IMF Carbon Price App

Revealing Price and Revenue Dynamics on Global Supply Chains

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Abstract

Carbon pricing is a pivotal strategy in combating climate change, serving as a cost-effective and flexible tool to reduce greenhouse gas (GHG) emissions. By assigning a monetary value to carbon emissions, it internalizes the external costs associated with climate change—such as extreme weather, health risks, and biodiversity loss—making polluters responsible for the environmental damage they cause. This approach incentivizes businesses and individuals to reduce their carbon footprint, steering economic activities towards more sustainable practices.

However, charging polluters raises the cost of producing goods and services that rely on fossil fuels, directly affecting industries such as manufacturing, transportation, and energy and indirectly affecting all economic activities. Effects on producers' prices, inflation, or competitiveness are crucial for policy makers. As companies face higher production costs, they may pass these increased expenses onto consumers in the form of higher prices. Through the global value chain, the ripple effect of these cost increases can propagate. As raw materials and intermediate goods become more expensive, the cumulative effect magnifies, leading to a general rise in prices across different activities and countries.

The Carbon Price App (CPA) developed by the authors of this paper facilitates the detailed analysis of price changes attributable to carbon pricing, targeting producers and consumers. This model integrates both the direct and indirect impacts on prices through the established methodology of input-output price modeling, while also considering the effect introduced by international trade through the global supply chain. To comprehensively address these dimensions, the paper is structured as follows:

Conceptual Framework: This section introduces a price model tailored to multi-regional input-output analysis, laying the foundation for understanding how carbon pricing influences prices across different regions.

Case Study: An illustrative case study demonstrates the practical application of the IMF's Carbon Price App, showcasing its utility in real-world scenarios.

Impact on Competitiveness: This part examines how carbon pricing affects competitiveness and delineates the rationale for implementing a cross-border carbon tax adjustment.

Way forward: This section aims at fostering discussions with potential users of the model to better understand actual and emerging data needs for policy making.

The concluding section looks ahead, discussing potential advancements and enhancements to the model to better capture the evolving dynamics of carbon pricing and its economic implications.

Introduction[1]

Carbon pricing is a financial charge imposed on the greenhouse gas (GHG) emissions generated from burning fossil fuels. It is designed to reduce greenhouse gas emissions and mitigate climate change. A tax is applied per ton of GHG emitted into the atmosphere, incentivizing businesses and individuals to decrease their carbon footprint by shifting towards cleaner energy sources and adopting more energy-efficient practices. The primary goal of carbon pricing is to internalize the external costs of climate change (e.g., extreme weather, sea-level rise) that are not reflected in the market prices of fossil fuels. By making carbon-intensive products and activities more expensive, carbon pricing encourages the economy to transition towards sustainable growth patterns and investments in renewable energy and technologies. Revenue generated from a carbon pricing can be used in various ways, including reducing other taxes (thereby making the policy revenue-neutral), investing in renewable energy and energy efficiency, or supporting communities and industries adversely affected by the transition to a low-carbon economy.

Imposing carbon pricing on polluters directly increases the cost of producing goods and services that depend heavily on fossil fuels. This price hike primarily impacts sectors like manufacturing, transportation, and energy, which are significant consumers of fossil fuels. These industries face immediate cost pressures as the price of carbon-intensive inputs rises. However, the implications of carbon pricing extend far beyond these sectors, affecting the broader economy in several ways. For businesses, the increased costs of production due to carbon pricing can lead to higher prices for their products. This is because firms, aiming to maintain their profit margins, often pass the added expenses onto consumers. The extent to which these costs are transferred, called the pass-through, depends on the market dynamics and the price elasticity of demand for the products in question. The general upward pressure on prices across various goods and services can contribute to inflationary trends. When the costs of raw materials and energy increase, it creates a cascading effect, pushing up prices across a wide array of sectors. This inflationary impact is a crucial consideration for policymakers, as it affects the purchasing power of consumers and can have broader macroeconomic consequences.

For businesses operating in international markets, carbon pricing can affect their competitiveness. Firms in countries with stringent carbon pricing mechanisms may find their products more expensive compared to those from countries with laxer or no carbon pricing. This discrepancy can lead to competitive disadvantages, potentially prompting discussions on mechanisms like border carbon adjustments to level the playing field. The interconnectedness of global supply chains means that the effects of carbon pricing are not confined within national borders. As the cost of raw materials and intermediate goods increases due to carbon pricing in one country, these cost increases can ripple through the global value chain. For example, a manufacturer in Country A that relies on steel produced in Country B, where carbon pricing has been implemented, will face higher costs, which can then affect the prices of finished goods in Country A and beyond. The cumulative effect of increasing costs at each stage of production and distribution magnifies the overall impact on prices. This can lead to a general rise in prices across different sectors and countries, affecting consumers worldwide. Policymakers must carefully consider these dynamics when designing and implementing carbon pricing to balance environmental objectives with economic and social impacts.

The cumulative impacts of carbon pricing on the global supply chain can be analyzed through the Carbon Price App (CPA), which is based on an advanced input-output price model that integrates a regional framework to connect countries engaged in international trade. The CPA encompasses 77 countries and 45 sectors, providing annual estimates from

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[1] The authors would like to thank Kristy Howell, Simon Black, Michael Stanger, and Karlygash Zhunussova for their valuable feedback, which greatly improved this paper. Any remaining issues are the authors' sole responsibility.

1995 to 2020. The CPA assesses the implications of carbon pricing on all GHGs, offering a granular examination of its effects on both output and input prices, as well as on final demand and the trade of goods and services across each country and industry.

Utilizing the input-output methodology, the model excels in distinguishing between the price effects originating from domestic carbon pricing mechanisms and those stemming from imported impacts—whether from a domestic tax or a tax instituted by a trading partner. This nuanced analysis allows for a detailed exploration of how carbon pricing influences prices within and across borders, thus providing valuable insights for policymakers.

While the CPA offers a detailed and focused analysis of the impacts of carbon pricing on prices, revenue, and global trade dynamics, it does not model behavioral responses to carbon pricing, such as considering structural shifts in the economy towards cleaner technology due to the carbon price. In contrast, the Climate Policy Assessment Tool (CPAT), developed by the IMF and World Bank (Black et al., 2023), enables, for a given country, to explore a broader spectrum of climate mitigation policies beyond carbon pricing. Both tools are valuable for policymakers and, in a way, complementary to each other; the CPA provides more industry granularity, allowing an understanding of the interconnections between countries and industries in terms of trade and how carbon pricing in one country industries can affect others worldwide. Meanwhile, the CPAT offers a more detailed analysis at the country level. Their applicability depends on the specific objectives and scope of the climate policy analysis being undertaken. However, insights from one model can inform the other and vice versa, making them complementary tools.

A case study focusing on the USA and Canada is presented in this paper to demonstrate the model's potential applicability in supporting policy analysis related to price changes. By highlighting the specific interactions between these two countries within the context of carbon pricing, the paper illustrates how the model can serve as a powerful tool for understanding and navigating the complex dynamics of international trade and environmental policy.

A Cross Border Carbon Tax Adjustment (CBCA) aims to equalize the competitive playing field between domestic industries subject to carbon pricing and foreign producers not facing such costs. It involves imposing a tax on imports from countries without carbon pricing, equivalent to the domestic carbon cost, and offering rebates or exemptions for exports to those countries. The goals are threefold: protect domestic industries from unfair competition, encourage global carbon emission reductions, and prevent carbon leakage — where production shifts to countries with laxer environmental standards. Carbon intensities — measures of carbon emissions per unit of production — play a crucial role in CBCA. They can be used to determine the tax on imports and rebates on exports by assessing the carbon footprint of goods, ensuring that carbon pricing is accurately reflected in international trade and fostering global emission reduction efforts. The authors have developed detailed estimates of relative carbon intensities by country, year, and detailed activities to better understand the implications of a CBCA based on carbon intensities.

Lastly, the paper outlines potential enhancements to the model, aiming to evolve it into a dynamic tool. This involves integrating price elasticities and accounting for behavioral adaptations as responses to changing environmental policies and market conditions. Additionally, the paper discusses refining the model to generate price-adjusted estimates suitable for sophisticated time series analysis. These improvements are intended to bolster the model's predictive accuracy and relevance, enabling it to better capture the complex interplay between carbon pricing, economic behavior, and market dynamics over time.

Estimation Methodology

A domestic input-output price model analyzes the relationship between industries within an economy to understand how changes in prices in one sector affect prices in other sectors. The underlying detailed source data are part of national accounts. The core of the input-output price model lies in identifying the inputs required for production in each industry and how these inputs are interlinked across different industries. For instance, an increase in the price of raw materials (input) for one industry could lead to higher production costs in that industry, which might then translate to higher prices for the outputs of that industry. These increased costs can ripple through the economy, affecting other industries that rely on these outputs as inputs. The model helps in understanding both the direct effects—how the change in price of inputs directly affects the production costs of an industry—and indirect effects—how these changes propagate through the economy, affecting other industries interconnected through supply chains.

The domestic input-output price model is particularly useful for policy analysis, enabling policymakers to predict the economy-wide impacts of carbon pricing. It offers a detailed perspective on how price changes in one sector can cascade through the economy, influencing overall price levels, inflation, and competitiveness across various industries.

The input-output price model is grounded in Leontief's input-output analysis framework, which uses a matrix representation to model the interdependencies between different sectors of an economy. This model can be extended to analyze price changes by incorporating the costs of inputs and the prices of outputs.

In a simplified explanation of the algebra involved in an input-output price model, consider an economy with n sectors. The output of each sector is used as an input by other sectors, creating a network of economic interactions. The technical coefficients matrix is represented by matrix A where each element a_{ij} represents the amount of output from sector i required to produce one unit of output in sector j. This matrix captures the direct input requirements between sectors. Let y be a column vector representing the final demand, and x be a column vector representing the total output of each industry. The total output x needed to meet the final demand y can be expressed as: $x = (I - A)^{-1}y$ where I is the identity matrix, and $(I - A)^{-1}$ is known as the Leontief inverse matrix. This equation calculates the total output required, considering both direct and indirect input requirements.

In the Leontief Price Model (Miller and Blair, 2022), also known as the cost-push input-output price model (Oosterhaven, 1996; Dietzenbacher, 1997), quantities are fixed, and the prices change, as opposed to the traditional Leontief demand-pull input-output quantity model, described above, where prices are fixed, and the quantities change.

The cost-push model works with the principle that prices of all industries are normalized to 1 to reflect the shares of the source industries valued added (VA) in the composition of the industries prices, this normalization is given by the equation below, where P is the matrix with the price normalization, v is the coefficients of value-added vector, and A is the matrix of technical coefficients.

$$P = diag(v)(I - A)^{-1}$$

As such, in the base year, the sum over a column of P will be 1, expressing equilibrium in the system.

This algebraic formulation allows the domestic model to capture how changes in the prices of inputs or other costs (like carbon pricing) can affect the prices of outputs across various sectors of the economy, taking into account the complex web of inter-sectoral dependencies. The model's estimated price changes are supplementary to existing taxes. Should a country have a carbon pricing system established, the modeled emissions cost per ton will compound upon these pre-existing taxes.

The model crafted by the authors interconnects the domestic price models previously discussed via the mechanism of international trade, thereby establishing a comprehensive framework for analyzing global economic dynamics. Developing a Multi-Regional Input-Output (MRIO) model involves creating a framework that captures the economic transactions between industries across different regions or countries, considering the flow of goods and services in a global context. This model extends the traditional domestic input-output analysis by incorporating international trade, enabling a comprehensive understanding of the global economy's structure and environmental impacts.

By applying the input-output price model to the ICIO data, the authors were able to assess the cumulative effect of carbon pricing across a domestic economy combined with the effects across countries through the global supply chain. The outcomes generated by the model are highly reproducible and are not contingent on speculative changes in variables. Instead, these outcomes are derived from solid inter-industry linkages ascertained from national accounts statistics, which are further enriched by inter-country relationships sourced from international merchandise trade and balance of payments data. Nevertheless, to ensure the integrity and consistency of the model, certain corrections have been applied to the official statistics, addressing any discrepancies encountered, particularly in relation to inter-country trade statistics. This methodology underscores the model's reliance on empirical data, providing a robust foundation for the analysis of economic interactions both within and across countries.

The Carbon Price App (CPA)

The model developed by the authors utilizes the Inter-Country Input-Output (ICIO) Database, estimated by the Organisation for Economic Co-operation and Development (OECD). This database models economic transactions and interdependencies between industries and countries worldwide. It encompasses 77 countries and 45 industries, providing annual estimates from 1995 to 2020. Additionally, the price model incorporates estimations of GHG emissions by country and industry, also sourced from the OECD[2].

The CPA, screenshot show in Figure 1, has been developed to run scenarios with the possibility to model the effect of carbon pricing for one country or a group of countries together, for one industry or a group of industries at a selected price for carbon. It provides revenue generated by the carbon pricing scheme and detailed estimates of price changes across industries and components of GDP. The CPA also provides estimates of price changes impacting trading partners. Detailed data can be downloaded from the app.

The case study in the next section illustrates some results that can be used for analytical and policy purposes. The underlying data allows further decomposition to estimate for example the import content of export which are typically used

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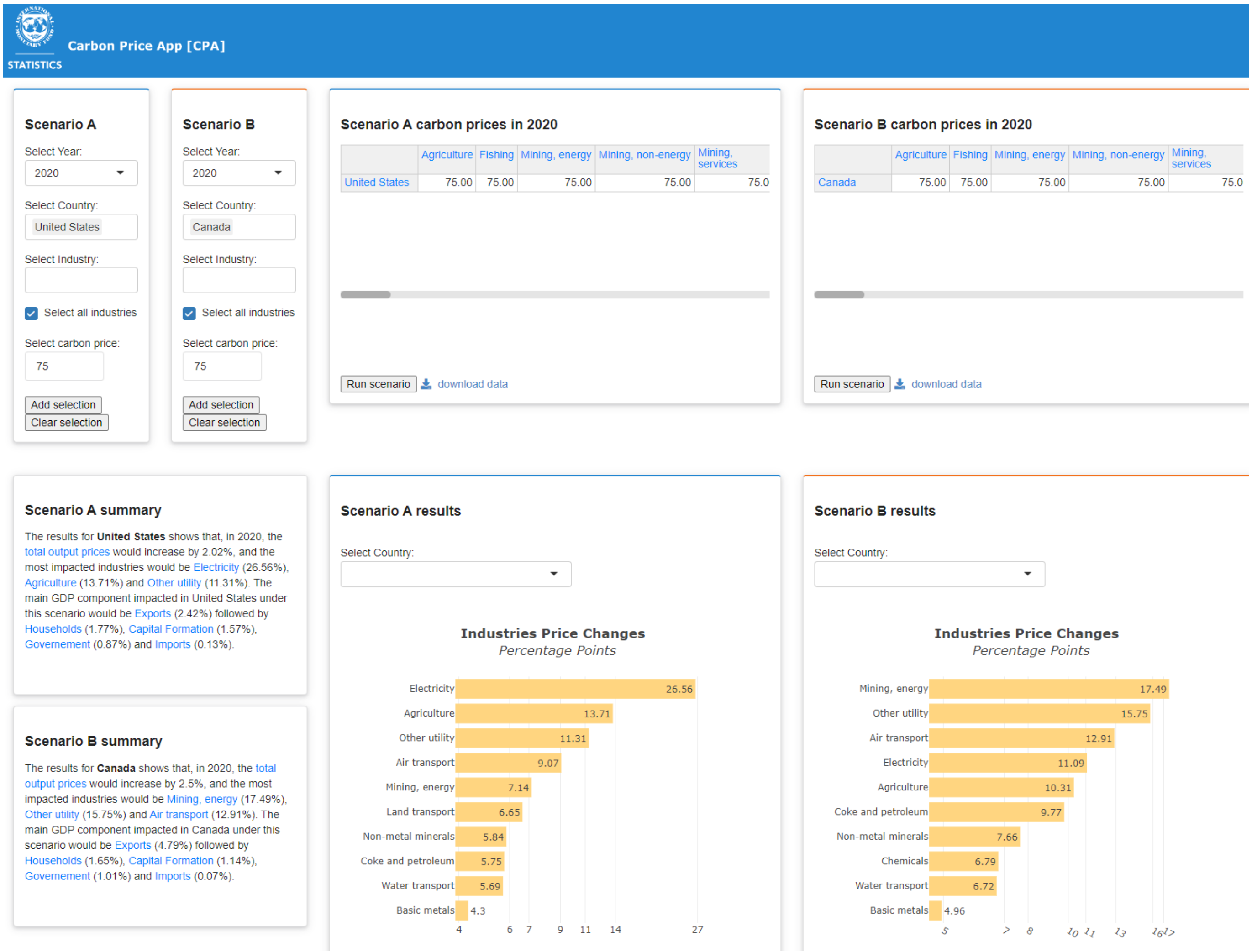
[2] See OECD ICIO and OECD Greenhouse Gas Footprint Indicators. For the USA, the greenhouse gas are sourced from the OECD Air Emissions Accounts.

to measure trade in value added estimates which consider the value added generated by each country in the global supply chain. The same methodology can be applied to emissions produced and consumed worldwide.[3]

Figure 1. Overview of the Carbon Price App (CPA)



Scenario A

Select Year: 2020

Select Country: United States

Select Industry:

☑ Select all industries

Select carbon price: 75

Scenario B

Select Year: 2020

Select Country: Canada

Select Industry:

☑ Select all industries

Select carbon price: 75

Scenario A carbon prices in 2020

	Agriculture	Fishing	Mining, energy	Mining, non-energy	Mining, services
United States	75.00	75.00	75.00	75.00	75.0

Scenario B carbon prices in 2020

	Agriculture	Fishing	Mining, energy	Mining, non-energy	Mining, services
Canada	75.00	75.00	75.00	75.00	75.0

Scenario A summary

The results for **United States** shows that, in 2020, the total output prices would increase by 2.02%, and the most impacted industries would be Electricity (26.56%), Agriculture (13.71%) and Other utility (11.31%). The main GDP component impacted in United States under this scenario would be Exports (2.42%) followed by Households (1.77%), Capital Formation (1.57%), Governement (0.87%) and Imports (0.13%).

Scenario B summary

The results for **Canada** shows that, in 2020, the total output prices would increase by 2.5%, and the most impacted industries would be Mining, energy (17.49%), Other utility (15.75%) and Air transport (12.91%). The main GDP component impacted in Canada under this scenario would be Exports (4.79%) followed by Households (1.65%), Capital Formation (1.14%), Governement (1.01%) and Imports (0.07%).

Scenario A results

Select Country:

Scenario B results

Select Country:

Source: Carbon Price App estimation

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[3] The authors welcome input from experts and prospective users of the data to improve the relevance of the model for decision makers and analysts by incorporating additional dimensions and functionalities to model.

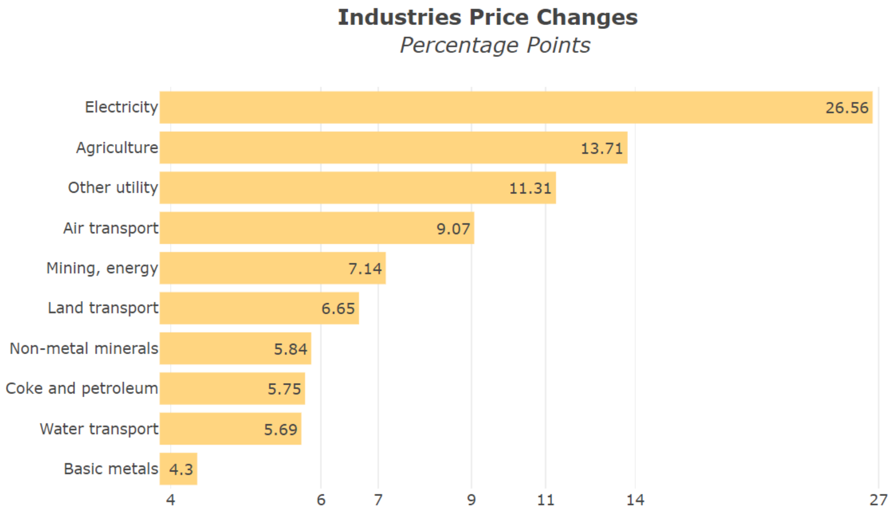
Case study: USA and Canada

United States and Canada share one of the largest and most comprehensive trading relationships in the world, with significant cross-border investments and deeply integrated supply chains across various sectors, including automotive, energy, and manufacturing. This example is discussed in this paper to illustrate the results that can be obtained from the multi-regional input-output carbon price model. For simplicity we considered a $75 USD carbon price per metric ton of CO_2 on all emissions in the US and Canada separately and then in both countries for 2020. While carbon pricing policies have traditionally been applied to specific sectors, the authors opted for a broader approach to evaluate the aggregate impact, rather than concentrating on individual activities.

Based on 2020 data, results for United States implementing a $75 USD carbon price on all industries, Figures 2 and 3 show that the total output prices would increase by 2.02%, and the most impacted industries would be Electricity (26.56%), Agriculture (13.71%) and Other Utility (11.31%). The main GDP component by expenditure impacted in United States, under this scenario, would be Exports (2.42% increase in prices) followed by Household Consumption (1.77%), Capital Formation (1.57%), Government Consumption (0.87%) and Imports (0.13%).

The main impact for the US would be on the output prices of electricity with a 26.56% increase followed by agriculture and other utility. More than 60% of the electricity in the US was generated from fossil fuel in 2020[4] and as a result, electricity generation is the first industry emitter of GHG and the main impacted by carbon pricing. The price vector depicted in the preceding graph illustrates the adjustments in prices by supply industries resulting from carbon pricing affecting all economic activities (i.e., production, consumption, and accumulation).

Figure 2. Industrial price changes resulting from carbon pricing applied to all industries, USA, 2020



Source: Carbon Price App estimation

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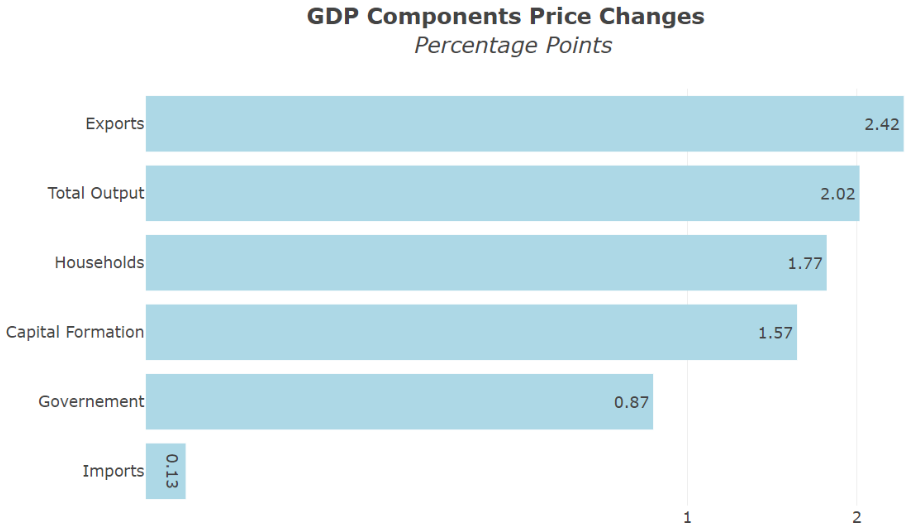
[4] Source: IEA Electricity Information https://www.iea.org/data-and-statistics/data-product/electricity-information

The varying influence on economic activities, such as GDP components, stems from the distinct contributions of each supplying industry to the overall total. Consequently, the impact on GDP components varies in accordance with the relative significance of supplying industries in the aggregate, as demonstrated in the subsequent graph produced by the IMF Carbon Price App.

Figure 3. Price changes on GDP by expenditure components resulting from carbon pricing applied to all industries, USA, 2020

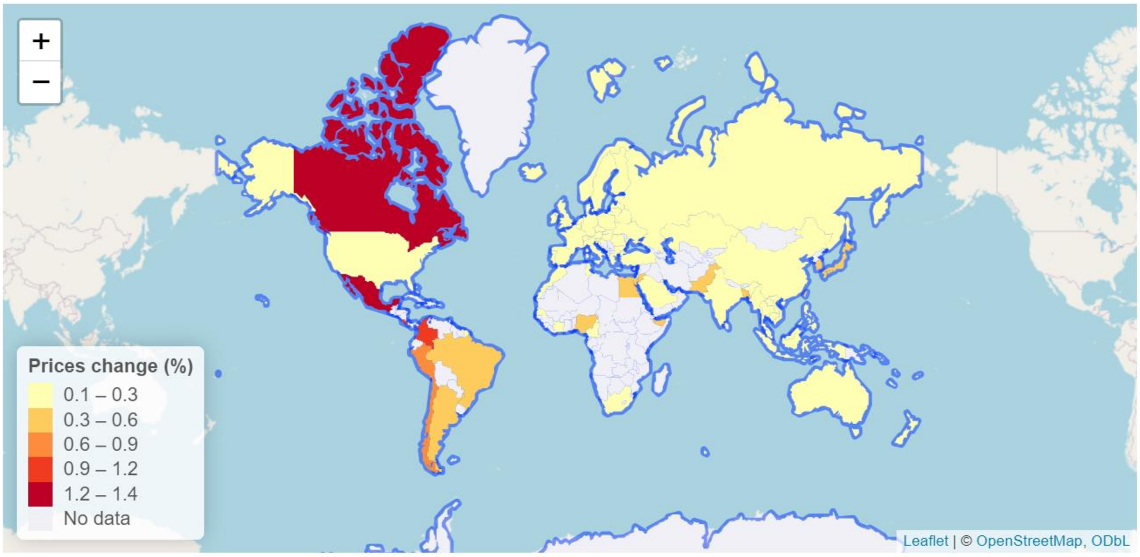


Source: Carbon Price App estimation

Price fluctuations impacting households hold significant relevance for policymakers in crafting compensation strategies that afford consumers the opportunity to transition towards more sustainable consumption practices. In-depth analysis of how price changes, driven by supplying industries, affect household consumption can inform the design of these policies. Furthermore, when this data is analyzed alongside household consumption patterns segmented by income levels, Figure 14, it enables the integration of social equity considerations. For instance, lower-income households tend to allocate a larger share of their consumption to goods with high greenhouse gas (GHG) emissions content, underscoring the need for policies that address both environmental and social justice objectives.

An increase in prices due to carbon prices would also impact main trading partners of the US depending on their level of economic integration. Canada and Mexico would be the most impacted countries in this case. Figure 4 shows the impact on import prices resulting from carbon pricing applied in all US industries generated by the IMF Carbon Price App. Detailed results can be downloaded from the app.

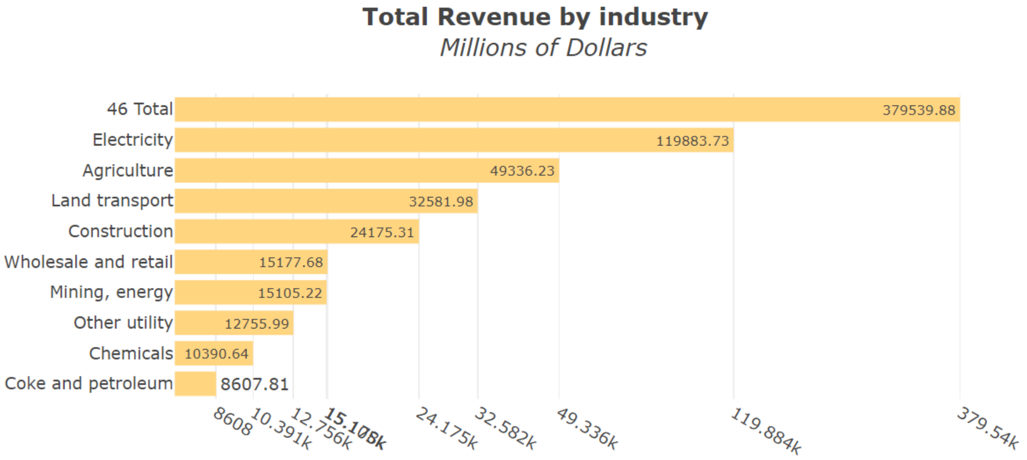
Figure 4. Global import price changes resulting from carbon pricing of $75 USD applied to all industries, USA, 2020



Source: Carbon Price App estimation

The total revenue generated from applying carbon pricing in the USA, as illustrated in Figure 5, is estimated to be $379,540 million USD. Notably, eight sectors account for approximately 76% of this revenue. These sectors include Electricity, contributing $119,884 million USD; Agriculture, with $49,336 million USD; Land Transport, adding $32,582 million USD; Construction, at $24,175 million USD; Wholesale and Retail, contributing $15,178 million USD; Mining of Energy, at $15,105 million USD; Other Utility Services, with $12,756 million USD; Chemicals, with $10,391 million USD; and Coke and Petroleum, adding $8,608 million USD.

Figure 5. Revenue by industry resulting from carbon pricing applied to all industries, USA, 2020

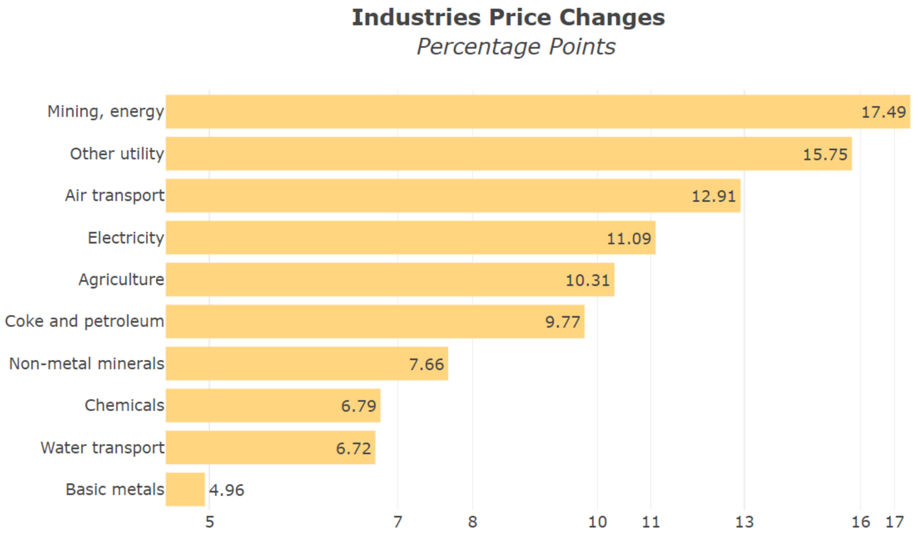


Source: Carbon Price App estimation

Results for Canada implementing a $75 USD carbon price on all industries, shown in Figures 6 and 7, reveal that total output prices would increase by 2.50%, and the most impacted industries would be Mining of energy products (17.49%), Other Utility (15.75%), Air Transport (12.91%) and Electricity (11.09%). The main GDP component by expenditure impacted in Canada under this scenario would be Exports (4.79%) followed by Household Consumption (1.65%), Capital Formation (1.14%), Government Consumption (1.01%) and Imports (0.07%).

In 2020, more than 82 percent of the electricity generation in Canada was reliant on non-fossil fuel sources, with hydroelectric sources playing a significant role in energy production[5]. Canada has a diverse energy mix, with a significant portion of its electricity coming from renewable sources such as hydro, wind, and solar, in addition to nuclear power. Fossil fuels contribute less to electricity generation compared to these sources, explaining why the impact on prices of electricity are more limited than in the Unites States.

Figure 6. Industrial price changes resulting from carbon pricing applied to all industries, Canada, 2020



Source: Carbon Price App estimation

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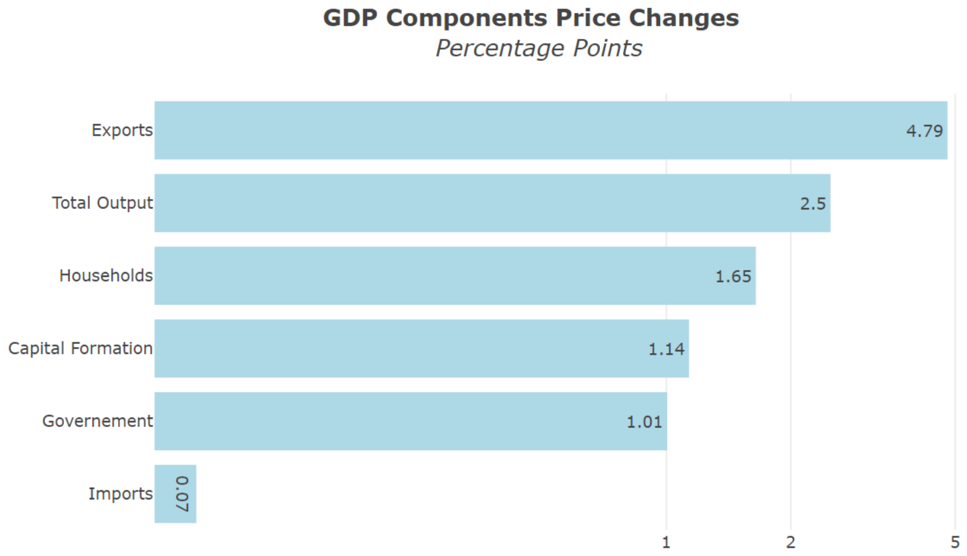
[5] Source: IEA Electricity Information https://www.iea.org/data-and-statistics/data-product/electricity-information

Figure 7. Price changes on GDP by expenditure components resulting from carbon pricing applied to all industries, Canada, 2020

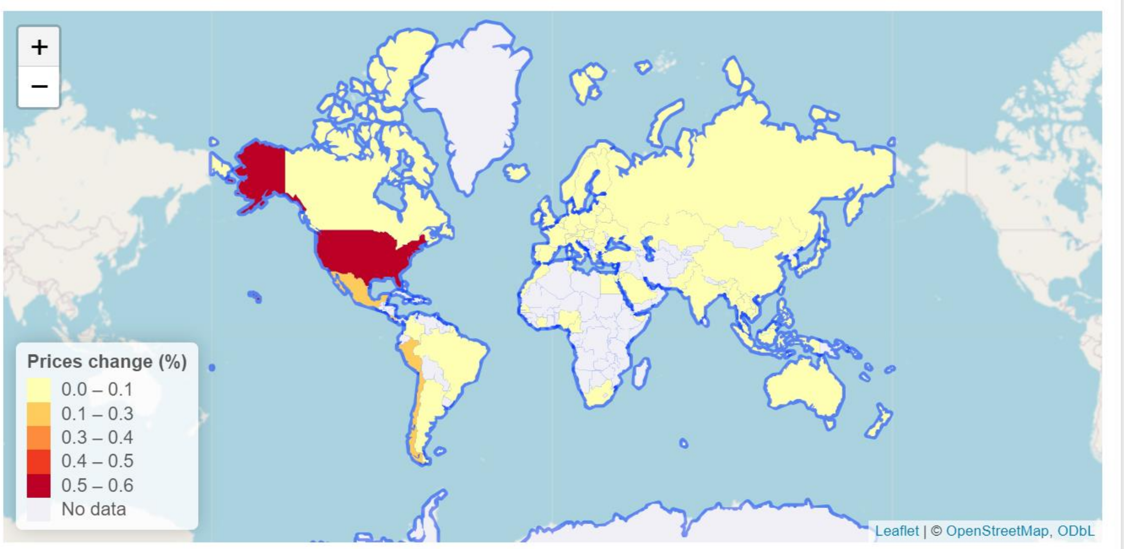


Source: Carbon Price App estimation

The U.S. and Canada have a substantial energy trading relationship. Canada is a significant exporter of crude oil, natural gas, and electricity to the U.S. The imposition of a carbon price on energy production in Canada could increase the cost of energy exports to the U.S., affecting energy prices and potentially leading to shifts in energy procurement strategies in both countries. After the implementation of a $75 USD carbon pricing across all industries, the output prices for coke and petroleum activities in Canada are projected to surge by 9.77%, whereas in the United States, the increase would be comparatively more modest at 5.75% if a similar carbon price was implemented. These projections are based on the scenario where each country adopts the carbon pricing strategy independently, rather than synchronously applying it across both nations. This differential impact underscores the varying sensitivities and structures of industries within each country to carbon pricing policies, highlighting the nuanced economic effects that can arise from independent environmental policy measures.

Echoing the findings observed for the United States, the imposition of carbon pricing in Canada is also projected to influence its principal trading partners, predominantly the United States, given the deep economic integration between the two countries. Figure 8 illustrates the ramifications on import prices stemming from the application of carbon pricing of $75 USD across all industries in Canada. This visualization underscores the interconnectedness of the North American economy and highlights how policy measures in one country can have significant ripple effects on its trading partners, particularly in terms of import cost adjustments.

Figure 8. Global import price changes resulting from carbon pricing of $75 USD applied to all industries, Canada, 2020

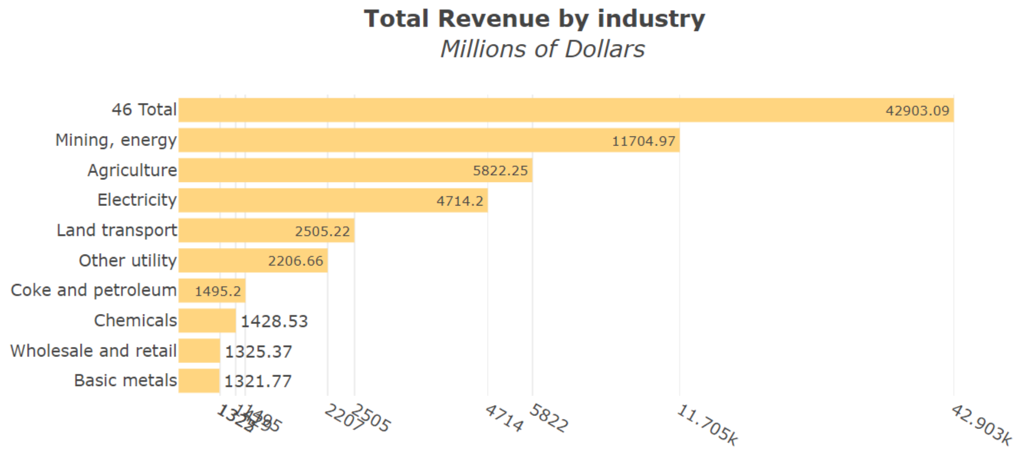


Source: Carbon Price App estimation

The estimated revenue from implementing carbon pricing in Canada, as depicted in Figure 9, totals $42,903 million USD. Remarkably, nine key sectors contribute about 76% of this total. The breakdown of contributions is as follows: Mining of Energy Products leads with $11.705 million USD; followed by Agriculture at $5,822 million USD; Electricity brings in $4,714 million USD; Land Transport brings $2,505 million USD; Other Utility Services generate $2,207 million USD; Coke and Petroleum industries contribute $1,495 million USD; Chemicals add $1,429 million USD; Wholesale and Retail sectors provide $1,325 million USD; and Basic Metals Manufacturing contribute with $1,322 million USD.

Comparing the impact of carbon pricing between the USA and Canada reveals significant differences in total revenue generation and sectoral contributions, with the USA's figure standing at $379,540 million USD, significantly surpassing Canada's $42,903 million USD. This underscores the larger scale of the American economy and its industrial sectors. While both countries see a substantial portion of their carbon pricing revenue, approximately 76%, originating from a concentrated set of sectors, the specific sectors contributing most significantly to this revenue highlight the unique economic and industrial profiles of each nation. Key overlapping sectors such as Agriculture, Electricity, and Land Transport suggest common areas of carbon intensity, yet the presence of distinct sectors like Construction in the USA and Basic Metals in Canada reflects their differing industrial landscapes.

Figure 9. Revenue by industry resulting from carbon pricing applied to all industries, Canada, 2020



Source: Carbon Price App estimation

By integrating the price vector, which reflects the effects of carbon pricing, into the final use categories of the multi-regional Input-Output Tables (IOTs), the model compiles anticipated changes in prices impacting these final use categories. Should both countries decide to implement a carbon price of $75 USD across all industries, the primary consequence would be an increase of 5.17% in the export prices for Canada. This increment is attributed to the cumulative impact of carbon pricing enacted simultaneously in both nations. For comparative analysis, this figure is juxtaposed against a scenario wherein carbon pricing is solely adopted by Canada, resulting in a 4.79% hike in the prices of Canadian exports.

The automotive industry between the U.S. and Canada is highly integrated, with components and finished vehicles frequently crossing borders during the production process. A carbon price in either country would increase production costs, affecting the price competitiveness of vehicles. If one country implements a carbon price mechanism, the cost of automotive parts and vehicles exported to the other would rise, potentially leading to adjustments in supply chains or consumer prices in both countries.

More specifically, a $75 USD carbon price implemented in the US on all industries would increase the output prices of the motor vehicles manufacturing industry by 2.09%. The impact on Canadian output prices for a similar carbon price implemented in Canada on all industries would be smaller with a 0.79% increase for the motor vehicles manufacturing industry.

This example underscores the importance of considering economic integration but also cross-border impacts when designing and implementing carbon pricing policies, to ensure that they effectively reduce emissions without unduly harming economic relationships. This is discussed in the next section.

Impact on competitiveness

To safeguard the competitiveness of industries affected by carbon pricing against those in countries without such measures, strategies can be devised to effectively extend comparable carbon costs to exports from these non-implementing countries. This approach ensures a level playing field, preventing any undue advantage that exporters from countries without carbon pricing might otherwise enjoy. By harmonizing the carbon costs across borders through these mechanisms, industries within carbon-pricing nations can remain competitive in the global market, mitigating the risk of carbon leakage and encouraging a more uniform adoption of carbon reduction practices worldwide.

A CBCA, also known as a Border Carbon Adjustment (BCA), is a policy mechanism aimed at leveling the playing field between domestic industries that are subject to carbon pricing (such as a carbon tax or emissions trading system) and foreign producers from countries with no or lower carbon pricing. The main objectives of a CBCA are to prevent carbon leakage (where businesses relocate production to countries with less stringent carbon regulations to save costs) and to maintain the competitiveness of domestic industries. For goods imported into a country with carbon pricing, the CBCA imposes a tax equivalent to what the carbon price would have been had the goods been produced domestically. This ensures that imported goods do not have a competitive advantage over similar domestically produced goods that are subject to carbon pricing. Conversely, the CBCA may provide rebates or exemptions for domestic industries exporting to countries without carbon pricing to ensure that their goods remain competitive in those markets. The implementation of CBCAs can vary between countries, but they must be designed to account for complex supply chains and accurately assess the carbon content of imported goods, which can be challenging.

By integrating multi-regional input-output models with emissions data, we can accurately gauge the greenhouse gas (GHG) content of internationally traded goods and services within the established input-output analytical framework. Specifically, the application of emissions intensities to the Leontief matrix yields emission multipliers. These multipliers, in turn, can be utilized to evaluate the carbon content associated with the final use components of national accounts, effectively measuring the carbon footprint of goods and services. Emissions intensities, which denote the direct emissions per unit of output, offer a crucial metric for assessing environmental impact. When comparing emissions intensities across different countries and industries, we can derive valuable insights into the potential effects of a CBCA. This comparative analysis not only highlights disparities in carbon efficiency but also underscores the role of CBCAs in mitigating competitive imbalances attributed to varying national carbon pricing policies.

If the USA were to implement a CBCA, based on the relative GHG content of imports, Tables 1 and 2, along with Figure 10, highlight the countries with the highest and lowest GHG intensities in motor vehicle manufacturing relative to the USA's intensities for this sector. These tables and figure specifically compare the total intensity—encompassing both direct and indirect emissions—per $1 million USD of output from a country's motor vehicle industry to that of the USA's motor vehicle industry. Consequently, countries exhibiting the highest intensities for motor vehicles would be most significantly impacted by the USA's application of a CBCA

Table 1. Highest relative GHG emission intensities for motor vehicle manufacturing compared to USA, 2020

Country	Relative GHG Emission Intensities
India	4.87
South Africa	3.38
Ukraine	3.25
Côte d’Ivoire	3.19
Saudi Arabia	2.65
Vietnam	2.61
Kazakhstan	2.55
Lao People’s Democratic Republic	2.47
Malaysia	2.32
Pakistan	2.15
Russia	2.06
China	1.92

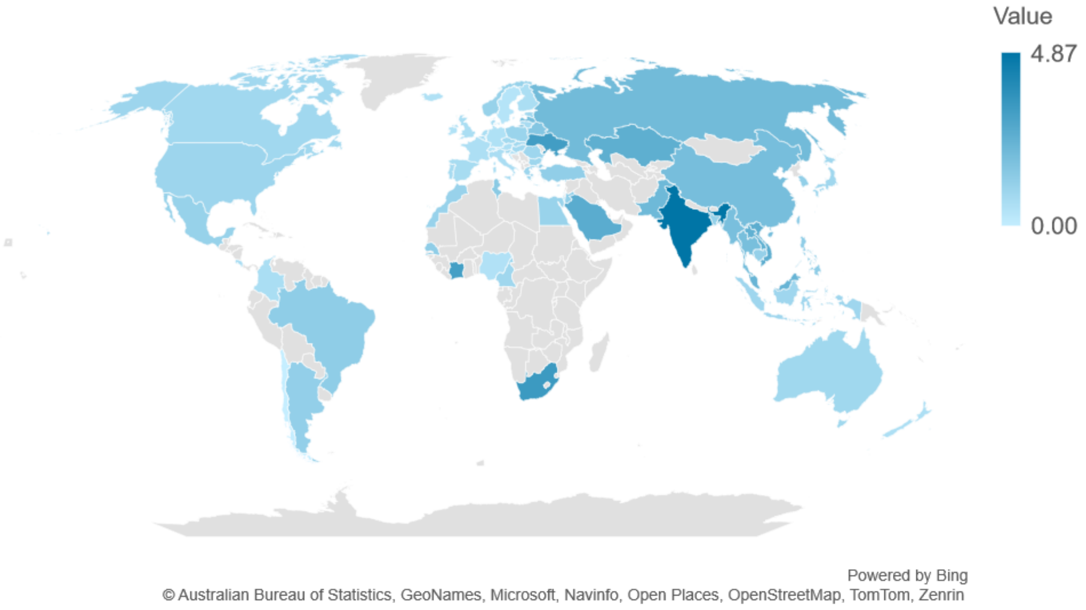
Source: Authors’ estimation

Table 2. Lowest relative GHG emission intensities for motor vehicle manufacturing compared to USA, 2020

Country	Relative GHG Emission Intensities
France	0.60
Austria	0.59
New Zealand	0.59
Israel	0.57
Germany	0.54
Iceland	0.53
Nigeria	0.51
Ireland	0.50
Croatia	0.48
Luxembourg	0.46
Sweden	0.41
Switzerland	0.36

Source: Authors’ estimation

Figure 10. Map of relative GHG emission intensities for motor vehicle manufacturing compared to USA, 2020



Source: Authors estimation

GHG intensities are key source data to estimate emission contents of imports. The European Carbon Border Adjustment Mechanism (CBAM) utilizes carbon intensities as a foundational element to calculate the carbon price applied to imports entering the European Union. Initiated to prevent carbon leakage the CBAM seeks to level the playing field for EU producers and their international counterparts. Essentially, it imposes a carbon price on imports of specific goods from outside the EU, mirroring the cost that EU producers incur under the EU's Emission Trading System (ETS). Starting with a focus on sectors at high risk of carbon leakage, such as cement, electricity, fertilizers, steel, and aluminum, the CBAM requires importers to buy carbon certificates that reflect the carbon price that would have been paid had the goods been produced under the EU's carbon pricing rules. The price of these certificates will be aligned with the price of EU ETS allowances, effectively putting a price on carbon emissions associated with imported goods.

The results generated by the Carbon Price App derive from regional input-output tables calculated in current prices. While these outcomes do not depend on predetermined hypotheses about the relationships between variables, but rather utilize the foundational structure of detailed national accounts statistics, it is vital for users to consider significant methodological considerations when interpreting the results. The main limitations of the dataset will be discussed in the following section[6].

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[6] The authors plan to use the feedback from potential data users to guide future enhancements aimed at addressing the principal limitations of the dataset.

Way Forward

Time series analysis

A progressively increasing carbon price provides businesses and consumers with a predictable framework, allowing them time to adapt. This gradual approach helps in transitioning towards low-carbon technologies and practices without causing sudden economic disruptions. When using time series from the carbon pricing model, users must meticulously assess the implications of price fluctuations over time, especially in scenarios where carbon pricing escalates progressively in real terms. For instance, a carbon price set at $75 USD in 2024 does not equate in economic impact to the same nominal amount in 1995, considering the general inflation and increased price levels of goods and services over time. Since all values used in the model are in current price, necessary adjustments are required, particularly for long periods of time and for recent periods when many economies experienced higher inflation after the COVID period.

Adjusting tax estimates for price changes is intricate, as finding a suitable deflator can be challenging. For household consumption, the Consumer Price Index (CPI) is generally accepted as an effective deflator. The CPI is also widely available. By using the CPI to adjust carbon pricing results, the authors argue that this yields a tax value that reflects consistent purchasing power for households over time. This method is particularly valuable for policymakers, offering a pragmatic approach to assess the real-term impact of carbon pricing amidst inflation. However, it is important to recognize potential biases this method may introduce. These include shifts in consumption patterns, discrepancies between the CPI coverage and actual household expenditure patterns—especially non-monetary consumption prevalent in developing economies—, and a fundamental disconnect between the CPI and the carbon price per ton.

Another approach to measure carbon pricing in real terms would be to use the price relative to a relevant product produced or used in the economy. The price of crude oil is a pivotal economic indicator due to its extensive influence on the cost of diverse goods and services, ranging from transportation to manufacturing. Crude oil is also a significant contributor to climate change. However, its price volatility poses challenges, potentially undermining analytical accuracy and introducing uncertainties into climate policy decisions. Given that electricity generation is a major source of global emissions, adjusting carbon pricing relative to electricity prices by country could offer insights. However, this approach faces obstacles, such as varying electricity rates across different user groups and the challenge of establishing an average rate applicable to each country in a multi-regional input-output model. Although electricity prices have historically been more stable than oil prices, they too can fluctuate significantly. Modeling carbon pricing based on these price changes could introduce unrealistic volatility from a policy standpoint, potentially leading to pro-cyclical price effects. Alternative approaches, like considering the relative carbon price to taxes on production—rather than transaction-based taxes such as value added taxes or sales taxes—over time, also encounters variability and comparability issues across countries. While key commodities or gold are sometimes proposed for real-term series analysis, they are not exempt from volatility. An alternative exploratory approach involves establishing a fixed ratio of carbon value to GDP over time, thereby determining the evolving value of a carbon tax.

$$fixed\ \frac{carbon}{GDP}\ ratio = \frac{value\ of\ carbon}{GDP} = \frac{carbon\ tax\ x\ emissions}{GDP}$$

This method calculates the total carbon tax per ton by applying the predetermined ratio of carbon value to GDP of a benchmark year multiplied by GDP estimates in current prices and divided by emissions. Such an approach does not account for an increase in the tax's real value over time but helps in identifying stable economic proportions between carbon value and GDP.

$$carbon\ tax = \frac{fixed\ \frac{carbon}{GDP} ratio\ xGDP}{emissions}$$

While the benefits and feasibility of various approaches is being investigated, utilizing a price deflator, such as the CPI or the producer price index, emerges as the most feasible solution. Table 3 shows the current price value of a $75 USD carbon price in 2020 which is also the carbon price in 2020 prices adjusted using the CPI for the US for a carbon price of $75 USD in 2020. The authors plan to explore this issue further, contingent on user’s feedback.

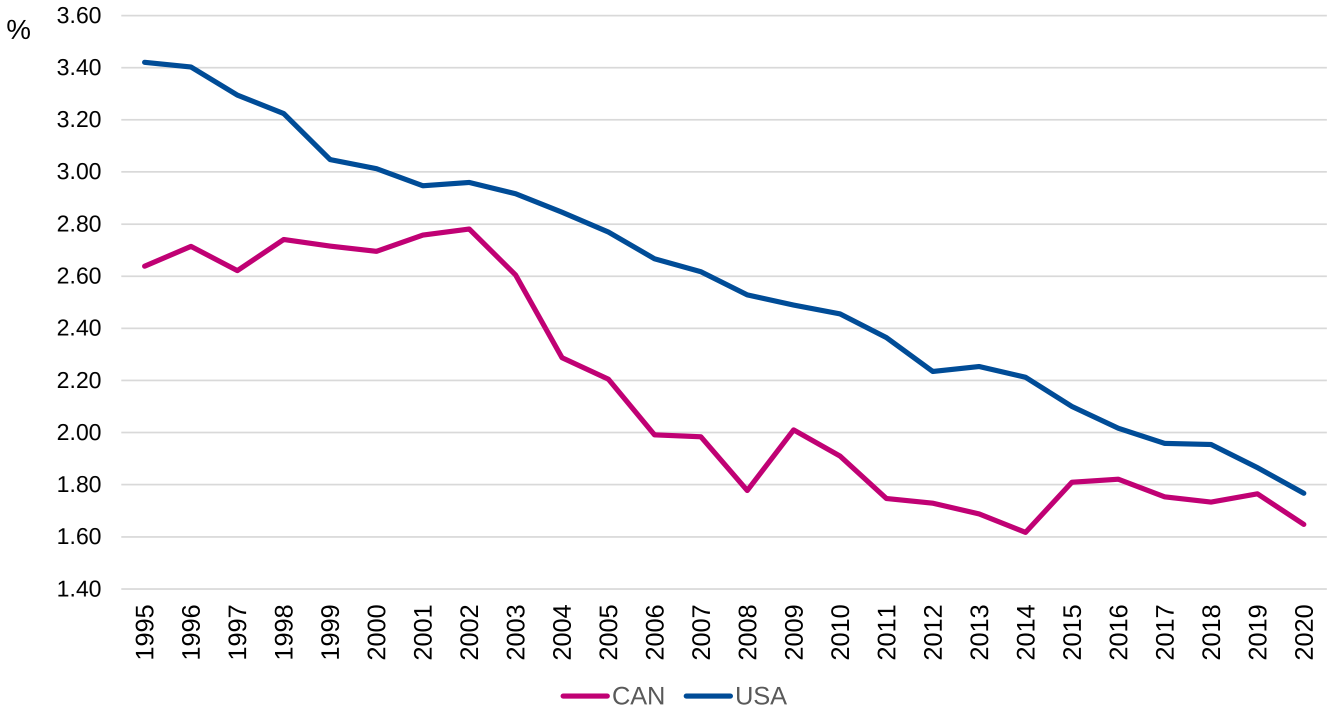
Table 3. Time series of a carbon price equivalent to $75 USD in 2020

YEAR	USA CPI (Consumer Price Index, All Items) Base year = 2020	Carbon price equivalent to $75 USD in 2020
1995	0.5888	44.16
1996	0.6060	45.45
1997	0.6202	46.52
1998	0.6298	47.24
1999	0.6436	48.27
2000	0.6653	49.90
2001	0.6842	51.31
2002	0.6950	52.13
2003	0.7108	53.31
2004	0.7298	54.74
2005	0.7546	56.59
2006	0.7789	58.42
2007	0.8011	60.09
2008	0.8319	62.39
2009	0.8289	62.17
2010	0.8425	63.19
2011	0.8691	65.18
2012	0.8871	66.53
2013	0.9001	67.51
2014	0.9147	68.60
2015	0.9158	68.68
2016	0.9273	69.55
2017	0.9471	71.03
2018	0.9702	72.77
2019	0.9878	74.09
2020	1.0000	75.00

Source: CPI from IMF International Financial Statistics (IFS), Carbon price estimated by the authors

Figure 11 illustrates the price effects on households' consumption in the USA and Canada, resulting from independently applying a carbon price equivalent to $75 USD in 2020, as shown in Table 3, from 1995 to 2020. The results indicate a trend of decreasing price impact from an equivalent tax in real terms throughout the period for both countries. In the USA, the price effect of the carbon price, deflated by the CPI, decreased from 3.42% in 1995 to 1.77% in 2020. In Canada, it dropped from 2.64% in 1995 to 1.65% in 2020. These findings suggest a reduction in the relative intensity of emissions in the bundle of goods and services consumed by households, indicating technological advancements that enabled industries to lower emission intensities over this time. Notably, the decline in the carbon pricing effect on household consumption prices was relatively more rapid in the USA than in Canada, hinting at quicker technological advancements in the USA. Consequently, imposing a carbon price on emissions-intensive industries could accelerate emission reductions in a country, with the price effects of this carbon price diminishing over time. This likely results in a more significant positive impact on reducing emissions and their impact on climate change. Although the CPA does not model technological change due to carbon pricing, a time-series analysis based on a constant carbon price sheds light on changes in households' consumption bundle emission intensities over the considered period.

Figure 11. Price effects on households' consumption in USA and Canada of a carbon price equivalent to $ 75 USD in 2020



Source: Authors' estimations

Pass-through

The outcomes yielded by the carbon price model, and its associated application discussed so far in this paper, rest on the premise that producers entirely transfer the cost increase from carbon pricing to consumers. However, this assumption warrants reevaluation in light of the varying conditions across different countries, economic environment, conditions of competition, and policy instruments. Reduced pass-through rates would significantly influence the dynamics of price adjustments across economies. A recent study of Konradt et al. (2024) focused on the Euro Area assumed a pass-through of 75 percent while Ganapati et al. (2020) suggested 70 percent of energy-driven changes to input costs are passed through to consumers. Other studies, like Lafrogne-Joussier et al. (2023), focused on increased energy-driven cost shocks showed a full pass-through. Carbon pricing policies represent a steady and foreseeable progression, contrasting sharply with the abrupt and unpredictable nature of rapid economic shocks, suggesting that the pass-through over longer periods of time and in a more predictable environment might be less than 100 percent.

To ensure that the model remains adaptable to user assumptions, the authors will investigate the possibility of incorporating a modifiable pass-through rate into the model, which could then be adjusted within the app.

Further disaggregation of carbon price impacts and tax revenue

The price model effectively distributes the impact of price changes and tax revenue among end-users due to carbon pricing, yielding accurate estimates of carbon costs and associated tax revenues in final uses like household consumption or exports. This model enables detailed analysis of carbon pricing and tax revenue across countries, including those without specific carbon pricing, by assessing their roles in the global value chain. For example, when a country implementing carbon pricing exports goods, these goods include a carbon price component. If these goods are further processed into different products abroad and re-imported, the carbon price is also reflected in the import prices. Utilizing a detailed multi-regional input-output model allows for a precise breakdown of these transactions for each element of the tables, distinguishing the effects of price changes and tax revenue on imported versus domestically produced products. This approach offers a comprehensive understanding of the impact of carbon pricing and tax revenue across international boundaries, providing insights into the global implications of carbon pricing strategies.

Taking the case study presented in this paper, as illustrated in Table 4, for the USA, the total revenue generated from implementing a carbon price of $75 USD in 2020 would amount to $379,540 million USD. This revenue represents 1.85% of the USA's economy value added. Out of this, $337,417 million USD (88.90%) would be borne by domestic consumers, while the remaining $42,123 million USD (11.10%) would be incorporated to foreign demand. This latter figure is slightly lower than the $45,344 million USD attributed to exports. The difference of $3,221 million USD represents the revenue from intermediate exports that were utilized in the production of final goods by other countries, which were then exported back to the USA.

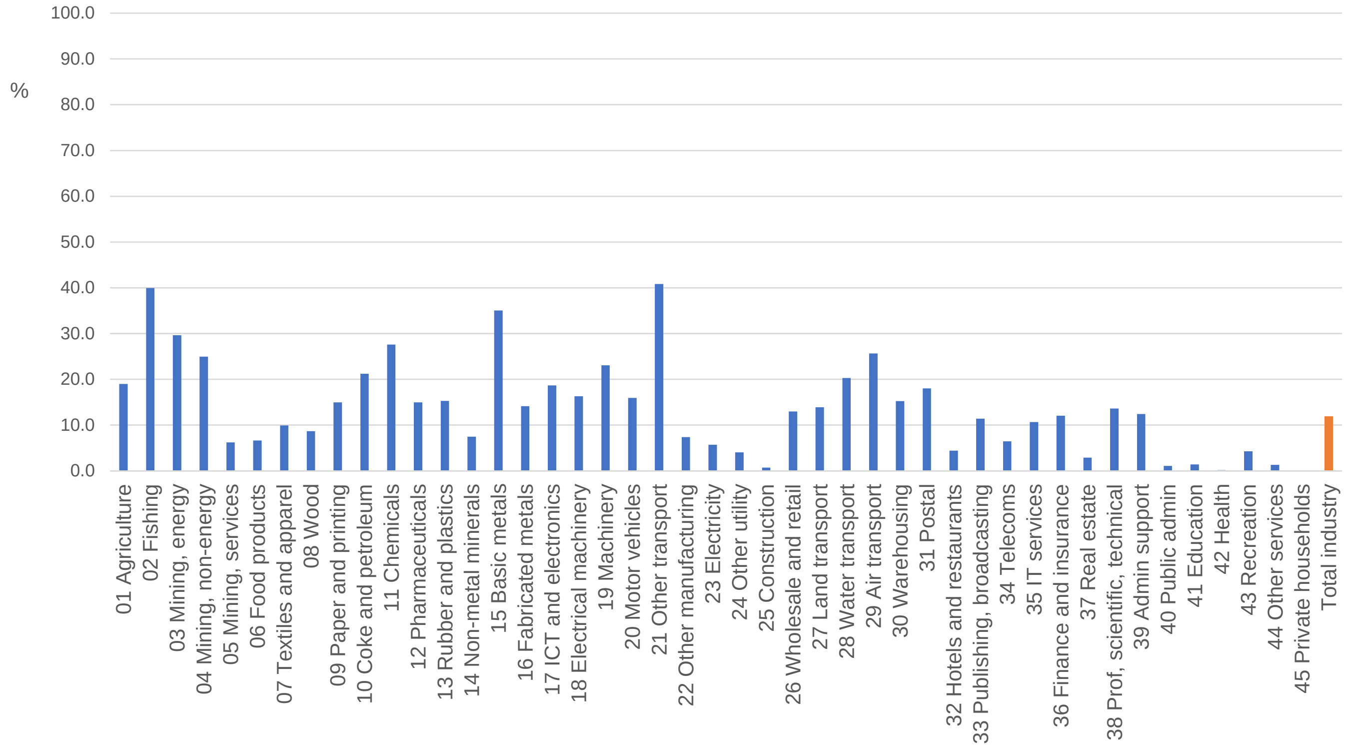
Table 4. Carbon pricing revenue incorporated in domestic and foreign demand, exports and returned in imports, resulting from applying a $75 USD carbon pricing to all industries in USA, USD Million, 2020.

Carbon Pricing Revenue in Million USD, 2020						
Country	**Revenue to VA ratio**	**Total**	**Incorporated in Domestic Demand**	**Incorporated in Foreign Demand**	**Incorporated in Exports**	**Returned Incorporated in Imports**
USA	1.85%	379,540	337,417	42,123	45,344	3,221

Source: Authors' estimations

Figure 12 delineates the proportion of the total tax paid by each industry that is included in its exports. For the Agriculture industry, 19.00% of the tax paid is exported to other countries, while the remaining 91.00% is borne by domestic consumers. Across the entire economy, 11.95% of the tax (equating to $45,344 million USD) is incorporated into exports. However, a portion of this, $3,221 million USD as detailed in Table 4, which represents 0.85% of the tax revenues, returns to the USA, being embedded in imports from other countries.

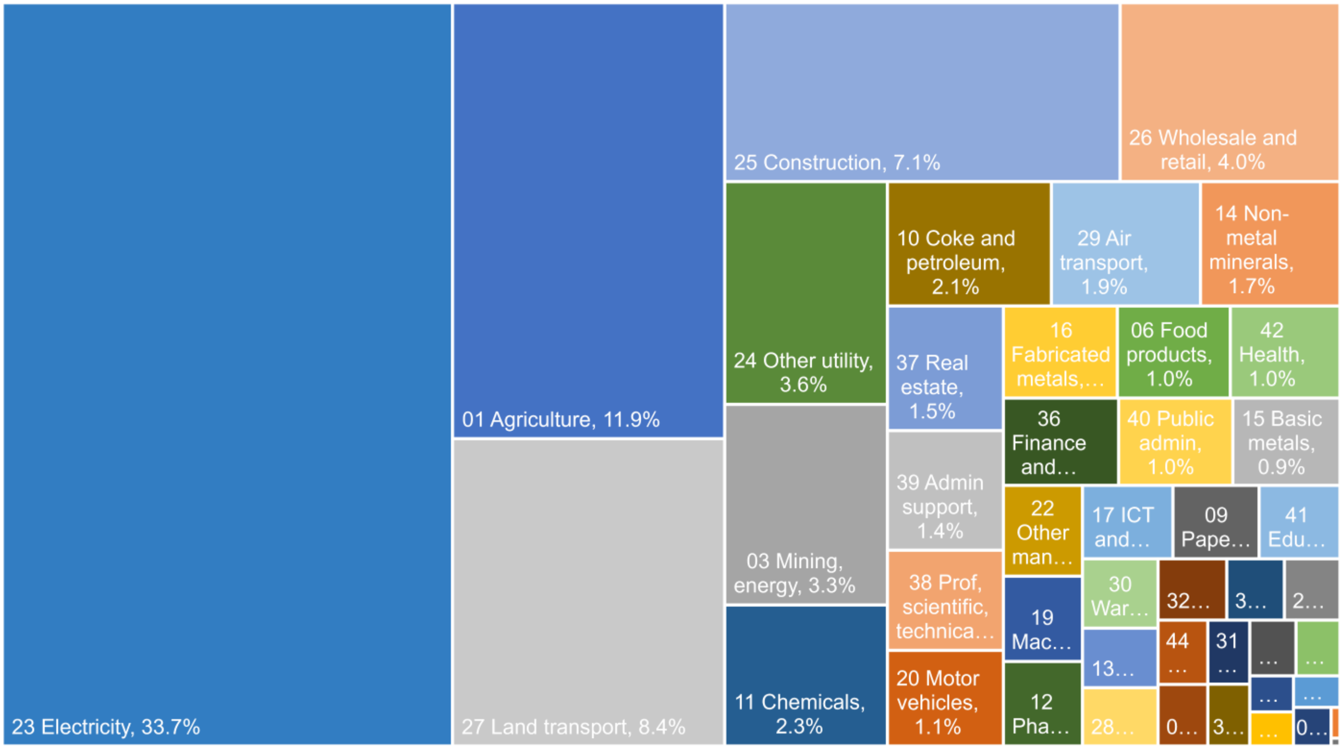
Figure 12. Carbon pricing revenue incorporated in the exports of USA, resulting from applying a $75 USD carbon pricing to all industries. Share in each industry (%), 2020.



Source: Authors' estimations

Figure 13 illustrates the proportion of each industry's contribution to the total tax revenue generated from domestic final demand, totaling $337,417 million USD. This figure highlights the industries that produce and deliver final goods and services to domestic consumers. Notably, the top five industries account for 65.1% of the total tax revenue. Specifically, the Electricity industry contributes 33.7%, Agriculture 11.9%, Land Transport 8.4%, Construction 7.1%, and Wholesale and Retail 4.0%.

Figure 13. Final demand industries share of the total carbon pricing revenue incorporated in USA domestic final demand (%), resulting from applying a $75 USD carbon pricing to all industries, 2020.

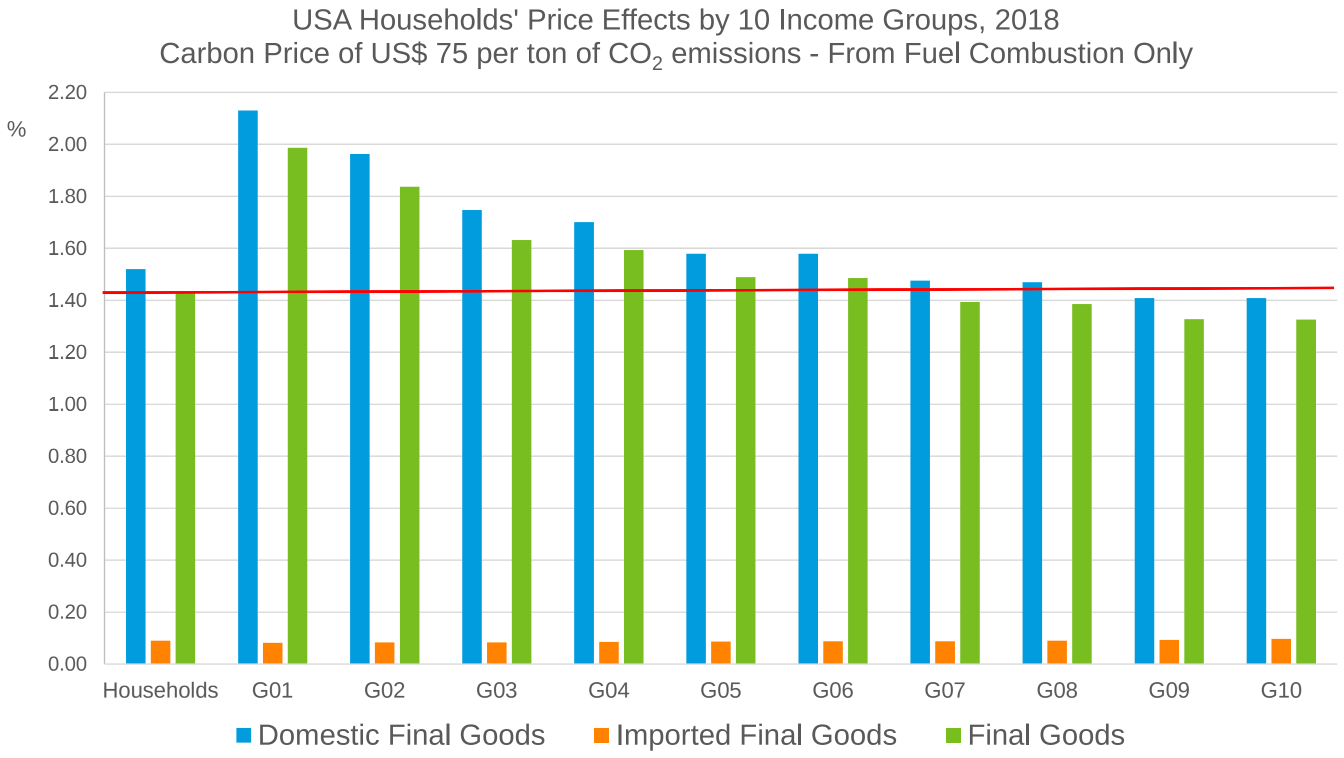


Source: Authors' estimations

Further breakdowns can be introduced in the analysis by other components such as the impact on different groups of households by income groups. Depending on the structure of their consumption, different household groups would be impacted differently by an increase in prices of goods and services resulting from carbon pricing. For example, poorer households allocate a larger portion of their budget to essential goods and services that have high carbon content, such as heating, electricity, and fuel. These are considered necessities, and demand for them is relatively inelastic, meaning that consumption does not significantly decrease as prices increase. In addition, transitioning to renewable energy sources or purchasing energy-efficient appliances or vehicles requires an upfront investment that might be beyond the reach of these households. The disproportionate expenditure on high carbon content products among poorer households underscores the importance of designing climate policies and carbon pricing mechanisms that are socially equitable. To mitigate the regressive impact of such policies, it is crucial to assess the impact on households considering the aspect of income distribution. Where available, income distribution data combined with multi-regional input-output tables can provide useful data for policy makers.

Figure 14 illustrates the possibility to undertake complex analysis combining income distribution while distinguishing the origin of price changes — imported versus domestic goods. Here, G01 represents the 10 percent poorest households. The results clearly show that the poorest income groups experience the most significant price increases in their consumption basket.

Figure 14. Price indices by households' income groups for a carbon price of $75 USD, USA, 2018[7]



Source: Authors' estimations

Price elasticities and responses to carbon pricing

The multi-regional input-output price model operates statically, anchored by an unchanging input structure and predetermined production ratios for each sector. When conducting economic impact assessments with multipliers, it presupposes constant cost or spending patterns relative to initial budget allocations. However, the core aim of carbon pricing lies in influencing behavioral adjustments towards lower-pollution goods and services consumption. Such behavioral shifts can be effectively captured and analyzed through the application of price elasticities.

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[7] This example was generated by the authors using an older version of the dataset than other numerical examples presented in this paper and considering only CO_2 emissions from fuel combustion.

Price elasticity of demand measures the responsiveness of the quantity demanded of a good or service to a change in its price. It is calculated as the percentage change in quantity demanded divided by the percentage change in price. If its absolute value is greater than 1, the demand is considered elastic, meaning consumers are highly sensitive to price changes. If it is less than 1, the demand is inelastic, indicating that consumers are less sensitive to price changes. A value of exactly 1 signifies unit elasticity, where the percentage change in quantity demanded equals the percentage change in price. The demand for energy products, which are impacted by carbon pricing due to related GHG emissions, is relatively inelastic in the short-term because alternative products are limited.

Introducing price elasticities in the price model could be envisaged in the future. This improvement has been discussed internally at the IMF. However, it would require significant work and would only be applied to the new Multi-Analytical Regional Input-Output Model (MARIO) under development and discussed in the following section.

Extensions of the price model

In 2023, the IMF launched an ambitious initiative by starting the development of MARIO, Guilhoto et al. (2023), a project tailored to meet the growing demands for accurate emission intensity calculations supported by comprehensive multi-regional input-output data. This innovative project aims to significantly diminish the prevalence of data gaps commonly encountered in the estimation processes of multi-regional input-output models. MARIO stands out because of its collaborative foundation, built through partnerships with several prominent international organizations that are working in the estimation of global input-output tables, including the Organization for Economic Co-operation and Development (OECD) – OECD (2024), Eurostat – Eurostat (2024), the United Nations Economic Commission for Latin America and the Caribbean (UNECLAC) – ECLAC (2020), and the Asian Development Bank (ADB) – Asian Development Bank (2022). Leveraging the IMF's extensive technical assistance program, MARIO is set to cover 212 economies. This includes all IMF member countries, thereby providing a broad and inclusive scope.

MARIO will offer insights spanning over three decades, from 1990 to 2023, enabling a longitudinal study of economic and environmental trends. The model will detail 178 products and 144 industries across 212 economies. Such granularity facilitates in-depth analysis on various themes, particularly those concerning climate change and environmental issues. One of the pivotal features of MARIO is its ability to capture international spillovers, thus providing insights into how the energy transition, emissions, material flows, and other strategic questions impact globally. MARIO's enhanced granularity and comprehensive geographic coverage will advance the understanding of climate change and environmental sustainability. It will also underpin the carbon price model.

An additional extension under consideration involves the creation of indicators designed to assess the potential impact of each industry on the stability of the banking system following the introduction of carbon pricing. While carbon pricing is recognized for its efficacy in reducing greenhouse gas emissions, it can also have unintended consequences on the solvency of companies, which, in turn, may affect the overall stability of the financial system, see Guth, M. et al. (2021) and Königswieser et al. (2021). These proposed indicators aim to incorporate various factors, including exposure to carbon taxes, the probability of a company defaulting, and the debt ratios of different industries. By accounting for these elements, the indicators would provide a more nuanced understanding of how carbon pricing might influence financial stability.

Final Comments

Implementing effective carbon pricing mechanisms is a complex endeavor that hinges on the ability to navigate through intricate data-related challenges. The model developed by the authors, rooted in the input-output framework, exemplifies a sophisticated approach to evaluating carbon pricing's effects on the economy's price dynamics. This methodology affords a detailed analysis of individual industries and the broader repercussions on key economic indicators such as household consumption, exports, and investment. The inclusion of inter-country dynamics within this model provides essential insights into the international inflationary effects and competitive dynamics induced by carbon pricing. Moreover, the model's ability to estimate revenues from carbon pricing and its industry-wide price impacts should help policymakers in devising strategies to mitigate adverse economic effects.

To further enhance this model's capabilities, incorporating price elasticities and behavioral adaptations would improve predictive accuracy and understanding the nuanced interplay between carbon pricing, economic behavior, and market dynamics. This would enable more informed policymaking by capturing how environmental policies influence economic actions over time. Additionally, refining the model for time series analysis by generating price-adjusted estimates will aid in grasping the long-term impacts and trends of carbon pricing policies, providing deeper insights into temporal shifts. Expanding the analysis of the CBCA with detailed carbon intensity estimates would refine the assessment of its impacts on international trade, supporting nuanced policy decisions to encourage global emission reductions without compromising competitive equity.

The Carbon Price App delivers detailed short-term price changes across 77 economies, providing granular data for various industries and GDP components. The forthcoming integration with the IMF's MARIO will significantly enhance the model by extending the time series coverage from 1990 to 2023, offering insights into 144 industries, and expanding geographical coverage to include 212 economies. This enhancement will not only increase the model's utility but also its relevance, making it an invaluable tool for policymakers. It aims to help them navigate the complexities of carbon pricing and balance environmental objectives with economic considerations.

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