing in Canada and the competitiveness implications onto Canadian firms are significantly affected by the revenue recycling scheme. *Dissou and Sun* (2013) find that a lump-sum revenue recycling under a carbon pricing regimen in Canada decreases welfare by -0.05 percent, decreases GDP at market prices by -0.3 percent, and increases unemployment by +0.65 percentage point, compared to a baseline of no carbon pricing. Reducing payroll taxes for both high and low skill workers, however, increases welfare by 0.57 percent, increases GDP at market prices by 0.16 percent, and decreases unemployment by 0.80 percentage point; with even greater magnitude macroeconomic effects in Canada when only payroll tax reduction is target to low skill workers. *Rivers* (2010) finds that revenue

recycling by reducing payroll taxes or capital taxes improves the competitiveness of industries that are more intensive in the factor in which taxes are decreased. This can coincidentally improve competitiveness but does not address carbon pricing induced competitiveness impacts. He finds that exempting trade exposed energy intensive firms from a carbon tax or an import tariff border carbon tax adjustment improves competitiveness of Canadian firms but reduces economic output by 4.12 percent and 3.58 percent and significantly decreases welfare. He finally finds that output-based rebating, dynamically reimbursing firms for their carbon emissions reductions without changing their production incentives, shows the least decline in competitiveness for energy-intensive firms in Canada with the smallest effect on output.

Carbon pricing policy of Canada is expected to go a long way in reducing emissions, while falling short of achieving the NDCs. *Chateau, Jaumotte and Schwerhoff* (2022a) find that existing policies until end-2021 (including carbon pricing) would lead to an economy-wide emission reduction of around 25 percent by 2030 (driven primarily by the power and EITE industries), while Canada's Fifth Biennial Report on Climate Change (2022) finds that policies up to November 2022 in addition to some pending policies discussed in the 2030 ERP[5] would lead to around 33 percent reduction in emissions by 2030, compared with the objective of cutting GHG emissions by 40-45 percent relative to 2005 levels by 2030.

Mexico

The climate change literature on Mexico illustrates with this key emerging economy the need for mitigation policies. *The Ministry of Environment and Natural Resources and the Ministry of Finance* (*SEMARNAT and SHCP, 2009*) found that the cost of inaction for Mexico in terms of damages outweighs the cost of mitigation policies, making the case for international cooperation. *Santoyo-Castelazo, Stamford, and Azapagic (2014)* find for Mexico large environmental co-benefits of decarbonizing electricity, such as higher air quality. *Veysey et al. (2016)* show that to achieve substantial emission mitigation, deep changes are needed including a decarbonization of the electricity sector and further changes in the energy sector. *Chateau, Bibas and Lanzi (2018)* discuss labor market implications of carbon taxation in a cross-country analysis covering Mexico. This shows that while blue-collar workers are expected to enjoy relative income gains in typical advanced economies, those are more exposed and rather loose in some emerging economies including Mexico. *Black et al. (2021)* find that increasing a comprehensive carbon tax to USD 75 per ton would enable Mexico to meet its NDC 2030 target and found no adverse output effect in such a scenario. They also discuss redistributive issues, flagging that recycling revenues uniformly could offset 85 percent of the burden on the average household, while targeted transfers would raise equity, reduce poverty, and assist vulnerable households, workers, and regions. With a cost-benefit analysis, the National Institute of Ecology and Climate Change (*INECC, 2021*) also finds that mitigation policies need not be costly, estimating net gains for the set of mitigation measures of the government.

B. Cross-Border Effects of Unilaterally Introduced Climate Change Measures

Cross-Border Spillovers

The literature on cross-border implications of climate policies has focused on potential carbon leakage and a possible reallocation of dirty production to countries with laxer climate policies. Despite the renewed policy

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[5] These include clean electricity regulations, strengthened methane regulations in the oil and gas sector targeting 75 percent reduction by 2030 and proposed landfill gas regulations.

interest in the cross-border consequences of climate policies, research on the intersection of environmental policies and trade is not new (e.g., *Baumol and Oates, 1988*). This theoretical literature opposes two main channels. The Porter Hypothesis (*Porter and van der Linde 1995*) posits that environmental stringency stimulates innovation and fosters cost-cutting efficiency gain; offsetting costs induced by such policies.[6] In contrast, the "pollution haven hypothesis" (PHH) considers that stringent environmental policies, such as those mitigating climate change, affect competitiveness of EITEs, encouraging specialization in EITEs in countries with less stringent policies (e.g., *Pethig 1976*). In response to the PHH concern, *Böhringer, Lange and Rutherford (2014)* have shown that countries that unilaterally optimize their policies would lessen environment taxation on EITEs solely for a terms-of-trade motive. Helm, Hepburn and Ruta (2012) have advocated for carbon border adjustments (CBAs) aiming at reducing carbon distortion generated by divergent trade policies and increasing incentives to build a coalition of interest for global mitigation. Nordhaus (2015) showed that such climate clubs penalizing outsiders with CBAs can be stable with high levels of abatement. Further, *Clausing and Wolfram (2023)* broaden the cooperation problem with policies that can differ not only along their mitigation ambition, but also along costs imposed on agents (e.g comparing carbon taxation in Canada and green subsidies in the United States). A complementary work rather focused on variations across fiscal instruments has considered how combinations of these can change the terms of trade like a devaluation, but abstracting from environmental concerns (*Farhi, Gopinath and Itskhoki. 2014*).

Empirical and modeling exercises suggest environmental policies can affect firms' competitiveness at the margin, but that effect is generally small. This literature review by *Dechezleprêtre and Sato (2017)* gathers evidence that taking the lead on environment stringency induces small, statistically significant adverse effects of on trade, employment, plant location, and productivity in the short run. They find these effects very small compared to key location determinants such as transport costs, proximity to demand, workers' skills or availability of raw materials. However, for some very energy-intensive sectors, effects can be larger. Accordingly, *Carbone and Rivers (2017)* find with a review of the CGE literature that policies designed to reduce economy-wide emissions by 20 percent could reduce EITE output by 5 percent and exports by 7 percent, but with a noticeable variability of results across models. With a meta-analysis covering 103 papers, *Cohen and Tubb (2018)* found no significant overall competitiveness effect of climate policies. Reflecting the focus of the literature, this meta-analysis mainly covers trade and competitiveness effects of policies penalizing brown production, rather than those fostering green activity, one exception being the inclusion or R&D subsidies. However, limitations of these studies are the inclusion of periods when carbon pricing levels were low and accompanying policies like free allocation of allowances in the EU which often preemptively addressed potential competitiveness losses.

Cross-border *competitiveness* effects of *various* policies become a topic of concern when countries implement uneven climate policies and shocks are large. Previous IMF work (*Chateau et al. (2022a)*) systematically compares the impacts of different policy instruments on competitiveness of EITE industries using illustrative policy shocks. Policies that provide a positive supply shock to the energy sector, like feed-in subsidies to renewables, could lead to a significant shift in the market shares of EITE industries. However, within the demand-side policies, compared to regulations, a carbon tax does not necessarily disadvantage a country's competitiveness since it can deliver efficient and flexible abatement and carbon revenues can be used to lower other taxes.

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[6] IMF-ENV does not provide the framework to test the Porter Hypothesis since efficiency gains and technology assumptions are exogenous to the model.

Expected Cross-Border Effects of the IRA

The bulk of the quantitative cross-border impact assessments of IRA focus on the impacts on the European Union (EU) and estimate the aggregate GDP impacts to be very small (see *Attinasi et al., 2023, Barrios et al., 2023, Fajeau et al. 2023 and Rusch et al. 2023*). However, sectoral impacts could be substantial. For example, *Attinasi et al. (2023)* investigate the sectoral impacts in EU, Mexico, Canada and China from the tax credits for EVs and the clean electricity manufacturing investment bonus (conditional on the sourcing requirements) under three IEA scenarios– stated policies, accelerated policies and net-zero[7]. The estimates of global trade losses are modest (between 0.2 percent (conservative) and 0.9 percent (net-zero) until 2030) with positive spillovers for Canadian and Mexican production in sectors targeted by the IRA (notably the EV batteries and renewable energy equipment sector).

However, to our knowledge, there is no study available yet assessing the cross-border effects of the climate measures of both the IRA and the Canadian subsidy package especially with a focus on the impacts in North America. Nonetheless, several types of benefits and concerns about potential international effects of the IRA have been discussed.

The first leg of concerns relates to the domestic content requirements embedded in the IRA, some of which might however have less impact than expected given post-IRA developments. A widespread concern about the local content requirements embedded in the IRA is that those could create incentives for firms to delocalize in the U.S. to fulfill these requirements, thereby hurting trading partners' economies. *Bown (2022)* and *Kleimann et al. (2023)* both explain, however, that these have somewhat been relaxed and might be further relaxed as time goes on. In particular, the sample of countries considered to have a free trade agreement with the U.S. (i.e. not subject to some of the local content requirements applying to batteries and critical minerals) might gradually include the EU, the U.K. and other countries (following the U.S.' clarification on the definition of a "free trade agreement", on March 31, 2023, and openness to further expand the sample of countries considered in this group, see *Bown, 2022*). Similarly, regulations clarifying the implementation of the requirements might prove to be less restrictive than initially anticipated, as shown by the regulation making vehicles eligible for the EV tax credits for U.S. consumers, to the extent they are leased (i.e. exempting leased vehicles from fulfilling the local content requirements applying to purchased vehicles). In our case, the domestic requirements that assembly takes place in North America or source countries to have a free trade agreement with U.S. will not affect the study, since we focus on cross border effects to Mexico and Canada in the paper, which both fulfill these criteria.[8] We will therefore focus on possible cross-border effects resulting from the IRA measures (mainly green tax credits or subsidies) themselves, independently of their domestic content requirements.

The second leg of concerns relates to the implementation of green subsidies in general, as opposed to other types of mitigation policies. The choice of the U.S. to subsidize green energy while other countries, like the EU, have opted for carbon pricing, may make certain energy-intensive industries artificially competitive in the U.S., potentially shift supply chains and incentivize relocation of production to the U.S. This could put other potential exporters at disadvantage and might therefore force trading partners to respond with countermeasures such as

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[7] The measures are modelled as only trade shocks (through changes in iceberg costs) with an accompanying assumption that the technology-driven investments under the IRA would lead to higher productivity in USMCA and lower productivity in the rest of the world.

[8] The IRA entails other domestic content requirements that allow for a 10 percent bonus tax credit if complied with, but those are unlikely to have a significant effect given the size of the granted bonus.

tariffs (which could be counterproductive as it would end up with same level of economic activity on EVs, for example, and same GHG emissions, however with excessive subsidies) or to adopt policies potentially less efficient that the ones they would have chosen otherwise (*see Bown, 2022, Kleimann et al., 2023, and BCG, 2022*).

Some, but not all of these concerns are echoed by the IFO Institute's survey (*Gründler et al., 2023*), on expected effects of the IRA from economic experts across the globe. Their main result is that, on a global scale, experts are little concerned about negative effects of the IRA on their domestic economy (with around 74 percent of the participants in the survey reporting that the IRA is not (yet) a significant topic in the public debates in their country). However, authors provide evidence that such perception is heterogenous across countries, with economic experts in Europe, notably, being highly concerned about the IRA, worried about firms leaving their countries in response to the generous tax credits and subsidies that come along with the IRA. According to the survey results, the global share of experts who fear firm outflows in response to the IRA is however low (about 25 percent).

On the positive side, the IRA is seen as potentially benefitting countries worldwide, even beyond its effect on global emissions. It could accelerate cost reductions in clean technologies, improving learning rates (through early R&D investments and de-risked commercialization from the U.S. moving early), catalyzing further deployment of green technologies worldwide and incentivizing the diversification of supply (when it comes to critical minerals to be produced from free trade partners, for example), and amplifying global trends around supply chain transparency (on emission reporting, for example), see *BCG (2022).* More generally, despite the competitiveness concerns underlined above, as emphasized by BCG, the IRA can also be seen as catalyzing action for countries to "race to the top" and ramp up their own efforts to accelerate the green transition.

In this context, our paper aims at assessing the potential cross border effects of the IRA on prices, production and trade, at a sectoral level, so as to contribute to the debate through a first quantification of some of these effects.

IV. Short Presentation and Main Results of Theoretical Model

A stylized general equilibrium model complements the large-scale IMF-ENV model to shed light on mechanisms at play (Annex I). This simple two-country general equilibrium model builds on the static model used by *Farhi, Gopinath and Itskhoki (2014)*, which shows how a set of conventional fiscal policies could be equivalent to a nominal devaluation under certain conditions, including when the exchange rate cannot be devalued. This model of 'fiscal devaluation' is augmented with two sectors, a green one that does not emit greenhouse gas and a brown one with emissions that are proportional to output. In that version, one country is implementing a carbon tax and the other country is implementing a green subsidy.

The stylized model shows that under some specific conditions, divergent climate policies in the form of carbon taxation in the domestic economy combined with green production subsidies in the foreign economy could amount to "beggar-thyself" and "beggar-thy-neighbor" policies. Insofar as carbon taxes and green subsidies can be modeled as sector-specific production taxes and subsidies that have aggregate implications on the cost of production, the two-sector model illustrates analytically how these two sectoral fiscal policies can mimic, at smaller aggregate magnitudes, the conventional aggregate fiscal policies in *Farhi, Gopinath and Itskhoki (2014)*, namely a combination of Value Added Tax (VAT) and payroll subsidy—or import tariffs and export subsidies. By doing so, the two-sector model provides a helpful framework for investigating the competitiveness implications of such climate policies. The competitive edge (disadvantage) ensuing from divergent climate policies is manifested through stronger (weaker) terms of trade and a possible equivalence with a nominal devaluation (revaluation), which—as in the original model—holds under certain specific conditions. Intuitively, a differential treatment of exports and imports (e.g. VAT is reimbursed to exporters but levied on importers) is key for fiscal devaluation to hold, which holds in the presence of divergent climate policies as from the perspective of the economy with green subsidies, a subset of its exports is subsidized whereas a subset of its imports (namely brown sector) is subject to taxes in the economy with carbon pricing.

This exercise points to some potential channels at play that could limit the competitiveness implications of climate policies in North America, as suggested by the limited cross-border spillovers found in our main quantitative model results. In the absence of some required policy and structural conditions for fiscal devaluation to hold, the competitiveness implications found using our stylized model would be expected to be smaller. In particular, the equivalence with a nominal devaluation does not hold under flexible exchange regimes, as the nominal exchange rate would be expected to work as buffer, partially reversing the aggregate competitiveness effects, in this case induced by climate policies. Second, the design of carbon pricing in Canada, which allows for heterogeneity across provinces and includes elements of a tradable performance standard for large industries, would also be expected to limit competitiveness effects as unlike an outright carbon tax, a tradeable performance standard does not tax the average firm for their unabated emissions. Third, alternative budget balancing assumptions could also partially offset: (i) the increased cost of production faced by domestic brown firms subject to carbon taxation; and (ii) the decreased cost of production faced by foreign green firms eligible for production subsidies. For example, revenue recycling of carbon taxes by decreasing payroll taxes and financing green subsidies by an increase in CIT (as designed in the IRA) end up partially offsetting the first-order impact of climate policies on the cost of production, hence partially reversing the first-order efficiency competitiveness implications of climate policies. This finding is also supported by the sensitivity analysis conducted around our quantitative results in subsection E of section VI. The stylized model

also illustrates how border carbon tax adjustments and countervailing duties and subsidies could counter domestic carbon tax and green subsidies.

The competitiveness implications found in the analytical results run through the impact of policies on the terms of trade, or in other words on the relative prices of domestic versus foreign goods, which is also the main channel through which cross-border implications are drawn in the quantitative CGE model. That said, both the stylized and the quantitative CGE model fall short of fully capturing the cross-border channel associated with investment decisions and locations which are believed to be particularly driven by investment subsidies (as enacted and modelled in part of the IRA package and in most of Canada's budget subsidies), hence partially limiting the cross-border impacts captured by this analysis.

V.   Model Description and Scenarios

IMF-ENV is a global recursive dynamic CGE model. The model is based on a neoclassical framework with almost-perfect markets for goods and production factors. It uses the GTAP 10 database (Aguiar et al., 2019) aggregated to 25 regions and 36 sectors. IMF-ENV captures domestic and international economic interlinkages between sectors and countries and therefore, is a suitable model for the analysis of policies leading to changes in the sectoral composition of economies like those resulting from decarbonizations efforts and cross-border implications. The model features capital vintages such that the representative firm's production structure and a firm's behavior are different in the short and long term. This implies that short-term elasticities of substitution across inputs in production processes (or substitution possibilities) are much lower than in the long term as reallocating capital that is already installed across sectors is more challenging than installing new capital. Figure 1a in Annex II shows the assumptions on relevant elasticities.

International trade is modelled with the Armington specification (see *Armington, 1969*). This means that trade flows are differentiated by the origin and destination country pair for each sector. Transport service margins differ across each country pair to reflect the distance between origin and destination countries. IMF-ENV directly links economic activity to environmental outcomes. Emissions of greenhouses gases (GHGs) and other air pollutants are linked to economic activities either with fixed coefficients, such as those for emissions from fuel combustion, or with emission intensities that nonlinearly decrease with carbon prices and are estimated using marginal abatement cost curves. Given the general equilibrium setting, the model explicitly accounts for trade-offs of mitigation policies on overall and sectoral output, economic costs, and welfare effects.

Five policy scenarios are constructed based on the implemented policies to evaluate the domestic and cross-border economic impacts of climate policies in North America. We follow the chronological order in which the policy measures were introduced. Such an ordering of scenarios allows us to draw insights on the extent to which, if at all, newly proposed policies are able to offset any negative cross-border impacts of previously introduced policies. In this spirit, in the Quantitative Results section, sub-sections A to C discuss the marginal impacts of new policies (i.e., the previous scenario acts as the reference for the subsequent one) and sub-section D discusses the impact of all policies modelled together relative to a traditional business-as-usual scenario.

The baseline in IMF-ENV is calibrated to reflect the current state of climate policies in the world. Prior to the introduction of the climate policy packages, the North American countries had nation-wide mitigation policies that promoted the expansion of green power and disincentivized the use of fossil-fuels for energy. This included carbon prices in Canada and Mexico, and investment tax credits for new capital investments in solar photovoltaic (PV) and output tax credits to wind power in the U.S. which were set to expire in 2022. All these policies are included in the baseline. Additionally, projections of shares of different technologies in electricity generation are based on official data sources. Oil price forecasts are taken from the *IEA (2022)* announced policies scenario.

Canada's carbon pricing system is simplified and modeled as an economy-wide carbon tax and the revenues are recycled through a decrease in personal income tax. Given that tradeable performance standards (which are part of Canada's carbon pricing system) are expected to reduce carbon tax spillovers (*Fischer, 2001*), the results of the simulations should be interpreted as the upper bound of Canada's carbon pricing spillovers. The IRA package is modelled as a combination of production and investment tax credits for clean energy including nuclear power, energy efficiency measures for building, higher uptake of EVs with some regulations for

sourcing requirements. In IMF-ENV, the climate policies are modelled to be budget neutral by keeping the income tax rate flexible. This implies that expenditure policies like subsidies are financed by increasing income tax rates while revenue generating policies like carbon taxes are recycled to lower income tax rates relative to baseline. Macroeconomic results are sensitive to assumptions regarding how revenues are recycled or how expenditures are financed. In subsection VI-D, we provide a sensitivity analysis of the results to different recycling schemes as recycling mechanisms also differ across provinces and may use a combination of fiscal tools (e.g. personal income tax, transfers, investment, VAT). Similarly, macroeconomic impacts of IRA in the U.S. will also be sensitive to how the expenditures are financed (see Footnote 13).

The authorities' green policy packages are translated to policy shocks in the model and the modelled policies are described in Table 1 and Table 1b in the Annex III. The North American green policies are of primary interest in this analysis. However, countries are not on track to achieve their climate pledges and thus, there is a large implementation gap (see *Black et al. 2022, United Nations Environment Programme, 2022*). Scaling up of climate policies would be needed before 2030 for countries to reach their NDC targets. Therefore, assessing the impacts of the North America policy packages under varying assumptions of international mitigation remains of interest. Scenario 1 is modelled under two policy assumptions for the rest of the world with varying degrees of decarbonization efforts—(i) low decarbonization i.e., the rest of the world continues with current policies, and (ii) high decarbonization i.e., the rest of the world reaches its NDC targets with a carbon tax. A comparison between these two scenarios illustrates the interaction between North American policy packages and policy actions in the rest of the world. This allows us to discuss the impact of that pace of decarbonization in the rest of the world on decarbonization efforts in North American countries.

Though the model provides several advantages to meaningfully answer the policy questions at hand, there are also limitations to this analysis. The policy portfolios introduced by the U.S. and Canada includes a variety of measures that target different sectors and technologies in development, and we only capture the measures mentioned in Table 1. We do not model measures to support carbon removal technologies, environmental, agricultural and conservation measures and methane fines. The model has less detail in its incorporation of microeconomic frictions and in assumptions of technological change and diffusion. For example, it assumes that labor can move between sectors without frictions such as retraining or migration. This means the model may underestimate the cost of policy changes in the short-run due to omitted adjustment costs. Furthermore, IMF-ENV captures trade-offs between domestic and global decarbonizations goals through impacts on international trade and does not consider channels that could lead to potential benefits to the rest of the world like learning-by-doing, technology diffusion and impacts on green FDI flows (see empirical analysis in *Hasna et al., 2023*).

Table 1. Scenario Description

Scenario	Description	Policies Modelled in North America
Reference	No-policy baseline	- Canada: Economy-wide carbon taxes rising to $50/tCO2 until 2030. - USA: - Output tax credits for wind power generation in the U.S. between 2016-2022, - Investment tax credits for new solar PV power in USA between 2016-2022. - Mexico: Climate policies that are equivalent to a carbon price of $3.3/tCO2. - Rest of the world (ROW): Climate policies that have been introduced by 2020, implemented as a carbon tax.
Scenario 1a	Canada's Carbon Pricing System	- Canada's carbon prices increase to up to $130/tCO2 by 2030 starting in 2022. In the scenarios, carbon tax revenues are recycled by decreasing labor income tax. - ROW implements current policies only, as in the baseline.
Scenario 1b	IRA in the U.S.	- In addition to policies in Scenario 1a, U.S. introduces IRA measures which include: *Production tax credits* for solar PV and wind power generation modelled as output subsidies starting in 2023 and increasing to 40 percent and 59 percent respectively, by 2030. *Manufacturing tax credits* for clean energy capital in solar PV and wind power generation modelled as subsidies to new capital starting in 2023 and rising to 70 percent and 50 percent respectively, by 2030. *Sourcing requirements* for semiconductor and motor-vehicle parts are modelled by increasing the iceberg trade costs faced by countries that do not qualify mainly China and Russia.[9] *Electric Vehicles (EV) tax credits* would expectedly lead to higher uptake rate for EVs in road transport and this is modelled via increased electrification of the road transport sector. *Nuclear Tax Credit* for preventing decommissioning of the existing nuclear plants before 2030. We endogenize the subsidy such that nuclear production remains identical to baseline production levels. *Energy efficiency* measures in buildings. - In this scenario, tax credits are assumed to be financed by higher labor income taxes. A sensitivity analysis pertaining to this assumption is presented below. - ROW implements current policies only.
Scenario 1c	Canada's green subsidies	- In addition to the policies in Scenario 1b, Canada introduces investment tax credits for solar PV and wind power generation starting in 2023 which are modelled as subsidies to new capital and increase to 15 percent by 2030. - ROW implements current policies only.
Scenario 1 or (*Scenarios 1ª + 1b + 1c)*	Current Policies Scenario	- Canada's carbon tax and green subsidies and U.S.' IRA measures are introduced together. - ROW implements current policies only.

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[9] The definition of the countries that qualify for the EV credit based on sourcing and assembly requirements has been evolving post-IRA introduction. Beyond established trade partnerships by U.S., Asian and European countries have already qualified or are expected to qualify for the EV tax credit. Therefore, we only apply the high iceberg trade costs to semiconductor and motor-vehicle parts imports from countries that are classified as foreign entities of concern (currently China, Russia, North Korea, and Iran) and are individually represented in the IMF-ENV aggregation.

Scenario 2	*NDC Scenario (see Box 1)*	• The existing policies in North American countries are coupled with a carbon tax to reach their corresponding NDC targets. • ROW implements a carbon tax to reach their NDC targets too.

VI. Quantitative Results

## A. Scenario 1a—Domestic and Cross-Border Effects of Canada's Carbon Pricing Policy[10]

As intended, tightening of Canada's carbon pricing is expected to raise the domestic costs and prices for the production and consumption of fossil fuels, hence reducing the share of fossil fuels in the Canadian energy mix. As shown in Figure 5, scaling up of the carbon taxes to USD130 (Can$170) per ton increases the producer prices in sectors with high emission intensity, notably for power generation (8 percent). As increased production costs faced by the Canadian oil and gas sector get passed through to consumers through higher prices of fuels and utilities, Canadian demand for energy is expected to decline, led by fossil fuels, in both the electricity and the fossil fuel extraction sectors. A lower domestic demand combined with a small loss in competitiveness in the electricity[11] and EITE sectors (loss of exports market share, i.e. share of Canada's exports over global exports in these sectors, by 0.3 percentage points and 0.1 percentage points, respectively) would in turn prompt a lower production of fossil fuels in Canada by 2030 in the energy sector for electricity generation and direct use in the magnitudes of 7.4 and 8.1 percent, respectively, relative to the reference scenario, as per our IMF-ENV model estimates. This is expected to be accompanied with a 5.5 percent lower employment in the fossil fuel sector, and 1.2 percent lower jobs in the electricity subsector powered by fossil fuels. Higher fossil fuel and electricity prices would trigger a decrease in fossil fuel and electricity demand from trading partners, with the latter being partially powered by coal, fuel and natural gas. On the other hand, Canadian external demand for fossil-fuel powered energy would also decrease, reflecting the smaller reliance on dirty sources of energy under a carbon tax. This in turn leads to a small drop in the U.S.'s exports market share in the fossil fuel extraction sector, with negligeable effects on Mexico's exports market shares. On the aggregate we find negative, yet relatively small, output and employment spillovers in the U.S. driven particularly by the natural gas sector, but negligeable or slightly positive cross-country spillovers to the sector in Mexico.

Carbon pricing is also expected to propel the greening of Canada's electricity, and energy sectors more broadly. Based on our model estimates, Canada's carbon pricing increases would significantly increase producer prices for electricity powered by fossil fuels (by 30 percent in 2030 relative to the reference scenario). While the policy-induced decreases of producer prices for electricity powered by renewable and nuclear energy are not significant enough to reverse the overall electricity price increases faced by consumers, the lower relative producer prices of green electricity prompt a sizable change in the electricity mix leading to an expansion by 7.3 percent and 10.3 percent of green electricity output and employment respectively. Similarly,

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[10] Estimated effects of the Canada climate package on GHG emissions are presented in Box 1.

[11] The GTAP database is constructed from Input-Output tables of countries and uses an algorithm to harmonize trade flows data across countries. A result of this harmonization process is that there are minor inconsistencies in some bilateral trade flows to keep the social accounting matrices balanced. In sectors that are trade-exposed and where trade of a commodity is not restricted to geographically close countries this is not a problem since the error is minimal. However, in the electricity sector, which is not highly traded, and requires countries to be geographically linked to be able to trade, the erroneous small bilateral trade values between regions that cannot trade is inconsistent with reported data. Since in our charts we show the market shares of the electricity sector, this results in the model over-estimating impacts on market shares of the ROW (see Footnote 1).

the electricity powered by fossil fuels would reduce output and employment by 7.4 percent and 1.2 percent in terms, respectively. This is equivalent to renewables (including nuclear) generating about three-quarters of the electricity in Canada by 2030.

Figure 5. Key Variables by 2030 in Scenario 1a, by Sector
Percent change in Scenario 1a (Canada carbon pricing), relative to No-policy baseline
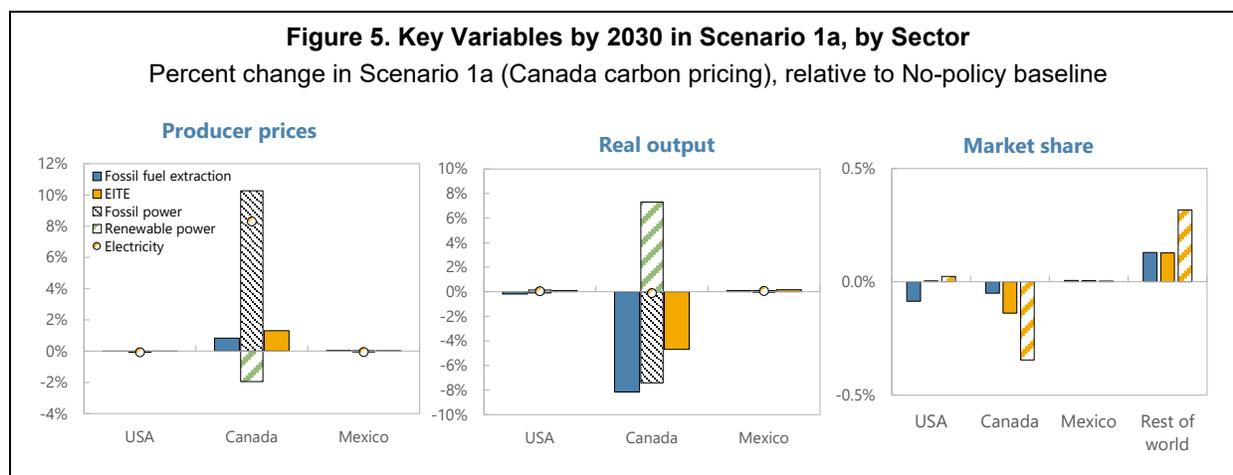
The ambitious unilateral carbon pricing policy is found to have important domestic aggregate and sectoral effects but muted spillovers to the U.S. and Mexico. The planned gradual increase of Canada's carbon pricing to Can$170 by 2030 would lead to a decline in the 2030 GDP level by around 0.2 percent in Canada relative to the reference baseline scenario in which carbon price in Canada is fixed at its 2022 level of Can$50. This is associated with a decline in real household consumption of around 0.2 percent and an increase in aggregate employment of 0.5 percent, by 2030. Aggregate effects of Canada's carbon pricing policy onto the U.S. and Mexico are negligible (see detailed result in Annex IV. A.).

B. Scenario 1b—Cross-Border Effects of the Inflation Reduction Act in the U.S.

The tax credit-based IRA slightly boosts U.S. competitiveness and somewhat deteriorates Canada and Mexico's competitiveness in the electricity sector, due to lower power prices and higher electricity supply in the U.S. More specifically, based on the IMF-ENV model, climate and energy related measures (see Table 1) in the Inflation Reduction Act are estimated to lower electricity prices at the consumer level by around 31 percent in the U.S. by 2030, thereby prompting higher electricity consumption by households. As expected from an expenditure-based policy, estimates show that lower electricity prices in the U.S. resulting from the IRA measures will boost electricity supply and thereby competitiveness of the U.S. economy vis-à-vis trading partners in the power sector. Overall, with the IRA, the U.S. gains market share in the electricity sector (i.e. U.S. exports of electricity as a share of total global exports of electricity) by around 0.7 percentage points by 2030, while Canada loses market share by around 1.3 percentage points, in addition to the market share loss resulting from the Canadian carbon tax scenario. This is mostly driven by higher electricity exports from the U.S. to the rest of the world (due to higher generation with subsidies) and to lower exports of electricity from Canada to the U.S (effect of lower external demand). However, it is worth noting that electricity exported from Canada to the U.S. is very small compared to U.S. production of electricity.

Figure 6. Key Variables by 2030 in Scenario 1b, by Sector
Percent change in Scenario 1b (U.S. IRA and Canada carbon pricing), relative to Scenario 1a (Canada carbon pricing)
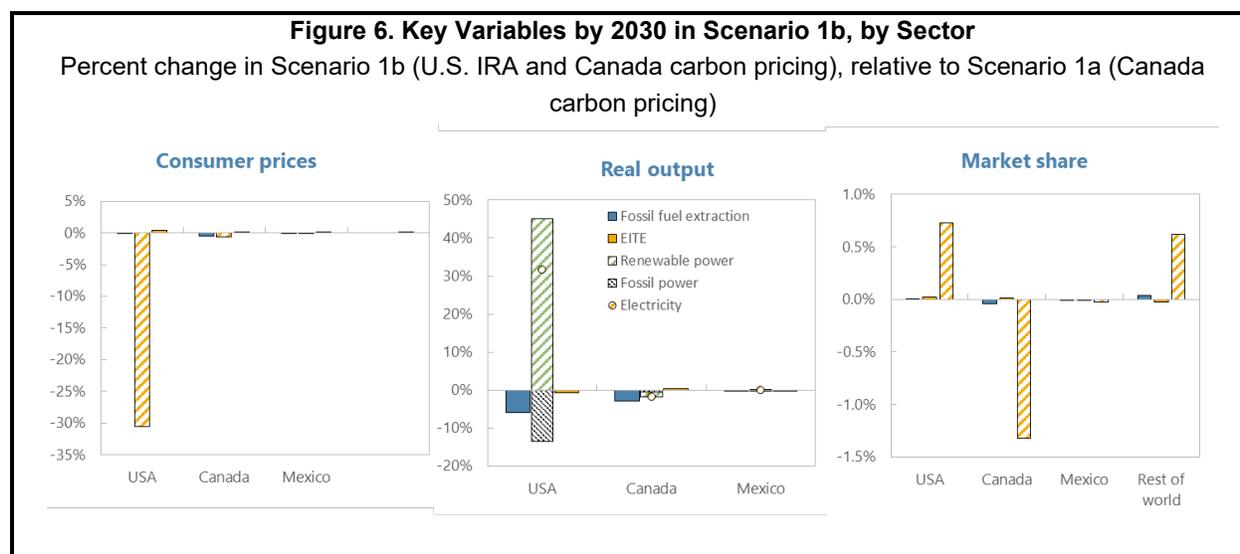
Greater reliance on clean energy from the IRA would lower U.S. demand for fossil fuel extraction and trigger a slight decline in its global market prices. This would lead to i) a reduction in fossil fuel extraction production in the U.S., and to a marginal reduction in Canada and Mexico; ii) and to a similar decline in jobs in this sector. Overall, with the IRA, the U.S. would gain market share in the electricity sector (i.e., U.S. exports of electricity as a share of total global exports of electricity) by around 0.7 percentage points by 2030, while Canada loses market share by around 1.3 percentage points, in addition to the market share loss resulting from the Canadian carbon tax scenario. This is mostly driven by higher electricity exports from the U.S. (due to higher generation with subsidies) and to lower exports of electricity from Canada to the U.S (as a result of lower external demand).

While having sectoral specific effects for fossil fuels and renewables (as described above), the IRA would have very limited aggregate effects on production and employment for Mexico and Canada. The IRA, introduced unilaterally in the U.S., would lead to a decline in overall GDP of around 1 percent in 2030 (equivalent to a cumulative reduction of 0.3 percent in GDP between 2023 to 2030) in the U.S. (primarily driven by higher income taxes—to finance green subsidies), as well as to a decline in aggregate employment of 0.6 percent and a reduction in real household consumption of around 1.3 percent, by 2030 (see detailed result in Annex IV. B.). Carbon leakage resulting from the sole IRA measures would be very limited. Not incorporating any of the new green policies being undertaken in the rest of the world, estimates suggest that the Inflation Reduction Act's incentives alone result in a very small "carbon leakage" to the rest of the world. More specifically, lower fossil fuel prices from lower U.S. demand for those is expected to only marginally increase consumption of fossil fuels in the rest of the world, offsetting only around 1 percent of the reduction in U.S. emissions enabled by the IRA.

C. Scenario 1c—Cross-Border Effects of Canada's Green Subsidies

Canada's green subsidies would help accelerate the greening of the country's electricity mix, with little impact in the U.S. and Mexico. Green subsidies in Canada's 2023-2024 federal budget are projected to increase

employment and output in the green powered electricity sector by 5.4 and 3.9 percent, respectively, and decrease employment and output in the fossil fuel powered electricity sector by 1.2 and 4.7 percent, respectively, by 2030, relative to Scenario 1b (see Figure 6). However, as opposed to the domestic price impact of the U.S.' IRA, simulated Canadian green subsidies will only have a mild impact on electricity prices relative to scenario 1b, falling short of reversing the competitiveness implications of Canadian Carbon Pricing and U.S. IRA onto the electricity sector. This may be due in part to the nature of green subsidies in Canada, which, as opposed to the U.S. reliance on production tax credits, are mostly investment tax credits affecting

Figure 7. Key Variables by 2030 in Scenario 1c, by Sector

Percent change in Scenario 1c (Canada's green subsidies and carbon pricing, and U.S. IRA), relative to Scenario 1b (IRA and Canada carbon pricing)
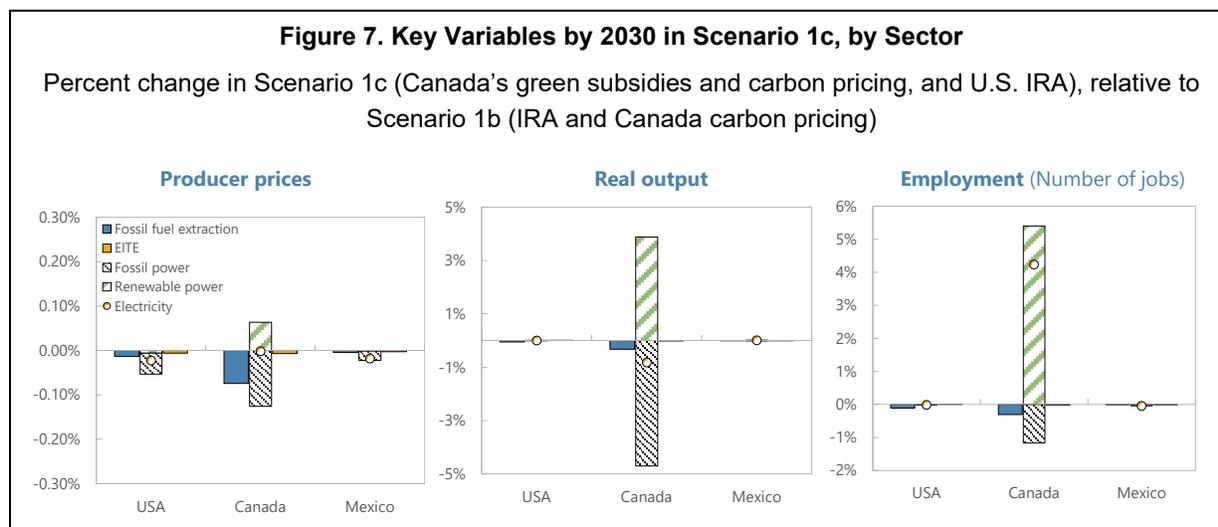
investment decisions, and less so costs and producer prices. Canadian green subsidies seem to have little impact on the fossil fuel extraction sector domestically, but the decreased reliance on fossil fuels in the electricity sector would in part reduce demand for U.S. fossil fuel (see detailed result in Annex IV. C.).

Even more pronounced than the finding under the IRA scenario 1b, aggregate domestic and foreign spillovers of Canada's green subsidies by 2030 are negligeable, despite the sectoral output implications discussed above. The GDP impact of Canada's green subsidies is marginally higher relative to the previous scenario. Consumption and output losses for Canada are in the order of 0.1 percent and the impact is broadly neutral on the U.S. and Mexico by 2030, relative to Scenario 1b.

D. Scenario 1—Combined Effects of the Joint U.S.' and Canada's Climate Policies

The preference of policy instruments used in existing as well as new climate policies in North American countries is diverse. Canada maintains carbon pricing as the central element in its climate mitigation policies with complementary green subsidy policies while the U.S. has kept green subsidies at the core of its climate agenda. Though both policies could deliver emission reductions the implied macroeconomic costs are different.

The choice of different climate policy instruments across U.S. and Canada impacts energy prices and supply differently. Our modelling exercise shows that subsidies to green energy source help lower energy prices and boost clean energy supply while on the contrary, carbon taxes tend to increase energy prices (see Figure 8). The current mitigation policies would increase the average producer price of electricity generation in Canada by 8 percent while decrease it by 25 percent in the U.S., relative to baseline levels in 2030. Consumer prices of electricity are lower by 30 percent in the U.S. In Canada, the carbon pricing instrument is the dominant driver of

changes in consumer prices and therefore, on average consumers would face a net increase in electricity prices by 3 percent. The strong supply side policies in the U.S. increase the electricity output by 32 percent by 2030 relative to baseline while the combination of supply and demand-side policies in Canada decrease electricity production on net by 1 percent by 2030.

Figure 8. Key Variables by 2030 in Combined Scenario 1, by Sector

Percent change in Scenario 1 (Canada's green subsidies and carbon pricing, and U.S. IRA), relative to baseline
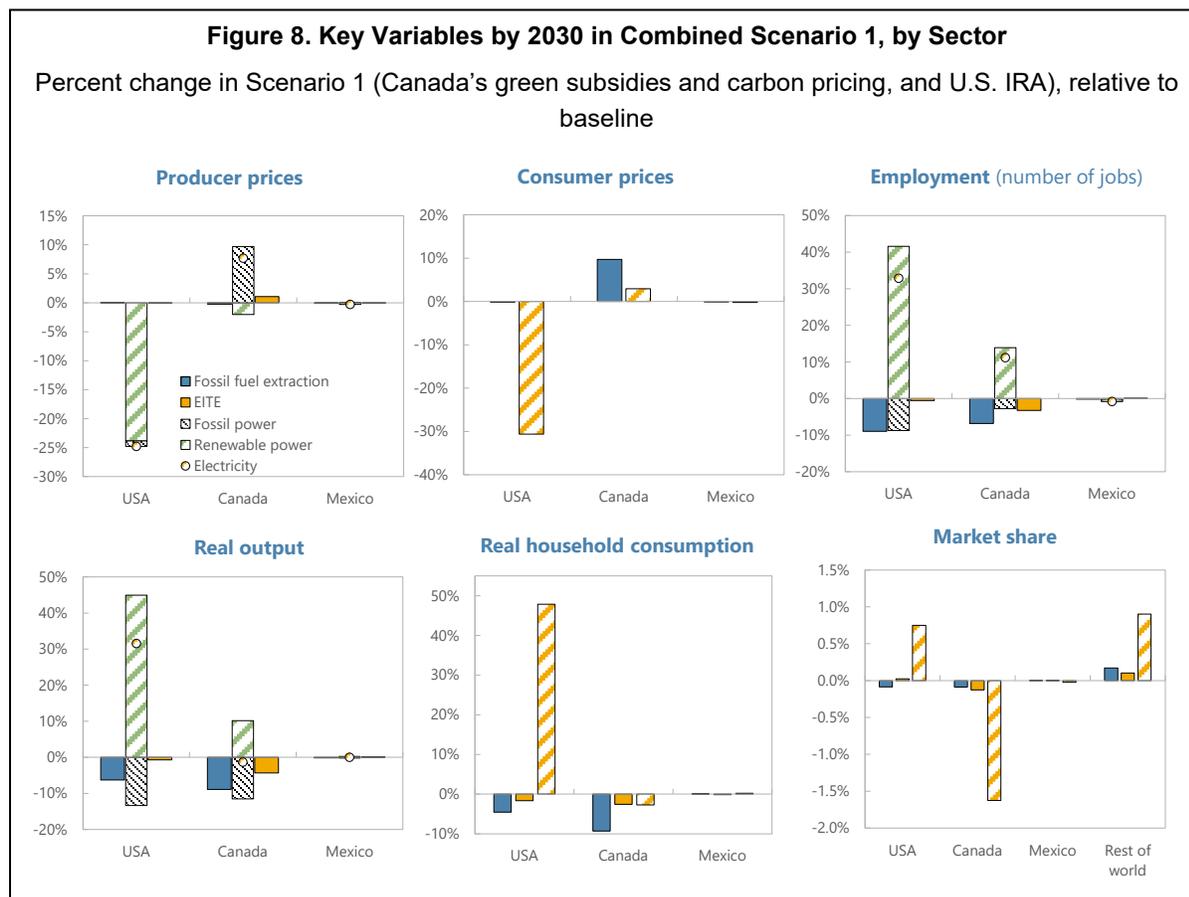
Higher output of the clean energy and relocation of workforce from carbon-intensive to green power generation sectors is expected in both countries. Lower demand from fossil fuel extraction sectors leads to a drop in the output and employment in these sectors both in Canada (9 percent and 7 percent, resp) and the U.S. (6 percent and 9 percent) relative to baseline. Climate packages deliver higher output of clean electricity technologies on net, accompanied by a shift of workforce from fossil generation to green generation technologies. This increases employment in the electricity sector by 33 percent in the U.S. and 11 percent in Canada. It is critical that active labor market policies support the transition of workers away from carbon-intensive sectors. Aggregate results are shown in Figure 9.

The U.S. gains market share in the electricity sector as a result of the IRA, while Canada loses market share in the same sector as a result of both the Canada carbon tax and the IRA—which is slightly offset by the introduction of Canada green subsidies. The Canada carbon tax deteriorates Canada's market share in the electricity sector through higher electricity prices. The various tax credits in the U.S. increase the competitiveness of electricity generation in the U.S. relative to its neighbors and therefore, the U.S. sees an increase in exports of electricity, combined with an increase in its market share for electricity, while Canada sees it market share decline further as a result of the IRA. It should be noted that the trade in electricity

between North American countries is a small share of aggregate bilateral trade but is of critical importance for sub-regional economic activity in these countries.

Finally, we discuss the heterogeneity of the impacts on producer prices, market shares and trade flows within the five EITE sectors. The weighted producer price of the EITE commodities has small changes relative to baseline prices in both Canada (small increase) and U.S. (small decrease). However, the estimate of impacts within the different EITE sectors are heterogenous. In Canada, producer prices for the EITE commodities increase between 0.3 percent (paper and paper products) and 2.9 percent (iron and steel) by 2030 relative to baseline with a small decrease of -0.2 percent in the non-

Figure 9. Aggregate Variables by 2030
(Percent change relative to baseline)

metallic minerals sector. In the U.S. the decrease in prices ranges between -0.3 (non-metallic mineral) and -1.5 percent (non-ferrous metals) by 2030 with a small increase of 0.3 and 0.5 percent in paper and paper products and chemical sectors, respectively. Even without the introduction of new domestic policies, producer prices in Mexico marginally fall in non-metallic minerals (-0.03 percent), iron & steel (-0.1 percent) and non-ferrous metals (-0.2 percent) sectors.

Under Scenario 1, the loss in global trade is 0.20 percent while the trade loss in the EITE sectors only is 0.17 percent relative to baseline by 2030. Though the impact on market shares of North American countries in the EITE sectors is limited (see Figure 7), there are differences in size of impacts across EITE sectors. The U.S. gains market share in non-ferrous metals (0.2 percentage points), iron and steel (0.1 percentage points) and non-metallic minerals (0.01 percentage points) while it loses market share in chemical products (-0.2 percentage points) and paper products (-0.3 percentage points), leading to a very small gain in the overall EITE market share. Within the EITE sectors, low energy prices brought by IRA in the U.S. increase trade flows from U.S. to the rest of the world in the non-ferrous metals (5 percent), iron & steel (4.6 percent) and non-metallic mineral (including cement) (1 percent). This is also accompanied by lower import flows in the U.S. from the rest of the world, ranging from a reduction of about 1 percent (paper and paper products, chemicals and non-ferrous metals) to 3.5 percent (iron and steel production).

Differently, in Scenario 1 Canada loses market share in chemical (0.17 percentage points) and iron and steel (0.08 percentage points) with almost no impact on other EITE sectors, leading to an overall loss in EITE sectors. Real exports from Canada to the rest of the world are lower in all the EITE sectors with the largest reduction seen in the iron and steel industry and lowest in non-ferrous metals (-0.2 percent). These changes are observed together with an increase in import flows in the iron and steel industry (3 percent) and non-metallic minerals (1.5 percent). The impact on the trade flows from and to Mexico in the EITE sectors on aggregate is marginal with almost no impact on the market shares.
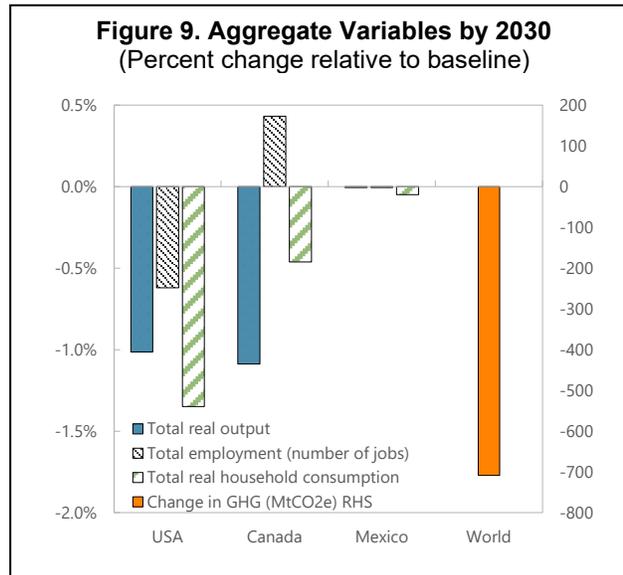
E. Sensitivity Analysis

GDP impacts of income-based policies like carbon tax are sensitive to how the revenues are recycled. We illustrate the sensitivity of our results under alternate revenue recycling assumptions for maintaining budget neutrality using Canada's carbon tax scenario (Scenario 1a). Canada's carbon pricing policy would reduce GHG emissions by around 29 percent relative to the no-policy baseline, by 2030, while its cost could vary between 0.2 and 1.2 percent of 2030 GDP depending on the revenue recycling mechanism as shown in Figure 10. The lower-end cost estimate obtains if carbon tax revenues are used to finance productive (possibly green) investment, while the higher-end obtains if these revenues are returned to households via transfers, whereas decreasing distortionary taxation in the form of decreasing personal income tax (PIT) or value-added tax (VAT) lead to moderate cost. Put another way, the choice of recycling scheme has a first-order impact on the output costs of

Figure 10. Canada: Carbon Pricing Implications on GDP in 2030
(Percent change relative to baseline)

mitigation. While the federal backstop design has opted for recycling mostly through direct transfers to households, some provinces use a mix of recycling targets that include some elements of decreasing distortionary taxation and increasing investment, among others. These results suggest that while the unilateral carbon pricing policy is the main driver behind efficiency losses, these can be substantially modified through a careful design of carbon revenue recycling. That said, policymakers may not be focused entirely on competitiveness and efficiency concerns and may also need to use these revenues to achieve equity objectives. However, transfers could be better targeted to the most vulnerable households to minimize their efficiency costs. The comparison of the blue bars suggests that the IRA policy in the U.S. does not impose any spillovers on the GDP costs resulting from Canada's domestic climate policies.
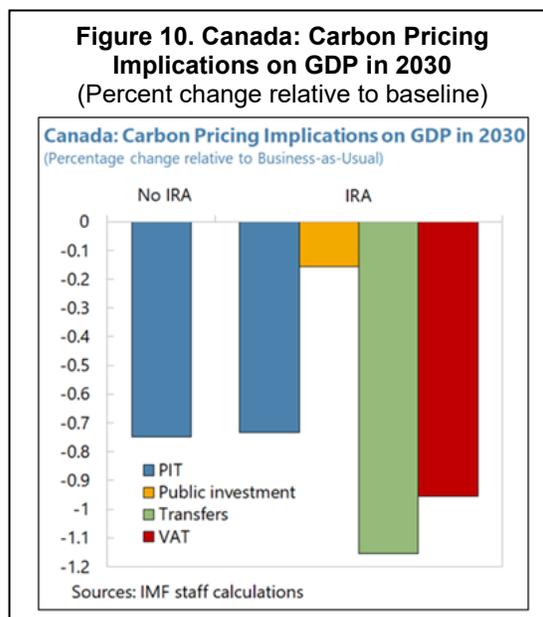
GDP impacts of expenditure-based policies (like the subsidies under IRA) are sensitive to the financing mechanism. In the simulations, an increase in wage income tax is used to finance the subsidies[12]. The labor income tax is distortionary and therefore, increasing the tax rate further increases the distortions in the economy. Contrary to this, financing the subsidies with a lumpsum tax on households does not impose distortions and therefore, the GDP level losses are marginally smaller.

Variations in assumptions on the financial sector across different model types also play a role in estimating impacts. Commonly in CGE models like IMF-ENV, the response of aggregate investment is constrained by savings-driven investment assumptions. This means that the savings rate as a share of GDP is exogenously defined and therefore, the model has limited ability for large shifts in aggregate investment levels. Under climate mitigation policy shocks, the changes in sectoral investments result from reallocation of investments within the economy through crowding out from brown to green sectors. Thus, the underlying assumption is that

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[12] We assume wage income taxes to finance the IRA package since they are less distortionary than capital taxes. In the context of redistribution of carbon tax revenues, several papers show that the efficiency and welfare gains from capital tax reduction are large compared to those from reductions in payroll taxes since capital taxes are very distortionary (see Morris 2015). These results are also informative for the reverse policy design where taxes are increased to finance green subsidies.

new investments in green sectors would be financed by divestment from brown sectors and other sectors of the economy. Differently, in other macroeconomic models like DSGE models, a large positive shock to total investments is possible and therefore, an increase in aggregate investment is usually observed with policies like green subsidies. In such models, the implicit assumption is that additional financing will be made available to the green sectors with only partial offset from a decline in the brown sector investments. Consequently, the difference in the investment dynamics could result in positive GDP impacts in DSGE models (driven by a positive impulse of overall investment) while the GDP impacts in CGEs will be negative (barring removal of any distortions like fossil fuel subsides (see Box 2 in IMF, 2023)).[13] In the context of the IRA policy, Voigts and Paret, (2024) use the forward-looking model GMMET to estimate the GDP impacts of the IRA policy and find a marginally positive impact on GDP with the IRA measures (0.2 percent increase from steady state by 2030).[14] The difference in the direction of GDP impacts between IMF-ENV and GMMET, for the IRA illustration, is largely driven by the response of the aggregate investments. Nonetheless, both models estimate the scale of impacts on annual GDP growth in the U.S. to be very limited.

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[13] See Pollitt, H., and Mercure, J.F., 2018 for a discussion on the role of monetary and financial sector treatment on economy-wide investments in macroeconomic models.

[14] Both Voigts and Paret (2024) and our paper do not model climate impacts. However, if these were accounted for, then the results from CGE models like IMF-ENV would deliver gains in GDP due to mitigation since the gains from mitigation are by far larger than the costs of inaction.

Box 1. Effect of reaching NDCs through subsidy- rather than only carbon tax-based policies in the U.S.

The IRA in the U.S. and the carbon tax and subsidy package in Canada deliver large emission reductions however, they do not deliver the full NDC target of these countries. The legislated policies in Canada and the U.S. should be complemented by additional policies to bridge the gap between policy ambition and implementation. We model two illustrative scenarios to highlight the differences in price impacts when the U.S. uses a policy mix of IRA and a carbon tax to bridge the implementation gap (*NDC with IRA scenario*) compared to a scenario when the full NDC goal is reached only with a carbon tax (*NDC with carbon tax*). The latter scenario can be seen as a benchmark of the cost-efficient policy option. In both scenarios, all the other countries use a carbon tax to meet their NDC goals.

While both scenarios are designed to deliver emission reductions aligned with the U.S. NDC target, there are differences in the impacts on energy prices and market shares of EITE sectors. In the *NDC with carbon tax* scenario, the carbon tax results in an increase in producer prices of electricity generation (4 percent rel. to BaU) and EITE sectors (1.1 percent rel. to BaU) in the U.S. In contrast, the producer prices of electricity generation decrease (-1.2 percent rel. to BaU) in the *NDC with IRA* scenario suggesting that the increase in producer prices due to the carbon tax are more than offset by the tax credit provisions of the IRA. The reduction in the power generation prices reduces input prices of energy, and therefore, there is a smaller increase in the producer prices of EITE sectors with the IRA in the policy mix compared to only when a carbon tax is used. The reduction in producer prices of energy gives the EITE industries in the U.S. a competitive advantage with the IRA, and the U.S. can retain a larger market share in the EITE sectors while the rest of the high-income countries see a marginally lower market share.

A broad carbon tax provides the least cost option to reducing emissions. Therefore, reaching the NDC target with the IRA and a carbon tax leads to somewhat higher GDP losses in the U.S. relative to using only a carbon tax policy, with the exact impact depending on fiscal assumption for recycling carbon revenues. Either choice of the policy instrument in the U.S. results in almost no spillover to the GDP costs for the rest of the countries.

Producer prices in the energy sector for U.S. (Percent deviation from baseline, 2030)	**Market Share of EITE Sectors** (Percent point deviation from baseline, 2030)
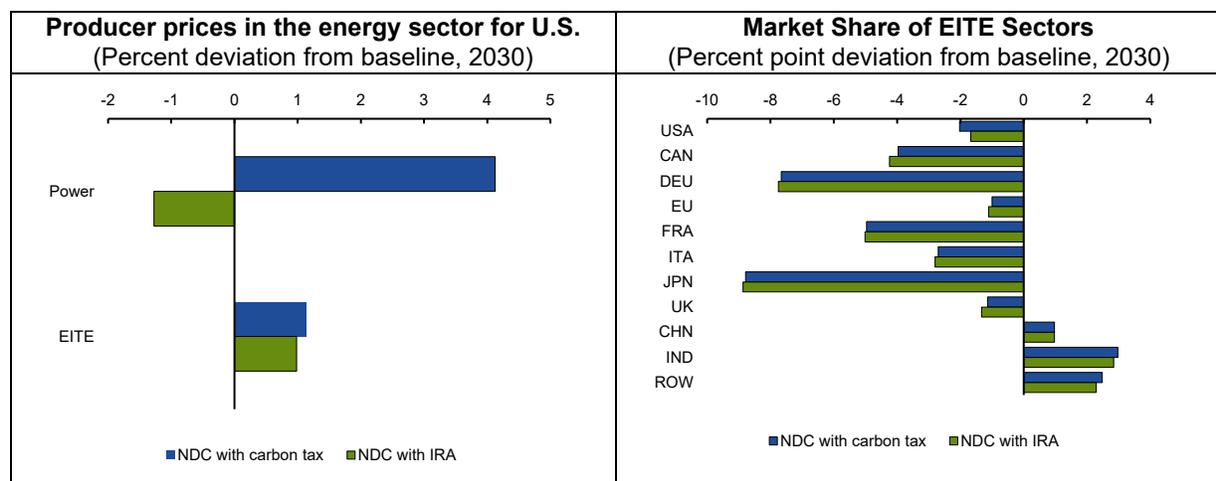
VII. Conclusion

Our paper quantifies competitiveness effects (namely, price effects, trade losses and reallocation of production by sector) of legislated climate policy packages, for home and neighboring countries within North America, as well as the GHG emission effects resulting from these policies. It also assesses how these cross-border effects could change if the U.S., Canada and Mexico were to achieve their NDCs through an extension (or amplification) of their current policies. We use the global computable general equilibrium model IMF-ENV developed in the IMF's Research Department for this purpose. This recursive dynamic model is able to provide an assessment up to 2030 and is particularly well-fitted for several reasons, including its global coverage, the embedded sectoral granularity and fiscal consistency, and the feature that it explicitly links economic activity to GHG emissions. Policies are modeled as budget neutral, offset by labor income taxes, and are in some cases simplified for simulation purposes. While the actual carbon pricing system in Canada varies across provinces and sectors (carbon tax, tradable performance system, cap and trade system, or hybrid), it is modeled as a uniform carbon tax. Green subsidies are modeled as production and investment tax credits in select green sectors, abstracting from other forms of climate mitigation policies.

While not sufficient on their own, Canada's carbon tax-led mitigation policies and the U.S.' Inflation Reduction Act are found to provide a significant push towards reaching these countries' NDCs and to boost the share of green electricity by 2030. Canada's carbon tax and green subsidies and the U.S.' IRA complement the policies already in place and will help the two countries further cut their emissions with overall GHG emissions reduced by around 29 percent and 35 percent respectively relative to 2005 levels by 2030, compared to goals of a 40-45 percent and 50-52 percent decline respectively. These new packages together with existing policies can thus bridge around two thirds of the gap towards NDCs. This is complemented with an increase in the share of green electricity from around 81 to 89 percent in Canada, and from around 52 to 73 percent in the U.S., relative to baseline, by 2030, a meaningful increase compared to a business-as-usual scenario. In the U.S., the IRA leads to greater reliance on clean energy and lower demand for fossil fuels and stimulates production and jobs in the electricity sector. through lower electricity prices and stronger demand for electricity. In Canada, climate mitigation policies make fossil fuel prices overall more expensive, significantly boosting employment and production in the renewables' sectors and reducing them in the fossil fuel sectors. In contrast to the U.S., the overall demand for electricity declines, largely driven by higher fossil fuel prices; nevertheless, employment in electricity generation increases on net.

To our knowledge, this paper is the first to quantify spillover effects of the recent climate mitigation policies introduced in both the U.S. and Canada. Beyond domestic impacts, we find cross-border competitiveness effects for neighbor countries within North America to be very limited and restricted to energy and EITE sectors. With IRA in the U.S. and carbon tax and green subsidies in Canada, the U.S. gains market share in the electricity sector while Canada loses market share. For the aggregate EITE sectors, changes in market shares from the introduced policies are found to be marginal in the three North American countries. Within the EITE sectors, the U.S. gains market shares in iron and steel, non-ferrous metals and non-metallic minerals sectors while Canada loses market shares in the iron and steel sector. Both the U.S. and Canada lose some market share in the chemicals sector. The potential for carbon leakage because of the recent Canada and U.S. climate policies within North America is found to be negligeable. And beyond model results, spillovers could be even smaller as some mitigation mechanisms (such as tradable performance standards in Canada) further dampen competitiveness effects.

These findings have important implications for the pursuit of climate mitigation policies worldwide. While their cross-border implications have been the subject of discussions, our results show that the recently implemented climate mitigation policies in Canada and the U.S. in fact do not seem to exert large macroeconomic impacts across countries, although some sectors might be more affected than others. In parallel, while we do not investigate these in the paper, there are good reasons to believe that in the long-term such policies would benefit other countries through other channels, such as catalyzing further deployment of green technologies worldwide, improving learning rates and accelerating efforts toward the green transition. Nonetheless in the short-term, there is a risk that competitiveness concerns could lead to a "subsidy race", putting developing countries that lack adequate fiscal space to implement similar policies at a disadvantage. Finally, one limitation of this analysis is that the stylized and the quantitative CGE models do not capture the cross-border channel associated with investment decisions and location.

Annex I. Stylized Model

I.   Model Set-Up

This model builds on Farhi et al. (2014) static model, which considers two countries, *H* (home) and *F* (foreign). This annex expands the model to two sectors: Brown (B) and Green (G). Denote by ψ the share of green goods in the domestic and foreign good consumption basket in each country:

$$C_H = C_{HG}^{\psi} C_{HB}^{1-\psi}$$
$$C_F = C_{FG}^{\psi} C_{FB}^{1-\psi}$$
$$C_H^* = C_{HG}^{*\psi} C_{HB}^{*1-\psi}$$
$$C_F^* = C_{FG}^{*\psi} C_{FB}^{*1-\psi}$$

Stars denote foreign country variables. For instance, C_H denotes consumption of home goods at home, and C_H^* consumption of home goods in the foreign country.

The associated price indexes of Home and Foreign good consumption baskets in home currency are:

$$P_H = \left(\frac{1}{1+\varsigma^c}\frac{P_{HG}}{\psi}\right)^{\psi}\left(\frac{P_{HB}}{1-\psi}\right)^{1-\psi}$$
$$P_F = \left(\frac{1}{1+\varsigma^c}\frac{P_{FG}}{\psi}\right)^{\psi}\left(\frac{P_{FB}}{1-\psi}\right)^{1-\psi}$$

Such that P_{HG}, P_{HB}, P_{FG}, and P_{FB} are Home-currency prices of the respective goods before consumption subsidy ς^c that applies only to green goods, but inclusive of carbon taxes, production green subsidies, and border adjustment tariffs and subsidies if any.

Similarly, we can construct consumption basket aggregators for brown and green good consumption in Home country such that:

$C_B = C_{HB}^{\gamma} C_{FB}^{1-\gamma}$ and $C_G = C_{HG}^{\gamma} C_{FG}^{1-\gamma}$;

with $\gamma \in [0,1]$ denoting bias for consumption of domestic goods. Associated price indexes would be:

$$P_B = \left(\frac{P_{HB}}{\gamma}\right)^{\gamma}\left(\frac{P_{FB}}{1-\gamma}\right)^{1-\gamma}$$
$$P_G = \frac{1}{1+\varsigma^c}\left(\frac{P_{HG}}{\gamma}\right)^{\gamma}\left(\frac{P_{FG}}{1-\gamma}\right)^{1-\gamma}$$

Note that $PC = P_H C_H + P_F C_F = P_B C_B + P_G C_G$;

Such that $P_H C_H = \frac{1}{1+\varsigma^c}P_{HG}C_{HG} + P_{HB}C_{HB}$, and $P_F C_F = \frac{1}{1+\varsigma^c}P_{FG}C_{FG} + P_{FB}C_{FB}$;

And $P_B C_B = P_{HB}C_{HB} + P_{FB}C_{FB}$, and $P_G C_G = \frac{1}{1+\varsigma^c}(P_{HG}C_{HG} + P_{FG}C_{FG})$.

Parallel specifications would apply for starred prices in foreign currency.

The home government budget constraint is

$$M + T + TR + B^g = 0$$

where M is money, T is a lump-sum (potentially negative) transfer to households, B^g are home government net foreign assets converted in home currency, and TR stands for all non-lump-sum fiscal revenues.

$$TR = \left(\frac{\tau^n}{1+\tau^n}\right)WN + \left(\frac{\tau^d}{1+\tau^d}\right)\Pi - \frac{\varsigma^c}{1+\varsigma^c}P_G C_G + \tau^c P_B C_B + \frac{\tau^{cvd}}{1+\tau^{cvd}}P_{FG}C_{FG} - \varsigma^{cvs}\mathcal{E}P_{HG}^* C_{HG}^*$$

where τ^n is a labor tax, τ^d a dividend tax, τ^{cvd} a countervailing duty on imported green goods and ς^{cvs} a countervailing subsidy for exported green goods. In the absence of border tax adjustments, the base of the carbon tax should be restricted to home-produced brown goods, yielding $\tau^C P_{HB} C_{HB}$

For the foreign country:

$$TR^* = \left(\frac{\tau^{*n}}{1 + \tau^{*n}}\right) W^* N^* + \left(\frac{\tau^{*d}}{1 + \tau^{*d}}\right) \Pi^* - \frac{\varsigma^{*c}}{1 + \varsigma^{*c}} P_G C_G - \varsigma^{*p} A_G^* Y_G^*$$

The other features of the model set-up are unchanged. In particular, money is introduced by means of cash-in-advance constraints:

$$PC \le M$$
$$P^* C^* \le M^*$$

The utility of the representative household is given by:

$$U = \frac{C^{1-\sigma}}{1-\sigma} - \kappa \frac{N^{1+\varphi}}{1+\varphi}$$

where N is the labor supply.

the household budget constraint

$$\frac{1}{1+\varsigma^c}(P_{HG} C_{HG} + P_{FG} C_{FG}) + P_{HB} C_{HB} + P_{FB} C_{FB} + M + T \le \frac{WN}{1+\tau^n} + \frac{\Pi}{1+\tau^d} + B^p$$

Goods are produced from labor using a linear technology:

$$C_{HG} + C_{FG}^* = Y_G = A_G N_G$$
$$C_{HB} + C_{FB}^* = Y_B = A_B N_B$$
$$N_G + N_B = N$$

For simplicity and without loss of generality we will assume $A_B = A_G = A$. Greenhouse gas (GHG) emissions are proportional to production in the brown sector, with similar technology at home and abroad:

$$E \equiv Y_B$$
$$E^* \equiv Y_B^*$$

And the carbon footprint of consumption includes carbon leakage via imported brown goods:

$$F \equiv C_{HB} + C_{FB}$$
$$F^* \equiv C_{HB}^* + C_{FB}^*$$

International markets

$$B + B^* \mathcal{E} = 0$$

Total home-country foreign assets:

$$B = B^p + B^g$$

Wage setting. Denote by $\theta_w \in [0,1]$, the degree of wage stickiness (at a first stage we will assume that it's equal to zero corresponding to fully flexible wages). The equilibrium wage rate would be:

$$W = \overline{W}^{\theta_w} \left[\mu_w \underbrace{(1 + \tau^n) \kappa P C^\sigma N^\varphi}_{\text{Marginal Rate of Substitution}}\right]^{1-\theta_w}$$

Such that $\overline{W}$ is the preset wage, $\mu_w \ge 1$ is the wage markup under imperfectly competitive labor market. The labor income tax τ^n will be used as the primary carbon tax revenue recycling or green subsidy financing tool.

Price setting using Producer Currency Pricing (PCP): Denote by $\theta_p \in [0,1]$, the degree of price stickiness (at a first stage we will assume that it's equal to zero corresponding to fully flexible prices). Assuming for

illustration that the home economy (e.g. Canada) implements carbon tax on the production of Brown goods, and that the Foreign economy (e.g. the U.S.) implements production subsidies to its green sector then prices in each of the following sectors would be determined as follows:

Brown domestic sector:
$$P_{HB} = \bar{P}_{HB}^{\theta_p} \left[\mu_p \underbrace{\frac{1}{1-\tau^C} \frac{W}{A}}_{\text{Marginal Cost}} \right]^{1-\theta_p} ;$$

Green domestic sector:
$$P_{HG} = \bar{P}_{HG}^{\theta_p} \left[\mu_p \frac{W}{A} \right]^{1-\theta_p} ;$$

Brown foreign sector:
$$P_{FB}^* = \bar{P}_{FB}^{*\theta_p^*} \left[\mu_p^* \frac{W^*}{A^*} \right]^{1-\theta_p^*} ;$$

Green foreign sector:
$$P_{FG}^* = \bar{P}_{FG}^{*\theta_p^*} \left[\mu_p^* \frac{1}{1+\varsigma^{*p}} \frac{W^*}{A^*} \right]^{1-\theta_p^*} ;$$

such that $\bar{P}_{HB}$ is a preset price, $\mu_p \geq 1$ is the price markup, τ^C is a carbon tax (illustrated here in the Home country for simplicity), and ς^p is a production subsidy for the green sector (illustrated here in the Foreign country for simplicity).

International Price Setting. Under the Producer Currency Pricing (PCP), producers would receive the same price from sales domestically and abroad. Allowing for the possibility of Carbon Border Adjustment in the Home country, which may take the form of a carbon tax levy on imported Brown goods and/or carbon tax reimbursement for exported Brown goods (both equivalent to the home carbon tax τ^C), as well as countervailing duties on imported green goods (τ^{cvd}) and/or countervailing subsidies for exported green goods (ς^{cvs}). The former would be a set of tools for border adjustment addressing the unilateral carbon pricing policy at home, while the latter set would be targeting the green subsidy policy in the foreign country. Therefore, under the *law of one price*, we would get

Brown sector: $P_{HB}^* = P_{HB} \frac{1}{\mathcal{E}} (1 - \tau^C);$ $P_{FB} = P_{FB}^* \mathcal{E} \frac{1}{1-\tau^C};$

Green sector: $P_{HG}^* = P_{HG} \frac{1}{\mathcal{E}} \frac{1}{1+\varsigma^{cvs}} ;$ $P_{FG} = P_{FG}^* \mathcal{E} (1 + \tau^{cvd});$

whereby $\mathcal{E}$ is the nominal exchange rate per unit of foreign currency (e.g. Can\$/USD).

We consider Financial autarky, which is equivalent to balanced trade, to abstract from valuation effects associated with exchange rate adjustments.

Financial autarky

No financial positions:
$$B = B^p + B^g = 0$$
Subtracting the budget constraints of the government from the one of households yields:
$$B = B^p + B^g = 0$$
$$\frac{1}{1+\varsigma^c} (P_{HG} C_{HG} + P_{FG} C_{FG}) + P_{HB} C_{HB} + P_{FB} C_{FB} - TR \leq \frac{WN}{1+\tau^n} + \frac{\Pi}{1+\tau^d} + B^p + B^g$$
$$P_G C_G + (1 - \tau^C) P_B C_B \leq WN + \Pi = P_G Y_G + P_B Y_B = PY$$
Likewise for the foreign country:
$$(1 + \varsigma^{*p}) P_G^* C_G^* + P_B^* C_B^* \leq W^* N^* + \Pi^* = P_G^* Y_G^* + P_B^* Y_B^* = P^* Y^*$$
Trade is balanced:
$$P_{FG}^* C_{FG} + P_{FB}^* C_{FB} = P_{HG}^* C_{HG}^* + P_{HB}^* C_{HB}^*$$
Assuming no consumption subsidy, this can be reformulated:
$$P_{FG}^* C_{FG} + P_{FB}^* C_{FB} + P_{FG}^* C_{FG}^* + P_{FB}^* C_{FB}^* = P_{HG}^* C_{HG}^* + P_{HB}^* C_{HB}^* + P_{FG}^* C_{FG}^* + P_{FB}^* C_{FB}^*$$

$$P_F^* Y^* = P_G^* C_G^* + P_B^* C_B^* = P^* C^*$$

II.   Analytical Characterization of Competitiveness Implications:

Terms of trade in the absence of border taxes and subsidies

In a static PCP economy, under a balanced trade assumption (i.e. financial autarky) the equilibrium nominal exchange rate follows from the balanced trade condition:

$$\mathcal{E} = \frac{M}{M^*}$$

This illustrates that the nominal exchange rate will adjust with monetary policy captured here with money supply.

The terms of trade is given by:

$$ToT = \frac{P_F}{P_H} = \frac{\left(\frac{1}{1+\varsigma^c}\frac{P_{FG}}{\psi}\right)^\psi \left(\frac{P_{FB}}{1-\psi}\right)^{1-\psi}}{\left(\frac{1}{1+\varsigma^c}\frac{P_{HG}}{\psi}\right)^\psi \left(\frac{P_{HB}}{1-\psi}\right)^{1-\psi}} = \mathcal{E}\left(\frac{\mu_p^* \frac{1}{1+\varsigma^{*p}}\frac{W^*}{A^*}}{\mu_p \frac{W}{A}}\right)^\psi \left(\frac{\mu_p^* \frac{W^*}{A^*}}{\mu_p \frac{1}{1-\tau^c}\frac{W}{A}}\right)^{1-\psi}$$

$$= \mathcal{E}\frac{\mu_p^* A W^*}{\mu_p A^* W}\left(\frac{1}{1+\varsigma^{*p}}\right)^\psi \left(\frac{1-\tau^c}{1}\right)^{1-\psi}$$

This follows from the price aggregators, along with the law of one price (in the absence of cross-border instrument), and the price setting equations under PCP, and illustrates how the carbon tax affects competitiveness, while green subsidies can boost it. While we have assumed here full price flexibility ($\theta_p^* = \theta_p = 0$) for the simplicity of the exposure, a similar pattern would hold, albeit dampened, with price rigidities.

To explain the role of wages in shaping this term of trade we can consider two extreme cases of fully rigid and fully flexible wages. With fully rigid wages W and W^* are exogenously set to $\bar{W}$ and $\bar{W}^*$. By contrast, with fully flexible wage and considering the particular case of log-utility for consumption, wages are linked to labor supply as follows:

$$W = (1+\tau^n)\kappa PCN^\varphi = (1+\tau^n)\kappa MN^\varphi$$

Substituting in the terms of trade equation gives:

$$ToT = \frac{\mu_p^* A(1+\tau^{*n})N^{*\varphi}}{\mu_p A^*(1+\tau^n)N^\varphi}\left(\frac{1}{1+\varsigma^{*p}}\right)^\psi \left(\frac{1-\tau^c}{1}\right)^{1-\psi}$$

This illustrates that labor taxation can be a mean of adjustment in lieu of trade policies, with the country implementing the carbon tax using the related revenues to reduce labor taxation, and the country implementing the green subsidy financing it with higher labor taxation. For instance, a government earning revenues $\tau^c P_{HB} C_{HB} = \tau^c \gamma(1-\psi)PC$ could consider a reduction of labor tax $\Delta\tau^n \approx \tau^c(1+\tau^n)\gamma(1-\psi)PC/(WN)$. This can be a meaningful offset and whether this matches the carbon tax competitive cost varies across countries, depending on the initial tax rate, trade openness and the labor income share. This is stylized here as the government could also use other instruments to balance the budget. For instance, tradeable performance standards recycle sectoral revenue back to those sectors that are subject to this scheme.

Terms of trade with carbon border tax and countervailing duties and subsidies

The nominal exchange rate will react to the carbon border tax, as well as to the countervailing duty carbon border tax and countervailing duties and subsidies:

$$\mathcal{E} = \frac{(1 - \tau^C)^{1-\Psi}}{(1 + \tau^{cvd})^{\Psi}} \frac{M}{M^*}$$

The terms of trade illustrates that carbon border tax adjustments and countervailing duties and subsidies would counter domestic carbon tax and green subsidies:

$$ToT = \mathcal{E} \frac{(1 + \tau^{cvd})^{\Psi} \left(\frac{1}{1 - \tau^C}\right)^{1-\Psi}}{\left(\frac{1}{1 + \varsigma^{cvs}}\right)^{\Psi} (1 - \tau^C)^{1-\Psi}} \frac{\mu_p^* A W^*}{\mu_p A^* W} \left(\frac{1}{1 + \varsigma^{*p}}\right)^{\Psi} \left(\frac{1 - \tau^C}{1}\right)^{1-\Psi} = \mathcal{E} \frac{(1 + \tau^{cvd})^{\Psi}}{(1 - \tau^C)^{1-\Psi}} \frac{\mu_p^* A W^*}{\mu_p A^* W} \left(\frac{1 + \varsigma^{cvs}}{1 + \varsigma^{*p}}\right)^{\Psi}$$

This can be streamlined using the equilibrium exchange rate from the balanced trade condition:

$$ToT = \frac{M}{M^*} \frac{\mu_p^* A W^*}{\mu_p A^* W} \left(\frac{1 + \varsigma^{cvs}}{1 + \varsigma^{*p}}\right)^{\Psi}$$

where the green subsidy is offset by the countervailing subsidy for exported green goods, and the carbon tax by the levies on imported goods. The latter does not show here as the same parameter τ^C is used for domestic carbon tax and for the cross-border carbon tax.

The discussion of the role of labor taxation can be extended to this case with trade instruments as well, considering against fully flexible wage and log-utility for consumption to ease the exposure:

$$ToT = \frac{\mu_p^* A (1 + \tau^{*n}) N^{*\varphi}}{\mu_p A^* (1 + \tau^n) N^{\varphi}} \left(\frac{1 + \varsigma^{cvs}}{1 + \varsigma^{*p}}\right)^{\Psi}$$

This illustrates that a mix of labor taxation (or other balancing instruments as discussed above) and trade policies may also be considered.

Annex II. IMF-ENV Assumptions on Parameters

Table 1a. Model Parameters and Calibration

Parameter	Values
Substitution between Process emissions bundle and Net-of-Emissions Output	Specific values per gas and sector; positive values for GHG emissions; zero for air pollutants
Substitution between intermediate demand and value-added bundles	• 0.2 agricultural sectors • [0.4;1.0] manufacturing and services sectors • [0.1;0.81] energy sectors • Always 0 for old vintage technologies
Substitution between intermediate goods and services	• 0 agricultural sectors • [0.1; 0.4] manufacturing and services sectors • 0.2 energy sectors
Substitution between Capital and Specific Factor	• 0.2 for new and 0 for old vintage technologies
Elasticity between Electricity and Non-electricity energy bundle	• 0.125 for old vintages, 1 for new vintages in all non-energy sectors • 0.025 for old vintages, 0.22 for new vintages in non-electric energy • 0.05 for all vintages in electricity
Elasticity between Coal and Non-Coal bundle	• 0.0625 for old vintages, 0.55 for new vintages
Elasticity between energy inputs in liquids bundle	• 0.125 for old vintages, 1.1 for new vintages
Armington trade elasticity, domestic versus imports	Varies from 0.9 to 5 depending on the sector, identical across regions. GTAP data are used.
Armington trade elasticity, import origins	Value equals from 0.9 to 10, generally twice higher than Armington trade elasticity for domestic versus imports

Annex III. Modelling Details

The policy measures that are modelled are closely aligned with Voigts and Paret (2024). The following table provides a description of selected measures, the corresponding policy shock and the policy lever through which the shock is implemented in the IMF-ENV model.

Table 2b. Description of Policy Shocks

	Policy Lever in IMF-ENV	Note on Interpretation of the Policy Lever
Inflation Reduction Act		
Clean Energy Production and Investment Tax Credits	Output subsidy of 40 percent subsidy to solar PV and 59 percent to wind power generation. It is based on Credit Suisse 2022 study.	Captures the general equilibrium effects as well as fiscal costs if these tax credits were financed by an increase in wage income taxes.
Advanced manufacturing production tax credit	Subsidy on new capital inputs in solar and wind.	
Nuclear Generation Credit	Output subsidy to avoid early decommissioning of existing nuclear plants	
EV Credit	Increasing the share of electricity in the energy inputs road transport services demanded by households.	Captures the general equilibrium effects of higher electrification of the road transport sector because of the EV subsidy but not the implied fiscal cost.
Residential Energy Efficiency measures	Improvement in energy efficiency	Captures the general equilibrium effects of higher energy efficiency in residential energy but not the implied cost.
Canadian Subsidy Package (Department of Finance Canada, 2023)		
Clean energy investment tax credits	Subsidy of 15 percent to new capital in renewables.	Captures the general equilibrium effects as well as fiscal costs if these tax credits were financed by an increase in wage income taxes.

Annex IV. Detailed Results

## A. Scenario 1a—Domestic and Cross-Border Effects of the Canada Carbon Tax

Key Variables by 2030, by Sector

Percent change in Scenario 1a (Canada carbon pricing), relative to No-policy baseline

29

Aggregate Variables by 2030 (Percent change relative to Canada No-policy baseline)
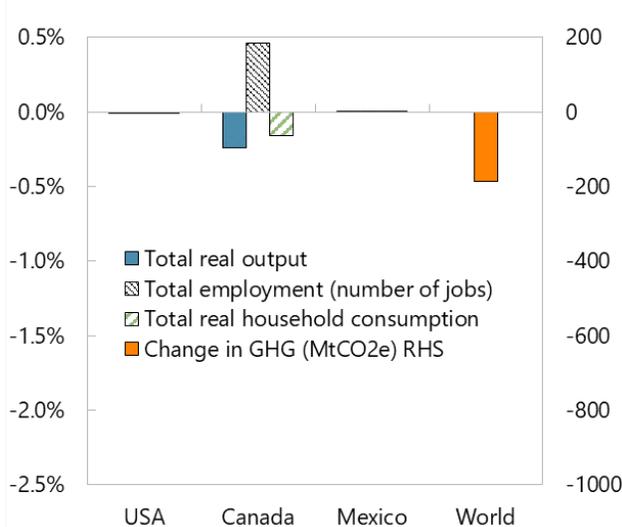
B. Scenario 1b—Domestic and Cross-Border Effects of the U.S.' Inflation Reduction Act

Key Variables by 2030, by Sector

Percent change in Scenario 1b (IRA and Canada carbon pricing), relative to Scenario 1a

Aggregate Variables by 2030 (Percent change relative to Canada carbon pricing Scenario 1a)
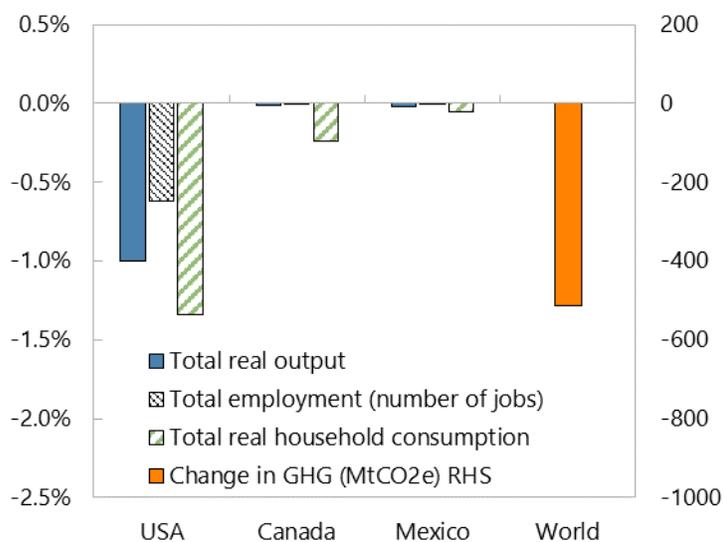
C. Scenario 1c—Domestic and Cross-Border Effects of the Canada Green Subsidies

Key Variables by 2030, by Sector

Percent change in Scenario 1c (Canada's green subsidies and carbon pricing, and U.S. IRA), relative to Scenario 1b (IRA and Canada carbon pricing)

Producer prices

Legend:
- Fossil fuel extraction
- EITE
- Fossil power
- Renewable power
- Electricity

Consumer prices

Employment (Number of jobs)

Real output

Real household consumption

Market share
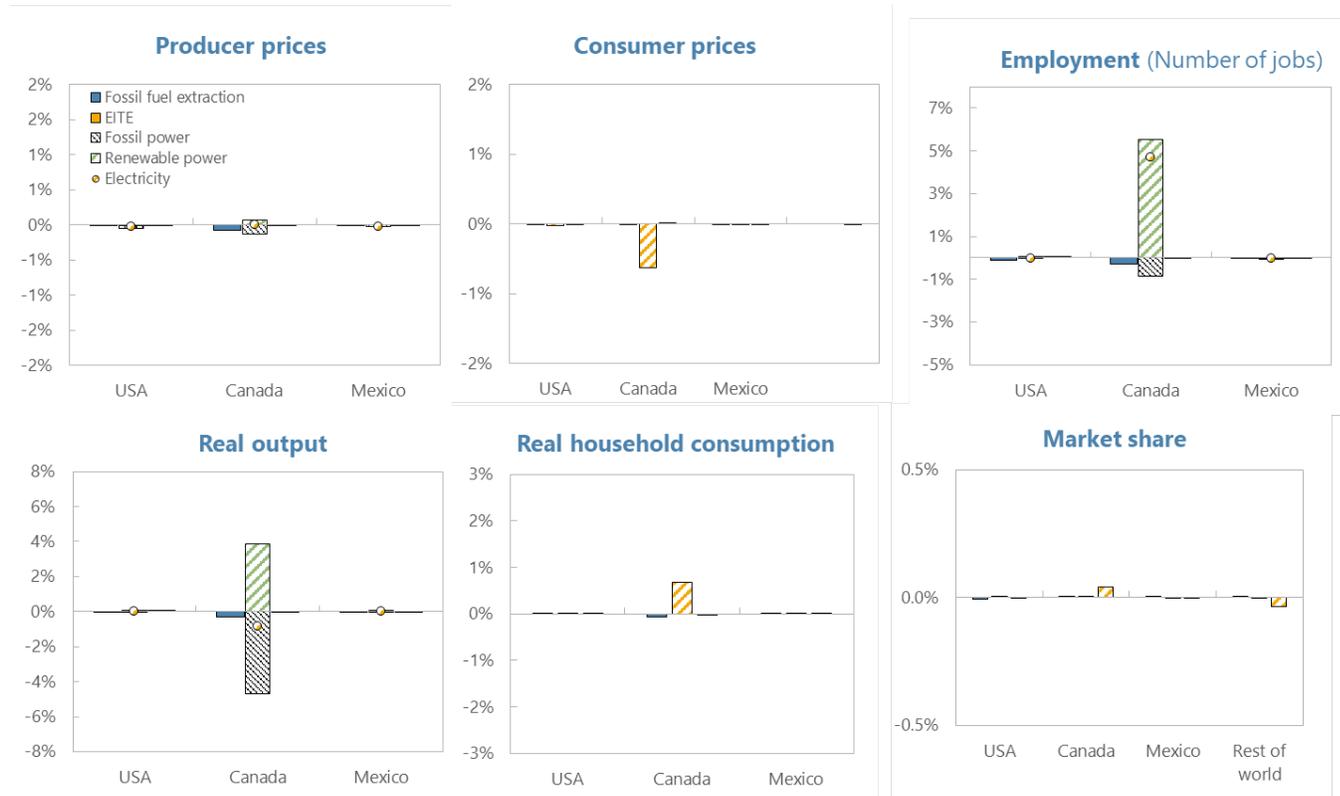
Aggregate Variables by 2030 (Percent change relative to U.S. IRA Scenario 1b)

Legend:
- Total real output
- Total employment (number of jobs)
- Total real household consumption
- Change in GHG (MtCO2e) RHS
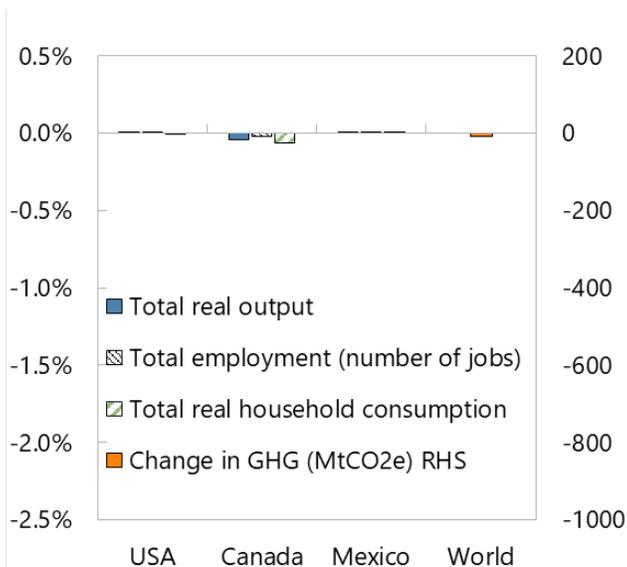
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