The Distributional Effects of Carbon Pricing Across Countries *

Mathilde Le Moigne† Simon Lepot‡ Marcos Ritel§ Dora Simon¶

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Abstract

We use a quantitative international trade model with climate policies to explore the distributional effects of carbon pricing across countries. Our analysis addresses two key questions facing global climate action: which countries bear the greatest burden of climate policies, and how these policies can be designed to ensure fairness. We present three main findings. First, efficient climate policies that disregard distributional concerns significantly exacerbate between-country inequality. Second, equity can be achieved alongside efficiency when climate policies are complemented by realistic international transfers, either equalizing carbon tax costs or accounting for historical emissions, with minimal economic impact on high-income countries. Third, carbon tax schemes with heterogeneous pricing—featuring lower rates for low- and middle-income countries— do not necessarily result in fairer outcomes.

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†University of Zurich

‡University of Zurich

§Kuehne Logistics University. Corresponding author: marcos.ritel@klu.org

¶University of Stavanger

1 Introduction

Climate change is one of the most pressing challenges of our time. It is driven by greenhouse gas (GHG) emissions, a pure externality that impacts all nations, though not in the same way. Low- and middle-income countries, in particular, are more vulnerable to climate hazards[1], despite their historically lower contributions to the cumulative stocks of GHG in the atmosphere. This disparity has led the Global South to push over time for differentiated contributions to the solution of the climate crisis that acknowledge that they suffer the most while having contributed the least to the problem. Such efforts, however, have not been particularly successful in being translated into actual policies. Indeed, opposition to this reasoning is often pointed out as a key reason why climate negotiations fail to deliver effective outcomes.

Despite its contentious character, the idea that low- and middle-income countries have different responsibilities in the fight against climate change is today one of the leading principles of climate action steering high-level climate talks, such as the Conference of the Parties (COP) meetings. This notion was first formalized in the United Nations Framework Convention on Climate Change (UNFCCC) of Earth Summit in Rio de Janeiro in 1992, with the principle of Common but Differentiated Responsibilities (CBDR). In essence, it acknowledges that all states have a shared obligation to address environmental destruction but denies equal responsibility to all states about environmental protection. Although more than 30 years old, the principle has recently been brought back to the center of climate negotiations in the context of the Paris Agreements, remaining a polarizing idea to date.

In this paper, we aim to inform this debate about climate action and global equity by conducting the first comprehensive quantitative analysis of the distributional effects of carbon policies across countries. We use a state-of-the-art quantitative trade model with climate policies to explore the case for differentiated contributions in the fight against climate change in the spirit of CBDR. To structure the analysis, we first establish a benchmark that asks what are the consequences of climate policies that disregard distributional concerns. This involves the adoption of a single global price for CO_2 equivalents (CO_2e), a Pigouvian-style tax that economists have long advocated as the optimal climate policy from a global

[1]The vulnerability of developing countries to the effects of climate change has been demonstrated repeatedly by the Intergovernmental Panel on Climate Change (IPCC) in the report of their second working group (Adler et al., 2022).

standpoint and also a popular proposal among policymakers and experts.[2,3] We explore the implications of such a taxation scheme for the global economy focusing on its impact on low- and middle-income markets.

We next ask whether efficient climate action can realistically incorporate principles of equity. We build on an insight from the public goods and externalities theory, which states that a global Pigouvian tax can only be optimal when accounting for egalitarian concerns in the presence of international lump-sum transfers (Sandmo, 2006).[4] We therefore quantify transfer schemes that are necessary to either equalize the present costs of global carbon taxation or to promote historical reparations based on accumulated cross-country GHG emissions since the Industrial Revolution. This allows us to discuss the feasibility of these transfers contrasting them with current trends in climate finance. Finally, we analyze some prominent proposals for carbon taxation that rely on heterogeneous pricing, with lower or no taxes adopted by low and middle-income countries. We assess how much such schemes can deliver in terms of fairness by comparing them to a benchmark scenario based on a global carbon tax with transfers that delivers the same reduction in GHG emissions. We explore two policy options that have recently gained prominence in climate discussions: (i) a unilateral carbon pricing scheme amongst a selected "club" of countries (Nordhaus, 2015) and (ii) heterogeneous carbon prices based on income levels following a recent proposal by the International Monetary Fund (IMF)(Parry et al., 2021).

Our investigation builds on a modern general equilibrium international trade model. It features multiple countries and sectors and a detailed description of the world economy, including trade in final and intermediate goods, sectoral heterogeneity, and input-output linkages (Armington, 1969; Caliendo and Parro, 2015). It includes 64 countries and regions and 45 tradable and non-tradable sectors. We leverage rich data on CO_2, CH_4, and N_2O emissions, which capture 93% of all GHG emissions. In the model, governments have access to an option of climate policy, a carbon tax paid by consumers and firms when purchasing final and intermediate goods. Our benchmark policy is a 100 USD/tCO_2e

[2] For instance, Nobel laureate Jean Tirole recently expressed this view arguing that: "since the emission of a ton of greenhouse gases causes the same environmental damage, wherever, whenever and however it is emitted, a single global price for CO_2 should guide public and private agents in their investment, production and consumption decisions" (Tirole, 2016).

[3] A uniform carbon tax is the optimal policy under global cooperation in a perfectly competitive environment and in the absence of distributional considerations. See Farrokhi and Lashkaripour (2021) for a characterization of optimal climate policies and their consequences in a general equilibrium environment.

[4] Sandmo extends the classic analysis of Paul Samuelson about the provision of public goods to an international setting. He shows that, in the absence of lump-sum transfers, if the global welfare function is egalitarian, a Pigouvian tax that addresses the global externality needs to be relatively lower for low-income countries. Also, the inclusion of transfers allows for the separation of efficiency and equity considerations in the optimal solution.

carbon tax, which is close to existent applied carbon taxes. Nonetheless, all conclusions of our analysis are robust to setting this policy at different levels.[5]

Our analysis delivers three main insights. First, we show that a uniform carbon tax strongly exacerbates between-country inequality. While it is commonly accepted that low and middle-income countries are affected the most by climate change (Adler et al., 2022), our analysis implies that these countries also bear most of the costs of climate action. This is a common claim surrounding climate talks, which our quantitative analysis allows us to put numbers on. At first glance, carbon taxes are an effective climate policy, with a 100 USD/tCO_2e carbon tax decreasing emissions by 28% at a real income loss of only 0.7% on average. However, this average masks a significant degree of heterogeneity across countries. Low- and middle-income countries experience real income losses of up to 7%, while high-income countries often experience a real income gain.

These results stem from a heavier carbon tax burden in the Global South, driven by two main factors. For starters, the Global South tends to specialize in more polluting industries. More specifically, low and middle-income countries are often more upstream in international value chains, providing raw materials that are notably more carbon-intensive than other sectors. This specialization also results in a more carbon-intensive consumption basket, as domestic production constitutes a large portion of domestic expenditure. Moreover, the Global South tends to produce using more polluting technologies thus emitting more in any given sector per dollar produced. Consequently, as carbon taxes causes the environmental cost of carbon to be reflected in relative prices, economic activity is reallocated towards greener sectors predominantly found in high-income markets.

Given that some countries experience a real income gain while others face a real income loss, there is a role for international transfers to equalize the economic costs of climate action. Our second result documents that realistic cross-country transfers of an average of USD200 per person from the Global North to the Global South could remedy this inequality while allowing for substantial emissions reduction led by the common carbon tax. We obtain this result from two different scenarios. One of them explores "equal-cost" transfers, which equalize real income losses from carbon taxation. Similar to climate action without redistribution, this scenario generates a decrease in global emissions of 28%, but this time with

[5]Note that the magnitude of the optimal global carbon tax is defined by the social cost of carbon. As noted by Blanchard et al. (2023) "there exists no consensus among economists about how large this Pigouvian carbon price should be." Our calibration is also close to Farrokhi and Lashkaripour (2021), which set the social cost of carbon in 2014 at 156 USD/tCO_2 based on estimates provided by the United States Environmental Protection Agency.

uniform international real income costs of 0.7%. The largest payers would be European countries and the U.S. and the largest receivers are large low- and middle-income countries, such as Kazakhstan, Russia, South Africa, and Southeast Asian countries. In total, equal-cost transfers would amount to USD 272 bn, which would involve tripling the current transfers provided by high-income countries for climate finance (OECD, 2022). While this is a substantial amount, its impact on the population of developed countries is in fact relatively modest. The highest transfers would need to be paid by Ireland in the amount of USD 2,000 per person per year. For the rest of the EU members and the U.S., the effective amount that should be paid by an individual in a year does not exceed USD 1,000.

The second type of transfer is a "historical polluter-pays" transfer, which aims to make the real-income cost of carbon taxation borne by a country proportional to its historical contribution to global cumulative emissions. In this scenario, the total amount of transfers required is slightly lower than in its equal-cost counterpart, at USD 255.7 billion, because the historical polluter-pays scheme allows for unequal economic costs based on historical responsibility. This is, for example, the case of Russia. Because Russia is a large producer of natural gas, it is heavily penalized by the carbon tax. In the equal costs scenario, Russia received transfers of the order of USD 404 per capita to bring its real-income cost up to par with other countries. Russia is, however, also a historical polluter, so in the polluter-pays scenario, its effective per-capita transfers decrease to less than USD 80 per person per year. Still, a common conclusion that emerges from the two scenarios is that countries that were receivers in the equal-costs scenario remain receivers in the historical polluter pays scenario, and payers remain payers. This is due to the fact that nations that benefited from the Industrial Revolution started to emit CO_2 during the 19th century and now have the highest levels of development.

Our third and final result shows that while heterogeneous pricing schemes may be politically more feasible and offer the advantage of reducing the likelihood of free-riding, they do not necessarily lead to fairer outcomes when compared to a global policy benchmark. We show that this is the case of a climate club formed by key global players necessary to deliver meaningful reductions in emissions.[6] Despite

[6] We specify the club with members imposing a USD100/tCO_2e carbon tax on domestic producers, as well as an analogous border tax that applies over imports of the rest of the world. This captures, for example, the state of carbon policies in the European Union, which combines the Emissions Trading System (ETS) with the new Carbon Border Adjustment Mechanism (CBAM). To simplify the discussion, we abstract from strategic behavior of members and non-members in the formation of the climate club and adopt an exogenous policy setting. Naturally, this implies that we cannot account for many determinants of this type of policy that are widely described by the literature. For example, countries excluded from the club could adopt retaliatory policies, such as raising import tariffs against members of the club. Still, our simple setting suffices to capture the heterogeneous pricing structure that could emerge from this policy proposal, which allows us to discuss its distributional consequences. For an analysis of strategic behavior and optimal

requiring no policy engagement from the majority of low and middle-income countries, this scenario would require 36% higher North-South transfers when compared to a global uniform tax benchmark generating the same reduction in emissions and would entail 10.6% higher global welfare costs. We find analogous results when analyzing the IMF's International Carbon Price Floor (ICPF) in multiple configurations, from a scheme restricted to the key players in the global economy to a scenario in which all countries participate according to their level of economic development.[7] In all configurations, the ICPF can never deliver both lower transfer requirements together with a more efficient climate policy. Hence, perhaps contrary to intuition, we show that heterogeneous carbon pricing is not a guarantee of increased fairness across countries. In fact, in the case of these mainstream policy proposals, it is more often the source of increased inequalities.

We conduct several robustness checks to validate our findings. First, we confirm that our results hold across different sets of trade elasticities derived using alternative methods from the literature. Our benchmark estimates rely on elasticities obtained through the approach in Caliendo and Parro (2015). Additionally, we directly incorporate elasticities from Fontagné et al. (2022) and also apply their methodology to estimate parameters using our dataset.

Second, we examine a supply-side carbon taxation scheme, which compared to a demand-side scheme benefits countries whose exports have higher carbon content. Under this approach, real income changes and transfer amounts differ for some countries, reducing the total transfer requirements by approximately 20%. However, the overall pattern remains consistent: low- and middle-income countries incur higher real income losses than high-income countries.

Third, we qualify our analysis by comparing the real income cost of climate action to the cost of inaction, measured by countries' social cost of carbon. Our findings demonstrate that, under efficient policies, most countries ultimately benefit from climate action, as the long-term costs of unmitigated climate change exceed the immediate costs of carbon taxation with transfers. These results additionally highlight the importance of striking a global compromise that balances the present-day economic burdens of climate action with the implementation of policies to mitigate climate change, as doing so serves the

policy setting in a climate club environment, see, for instance, Farrokhi and Lashkaripour (2021).

[7] In our counterfactuals, we follow the three floor prices proposed by the Fund: USD75/tCO_2e for high-income economies, USD50/tCO_2e for upper-middle-income economies and USD25/tCO_2e for lower middle and low-income economies. We analyze the two scenarios proposed by the IMF - a club composed of Canada, China, the European Union, Great Britain, India, and the United States, as well as all G20 economies - plus our own key players scenario which we describe below and a scenario in which all countries participate according to their level of economic development.

long-term interests of most nations.

Finally, we show that our findings remain robust in a framework with endogenous emission intensities, as in Copeland and Taylor (2003). While our benchmark model allows for reduction in total emission intensities along the supply-chain through sourcing from greener suppliers, it holds emission intensities at each production stage fixed. We show that allowing firms to invest in abatement technologies that reduce direct emission intensities does not offset the disproportional burden of carbon taxation in low and middle-income countries. As a result, our main conclusions remain unchanged.

This paper contributes to several strands of the literature. Our study adds to the extensive literature on international trade, trade policy and greenhouse gas emissions. Earlier studies focused on small-scale models, often analyzing the effects of unilateral climate policy on trade, notably on leakage (e.g. Markusen (1975); Hoel (1996); Copeland (1996))[8].

More recently, several studies started to employ quantitative trade models to study environmental and trade policies. Closer to our analysis of global carbon policies is Farrokhi and Lashkaripour (2021). They analyze the efficacy of optimal environmental and trade policies- specifically carbon border taxes and climate clubs with trade penalties - as tools to enforce global climate cooperation and reduce carbon emissions. We add to this literature by focusing on the socioeconomic impacts of global climate policies on low and middle-income regions and by exploring solutions to offset these impacts, thus addressing an equity dimension often overlooked in broader analyses of trade and the environment.

We also add to the emerging literature on the distributional effects of climate change and of carbon taxation. Krusell and Smith (2022) use an integrated assessment model to show that the impacts of climate change vary strongly across different regions. Kotlikoff et al. (2021) investigate the potential for uniformly beneficial outcomes from carbon taxation across different regions and generations, using an overlapping generations model. Closer to our study are Cavalcanti et al. (2020) and Finkelstein-Shapiro and Nuguer (2023). Cavalcanti et al. evaluate the aggregate and distributional effects of climate change mitigation policies in a closed-economy general equilibrium model, specifically focusing on the impacts of carbon taxes across different sectors. Finkelstein-Shapiro and Nuger examine the impacts of a carbon tax on labor markets and macroeconomic outcomes in emerging economies. They use a search and matching macroeconomic model that includes pollution externalities from energy production, endogenous green-

[8]Other studies that analyze the effects of unilateral climate policy on trade include (Felder and Rutherford, 1993; Babiker, 2005; Elliott et al., 2010, 2012; Aichele and Felbermayr, 2012; Hémous, 2016; Böhringer et al., 2016; Kortum and Weisbach, 2021; Weisbach et al., 2023; Larch and Wanner, 2017, 2024)

technology adoption, and dynamics between formal and informal sectors. Both studies follow a closed economy approach and calibrate their models to a few countries only (US, China Brazil for Cavalcanti et al. and emerging economies for Finkelstein-Shapiro and Nuger). While their work focuses on within-country inequality and the effects on employment, we complement this literature by adopting a global perspective, covering the distributional effects of carbon policies across many countries and sectors.

Last, we also have points in contact with the integrated assessment model literature, which analyzes the aggregate effects of climate change and climate policy on the economy. (Nordhaus, 1993, 2018; Golosov et al., 2014; Boyce, 2018). We add an international economics dimension to the benefits and costs of climate policy.

2 Model

In this section, we develop a static, multi-country, multi-industry general equilibrium model of international trade in which governments have an option of climate policy. International trade is modeled as in Armington (1969). The production structure accounts for trade in final and intermediate goods, sectoral heterogeneity, and input-output linkages, as in Caliendo and Parro (2015).[9]

There are $\mathcal{N}$ countries denoted by i (for origin) and j (for destination) producing a local-specific variety of $\mathcal{S}$ sectors denoted by s' (produced by origin i) and s (destination sector if in a value chain). Varieties of good s' produced by i and imported in country j are traded and subjected to iceberg trade costs $\tau_{is'j}$ such that $\tau_{is'i} = 1$. Countries are endowed with an exogenous inelastic supply of labor L_i that is internationally immobile.

2.1 Carbon tax

A carbon tax is imposed on each good or service produced in the economy. Consumers of final goods pay the tax when consuming the good, and producers pay the tax on intermediate inputs they use in production. The tax is paid in the final destination country (i.e. by importers) and redistributed within that country as a lump sum to consumers. In its most general form the tax is denoted $t^e_{is'j}$ where i

[9] It is well understood today that general equilibrium models with distinct microfoundations have the similar predictions in equilibrium (Arkolakis et al., 2012). In our case, our quantitative model would yield the same predictions as a more complex framework, such as, for instance, an Eaton and Kortum (2002) model with trade in intermediates. We keep the Armington (1969) assumption to simplify the exposition.

denotes the origin country producing good or service s' destined for consumption in country j. It is meant to apply a price to each ton of carbon emitted such that

$$t^e_{is'j} = t_{is'j} * e_{is'}$$
$$e_{is'} = \frac{CO2_{is'}}{Y_{is'}}$$

with t denoting a dollar amount to be imposed on a ton of CO_2e (e.g. \$100) and $e_{is'}$ denoting the direct emission intensity of production of good s' in country i.[10]

We assume that direct emission intensities are not affected by policy. However, this does not imply that emission intensities in production are fixed because firms are allowed to re-optimize their input bundle in response to policy shocks. Hence, a carbon tax may lead to lower emission intensities along the supply chain as firms sourcing decisions move away from carbon intensive inputs towards greener alternatives.[11]

2.2 Demand

Consumers have Cobb-Douglas-CES preferences across sourcing origins for a given sector:

$$U_j = \prod_{s'} {U_{s'j}}^{\beta_{s'j}}$$
$$U_{s'j} = \left(\sum_i a_{is'}^{(1/\sigma_{s'})} q_{is'j}^{(\sigma_{s'}-1)/\sigma_{s'}} \right)^{\sigma_{s'}/(\sigma_{s'}-1)}$$

[10]Note that due to data restrictions, $e_{is'}$ is calculated in terms of tons of CO_2e emitted per \$ of output. In practice, because the tax $t^e_{is'j}$ is applied as an *ad valorem* tax it is equivalent to apply a per-unit tax on GHG emissions:

$$p_{is'j}\left(1 + t_{is'j} \times \frac{CO_{2,is'}}{p_{is'j}q_{is'j}}\right) q_{is'j} = p_{is'j}q_{is'j} + t_{is'j} \times CO_{2,is'}$$

[11]Total emission intensities can be formally computed as follows. Let us call $TE_{is'}$ the total emissions intensity along the supply chain of a good produced in sector s' in country i. Then TE is the unique positive solution of:

$$p_{is'}q_{is'}TE_{is'} = p_{is'}q_{is'}e_{is'} + \sum_{js} m_{jsis'}p_{jsi}TE_{js} \tag{1}$$

This equation decomposes total emissions into two components: direct emissions at the final stage of the supply chain and the cumulative emissions from all intermediate production steps. Using this formulation, we demonstrate that our results are also driven by significant changes in total emissions, particularly in low- and middle-income markets in Figure 6.

in which $a_{is'}$ is an origin-sector specific preference shifter, $\sigma_{s'}$ is a sector-specific elasticity of substitution, and $\beta_{s'j}$ is country j's expenditure share in sector s', such that $\sum_{s'} \beta_{s'j} = 1$.

2.3 Production

Markets are perfectly competitive. Production of good s in country j requires labor and intermediate inputs from all the sectors of the economy. These are combined in a Cobb-Douglas fashion with constant returns to scale. Denoting q_{js} the quantity of output s produced in j we have:

$$q_{js} = A_{js} \left(\frac{L_{js}}{\gamma_{j,Ls}} \right)^{\gamma_{j,Ls}} \prod_{s'} \left(\frac{m_{s'js}}{\gamma_{s'js}} \right)^{\gamma_{s'js}}$$

in which L_{js} is the amount of labor used in j to produce s; $m_{s'js}$ is the amount of intermediate input of sector s' used in j to produce s; $\gamma_{j,Ls}$ is the cost share of labor in production; and $\gamma_{s'js}$ is the cost share of input s' used in the production of s in country j, with $\gamma_{j,Ls} + \sum_{s'} \gamma_{s'js} = 1$. A_{js} is an exogenous productivity shifter.

Note that intermediate inputs can be sourced domestically or imported, so that $m_{s'js}$ is a CES aggregate of country i-specific varieties of the input:

$$m_{s'js} = \left(\sum_i b_{is's}^{(1/\eta_{s's})} m_{is'js}^{(\eta_{s's}-1)/\eta_{s's}} \right)^{\eta_{s's}/(\eta_{s's}-1)}$$

in which $b_{is's}$ is a preference shifter for variety i of product s' used in the production of s and $\eta_{s's}$ is the elasticity of substitution between origins of good s' used in the production of good s.

2.4 Equilibrium in Levels

Utility maximization subject to the budget constraint implies that each firm faces standard CES demands:

$$q_{is'j} = a_{is'} [p_{is'} \tau_{is'j} (1 + t^e_{is'j})]^{-\sigma_{s'}} I_{s'j} \, {P^c_{s'j}}^{(\sigma_{s'}-1)} \tag{2}$$

in which $p_{is'}$ is the price of a good from sector s' produced in country i, $I_j = \sum_i q_{is'j} p_{is'j}(1 + t^e_{is'j})$ is country j's income and $\overset{c}{P}_{s'j}= \left(\sum_i a_{is'}[p_{is'j}(1 + t^e_{is'j})]^{(1-\sigma_{s'})}\right)^{\frac{1}{(1-\sigma_{s'})}}$ is a standard CES consumer price index.

Cost minimization subject to production technology constraints implies that:

$$m_{is'js} = b_{is's}[p_{is'}\tau_{is'j}(1 + t^e_{is'j})]^{-\eta_{s's}} E_{s'js}\ \overset{\pi}{P}_{s'js}^{(\eta_{s's}-1)} \tag{3}$$

in which w_j is the wage in j, $E_{s'js} = \sum_i m_{is'js} p_{is'j}(1 + t^e_{is'j})$ is the expenditure of sector s firms in country j with sector s' inputs and $\overset{\pi}{P}_{s'js}= \left(\sum_i b_{is's}[p_{is'j}(1 + t^e_{is'j})]^{(1-\eta_{s's})}\right)^{\frac{1}{(1-\eta_{s's})}}$ is the appropriate index of intermediate goods. The price of the input bundle is a Cobb-Douglas aggregation of the wage rate and the price of intermediate inputs:

$$p_{is'} = \frac{(w_i)^{\gamma_{i,Ls'}}}{A_{is'}} \prod_k (\overset{\pi}{P}_{kis})^{\gamma_{kis}} \tag{4}$$

Market clearing implies that the consumer balance equalizes expenditure with final goods I_j to the wage bill plus revenues from carbon taxes obtained from the consumption of intermediates:

$$I_j = \sum_s w_j L_{js} + \sum_{i,s',s} p_{is'j} m_{is'js} t^e_{is'j} + D_j \tag{5}$$

in which D_j is an exogenous and fixed deficit for each country, with $\sum_j D_j = 0$.[12]

Market clearing also implies that in the producer balance expenditure with intermediate inputs and wages $E_{js} = \sum_{s'} E_{s'js}$ is equal to the revenue obtained from domestic and foreign sales:

$$E_{js} = \sum_i \left(p_{jsi} \left(q_{jsi} + \sum_{s'} m_{jsis'} \right) \right) \tag{6}$$

By summing (5) and (6) we obtain the country trade balance, where taxes cancel out because they are domestic:

$$\sum_{i,s'} p_{is'j} q_{is'j} + \sum_{i,s',s} p_{is'j} m_{is'js} = D_j + \sum_{i,s} \left(p_{jsi} \left(q_{jsi} + \sum_{s'} m_{jsis'} \right) \right) \tag{7}$$

Last, labor market clearing in each country implies that:

[12]Notice that carbon taxes obtained from imports of final goods are absent from the expression (5) as they are both paid by consumers and rebated lump-sum to them.

$$\sum_s \gamma_{j,Ls} \frac{E_{js}}{w_j} = L_j \tag{8}$$

We define an equilibrium under carbon taxes $\{t_{is'j}\}$ as a set $\{q_{is'j}, m_{is'js}, p_{is}, I_j, E_{js}, w_j\}$ that satisfies equilibrium conditions (2), (3), (4), (5) and (6) for all i, j, s' and s.

2.5 Equlibrium in changes

In order to take the model to the data, we use Dekle et al. (2007)'s "exact hat algebra", which is now standard in the literature. This involves re-writing variables as linear changes from the baseline. In what follows, a baseline version of a variable x is denoted by x^B. The proportional change is then given by $\tilde{x} = x/x^B$. Observe that this procedure has the advantage of eliminating the parameters that are hard to observe in the data, such as preference shifters $a_{is'}$ and $b_{is's}$, productivity shifters A_{js} and iceberg trade costs $\tau_{is'j}$, thus simplifying the quantitative analysis. It also implies that the model perfectly matches the global pattern of trade and production described by the data in the baseline.

Following this procedure, changes in the demand for final goods, the demand for inputs, price indexes, and ex-factory prices are given by:

$$\widetilde{q}_{is'j} = \widetilde{I}_{s'j}[\widetilde{p}_{is'}(1 + t^e_{is'j})]^{-\sigma_{s'}} \; \widetilde{\overset{c}{P}}_{s'j}^{(\sigma_{s'}-1)} \tag{9}$$

$$\widetilde{\overset{c}{P}}_{s'j} = \left(\sum_i [\widetilde{p}_{is'}(1 + t^e_{is'j})]^{(1-\sigma_{s'})} \left(\frac{q^B_{is'j} p^B_{is'j}}{I^B_{s'j}} \right) \right)^{\frac{1}{(1-\sigma_{s'})}} \tag{10}$$

$$\widetilde{m}_{is'js} = \widetilde{E}_{s'js}[\widetilde{p}_{is'}(1 + t^e_{is'j})]^{-\eta_{s's}} \; \widetilde{\overset{\pi}{P}}_{s'js}^{(\eta_{s's}-1)} \tag{11}$$

$$\widetilde{\overset{\pi}{P}}_{s'js} = \left(\sum_i [\widetilde{p}_{is'j}(1 + t^e_{is'j})]^{(1-\eta_{s's})} \left(\frac{m^B_{is'j} p^B_{is'js}}{E^B_{s'js}} \right) \right)^{\frac{1}{(1-\eta_{s's})}} \tag{12}$$

$$\widetilde{p}_{js} = \widetilde{w}_j^{\gamma_{j,Ls}} \prod_{s'} \widetilde{\overset{\pi}{P}}_{s'js}^{\gamma_{s'js}} \tag{13}$$

Changes in the market clearing conditions are given by:

$$\widetilde{I}_{s'j} = \sum_{s} \widetilde{w}_j \widetilde{L}_{js}(w_j^B L_{js}^B) + \sum_{i,s',s} \widetilde{p}_{is'} \widetilde{m}_{ijs's} t_{ijs'}^e (p_{is'j}^B m_{is'js}^B) + D_j^B \tag{14}$$

$$\widetilde{E}_{js} = \sum_{i} \left(\widetilde{p}_{js} \widetilde{q}_{jsi}(p_{jsi}^B q_{jsi}^B) + \sum_{s'} \widetilde{p}_{js} \widetilde{m}_{jsis'}(p_{jsi}^B m_{jsis'}^B) \right) \tag{15}$$

$$\sum_{s} \frac{\widetilde{E}_{js}}{\widetilde{w}_j} L_{js}^B = L_j \tag{16}$$

In Appendix C, we show that the model expressed in changes can be reduced to a parsimonious $N \times S$ system that we use to explore the consequences of climate policies and international transfers that account for distributional concerns.

2.6 International Transfers

A main goal of our analysis is to quantify international monetary transfers that could be used to balance the costs involved in the widespread adoption of climate policies. In this subsection, we explain how we formally introduce such transfers in the theoretical framework outlined above.

First, notice that domestic real income is given by total expenditure with final goods deflated by the domestic consumer price index. Hence, the associated real income changes are defined by:

$$\tilde{W}_j = \frac{\widetilde{I}_j}{\Pi_{s'} \widetilde{P}_{s'j}^{\beta_{s'j}}} \tag{17}$$

We use this measure of real income to solve for two types of contribution schemes. First, an "equal-cost" scenario, which makes sure that the adoption of a global carbon tax leads to uniform real income changes across countries irrespective of their present-day relative contribution to total GHG emissions. Second, a "historic polluter pays" transfer scheme that ensures that the real income costs of climate policies are proportional to the country's cumulative GHG emissions since the onset of the Industrial Revolution. Next, we provide more details on how we formally model both types of schemes.

Equal Cost Transfers We define international transfers as an exogenous income source at the country level, T_j. In the "equal cost transfer" case, we compute transfers paid or received such that the real income changes induced by the carbon tax are equalized across countries. Formally, we want to solve the general equilibrium such that:

$$\widetilde{W}_j = \widetilde{W} \tag{R1}$$

$$\sum_j T_j = 0 \tag{R2}$$

Restriction (R1) implies that cross-country real income changes that results from the adoption of a global carbon tax are the same. Restriction (R2) is a zero-sum condition that makes sure that transfers are balanced. By rewriting R1 we can explicitly solve for each country's equal cost transfer:

$$T_j = H_j \frac{\sum_j G_j}{\sum_j H_j} - G_j \tag{18}$$

where $H_j = \left(I_j^B \times \Pi_{s'} \widetilde{P}_{s'j}^{\beta_{s'j}} \right)$ and $G_j = \sum_s w_j L_{sj} + \sum_{is'} p_{is'j} q_{is'j} t^e_{is'j} + \sum_{is's} p_{is'j} m_{is'js} t^e_{is'j} + D_j$. To back out T_j in this case, we add (18) as a fixed point to the algorithm described in Appendix C together with condition (R2).

Historic polluter-pays transfer For this type of contribution scheme, we want to compute country-level international transfers T_j that are proportional to historical emissions of GHG in each country. We achieve this by solving the general equilibrium such that:

$$(\widetilde{W}_j - 1) W_j^B = \Gamma \left[\frac{Z_j}{\sum_j Z_j} \right] \tag{R3}$$

$$\sum_j T_j = 0 \tag{R4}$$

where W_j^B is a measure of real income in the baseline, Z_j are historical greenhouse gas emissions in country j and Γ is an endogenous proportionality factor. Restriction (R3) implies that changes in real income are proportional to the share of historical emissions in each country. Restriction (R4) is a zero-sum condition as before. Again, we can use the two conditions to explicitly solve for transfers T_j:

$$T_j = H_j - G_j + \Omega_j^B H_j \frac{\sum_j (G_j - H_j)}{\sum_j \Omega_j^B H_j} \tag{19}$$

where G_j and H_j are defined as before and $\Omega_j^B = \left[\frac{Z_j}{\sum_j Z_j} \right] \frac{1}{C_j^B}$. Notice that the zero-sum condition determines the proportionality factor:

$$\Gamma = \frac{\sum_j (G_j - H_j)}{\sum_j \Omega_j^B H_j} \tag{20}$$

To back out transfers in this case, we add expressions (19) and (20) as a fixed point to the algorithm described in the Appendix C.[13]

3 Data

This section describes the data sources, the data treatment, and the calibration of the parameters.

3.1 Data sources

Data on production, consumption, and trade flows come from the OECD Inter-Country Input-Output (ICIO) tables (OECD, 2023). The ICIO tables report data on intermediate input use, final demand, consumption expenditure of various accounting units, value-added and gross output in 45 distinct sectors for 67 countries, including a Rest of the World aggregate, from 1995 to 2018. The model is calibrated with trade, production and emissions data in 2018. We use the remaining years to back out some key parameters of the model, as we explain below. We combine this data with estimates of the labor force from the World Bank (WB, 2024).

Data on greenhouse gas emissions in CO_2 equivalents are constructed by combining three different datasets: the OECD Carbon Dioxide Emissions Embodied in International Trade dataset (TECO2) (OECD, 2021), the FAOSTAT Domain Emission Totals (FAO, 2023), and the European Commission's Emissions Database for Global Atmospheric Research (EDGAR) (European Commission, 2023). The TECO2 dataset is constructed by combining the ICIO tables with the International Energy Agency's database on Greenhouse Gas Emissions from Energy (IEA, 2024). It provides CO_2 emissions from fuel combustion in production of the 45 sectors and 67 countries of the ICIO for the period 1995 to 2018. To extend the emissions coverage and include non-energy-related emissions, we make use of the CO_2, CH_4 and N_2O emissions from the two remaining datasets: we use the FAO data for emissions from

[13] Since we cannot observe sector-level price indexes in the data, we use consumption data in the baseline to solve for transfers in the "historical polluter pays" scheme. As shown in Figure 33, this procedure leads as intended to a counterfactual equilibrium in which carbon taxes and transfers imply a perfect correlation between changes in real income and the historical cross-country pattern of GHG emissions.

agriculture, forestry, and land-use,[14] and the EDGAR database[15] for emissions from industrial processes and product use as well as fugitive emissions. We describe how we combine the datasets in detail in the Appendix under section A. Section B in the Appendix provides a description of changes in emissions by gas and by source between 1995 and 2018.

Figure 1 shows the total emissions intensities by sector. The y-axis shows all sectors in the final data set, where we group all the services sectors for readability. The x-axis shows the total emissions intensity of a sector in tons of CO_2e across countries. There are two main takeaways. First, there is large variation in total emission intensities across sectors. Water and air transport, the agricultural sector, the mining sectors, energy, and raw materials are among the most polluting sectors. Second, there is a large variation in total emission intensities across different countries. Notice this variation is more pronounced for highly carbon intensive sectors, as energy and agriculture.[16]

3.2 Calibration

There are three key parameters in the model that require calibration, all of which are internally calibrated using data from the year 2018.

First, the elasticity of substitution across origins in consumption and intermediate input use. We assume $\sigma_{s'} = \eta_{s's} = \eta_{s'}$ and estimate it following the method described by Caliendo and Parro (2015). To ensure robustness, we provide two alternative specifications: one based on the method described in Fontagné et al. (2022), and another directly using the elasticities provided by Fontagné et al. (2022), mapped to our industry classification. Table 1 in the Appendix show the results. Elasticity estimates fall within the usual range observed in the literature.

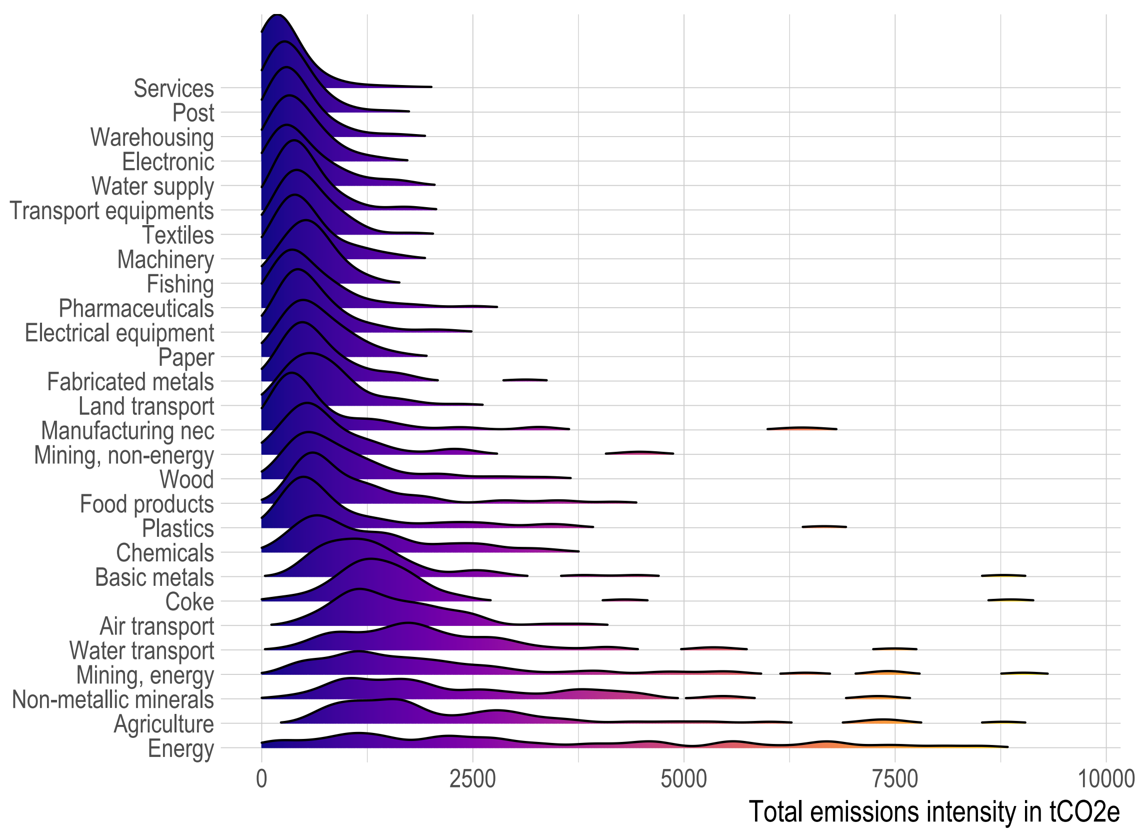
Second, we calibrate the Cobb-Douglas utility parameters (expenditure shares) $\beta_{s'j}$. These parameters are determined from the data as the ratio of consumption expenditure to total expenditures. Third, we calibrate the Cobb-Douglas production function parameters. The expenditure shares $\gamma_{s'js}$ are calibrated from the data as the ratio of intermediate input expenditures to gross output. Additionally, the

[14]The FAO dataset contains estimates of GHG emissions computed at Tier 1 following the IPCC Guidelines for National GHG Inventories. It includes estimates of 16 emission categories for 191 countries from 1961 to 2019.

[15]The EDGAR dataset reports among other substances direct GHG calculations of 35 IPCC emissions categories for 232 countries from 1970 until 2018.

[16]Plotting the density of the emissions intensity in % deviation from the sectoral mean in Figure 30 in the Appendix, we can observe a positive skew. That means that there are a few countries that have a much higher emission intensity than the average country in a given sector.

Figure 1: Total Emissions Intensity Across Sectors



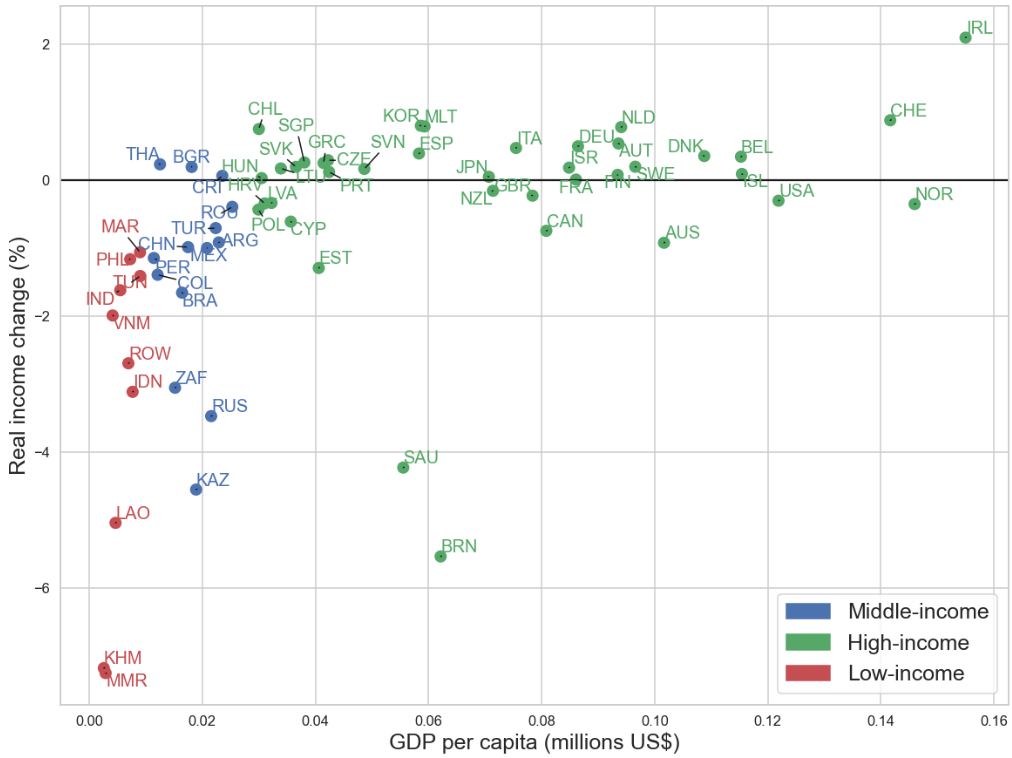
labor share parameter $\gamma_{j,Ls}$ is calibrated as the value added in gross output.

4 Results

4.1 Carbon taxes

We begin by presenting the results for the counterfactual scenario of a 100 USD/tCO_2e carbon tax, focusing first on its macroeconomic impacts. Overall, the carbon tax is highly effective at reducing emissions while imposing relatively modest economic costs. Under our benchmark policy, global emissions decrease by 28%, real incomes decline by 0.7%, and global gross output falls by 0.5%. Notably, the share of output traded internationally remains constant at 13%, underscoring the crucial role of international trade in mediating the distributional effects of carbon pricing. This highlights the critical role of international trade in shaping the distributional effects of carbon pricing, as policy responses

Figure 2: Real income changes



Note: This figure illustrates the changes in real income across countries following the implementation of carbon taxes, categorized by GDP per capita levels.

depend on firms and consumers leveraging access to international markets.[17]

4.1.1 Country effects

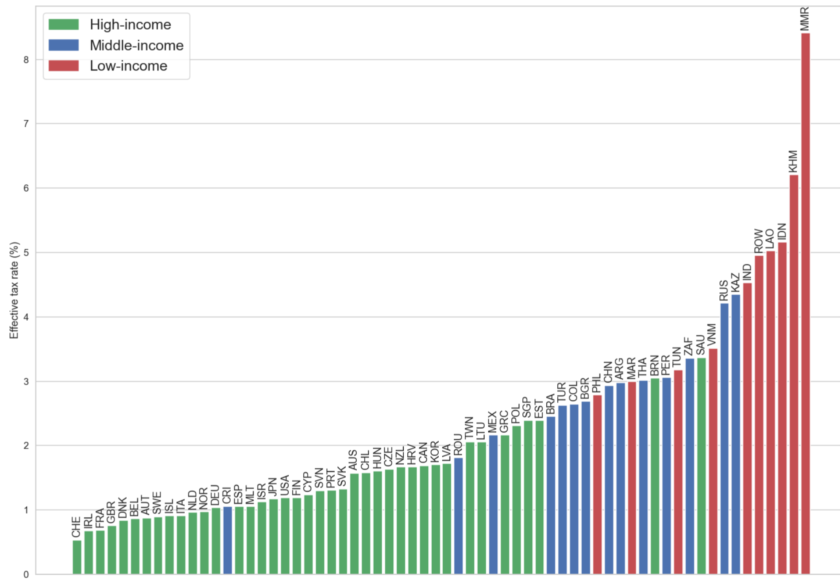
The macroeconomic effects, however, conceal significant heterogeneity across countries. Figure 2 illustrates the real income changes for each country relative to their GDP per capita.[18] The figure reveals that most low- and middle-income countries experience substantial declines in real incomes, whereas many high-income countries achieve real income gains. This disparity arises from the disproportionate carbon tax burden borne by low- and middle-income markets.

Figure 3 further highlights this discrepancy by displaying the effective tax rate, calculated as the total tax paid by producers and consumers in a country divided by the country's total expenditure. The data show that effective tax rates in high-income countries typically range between 1–2%, while in low-income countries, they can reach up to 8%.

[17] As shown in Le Moigne et al. (2024), within a similar framework, over one-third of the emission reductions from a carbon tax are driven by the environmental gains from trade, as countries reallocate production in line with their environmental comparative advantage.

[18] Section 6.2 provides results for real income changes under a producer tax instead of a consumer tax.

Figure 3: Effective tax rate



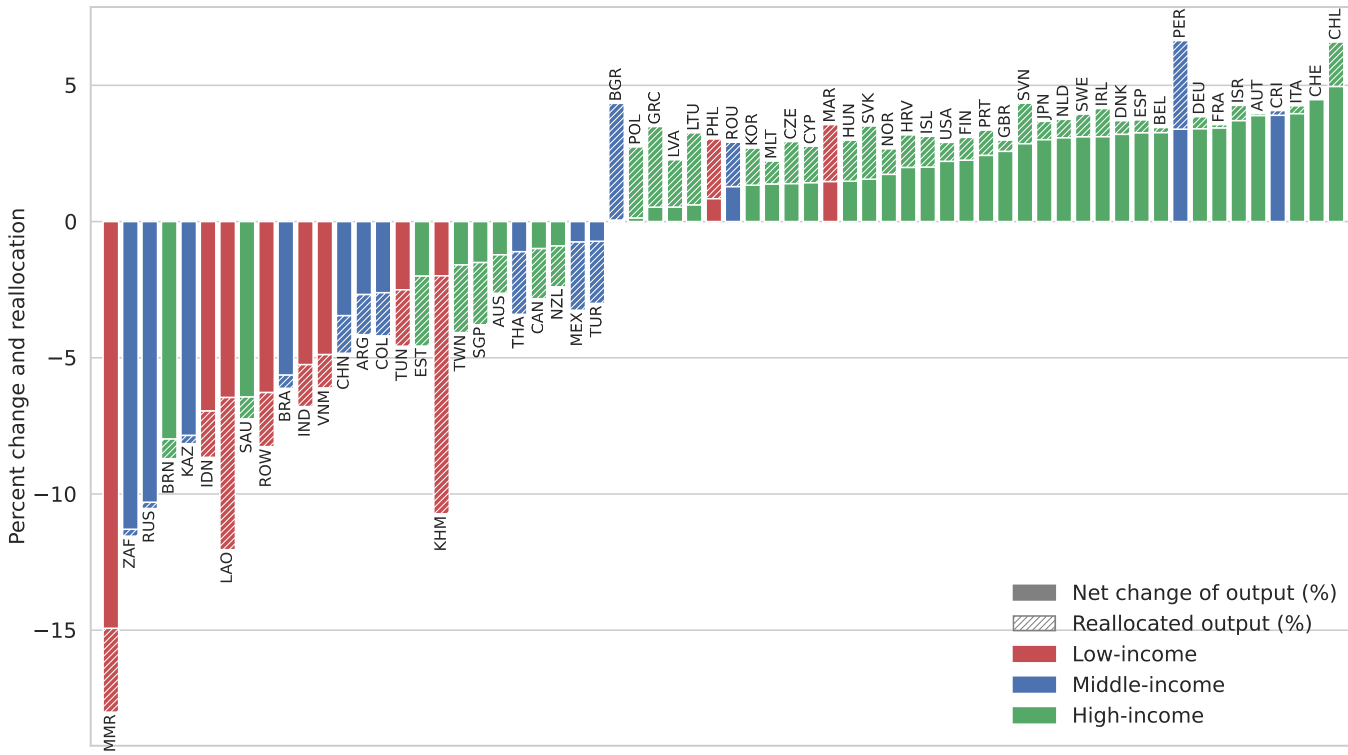
Note: This figure displays the effective carbon tax rates across countries, grouped by income levels. The tax rates are calculated as the total tax burden (combining producer and consumer taxes) divided by the total national expenditure.

We further investigate the impact of the carbon tax on different countries by examining the reallocation of economic output across nations. Figure 4 illustrates the net change in output alongside the percentage of reallocated output. The total output decrease across all sectors in a country is represented by the sum of the two bars, with the hatched orange bar indicating the total output increase across all sectors. The blue bar reflects the net change in output, while the hatched orange bar represents the reallocated output.

Our findings reveal that low- and middle-income countries not only experience the largest decreases in net output but also undergo more significant reallocation of their output. Most low- and middle-income countries in our sample see a decline in gross output, while high-income economies typically experience either net zero changes or net gains. These substantial reallocation effects highlight that the sectoral composition of low- and middle-income countries is less aligned with environmental comparative advantages (Le Moigne et al., 2024). Consequently, the carbon tax imposes greater adjustments on these countries, not only in terms of income losses but also in the redistribution of resources across sectors.

Beyond these domestic reallocation effects, carbon taxes lead to profound changes in cross-country patterns of international trade. To illustrate this, Figure 5 depicts changes in trade flows across countries.

Figure 4: Within Country Output Reallocation

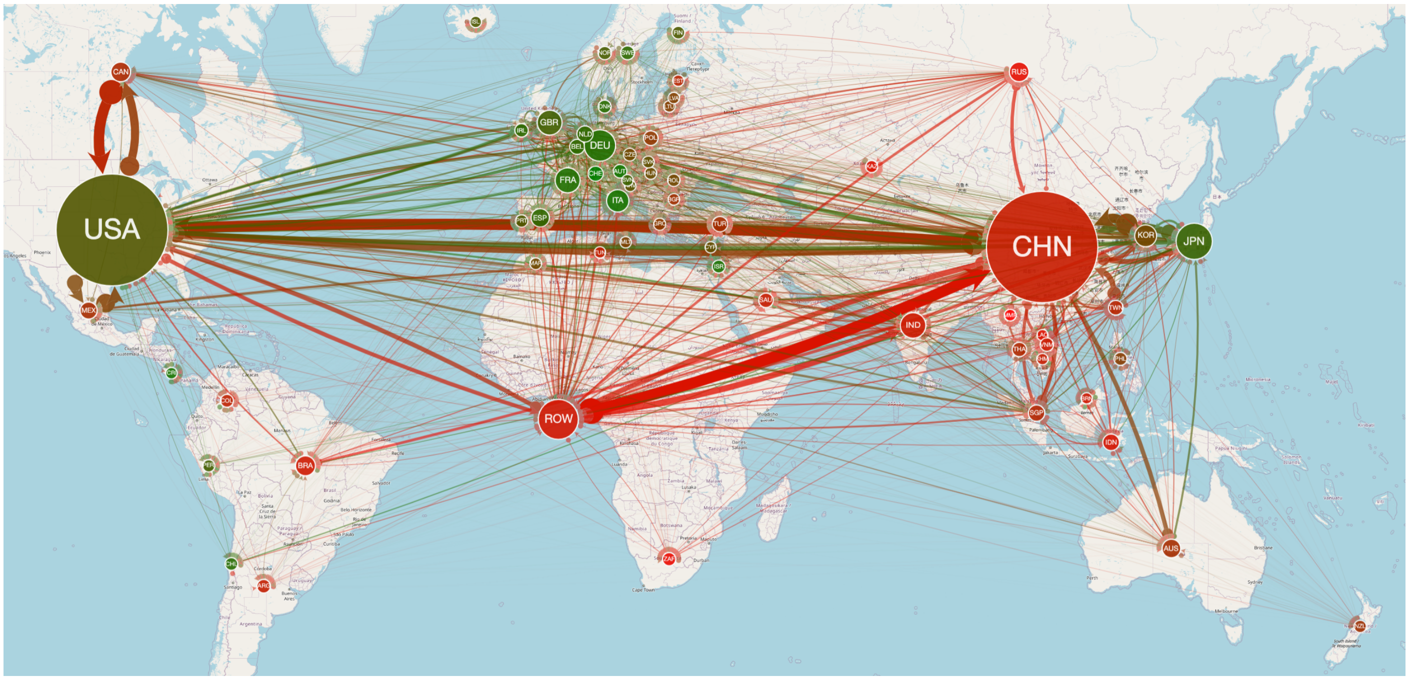


Note: This figure illustrates the economic impact of carbon taxes on different countries, categorized by their income levels. It displays the net change in output as well as the reallocation of output across sectors within each country. The sum of the two bars represents the total output decrease in all sectors in a country, the hatched orange bar represents the total output increase in all sectors. Thus, the blue bar is the net change in output and the hatched orange bar is the reallocated output.

The size of each country node represents the total output volumes traded (exports) in 2018. The color of the nodes represents the change in exports relative to the 2018 baseline and relative to the median decline. This latter precision is important to understand the graph: overall the model prescribes a decline in production and trade, so that most trade flows decline. The comparison to the median (in white) allows us to identify countries whose exports increase or decrease less than the median (in green) from countries whose exports are relatively more affected by the tax (in red). The size of the edge (arrow in between country pairs) represents the volumes of trade from a given exporter (indicated by a nodule) to a given importer in the data in 2018. The color of the edge represents the change in export volumes relative to the baseline and relative to the median. Overall, trade in high-income countries, such as the United States, Europe, and Japan, increases relative to the median change in trade patterns in response to the carbon tax. In contrast, trade decreases in low- and middle-income countries, such as China, reflecting that the uneven impact of the tax on global trade is correlated with income levels.

Changes in global trade are driven not only by shifts in consumption patterns, but also by ad-

Figure 5: Micro effects of carbon taxes: All sectors

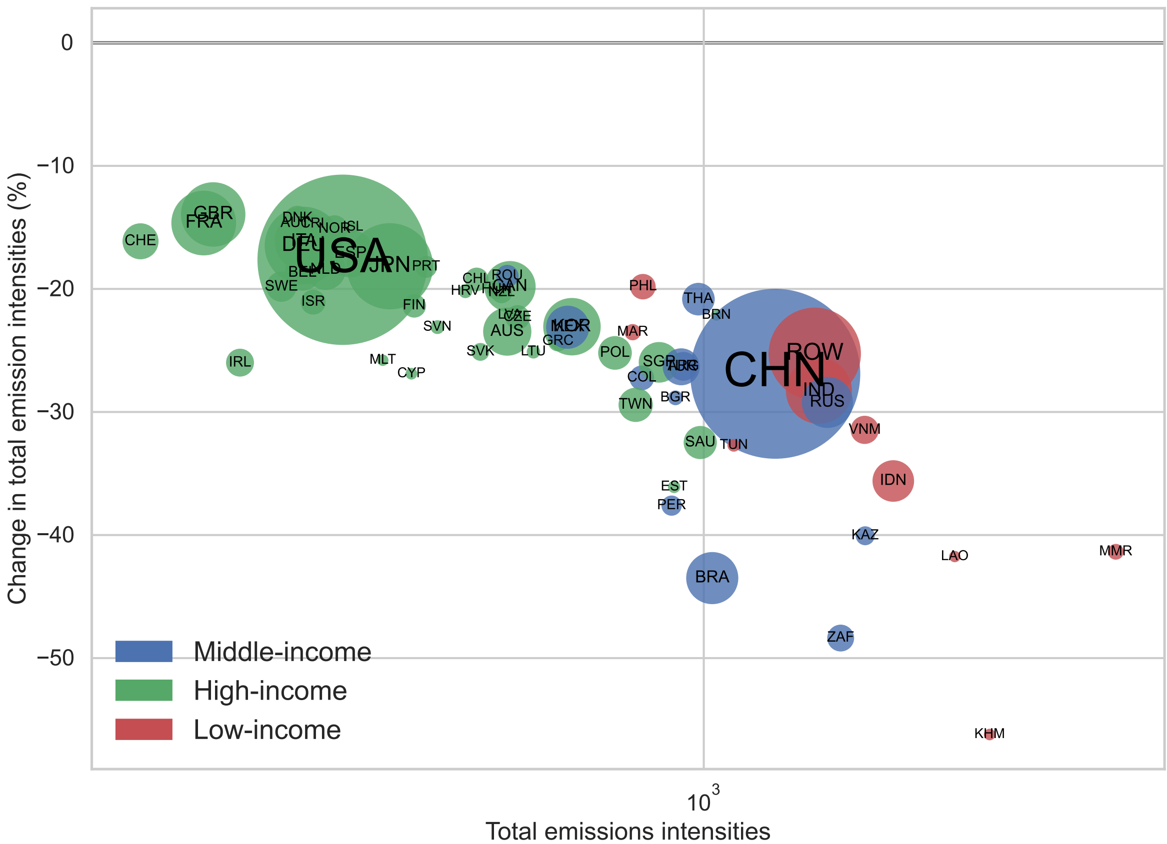


justments firms make to reduce the emission intensity of their production, primarily through building cleaner supply chains. Figure 6 highlights these firm-level adjustments by showing the average changes in total emission intensities across sectors along the supply chain following the implementation of a 100 USD/tCO_2e carbon tax. Notably, all countries achieve a reduction in carbon intensity of 10% or more, demonstrating the widespread impact of the tax. Low- and middle-income countries, in particular, exhibit a stronger response to taxation, with emission intensities decreasing more in these regions compared to high-income countries.

4.2 Transfers

In this section, we explore international transfer schemes designed to compensate countries that incur losses from climate action. As shown in the previous section, developing countries disproportionately bear the economic burden of climate change mitigation policies. We demonstrate that moderate monetary transfers between countries can effectively redress this imbalance, ensuring a more equitable distribution of costs.

Figure 6: Change in Total Emissions Intensities



Note: This figure illustrates the average changes in total emission intensities across sectors following the implementation of a 100 USD/tCO_2e carbon tax. See Footnote 12 for a description of the formula used to calculate total emission intensities, which account for both direct emissions at the final production stage and cumulative emissions from all intermediate steps along the supply chain.

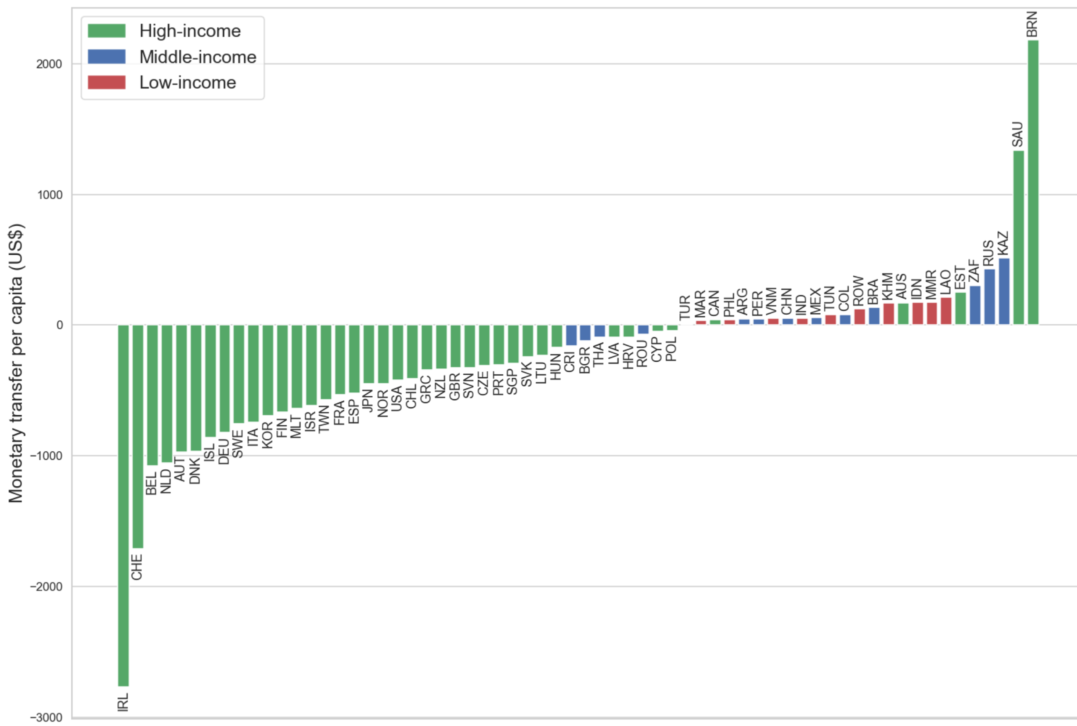
4.2.1 Equal Cost Transfers

Our first scenario is an "equal-costs" type of transfer, in which the goal is to perfectly equalize the real income costs of climate action.[19] While this scenario does not fully implement the CBDR principle, as it does not account for differentiated responsibilities, it does ensure that at least low and middle-income countries do not bear the bulk of the economic costs.

The results indicate that pairing the global common carbon tax with monetary transfers significantly smoothens its overall impact compared to a scenario without transfers. While the reduction in global emissions remains the same (–28%) and the aggregate real income cost is identical (–0.7%), the gross output decline is lower (–2.1% compared to –2.6% previously). Furthermore, real income changes are uniformly negative but remain below 1% for all countries, ensuring that the economic burden is distributed equally, regardless of each country's relative contribution to the climate crisis.

[19] We show results for the equal cost transfers with a producer instead of a consumer tax in section 6.2.

Figure 7: Equal Cost Transfers by Country



To equally split the costs of the carbon tax, fair transfers need to allocate resources according to countries' income levels. This can be seen in Figure 7, which displays per capita transfers (in dollars) for all countries in the sample. A negative transfer represents an international side payment, while a positive one is an additional income source. Notice that with the exception of the two outliers that are Bahrain and Saudi Arabia,[20] the figure demonstrates that high-income countries generally need to provide monetary transfers to low- and middle-income countries to balance the economic burden of a global carbon tax. The largest contributors are European countries and the U.S., whereas the largest beneficiaries include Kazakhstan, Russia, South Africa, and Southeast Asian countries.

To put our results in perspective, it is useful to compare them with real-world commitments of high-income countries for meaningful mitigation actions in low- and middle-income regions. For instance, at the 15th Conference of Parties (COP15) of the UNFCCC in Copenhagen in 2009, high-income countries

[20]While being already quite rich, Bahrain and Saudi Arabia are heavily penalized by the carbon tax as their main economic activity is oil production (albeit with the greenest emission intensities in the data for the sectors of mining and energy). Since our scenario only cares about making the economic cost of the tax equal across countries and ignores entirely geopolitical considerations, they become large beneficiaries of such transfers.

committed to a collective goal of mobilizing $100 billion per year by 2020. According to a monitoring report of the OECD, a total of USD 83.3 billion in climate finance was provided and mobilized by high-income countries in 2020, falling short of the pledged amount (OECD, 2022).

In comparison to the "USD 100 billion per year" pledge of successive COPs, our model indicates that, under a global carbon tax, the transfers required to equalize the economic costs of climate action across countries amount to USD 272 billion. While this figure is three times larger than the latest pledge, the burden on the population of developed countries remains relatively modest. The highest per capita transfers would be paid by Ireland at approximately USD 2,000 per person per year, followed by Switzerland at around USD 1,400 per person per year. For other EU member states and the U.S., the annual per capita contribution does not exceed USD 1,000. Conversely, because poorer countries typically have larger populations, the per capita transfers they receive are lower—for example, USD 600 for Kazakhstan and less than USD 200 for Laos and Indonesia. The equal-costs scenario suggests that, even without accounting for historical emissions, achieving socio-economic equality in the context of optimal climate action is attainable with relatively modest transfers.

4.2.2 Historical Polluter-Pays Transfers

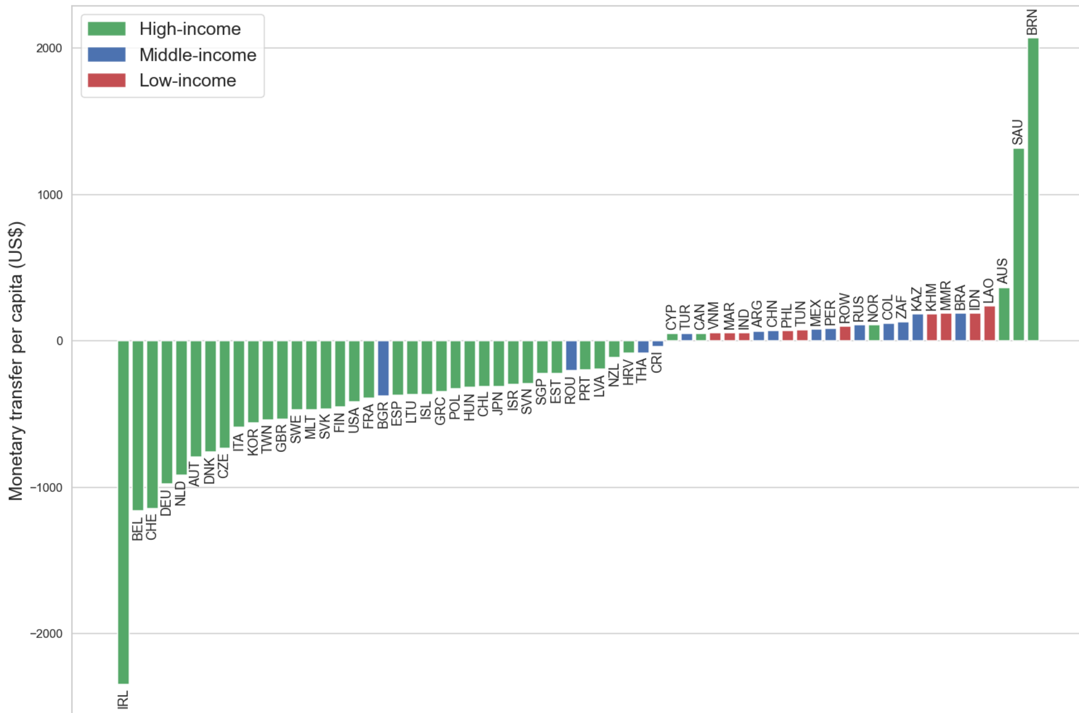
We now examine the international monetary transfers required under a polluter-pay scheme. This approach ensures that the real-income costs borne by each country are proportional to their historical contribution to global cumulative emissions.[21] In this case, transfers align economic costs with historical emissions.[22] For example, under this scheme the U.S. bears 25% of the aggregate economic costs, China bears 13%, and Brazil bears 1%, reflecting their respective contributions to total greenhouse gas emissions. Similar to the equal-costs scenario, the polluter-pay scheme leads to smoother outcomes compared to climate action without redistribution: the global reduction in emissions remains at –28%, the global real income cost stays at –0.7%, and the decline in gross output remains lower at –2.1%.

In terms of transfers, three key points emerge. First, the total amount of transfers required under the polluter-pays scenario is slightly lower than in the equal-cost scenario, amounting to USD 255.7

[21]Figure 31 in the Appendix displays historical cumulative emissions per capita for each country, based on data from Ritchie (2019). The data show that countries with the highest GDP per capita are also responsible for the largest share of historical emissions per capita, while low-income countries have historically contributed very little. Additionally, Figure 32 in the Appendix shows that the U.S. accounts for approximately 25% of cumulative historical emissions, followed by China at around 14%.

[22]Figure 33 in the Appendix illustrates the resulting perfect correlation between changes in real income and each country's share of cumulative historical emissions.

Figure 8: Historical Polluter Pays Transfers by Country



billion. This reduction reflects the focus of the equal-cost scenario on equalizing economic costs across countries, whereas the polluter-pays scenario accommodates unequal economic costs based on historical emissions. Consequently, per-capita transfers are also lower, with the maximum amount required now less than USD 2,000 per person per year, still paid by Ireland.

Second, the distribution of transfers remains consistent, with high-income countries as net payers and low- and middle-income countries as net receivers, as illustrated in Figure 8. There is a clear positive correlation between current per-capita GDP and historical contributions to global cumulative emissions. This alignment is unsurprising, as countries that reaped the benefits of the Industrial Revolution began emitting GHG in the 19th century and now enjoy the highest levels of development.

Third, the differences in the distribution of transfers implied by the equal-costs and by the polluter-pays scenarios (comparing Figures 7 and 8) are revealing of countries' current and historical responsibilities in climate change. Countries that ought to pay a transfer in the equal costs world remain payers in the polluter-pays scenario, but their relative contributions change, to reflect individual countries' weight in historical emissions. For example, France's effective transfer per capita is now lower than that of Great Britain, because France's historical energy sector has focused on carbon-neutral nuclear power, while Great Britain's energy mix has been historically borne by coal and later oil and gas.

Similarly, receiving countries in the equal-costs scenario remain so in the polluter-pays scenario, albeit receiving different amounts. This is for example the case of Russia: because Russia is a large producer of natural gas (which belongs in our data to the energy sector, one of the sectors with the highest emission intensity), it is heavily penalized by the carbon tax (see Figure 3, Russia has an effective tax rate of 6% when the global carbon tax is set at \$100/tCO_2e). In the equal costs scenario, Russia received transfers of \$404 per capita, in order to bring its real-income cost to par with other countries. Russia is, however, also a historical polluter so that in the polluter-pays scenario, its effective per-capita transfers are decreased to less than \$80 per person per year. The opposite is true of Brazil: Currently, the third largest exporter of agricultural products globally, Brazil's real income loss in response to a \$100/tCO2 without redistribution is relatively high (–1.8%, to be compared to the global cost of –0.7%). In the equal-costs scenario, this implies that Brazil receives per capita transfers of \$115. However, Brazil only recently started to contribute to cumulative emissions (albeit at an accelerating rate, with a current contribution of 1%). This is taken into account in the polluter-pays scenario so that Brazil receives per capita transfers of \$170 in this case.

5 Heterogeneous Carbon Pricing

In this section, we examine the implications of heterogeneous carbon pricing schemes, where countries adopt varying levels of carbon taxation. These schemes are often considered more politically feasible, as they circumvent the need for universal coordination and mitigate the risk of free-riding. Rather than analyzing strategic incentives, we focus on evaluating the distributional impacts of these schemes by comparing them to a global policy benchmark. Our analysis centers on two prominent policy options currently shaping the policy debate: (i) a unilateral carbon pricing scheme implemented by a select "club" of countries, complemented by a carbon border adjustment mechanism, and (ii) heterogeneous carbon prices based on income levels, as proposed by the International Monetary Fund (IMF) (Parry et al., 2021).

When investigating each scenario, we focus on the following question: does the proposed scheme introduce more or less fairness between the economic North and the economic South? Our analysis benchmarks these policies against a counterfactual scenario that achieves the same level of emissions reduction through a global carbon tax paired with "equal costs" transfers. By holding the emissions reduction constant, we can isolate the impact of price heterogeneity on fairness, by comparing the required transfers, and on efficiency, by evaluating the associated real income costs.

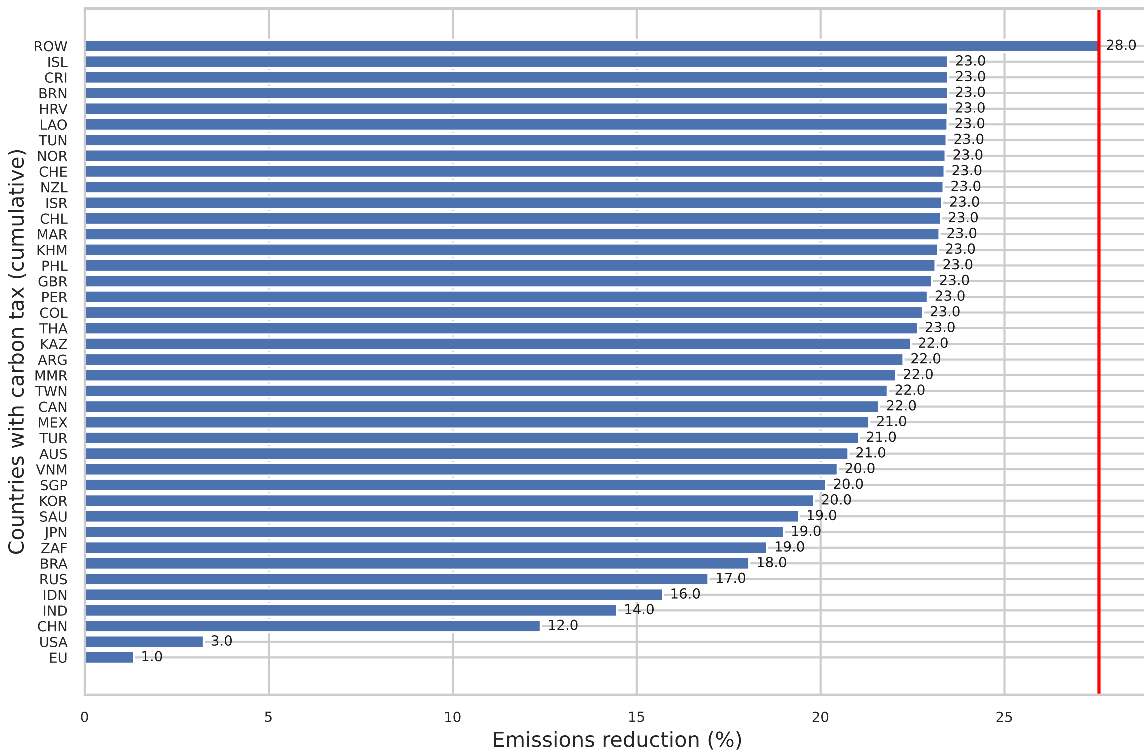
5.1 Climate Club with a Carbon Border Adjustment Mechanism

To model the scenario of a climate club with a carbon border adjustment mechanism, we draw on the structure of the European Union's Emissions Trading Scheme (ETS) and Carbon Border Adjustment Mechanism (CBAM). The CBAM was conceived as a complement to the ETS to preserve the competitiveness of European companies in a context where the EU imposes a unilateral carbon price on its producers. In essence, the ETS functions as a producer tax, requiring European producers to purchase the right to emit GHGs during their production processes. This tax increases the cost of European goods, making them less competitive compared to imports from countries without similar carbon pricing. To address this disparity, the CBAM applies a comparable carbon price to foreign goods imported into the EU if they are not already subject to a carbon tax in their country of origin.

To assess the fairness implications of domestic carbon taxation paired with a border adjustment mechanism, we simulate the formation of a climate club comprising key players from both the Global North and South. This club includes the EU, the U.S., China, India, Indonesia, Russia, Brazil, and South Africa. Club members impose a carbon tax of 100 USD/tCO_2eq on their domestic producers while simultaneously applying a consumption tax on all imports entering their markets. This selection of countries is based on their significant contributions to emissions reductions under a uniform carbon tax, as illustrated in Figure 9. The figure shows the cumulative emissions reductions achieved as more countries adopt a carbon tax, progressing from the bottom to the top. When these key players alone implement a 100 USD/tCO_2eq tax, an 18.5% reduction in global emissions is achieved—representing two-thirds of the maximum reduction possible with global adoption. Importantly, this scenario does not include carbon pricing for the majority of low- and middle-income countries, which is a critical aspect of our discussion on the distributional consequences of the climate club.[23]

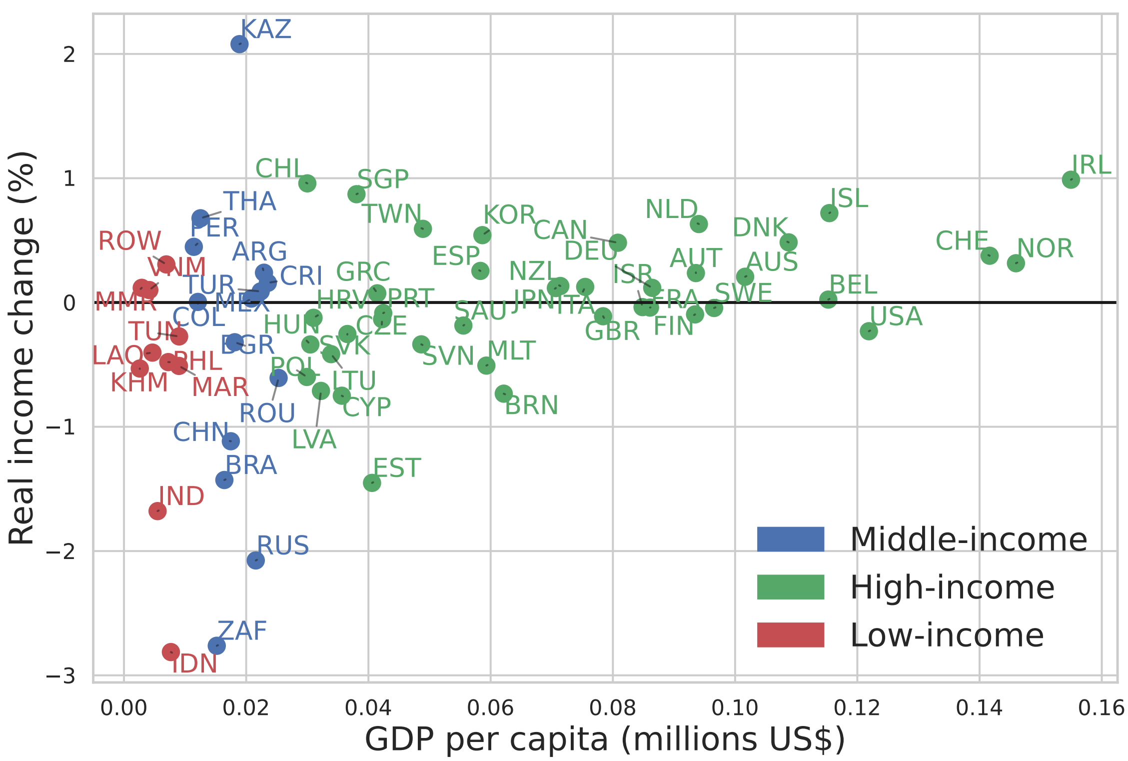
[23] We also simulate a climate club configuration limited to EU countries. In this case, the emissions reduction is only 1.4% of global emissions. This outcome reflects the relatively clean production processes already prevalent in Europe

Figure 9: Incremental Carbon Taxes



Note: This figure depicts emissions reduction when imposing a uniform carbon tax of USD100/ton of CO_2 on an incrementally larger set of countries. The x-axis depicts the emissions reduction, while the y-axis indicates which country is newly added to the scenario (from the bottom to the top).

Figure 10: Real Income Changes by Country - Climate Club



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compared to other regions and the high level of intra-EU trade, which limits additional emissions reductions.

The results indicate that a climate club comprising "key players" would impose a global welfare cost that is 10.6% higher than the scenario of a uniform global carbon tax, assuming both achieve an identical reduction in global emissions (in this case, –19%). This corresponds to a world where carbon is priced at USD 60/tCO_2eq, illustrating that such a climate club is relatively less efficient than a uniform global carbon tax. Figure 10 shows the real income changes associated with the creation of the climate club. Notably, low- and middle-income countries still disproportionately bear the costs of the policy, even though many of them are not active participants. This finding underscores the critical role of international trade and global supply chains in shaping the distributional effects of carbon policies, as income effects are heavily influenced by cross-country linkages.

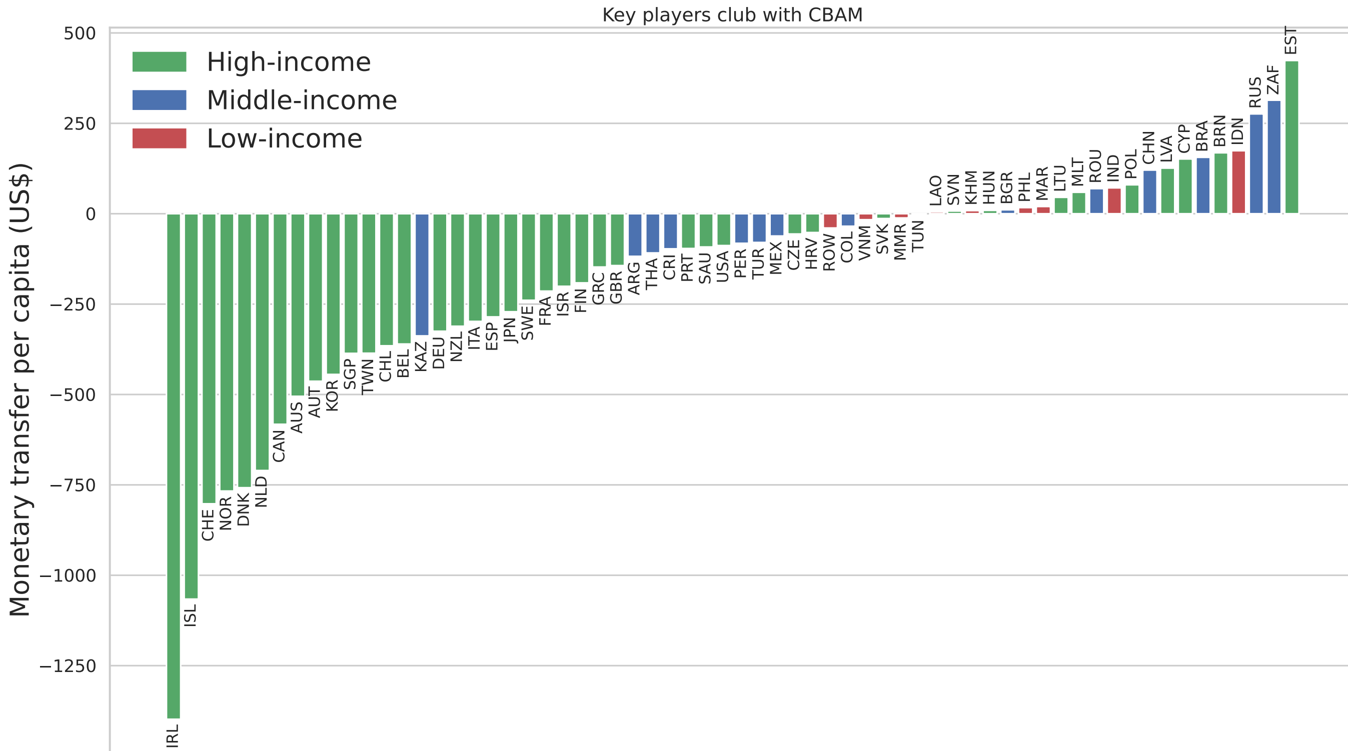
But what does the climate club imply in terms of fairness? Comparing the North-South transfers required to equalize the real income costs of carbon pricing for all countries under the climate club scenario with those under the benchmark of a uniform global carbon tax paired with "equal-cost" transfers, we find that the climate club is actually less fair. It requires transfers totaling USD 201 billion, 36% more than in the benchmark scenario. Thus, the argument that heterogeneous carbon pricing schemes are inherently fairer does not hold in this case.

Figure 11 further illustrates the associated transfers. While the majority of transfers are still made by high-income countries, many of these countries now feature as receivers. Compared to the uniform tax scenario shown in Figure 7, it is evident that the climate club alters the correlation between transfers and income levels. This is because, unlike the global tax benchmark, the climate club policy fails to adequately target cross-country and cross-sector variation in emission intensities, which, as shown earlier, are strongly correlated with income levels.

5.2 IMF International Carbon Price Floor

The International Carbon Price Floor (ICPF), proposed by the IMF in June 2021, aims to align near-term climate goals with credible policy actions (Parry et al., 2021). The proposal relies on two main components: (i) a core "club" of key large emitting countries to simplify negotiations, and (ii) a focus on establishing a minimum carbon price that each participating country must impose on their CO_2 emissions. The IMF identifies two possible configurations for the club: one comprising Canada, China, the European Union, Great Britain, India, and the United States, and another including all G20 coun-

Figure 11: Equal Cost Transfers by Country - Climate Club



tries. The proposal represents a middle ground between a global uniform carbon tax often advocated by economists and the climate club scenarios discussed earlier. The IMF calibration suggests three floor prices: USD 75/tCO_2eq for advanced economies, USD 50/tCO_2eq for high-income emerging markets (EMEs), and USD 25/tCO_2eq for low-income EMEs.

In our simulations, we analyze the two IMF-proposed scenarios (the restricted group and the G20), a scenario including our previously defined "key players," and one in which all countries participate in the ICPF according to their income levels.[24] We compare the welfare costs and the 'equal cost' transfers in each ICPF scenario with those of a global carbon tax paired with transfers that achieve the same emissions reductions.

Our results show that the ICPF scenario including only Canada, China, the European Union, Great Britain, India, and the United States results in North-South transfers that are 4.6% higher than those required by a global uniform carbon tax. Expanding the ICPF to include G20 countries reduces this difference, requiring transfers only 1.2% higher than the benchmark. When applied to "key players" and all countries, the ICPF results in lower transfer requirements, with reductions of 3.4% and 5.5%,

[24] For the all-country scenario, we use the World Bank's classification of countries by income level, available at: https://datatopics.worldbank.org/world-development-indicators/the-world-by-income-and-region.html. Figure 34 in Appendix E shows how GDP per capita relates to heterogeneous carbon prices in this scenario.

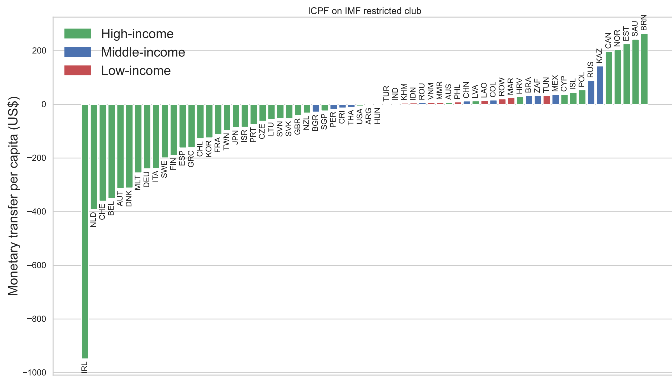


Figure 12: Equal Cost Transfers by Country - IMF Proposal - Restricted Club

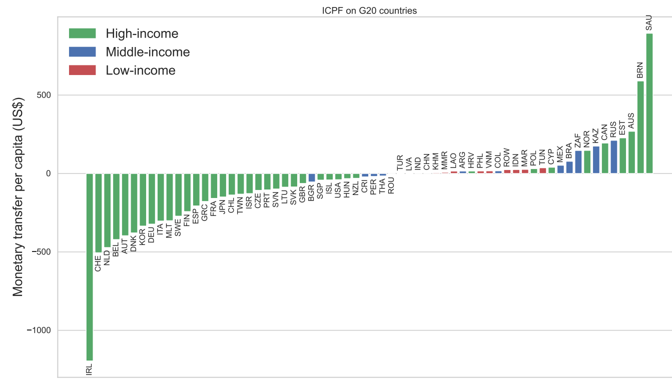


Figure 13: Equal Cost Transfers by Country - IMF Proposal - G20 Countries

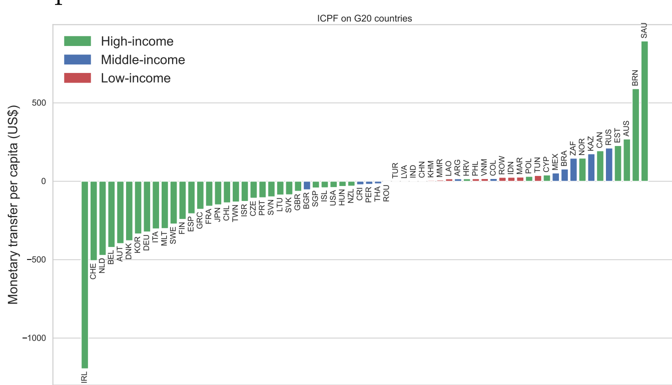


Figure 14: Equal Cost Transfers by Country - IMF Proposal - All Countries

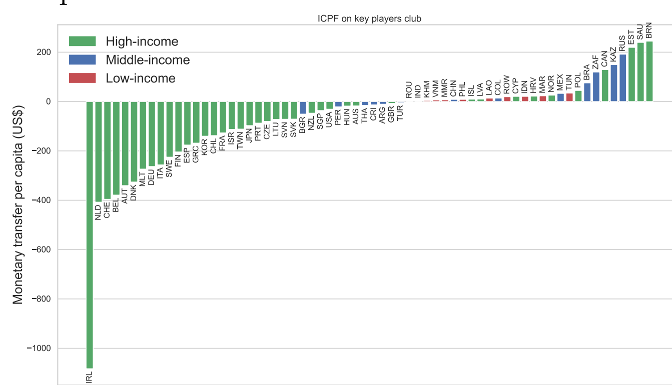
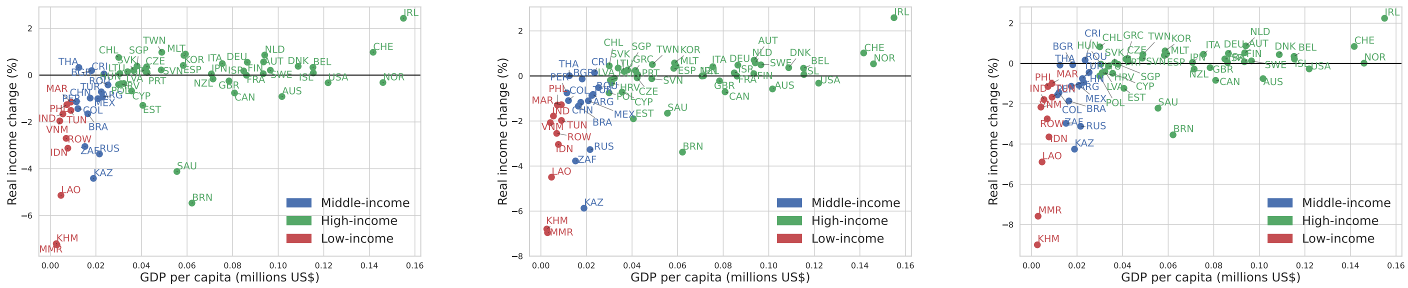


Figure 15: Equal Cost Transfers by Country - IMF Proposal - Key Players

respectively, compared to the uniform carbon tax scenario. Figures 12, 13, 14, and 15 illustrate the distribution of transfers in each scenario. Similar to the climate club case, high-income countries remain the primary payers. However, the correlation between transfers and income levels is weaker, even in the all-country scenario, as the policy does not directly address the cross-country and cross-sector variation in emission intensities.

In terms of efficiency, the restricted ICPF scenario proposed by the IMF is the least fair and least efficient among the options analyzed, with welfare costs 1.3 times higher than the uniform carbon tax benchmark (132%). The G20 scenario reduces real income costs to 50% above the benchmark, while the "key players" and all-country scenarios result in costs 67% and 12% higher, respectively. Although none of the studied ICPF scenarios surpass the efficiency of a global uniform tax with transfers, the inclusion of more countries in the scheme consistently reduces inefficiency.

Overall, our analysis suggests that the IMF proposal does not offer a clear advantage in fairness compared to a global uniform carbon tax paired with North-South transfers. Even in the best-case scenario, where all countries participate, the modest reduction in required transfers comes at the expense



(a) Caliendo-Parro estimation (b) Aggregated elasticities (c) Fontagne estimation

Figure 16: Real income Changes by Elasticity

of higher real income costs.[25]

6 Robustness

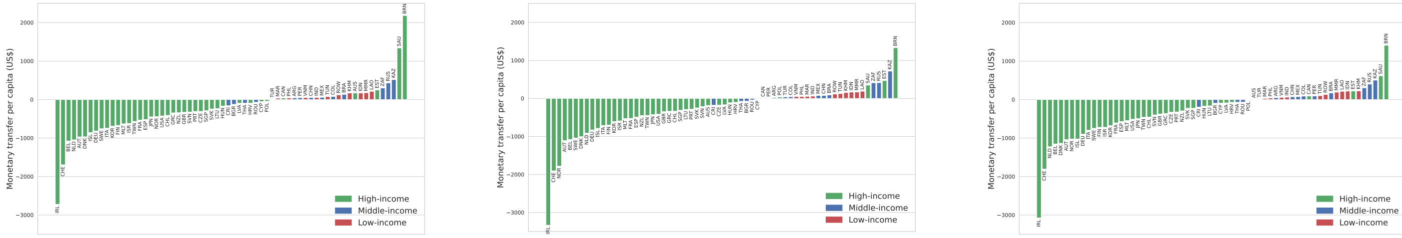
In this section, we evaluate the robustness of our findings across several dimensions. First, we test alternative trade elasticity estimates. Second, we examine the implications of applying a producer tax scheme instead of the consumer tax scheme used in the main analysis. Third, we extend our framework to incorporate endogenous emission intensities, allowing firms to invest in abatement technologies. Last, we assess the plausibility of our results by examining whether the predicted shifts in production and trade patterns fall within realistic bounds.

6.1 Elasticities

In this section, we assess the robustness of our results by testing different values of the trade elasticity. Our main analysis relies on elasticities estimated using the method outlined in Caliendo and Parro (2015). To ensure the robustness of our findings, we also consider two alternative sets of elasticities. First, we adopt the elasticities provided in Fontagné et al. (2022), aggregated to match our sectoral definitions. Second, we apply the method in Fontagné et al. (2022) to estimate elasticities using our dataset, supplemented with tariff data from Fontagné et al. (2022). Additional details regarding the estimation of elasticities are provided in Appendix D.

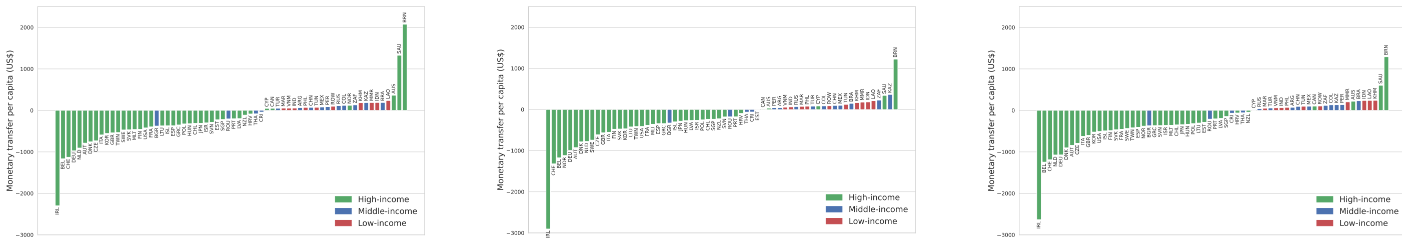
The results shown in Figure 16 highlight changes in real income for each country across all three sets of elasticities. The overall pattern remains consistent: high-income countries generally experience gains, while low- and middle-income countries face losses. However, the precise percentage changes

[25]Figures 35, 36, 37, and 38 in the Appendix present changes in real income by country for each scenario.



(a) Caliendo-Parro estimation (b) Aggregated elasticities (c) Fontagne estimation

Figure 17: Equal Cost Transfers by Elasticity



(a) Caliendo-Parro estimation (b) Aggregated elasticities (c) Fontagne estimation

Figure 18: Polluter Pays Transfers by Elasticity

in real income vary slightly depending on the elasticity set, as they are influenced by the sectoral specialization of individual countries. For instance, Saudi Arabia exhibits a smaller real income decline when using the aggregated or Fontagne elasticities, as the higher elasticities for the mining sector in these methods allow for greater reallocation away from that sector under a carbon tax.

Figures 17 and 18 display the results for equal-cost and polluter-pays transfer scenarios, respectively, across all elasticity sets. Observe that the magnitude of the transfers vary slightly with the different estimation methods. For instance, transfers received by Brunei and Saudi Arabia are lower when they are backed out with the elasticities from Fontagné et al. (2022) or the ones estimated using their method. In this case, this happens because the Caliendo and Parro elasticity in the Mining and Energy sector, which is disproportionally important for these two countries, is relatively lower, as described in Table 1. This difference magnifies the negative impact of the carbon tax through a more severe terms-of-trade loss, thus requiring higher transfers to equalize the welfare costs of climate action. Still, notice that the main conclusions of the paper are robust to the different elasticities: irrespective of the type of transfer, the cross-country distribution implies that high-income countries should pay and low- and middle-income countries should receive them.

6.2 Producer taxes

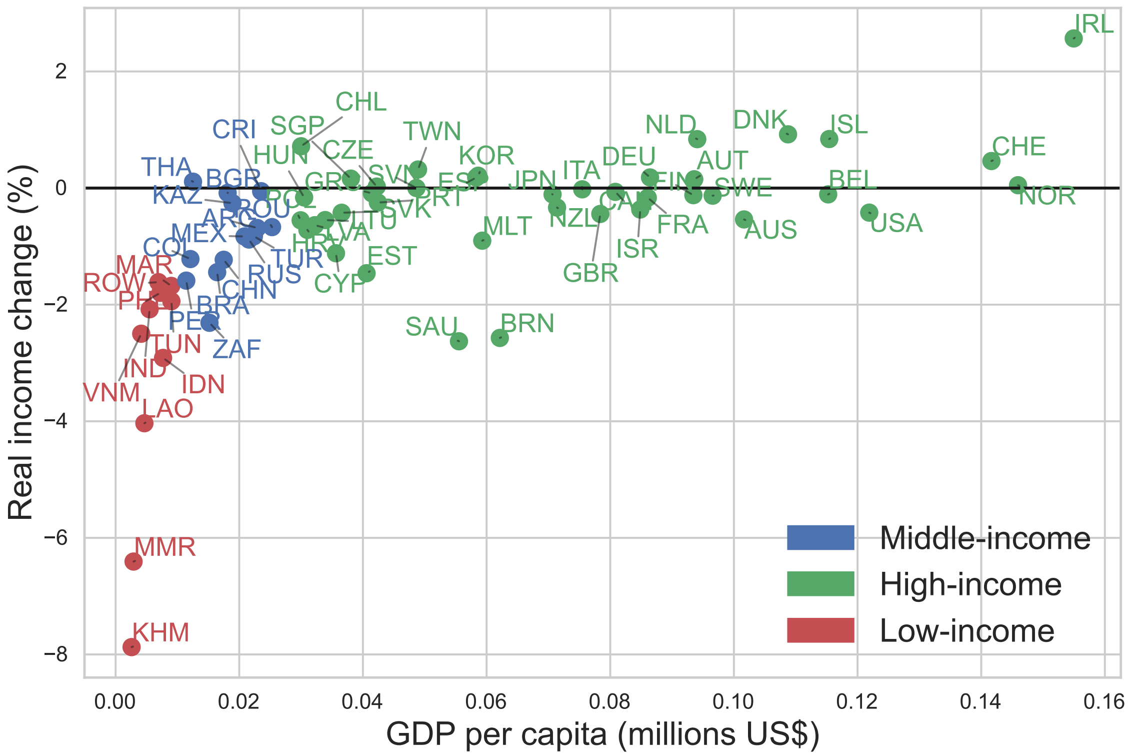
This section compares the main results under a producer tax scheme to those under the consumer tax scheme used in the main analysis. In the main part of the paper, the carbon tax is levied at each step of intermediate or final consumption, with the revenue rebated lump-sum within the country of consumption. In contrast, the producer tax scheme levies the carbon tax at each step of production for intermediate inputs or final goods, with the tax revenue rebated lump-sum to the consumers of the country of production. In practice, real-world tax schemes often fall somewhere between these two approaches. For instance, the EU ETS resembles a producer tax, while the CBAM addition to the EU ETS is more similar to a consumer tax. Rather than advocating for one approach over the other, we use the consumer tax scheme in the main analysis and examine the robustness of our results under the producer tax scheme.

In terms of aggregate outcomes, the results of the model remain unchanged: emissions decrease by 28%, and average real income decreases by 0.7%. However, the distribution of real income changes across countries differs under the producer tax scheme. Figure 19 illustrates these changes. While the specific values vary for some countries, the overarching conclusion remains consistent: low- and middle-income countries experience larger real income decreases compared to high-income countries.

The case of Saudi Arabia and Brunei highlights the differences between the two tax schemes. Under the consumer tax scheme, these countries experience real income decreases of approximately 4% and 5%, respectively. However, with the producer tax, their real income decreases are reduced to around 2.5% for both countries. This is because a significant portion of the carbon-intensive production in Saudi Arabia and Brunei is exported. In the consumer tax scheme, carbon tax revenues are distributed to the importing countries, whereas in the producer tax scheme, these revenues remain in the producing countries. As a result, the real income impact is less severe for Saudi Arabia and Brunei under the producer tax. Overall, the economic costs are more evenly distributed under the producer tax scheme. The standard deviation of welfare changes decreases from 0.019 under the consumer tax to 0.015 under the producer tax

Figure 20 illustrates the per capita transfers required under the producer tax scheme. Once again, the most significant changes are observed for Saudi Arabia and Brunei, both of which require substantially lower transfers in the producer tax scenario. Overall, the total aid needed from high-income to low-

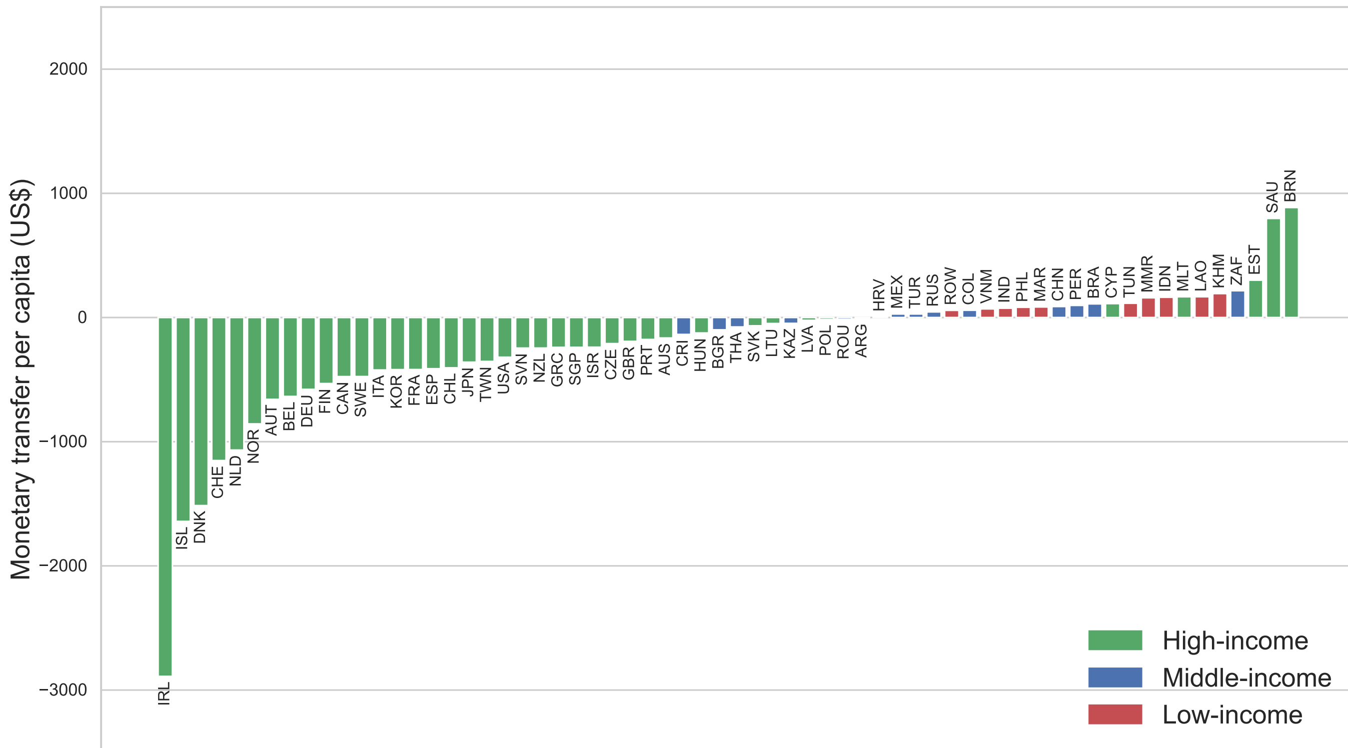
Figure 19: Producer Tax - Real income changes



Note: This figure illustrates the changes in real income across countries following the implementation of carbon taxes, categorized by GDP per capita levels.

and middle-income countries decreases from 292.5 billion dollars to 229.8 billion dollars, representing a 21.5% reduction in necessary aid. This reduction arises from the redirection of tax revenue under the producer tax scheme. In this framework, countries with more carbon-intensive production are heavily taxed, but they retain the tax revenue domestically. In contrast, under the consumer tax scheme, the tax revenue flows to the consuming (often richer) countries. While the economic impact of the tax, particularly in terms of competitiveness losses, remains the same across both schemes, the producer tax scenario better aligns tax revenue with the source of emissions, reducing the need for international transfers.

Figure 20: Producer Tax - Equal Cost Transfers by Country



6.3 Climate Damages

In this section, we extend our analysis and account for carbon tax-led changes in welfare that account for countries' unequal exposure to climate damages. To do so, we follow Shapiro (2016) and define an augmented measure of utility in country j as the product of Cobb-Douglas CES preferences over varieties and damages from carbon emissions:

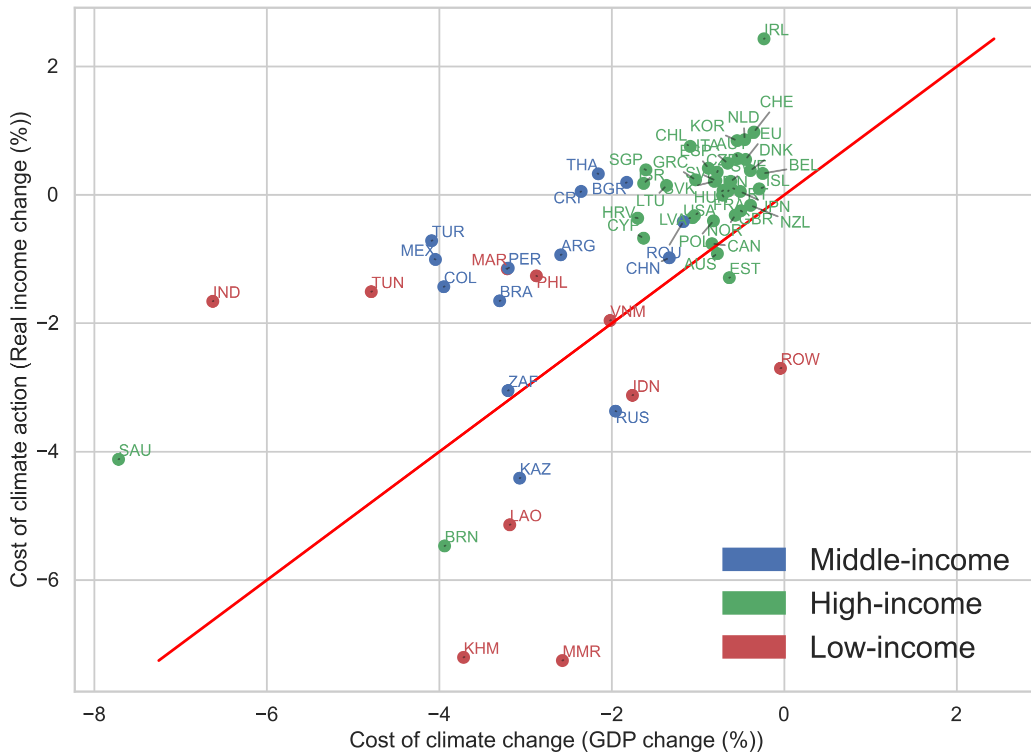
$$U_j^* = \left[\prod_{s'} {U_{s'j}}^{\beta_{s'j}}\right]\left[\frac{1}{1+\delta_j(CO_2 - CO_2^B)}\right]$$

where δ_j is country j's exposure to climate damages, CO_2 and CO_2^B and counterfactual and beseline emissions and $U_{s'j}$ and $\beta_{s'j}$ are defined as before.

We obtain data for country-specific climate damages from Ricke et al. (2018). This data set provides heterogeneous social cost of carbon (scc) estimates for different countries in a plethora of scenarios.[26] In line with the carbon tax in the main part of the paper, we set the global social cost of carbon to

[26]We use the following parameters and scenarios: ssp=SSP3, rcp=RCP85, run=BHM-LR, prtp=2, dmgfuncpar=estimates, climate=expected. For a detailed explanation of these options see the readme file from Ricke et al. (2018).

Figure 21: Cost of Climate Action vs. Climate Damage

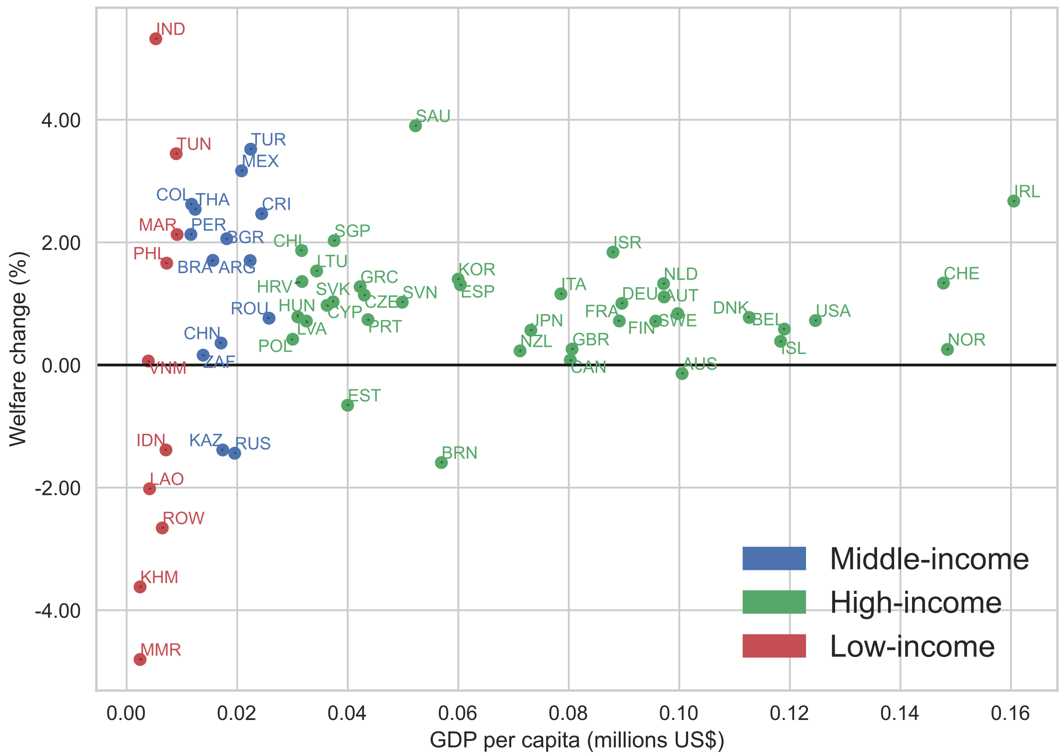


100 USD/tCO_2e. We then calculate $\delta_j = \frac{scc \; scc_j}{\sum_j scc_j GDP_j}$, thus translating the country-specific social cost of carbon into multiplicative changes in GDP and normalizing the change at global scale to our chosen scc.

Figure 21 illustrates the trade-off between the cost of climate action and the cost of inaction. The y-axis represents the real income change resulting from a 100 USD/tCO_2e carbon tax (the cost of climate action), while the x-axis displays the cost of climate change as a percentage of GDP. Two outliers, Taiwan (31% climate damage) and Malta (14% climate damage), are excluded for clarity. Countries positioned above and to the left of the red line face greater costs from climate damages than from climate action, while those below and to the right face higher costs from climate action. Figure 22 extends this analysis by presenting the welfare changes from a 100 USD/tCO_2e carbon tax, accounting for both real income changes and the avoided costs of climate damages. Even though climate action results in net welfare gains for many countries, heterogeneous climate damages mean that welfare is not uniformly positive.

While this analysis provides valuable insights, it is important to note that the data for the heterogeneous social cost of carbon is highly sensitive to the chosen parameters. The estimates from Ricke et al. (2018) come with very wide confidence intervals, with the global social cost of carbon ranging

Figure 22: Welfare Change



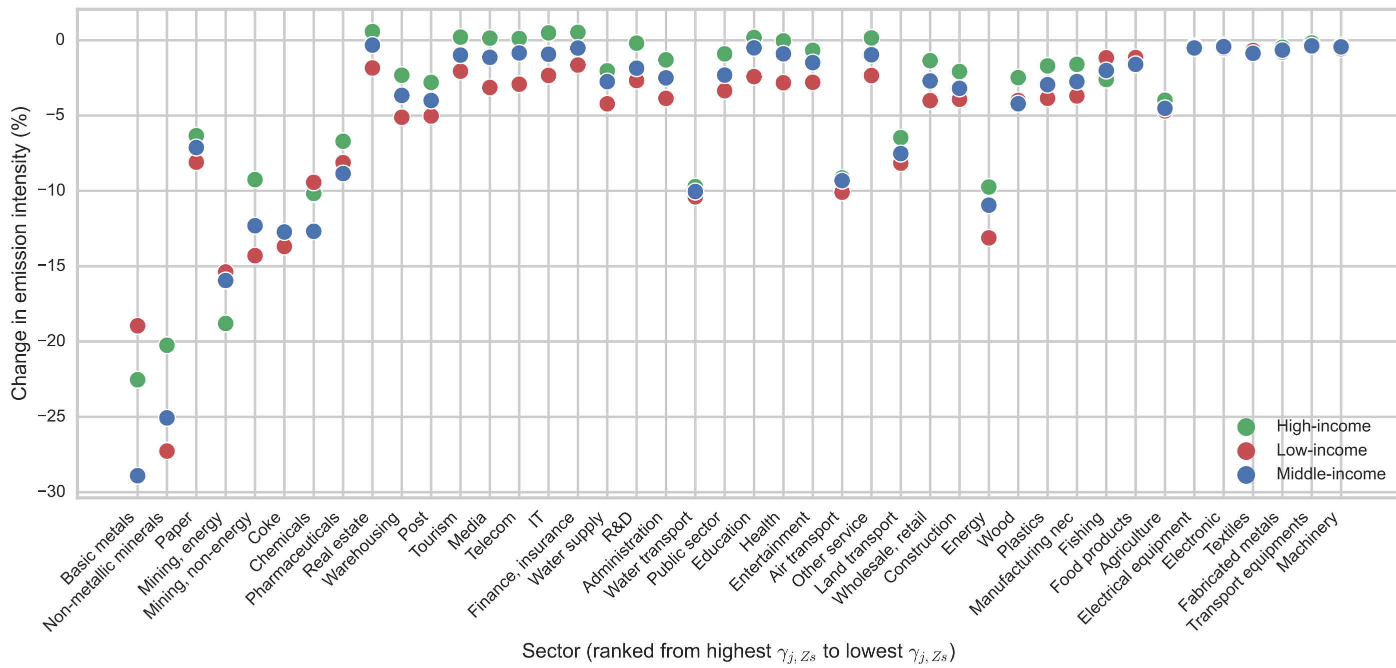
from negative values to over 2000, depending on the scenario. Furthermore, the relative ordering of countries changes significantly across different scenarios. Given these uncertainties, we caution against placing too much emphasis on this analysis.

6.4 Endogenous Emission Intensities

In this section, we evaluate the robustness of the main results by extending our framework to include endogenous emission intensities. Recall that in our benchmark carbon taxation induces firms to source inputs from greener suppliers, thereby reducing emissions along the supply chain. However, direct emission intensities remain fixed. This assumption could influence our results if some of the real income costs of carbon taxation could be mitigated through technological upgrade in low- and middle-income regions.

To verify this point we allow direct emission intensities to respond to policy interventions. We follow Copeland and Taylor (2003) and allow firms to engage in abatement by allocating to this end a fraction of their inputs. As Copeland and Taylor show, this formulation is equivalent to assuming a Cobb-Douglas production function that includes carbon as one of the production inputs. Adapted to our setting, this implies that the production function is given by:

Figure 23: Changes in Direct Emission Intensities - Abatement Model



Note: This figure shows averages changes in total emissions as a share of output. Sectors are ordered by the share of carbon taxes in production costs.

$$q_{js} = A_{js} \left(\frac{L_{js}}{\gamma_{j,Ls}} \right)^{\gamma_{j,Ls}} \left(\frac{Z_{js}}{\gamma_{j,Zs}} \right)^{\gamma_{j,Zs}} \prod_{s'} \left(\frac{m_{s'js}}{\gamma_{s'js}} \right)^{\gamma_{s'js}}$$

where Z_{js} is the amount of carbon (or inputs generating direct GHG emissions) employed in production and $\gamma_{j,Zs}$ is the share of production costs attributed to carbon taxes, such that $\gamma_{j,Ls} + \gamma_{j,Zs} + \sum_{s'} \gamma_{s'js} = 1 \; \forall s$. All other variables are defined as before.

Under this framework, cost minimization yields the following price equation:

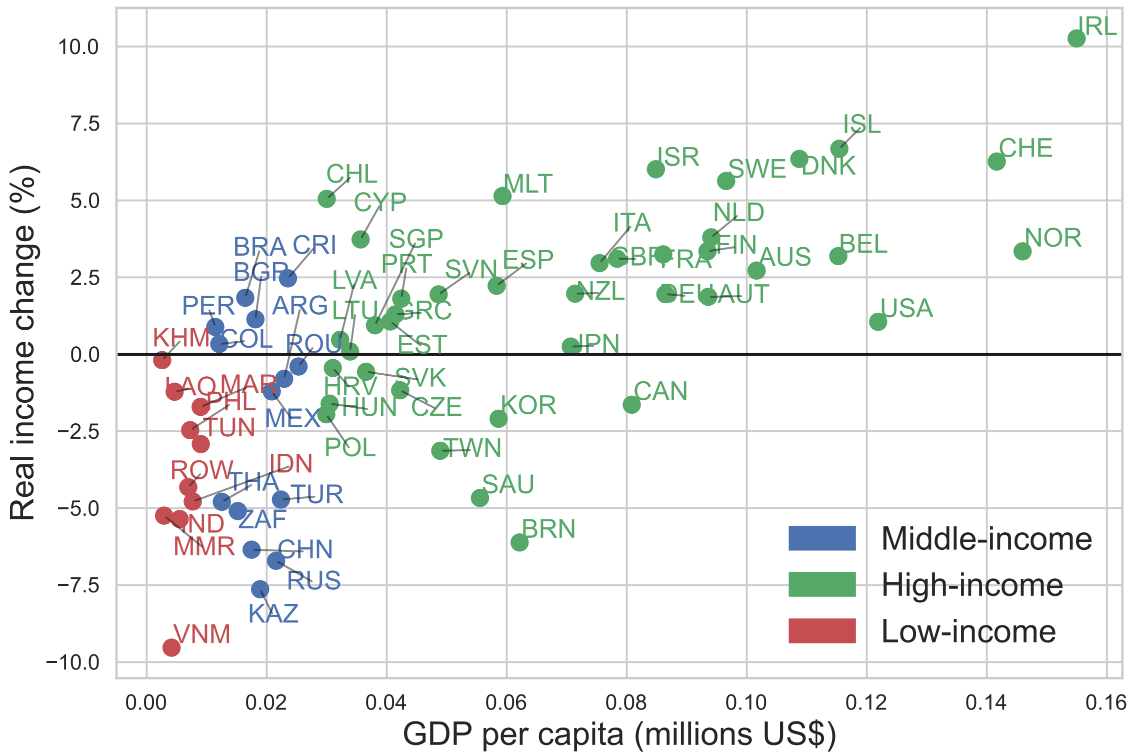
$$p_{js} = \frac{1}{A_{js}} (w_j)^{\gamma_{j,Ls}} (\tau_{js})^{\gamma_{j,Zs}} \prod_{s'} \left(P^{\pi}_{s'js} \right)^{\gamma_{s'js}},$$

where τ_{js} denotes the regulated price of carbon, which is not freely traded but set by governments.[27]

To compare the results from this extended model with the benchmark specification, we express its equilibrium in changes and simulate the same counterfactual scenario: the adoption of a uniform 100 USD/tCO_2e carbon tax. This additionally requires calibrating the Cobb-Douglas shares $\gamma_{j,Zs}$. Since credible estimates for all countries and sectors in our sample are not readily available, we borrow

[27] In this version of the model, we follow Shapiro and Walker (2018) and assume for simplicity that revenue from carbon taxes are lost due to rent-seeking.

Figure 24: Real Income Changes by Country - Abatement Model



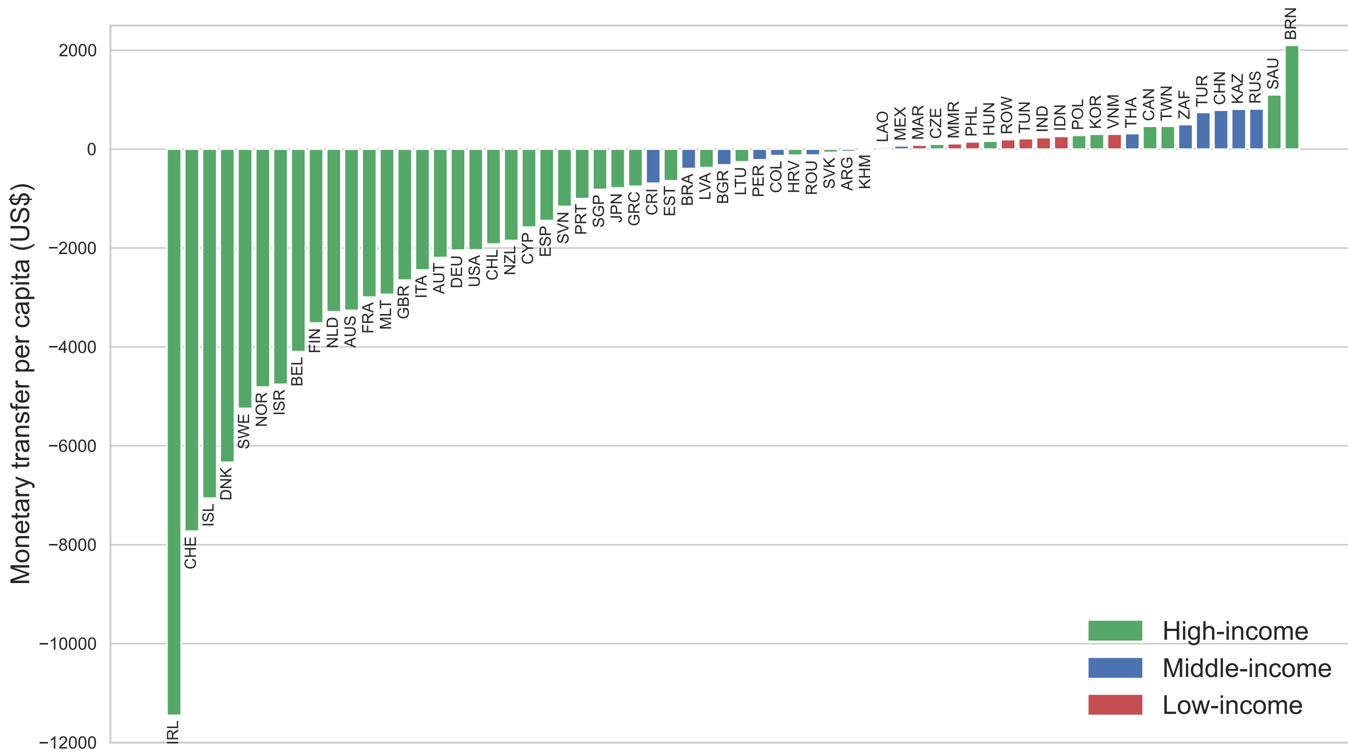
estimates from Shapiro and Walker (2018) based on data for U.S. firms and major air pollutants. Table 2 in the Appendix displays the values and our sector concordance. One important limitation of this approach is the assumption that U.S. environmental regulatory conditions apply uniformly across all countries in the sample.

Before presenting the results, it is useful to examine counterfactual changes in direct emission intensities. Figure 23 presents average changes by sector and income group, with sectors ordered by the cost share of pollution. Two key patterns emerge. First, sectors with higher pollution cost shares exhibit more pronounced changes in emission intensities across all income groups. Second, low- and middle-income countries promote more abatement, mitigating some of the tax burden that stem from their reliance on more carbon-intensive technologies in the baseline.

Figures 24 and 25 summarize changes in real income and the monetary transfers required to equalize the costs of climate action. Consistent with earlier findings, low- and middle-income countries bear the bulk of the real-income costs and equal cost transfers require resource flows from high-income to low- and middle-income countries. However, the magnitudes of both real income effects and transfers are more pronounced under the model with abatement.

This happens because the model with abatement implies a higher tax burden on low and middle-

Figure 25: Equal Cost Transfers by Country - Abatement Model



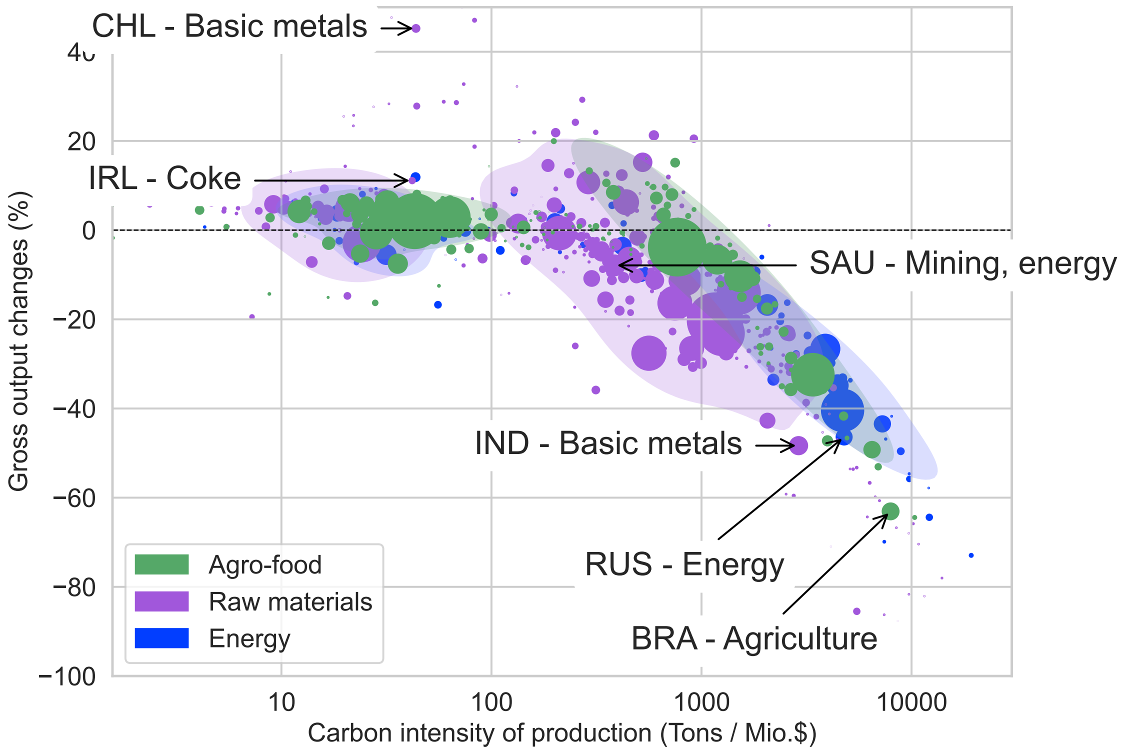
income countries that offsets the benefits of lower emission intensities. To see this point, notice that the Cobb-Douglas formulation implies a positive baseline price for carbon inputs that accounts for cross-country and cross-sector differences in emission intensities. Consequently, carbon is relatively cheaper in low- and middle-income countries and more expensive in high-income ones. When a uniform carbon tax is applied, this leads to more significant price increases and real income adjustments in low- and middle-income countries. Conversely, high-income countries experience a more pronounced real income gains as the tax burden is lower because the price of carbon inputs is already high in the baseline. Despite these differences, the main conclusions of the paper remain robust.[28]

6.5 Plausibility

This section explores whether our model delivers plausible results. Carbon taxes lead to a shift in production patterns towards greener sectors and greener source countries. If a country produces a good

[28]This difference in baseline prices is absent from our benchmark model. Specifically, our ad-valorem formulation of the carbon tax implicitly assumes a "Leontief-style" production structure that combines labor, intermediate inputs, and carbon for the production of each good. In this case, baseline carbon prices are negligible, which is consistent with the minimal carbon taxation levels observed in the baseline year. For example, the World Bank Carbon Dashboard reports that in 2018 the carbon price in the European ETS— one of the most ambitious carbon pricing schemes— was 16.36 USD/tCO_2e, covering only 38% of emissions.

Figure 26: Plausibility



Note: This figure shows the percentage changes in gross output and the carbon intensity of production for country-sector pairs as a result of the carbon tax.

with a greener production technology, that country-sector pair will experience an increase in production. Here, we explore whether the increases the model predicts are plausible. Figure 26 shows the changes in gross output as a result of the carbon tax, in percent, for different country pairs ordered by the carbon intensity of production. We focus on three sector groups for which it might be particularly hard to increase production, namely the agro-food sector, raw materials, and energy. The graph shows that the most extreme increase in production predicted by the model is around 40%.

7 Conclusion

This paper provides a comprehensive quantitative analysis of the distributional effects of carbon pricing across countries. Leveraging a modern, multi-country, multi-sector quantitative trade model, we investigate the implications of various carbon taxation schemes, identifying the inequities they create and proposing strategies to ensure fairness while maintaining economic efficiency. Our findings serve as critical benchmarks with immediate relevance for policymaking.

We find that while a uniform carbon tax effectively reduces global emissions, it disproportionately impacts low- and middle-income countries, exacerbating global economic inequalities. Redistribution mechanisms—whether aimed at equalizing the costs of climate action or addressing historical GHG emission patterns—could mitigate these disparities. Implementing such mechanisms would require tripling current climate finance levels, yet this translates into a relatively modest per capita cost for high-income countries. Furthermore, we find that heterogeneous pricing schemes, such as climate clubs or the IMF's carbon taxation proposal, do not inherently produce fairer outcomes compared to global policies paired with redistribution.

This study highlights important directions for future research. Examining how technological innovation or diffusion, particularly in clean energy stimulated by carbon taxation, might influence the distributional impact of climate policies offers a promising avenue for further exploration.

References

Adler, C., Wester, P., Bhatt, I., Huggel, C., Insarov, G., Morecroft, M., Muccione, V. and Prakash, A. (2022). *Cross-Chapter Paper 5: Mountains*, Cambridge University Press, Cambridge, UK and New York, USA, pp. 2273–2318.

Aichele, R. and Felbermayr, G. (2012). Kyoto and the carbon footprint of nations, *Journal of Environmental Economics and Management* **63**(3): 336–354.
URL: *https://www.sciencedirect.com/science/article/pii/S0095069611001422*

Arkolakis, C., Costinot, A. and Rodríguez-Clare, A. (2012). New trade models, same old gains?, *American Economic Review* **102**(1): 94–130.

Armington, P. S. (1969). The geographic pattern of trade and the effects of price changes, *IMF Econ Rev 16* **16**: 179.201. Symposium on Growth and International Trade: Empirical Studies.

Babiker, M. H. (2005). Climate change policy, market structure, and carbon leakage, *Journal of international Economics* **65**(2): 421–445.

Blanchard, O., Gollier, C. and Tirole, J. (2023). The portfolio of economic policies needed to fight climate change, *Annual Review of Economics* **15**(Volume 15, 2023): 689–722.
URL: *https://www.annualreviews.org/content/journals/10.1146/annurev-economics-051520-015113*

Boyce, J. K. (2018). Carbon pricing: effectiveness and equity, *Ecological Economics* **150**: 52–61.

Böhringer, C., Carbone, J. and Rutherford, T. (2016). The strategic value of carbon tariffs, *American Economic Journal: Economic Policy* **8**: 28–51.

Caliendo, L. and Parro, F. (2015). Estimates of the trade and welfare effects of nafta, *The Review of Economic Studies* **82**(1 (290)): 1–44.

Cavalcanti, T., Hasna, Z., Santos, C. et al. (2020). *Climate Change Mitigation Policies: Aggregate and Distributional Effects*, JSTOR.

Copeland, B. R. (1996). Pollution content tariffs, environmental rent shifting, and the control of cross-border pollution, *Journal of international Economics* **40**(3-4): 459–476.

Copeland, B. R. and Taylor, M. S. (2003). *Trade and the Environment: Theory and Evidence*, Princeton Series in International Economics, Princeton University Press, Princeton, NJ.

Dekle, R., Eaton, J. and Kortum, S. (2007). Unbalanced trade, *American Economic Review* **97**(2): 351–355.

Eaton, J. and Kortum, S. (2002). Technology, geography, and trade, *Econometrica* **70**(5): 1741–1779.

Elliott, J., Foster, I., Kortum, S., Khun Jush, G., Munson, T. and Weisbach, D. (2012). Unilateral carbon taxes, border tax adjustments, and carbon leakage, *SSRN Electronic Journal* .

Elliott, J., Foster, I., Kortum, S., Munson, T., Cervantes, F. P. and Weisbach, D. (2010). Trade and carbon taxes, *The American Economic Review* **100**(2): 465–469.
URL: *http://www.jstor.org/stable/27805040*

European Commission, J. (2023). Emission database for global atmospheric research (edgar). Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL), release version 4.tox2 global gridmaps.
URL: *https://edgar.jrc.ec.europa.eu/*

FAO (2023). Faostat emissions totals. License: CC BY-NC-SA 3.0 IGO. Accessed: April 15, 2024.
URL: *https://www.fao.org/faostat/en/data/GT*

Farrokhi, F. and Lashkaripour, A. (2021). Can trade policy mitigate climate change, *Unpublished Working Paper* .

Felder, S. and Rutherford, T. F. (1993). Unilateral co2 reductions and carbon leakage: The consequences of international trade in oil and basic materials, *Journal of Environmental Economics and Management* **25**(2): 162–176.
URL: *https://www.sciencedirect.com/science/article/pii/S0095069683710405*

Finkelstein-Shapiro, A. and Nuguer, V. (2023). Climate policies, labor markets, and macroeconomic outcomes in emerging economies, *Labor Markets, and Macroeconomic Outcomes in Emerging Economies (January 19, 2023)* .

Fontagné, L., Guimbard, H. and Orefice, G. (2022). Tariff-based product-level trade elasticities, *Journal of International Economics* **137**: 103593.

Golosov, M., Hassler, J., Krusell, P. and Tsyvinski, A. (2014). Optimal taxes on fossil fuel in general equilibrium, *Econometrica* **82**(1): 41–88.

Head, K. and Mayer, T. (2014). Gravity equations: Workhorse,toolkit, and cookbook, Vol. 4, Elsevier, chapter Chapter 3, pp. 131–195.

Hémous, D. (2016). The dynamic impact of unilateral environmental policies, *Journal of International Economics* **103**: 80–95.

Hoel, M. (1996). Should a carbon tax be differentiated across sectors?, *Journal of Public Economics* **59**(1): 17–32.
URL: *https://www.sciencedirect.com/science/article/pii/0047272794014906*

IEA (2024). Greenhouse gas emissions from energy. Accessed: April 15, 2024.
URL: *https://www.iea.org/data-and-statistics/data-product/greenhouse-gas-emissions-from-energy*

Kortum, S. and Weisbach, D. (2021). Optimal unilateral carbon policy, *SSRN Electronic Journal* .

Kotlikoff, L. J., Kubler, F., Polbin, A. and Scheidegger, S. (2021). Can today's and tomorrow's world uniformly gain from carbon taxation?, *Technical report*, National Bureau of Economic Research.

Krusell, P. and Smith, Anthony A, J. (2022). Climate change around the world, *Working Paper 30338*, National Bureau of Economic Research.
URL: *http://www.nber.org/papers/w30338*

Larch, M. and Wanner, J. (2017). Carbon tariffs: An analysis of the trade, welfare, and emission effects, *Journal of International Economics* **109**: 195–213.

Larch, M. and Wanner, J. (2024). The consequences of non-participation in the paris agreement, *European Economic Review* **163**: 104699.
URL: *https://www.sciencedirect.com/science/article/pii/S001429212400028X*

Le Moigne, M., Lepot, S., Ossa, R., Ritel, M. and Simon, D. (2024). A quantitative analysis of sustainable globalization. Unpublished manuscript.

Markusen, J. R. (1975). International externalities and optimal tax structures, *Journal of international economics* **5**(1): 15–29.

Nordhaus, W. (2015). Climate clubs: Overcoming free-riding in international climate policy, *American Economic Review* **105**(4): 1339–1370.

Nordhaus, W. (2018). Projections and uncertainties about climate change in an era of minimal climate policies, *American economic journal: economic policy* **10**(3): 333–360.

Nordhaus, W. D. (1993). Optimal greenhouse-gas reductions and tax policy in the" dice" model, *The American Economic Review* **83**(2): 313–317.

OECD (2021). Trade in embodied co2 (teco2) database. Accessed: April 15, 2024.
URL: *https://www.oecd.org/sti/ind/carbondioxideemissionsembodiedininternationaltrade.htm*

OECD (2022). *Aggregate Trends of Climate Finance Provided and Mobilised by Developed Countries in 2013-2020*.
URL: *https://www.oecd-ilibrary.org/content/publication/d28f963c-en*

OECD (2023). Oecd inter-country input-output database. Accessed: April 15, 2024.
URL: *http://oe.cd/icio*

Parry, I. W., Black, S. and Roaf, J. (2021). Proposal for an international carbon price floor among large emitters, IMF Staff Climate Note.
URL: *https://www.imf.org/en/Publications/staff-climate-notes/Issues/2021/06/15/Proposal-for-an-International-Carbon-Price-Floor-Among-Large-Emitters-460468*

Ricke, K., Drouet, L., Caldeira, K. and Tavoni, M. (2018). Country-level social cost of carbon, *Nature Climate Change* **8**(10): 895–900.
URL: *https://doi.org/10.1038/s41558-018-0282-y*

Ritchie, H. (2019). Who has contributed most to global co2 emissions?, *Our World in Data* . https://ourworldindata.org/contributed-most-global-co2.

Sandmo, A. (2006). Global public economics: Public goods and externalities, *Économie publique/Public economics* **18-19**(1-2). Online since 17 October 2007, accessed on 13 May 2024.
URL: *http://journals.openedition.org/economiepublique/4282*

Shapiro, J. S. (2016). Trade Costs, CO2, and the Environment, *American Economic Journal: Economic Policy* **8**(4): 220–254.

Shapiro, J. S. and Walker, R. (2018). Why is pollution from us manufacturing declining? the roles of environmental regulation, productivity, and trade, *American Economic Review* **108**(12): 3814–3854.
URL: *https://www.aeaweb.org/articles?id=10.1257/aer.20151272*

Tirole, J. (2016). Carbon pricing of a climate coalition.

WB, W. B. (2024). World development indicators database.

Weisbach, D., Kortum, S., Wang, M. and Yao, Y. (2023). Trade, leakage, and the design of a carbon tax, *Environmental and Energy Policy and the Economy* **4**: 43–90.

A Data treatment

Aggregations

To avoid sparseness of the input output table and zero gross outputs, we aggregate the following countries:

- Luxembourg and Belgium: subsequently labeled `BEL` in all data
- Hong-Kong and China: subsequently labeled `CHN`
- Malaysia and Singapore: subsequently labeled `SGP`

as well as the following sectors:

- 'Mining and quarrying, energy producing products' [D05T06] with 'Mining support service activities' [D09]: subsequently labeled as [D05T06] (Mining, energy)
- 'Motor vehicles, trailers and semi-trailers' [D29] with 'Other transport equipment' [D30]: subsequently labeled [D29T30] (Transport equipments)

These aggregations leave us with a sample of 64 countries (incl. ROW aggregate) and 42 sectors from 1995 to 2018.

ICIO

The raw ICIO tables records negative values for some accounts of final consumption or value added. As the model cannot accommodate these negative values, we redistribute the negative parts in the table while respecting the following constraints:

- the sum of the columns and the sum of the rows must remain equal,
- the technical coefficients within the IO table (intermediate input spending over gross output ratio, corresponding to the parameters γ in the model) must remain constant equal to the raw ratios.

FAO

We keep only FAO Tier 1 emissions by subcategories belonging to the category 'Agricultural Land' with the exception of 'On-farm Energy Use', since these emissions are already contained in the TECO2 emission data.[29] The remaining observations are then aggregated into the 64 countries with the ROW aggregate and are assigned to the 'Agriculture' sector.

[29] The category 'Agricultural Land' includes the following subcategories: 'Fires in humid tropical forests', 'Fires in organic soils', 'Net Forest conversion', 'Drained organic soils', 'Synthetic Fertilizers', 'Crop Residues', 'Manure left on Pasture', 'Manure applied to Soils', 'Manure Management', 'Enteric Fermentation', 'Savanna fires', 'Burning - Crop residues', 'Rice Cultivation', 'On-farm Energy Use'

EDGAR

We first combine different time series extracts of the EDGAR database, namely the 'CH4', 'CO2_excl_short-cycle_org_C' and 'N2O' data sheet by converting the emissions into CO_2 equivalents according to the respective AR4 100-year GWP value.[30] We then aggregate the data into our 63 sample countries and create the ROW aggregate with the remaining countries. To assign the IPCC emission categories to our various sample sectors, we rely on the exact definition of the IPCC emission category compared to the ISIC rev.4 codes comprised in our sample sector definition.

For IPPC category 'industrial process and product use emissions' (chapter 2), we apply the following conversion:

IPCC category	Name	Sample sector
2.A	Mineral Industry	Non-metallic minerals
2.B	Chemical Industry	Chemicals
2.C	Metal Industry	Basic metals
2.E	Electronics Industry	Electronic
2.F	Product Uses As Substitutes For Ozone Depleting Substances	Energy

For the IPCC categories "fugitive emissions" (chapter 1.B) we proceed in two steps. Based on the categories definitions we have a direct mapping for the subcategory 'Oil and Natural Gas' (1.B.2) assigned to the sample sector 'Mining, energy'. The subcategory 'Solid Fuels' (1.B.1) however matches with different sample sectors: 'Mining, energy', 'Mining, non-energy', 'Wood', and 'Coke, petroleum'. We therefore disaggregate the IPCC aggregate "Solid fuelds" into the respective sample sectors by using as a disaggregation weights the share of emissions from fuel burning of each sample sector in the total.[31] This procedure results in disaggregated emissions as presented in Figure 1.

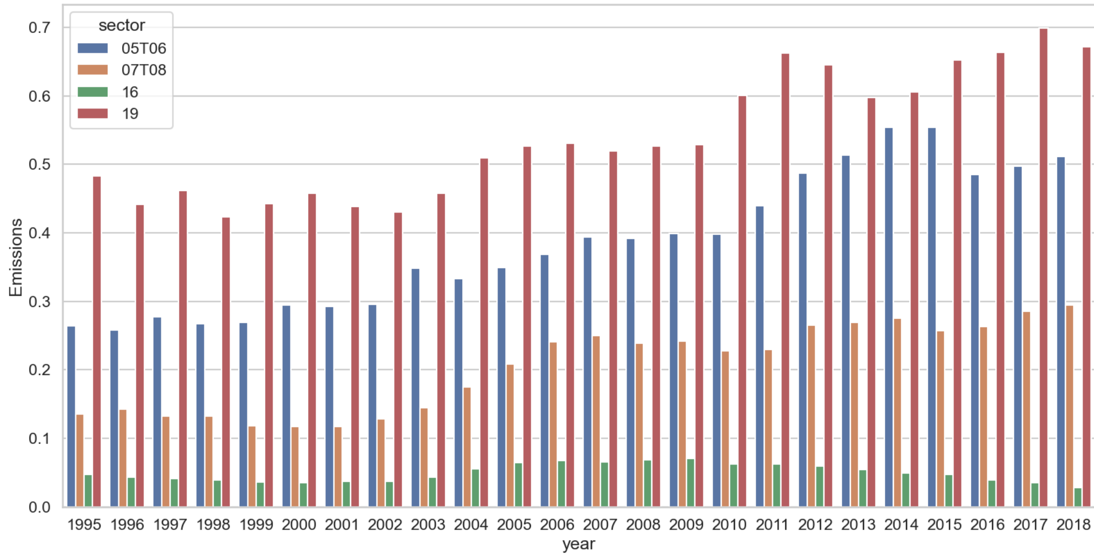
Notes on data uncertainty

Direct emissions from land use, chemical processes or fugitive emissions are difficult to measure or estimate. As a result, the data we use to complement emissions from fuel consumption is subject to large uncertainty ranges. These ranges are reported for the EDGAR database (and covers the agricultural emissions obtained in the FAO as well).

[30] The AR4 100-year GWP values are 25 for CH_4 and 298 for N_2O.

[31] Note that we did not include the IPCC categories 2.D 'Non-Energy Products From Fuels and Solvent Use' and 2.G 'Other Product Manufacture and Use' since a clean mapping from the IPCC categories to the corresponding sample sectors is not as easily separable.

Figure 27: Sectoral emission disaggregation



B Data description

Figure 28 shows the evolution of the different types of greenhouse gas emissions that we account for in the data from 1995 to 2018. The y-axis is measured in Gigatons of CO_2e. Carbon dioxide (CO_2) is the main contributor to greenhouse gas emissions, while methane (CH_4) and nitrous oxide (N_2O) are non-negligible components as well. The striped part of emissions refers to data that exists, but that we cannot unambiguously map to our sector classification. Additionally, we do not consider F-Gas emissions. All in all, we cover around 93% of total emissions in 2018. Figure 29 shows the evolution of emissions according to their source, again in Gigatons of CO_2e. The brown areas on the bottom of the graph (energy, industries, transports) stem from the TECO2 dataset and relate to fuel combustion. The agricultural and forestry emissions stem from the FAO dataset, while the fugitive emissions and industrial process emissions stem form EDGAR. This graph shows why including methane and nitrous oxide emissions is important: Emissions related to agriculture are a large share of the overall emissions. If we only considered emissions from fuel combustion, the impact of the agricultural sector to greenhouse gas emissions would be neglected.

Figure 28: Emissions by Gas

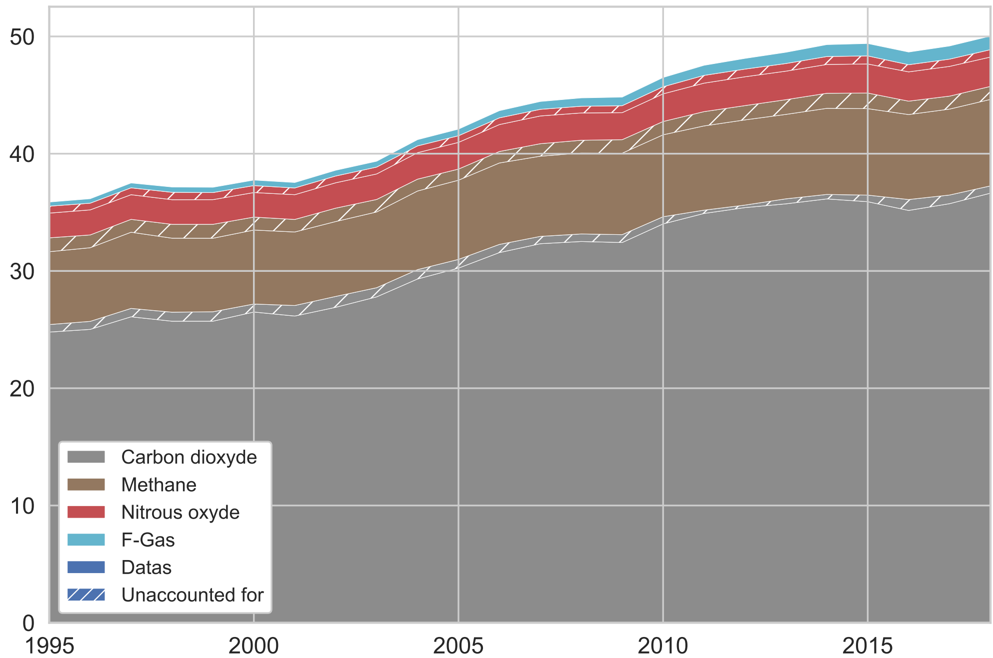
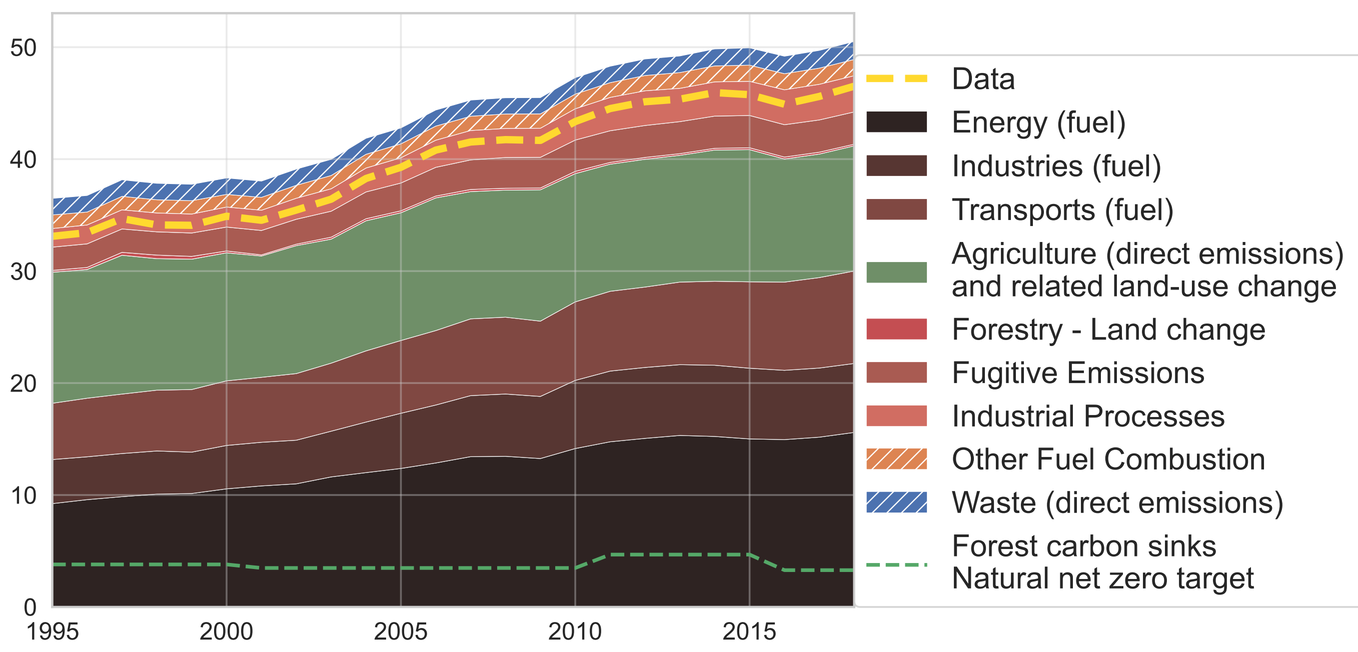


Figure 29: Emissions by Source



C Solving algorithm

In this section, we detail how we reduce the model to a $N \times S$ system that we use to back out counterfactual results. The aim is to reduce the number of variables, while keeping the system as linear as possible.

Equations (9) and (10) imply that :

$$\widetilde{q}_{is'j} = \widetilde{I}_j \widetilde{q}_{is'j}{}^{\circ} \tag{21}$$

where $\widetilde{q}_{is'j}{}^{\circ} = [\widetilde{p}_{is'}(1+t^e_{is'j})]^{-\sigma_{s'}} \, \widetilde{P^c_{s'j}}^{(\sigma_{s'}-1)}$ only depends on the change of prices and the baseline. Useful to note that his inverse is linear in any change of set of prices : $\widetilde{q}_{is'j}{}^{\circ}(\alpha\widetilde{p}) = \widetilde{q}_{is'j}{}^{\circ}(\widetilde{p})/\alpha$. This is the most general expression of the change of quantities traded so that the condition of consumer spending is respected by construction because : $\sum_{i,s'} \widetilde{p}_{is'}(1+t^e_{is'j})\widetilde{q}_{is'j}{}^{\circ}(p^B_{is'j}q^B_{is'j}) = I^B_j$. The form of this expression represents that if the income of the consumer increases (or decreases), he will proportionally increase his consumption from every country/sector. $\widetilde{q}_{is'j}{}^{\circ}$ contains all the information of the reorganisation of his consumption if his income didn't change in the counterfactual world.

Similarly, for intermediates, equation (11) together with $\widetilde{E}_{s'js} = \widetilde{E}_{js}$ imply that :

$$\widetilde{m}_{is'js} = \widetilde{E}_{js}\widetilde{m}_{is'js}{}^{\circ} \tag{22}$$

where $\widetilde{m}_{is'js}{}^{\circ} = [\widetilde{p}_{is'}(1+t^e_{is'j})]^{-\eta_{s's}} \, \widetilde{P^{\pi}_{s'js}}^{(\eta_{s's}-1)}$ has the same properties as $\widetilde{q}_{is'j}{}^{\circ}$. The construction makes sure that the producer spending is respected.

Having the consumer and producer spending respected by construction, we need to compute the consumer and producer revenue. We use equations (16) with $\widetilde{E}_{js} = \widetilde{Y}_{js}$ to compute the wages change under a change of spending of the producer:

$$\widetilde{w}_j = \frac{\sum_s \widetilde{E}_{js} L^B_{js}}{L_j} \tag{23}$$

We have then made sure that the solution respects the labor market clearing condition and the constitutive equation of production $L_{js} = \gamma_{j,Ls}\frac{Y_{js}}{w_j}$, and we can write the consumer revenue and producer spending from the consumer and producer clearing equations :

$$\widetilde{I}_j I^B_j = \sum_s \widetilde{E}_{js} L^B_{js} w^B_j + \sum_{i,s'} \widetilde{I}_j \widetilde{p}_{is'} t^e_{is'j} \widetilde{q}_{is'j}{}^{\circ}(p^B_{is'j}q^B_{is'j}) + \sum_{i,s',s} \widetilde{E}_{js}\widetilde{p}_{is'} t^e_{is'j} \widetilde{m}_{is'js}{}^{\circ}(p^B_{is'j}m^B_{is'js}) + D^B_j \tag{24}$$

$$\widetilde{E}_{is'}E^B_{is'} = \sum_j \widetilde{I}_j \widetilde{p}_{is'}\widetilde{q}_{is'j}{}^{\circ}(p^B_{is'j}q^B_{is'j}) + \sum_{j,s} \widetilde{E}_{js}\widetilde{p}_{is'}\widetilde{m}_{is'js}{}^{\circ}(p^B_{is'j}m^B_{is'js}) \tag{25}$$

We then use (24) in (25):

$$\begin{aligned}\widetilde{E}_{is'}E^B_{is'} = \widetilde{p}_{is'}\Bigg(&\sum_{j,s} \widetilde{E}_{js}\left[\widetilde{q}_{is'j}{}^{\circ}(p^B_{is'j}q^B_{is'j})\frac{L^B_{js}w^B_j + \sum_{i,s'}\widetilde{m}_{is'js}{}^{\circ}\widetilde{p}_{is'}t^e_{is'j}(p^B_{is'j}q^B_{is'j})}{I^B_j - \sum_{i,s'}\widetilde{q}_{is'j}{}^{\circ}\widetilde{p}_{is'}t^e_{is'j}(p^B_{is'j}q^B_{is'j})} + \widetilde{m}_{is'js}{}^{\circ}(p^B_{is'j}m^B_{is'js})\right] \\ &+ \sum_j \frac{D_j\widetilde{q}_{is'j}{}^{\circ}(p^B_{is'j}q^B_{is'j})}{I^B_j - \sum_{i,s'}\widetilde{p}_{is'}t^e_{is'j}\widetilde{q}_{is'j}{}^{\circ}(p^B_{is'j}q^B_{is'j})}\Bigg)\end{aligned} \tag{26}$$

$$\widetilde{p}_{js} = \left(\sum_{s'} \widetilde{E}_{js'}\frac{L^B_{js'}}{L_j}\right)^{\gamma_{j,Ls}} \prod_{s'} \widetilde{P}^{\pi}_{s'js}{}^{\gamma_{s'js}} \tag{27}$$

with the last equation expressing the cost of production from the solution of the cost minimization of the production costs of the producer (13). We have thus reduced the equations to a system of two non-linear equations (26) and (27) of the two fundamental hat quantities $(\widetilde{E}, \widetilde{p})$. Since we have explicit expressions of the variables on the right hand side, we can solve numerically this system with a nested fixed point routine.

The solution space of this system of equations is of dimension 1, any linear transformation $\alpha(\widetilde{E}_{\text{sol}}, \widetilde{p}_{\text{sol}})$ of a solution of the system is also solution. We need to add one numeraire constraint to make the solution unique.

$$\widetilde{X}_{\text{numeraire}} = 1 \tag{28}$$

The numeraire can be any quantity constructed with a linear combination of $(\widetilde{E}_{\text{sol}}, \widetilde{p}_{\text{sol}})$. We use the wage in the USA as a numeraire, so we need to enforce that $\widetilde{E}_{\text{sol}}$ respects :

$$\sum_{s'} \widetilde{E}_{USA,s'}\frac{L^B_{USA,s'}}{L_{USA}} = 1 \tag{29}$$

So we can solve for any solution $(\widetilde{E}_{\text{sol}}, \widetilde{p}_{\text{sol}})$ of (26) and (27) and construct :

$$\left(\frac{\widetilde{E}_{\text{sol}}}{\sum_{s'} \left(\widetilde{E_{\text{sol}}}_{USA,s'} \frac{L^B_{USA,s'}}{L_{USA}} \right)}, \frac{\widetilde{p}_{\text{sol}}}{\sum_{s'} \left(\widetilde{E_{\text{sol}}}_{USA,s'} \frac{L^B_{USA,s'}}{L_{USA}} \right)} \right) \tag{30}$$

that is the unique solution that respects (26), (27) and (29). Our results are robust to other choices of numéraire, such as global GDP or total global output.

D Elasticity estimation

Table 1 shows the elasticities for the different estimation methods. Most methods to estimate elasticities rely on the gravity equation, which maps trade flows to trade costs like distance and tariffs. All results in the main part of the paper are based on the elasticities in column 3 which we estimate along the lines of Caliendo and Parro (2015). This method uses a fixed-effects strategy to isolate the effect of trade costs on trade flows. We use all years of the data to create the fixed-effects following Caliendo and Parro (2015). The fifth column relies on the estimation method in Fontagné et al. (2022), where we use lagged tariffs as instruments for the tariffs in a regression of the gravity equation. For that, we use the tariff data in Fontagné et al. (2022), aggregate it to our level of sectoral aggregation, and combine it with our trade flow data. To estimate the elasticities, we regress log tariffs on log trade flows, together with multilateral resistance terms, importer-year, and exporter-year fixed effects. Three-year lags of tariffs serve as instruments for the tariffs. Column 7 shows the simplest method we use: We take existing elasticities and map them to our sector categorization. For that, we use the elasticities in Fontagné et al. (2022) and aggregate them so that on average, they yield the number 4 which is in line with the preferred elasticity in Head and Mayer (2014). The aggregation is necessary because we have a much less granular sectoral composition than Fontagné et al. (2022). We replace elasticities that have the wrong sign, are insignificant, or cannot be estimated due to a lack of tariff data by the mean.

E Additional Figures

Figure 30: Density of emissions intensity

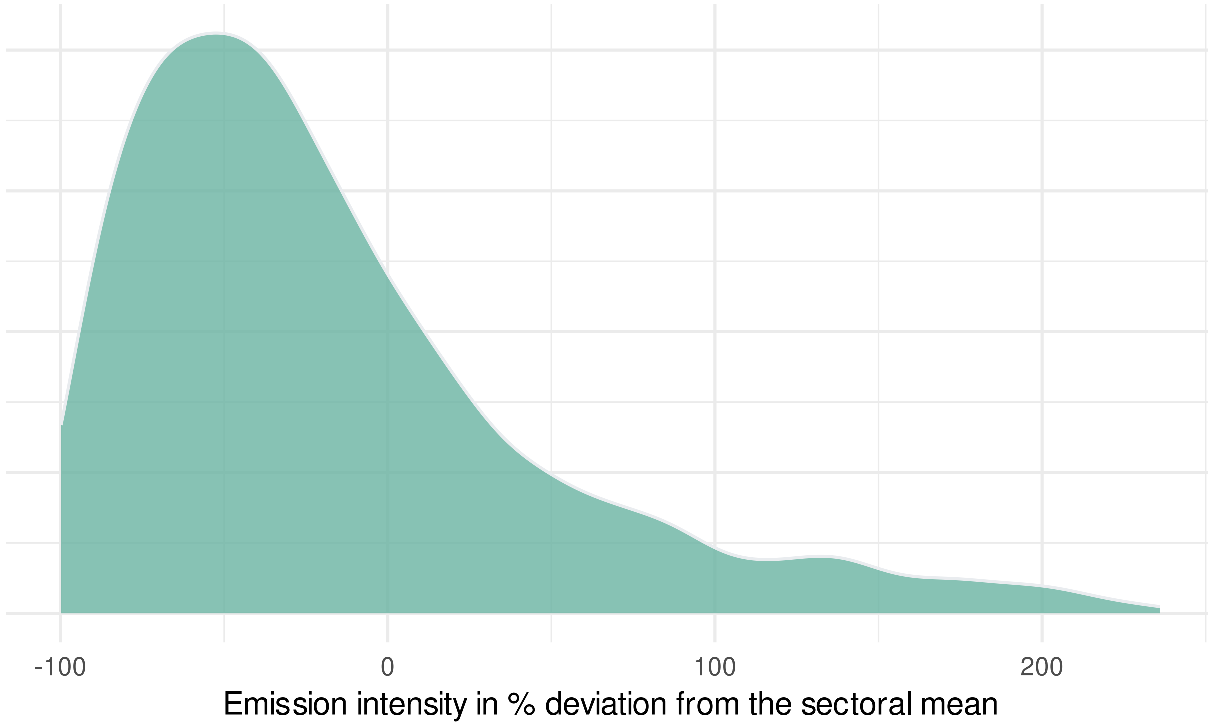
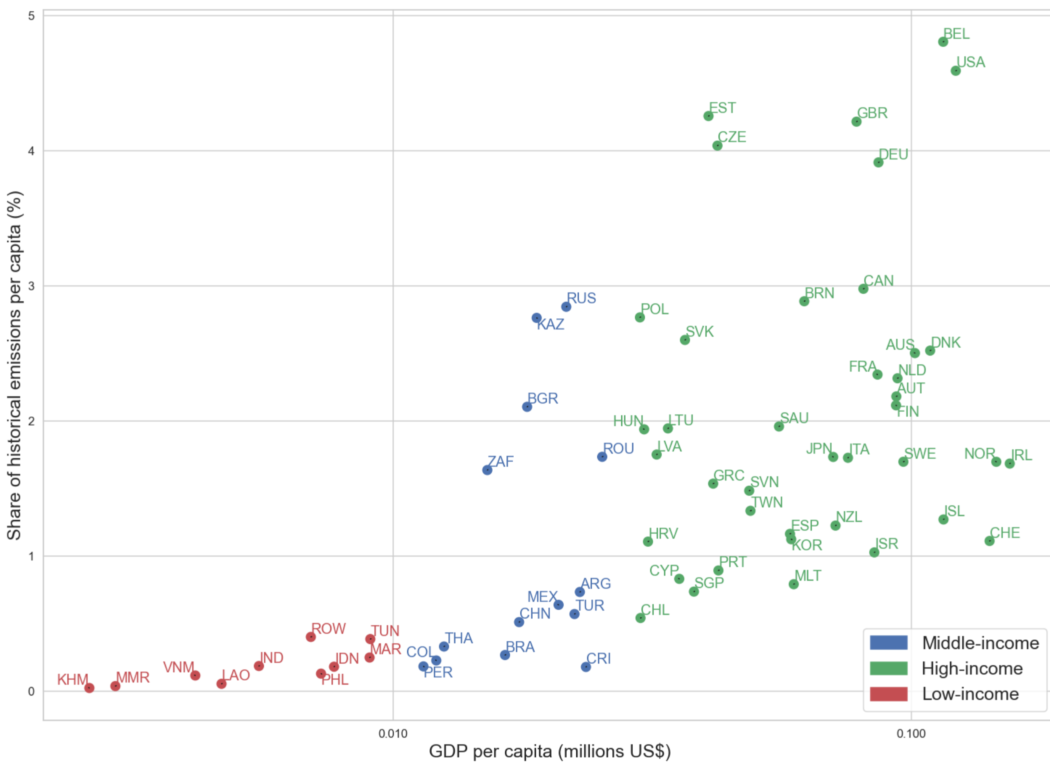


Figure 31: Historical Emissions



Note: Source: Ritchie (2019)

Table 1: Elasticities

Sector	Sector Names	CP Elasticity	CP SE	FG Elasticity	FG SE	Agg Elasticity
01T02	Agriculture	4.95	0.14	8.27	0.69	3.48
03	Fishing	2.58	0.10	2.47	0.46	3.45
05T06	Mining, energy	1.78	0.26	5.08	1.14	10.38
07T08	Mining, non-energy	3.29	0.23	4.58	1.04	9.14
10T12	Food products	4.05	0.14	6.31	0.44	3.15
13T15	Textiles	5.17	0.14	5.75	0.56	3.44
16	Wood	5.02	0.13	5.69	0.58	2.97
17T18	Paper	4.54	0.14	6.86	0.62	3.81
19	Coke, petroleum	3.49	NA	0.00	1.41	5.96
20	Chemicals	3.77	0.19	6.72	0.85	4.49
21	Pharmaceuticals	4.10	0.23	5.33	1.08	4.97
22	Plastics	4.17	0.13	6.19	0.55	3.00
23	Non-metallic minerals	3.68	0.16	5.36	0.73	3.41
24	Basic metals	5.86	0.24	7.19	1.14	6.25
25	Fabricated metals	4.87	0.14	5.89	0.66	2.65
26	Electronic	2.19	0.16	5.63	0.72	2.84
27	Electrical equipment	3.24	0.13	6.00	0.58	2.59
28	Machinery	2.91	0.14	6.02	0.63	2.93
29T30	Transport equipments	3.49	NA	4.95	NA	3.93
31T33	Manufacturing nec	4.90	0.14	6.56	0.61	3.13
35	Energy	3.78	0.13	1.71	0.47	3.76
36T39	Water supply	1.91	0.21	5.05	1.12	6.55
41T43	Construction	3.49	NA	4.95	NA	3.05
45T47	Wholesale, retail	3.49	NA	4.95	NA	3.05
49	Land transport	3.49	NA	4.95	NA	3.05
50	Water transport	3.49	NA	4.95	NA	3.05
51	Air transport	3.49	NA	4.95	NA	3.05
52	Warehousing	3.49	NA	4.95	NA	3.05
53	Post	3.49	NA	4.95	NA	3.05
55T56	Tourism	3.49	NA	4.95	NA	3.05
58T60	Media	4.03	0.17	5.15	0.81	5.36
61	Telecom	3.49	NA	4.95	NA	3.05
62T63	IT	3.49	NA	4.95	NA	3.05
64T66	Finance, insurance	3.49	NA	4.95	NA	3.05
68	Real estate	3.49	NA	4.95	NA	3.05
69T75	R&D	3.76	0.15	2.38	0.71	5.57
77T82	Administration	2.46	0.10	2.62	0.55	4.71
84	Public sector	3.49	NA	4.95	NA	3.05
85	Education	2.80	0.11	2.78	0.52	5.66
86T88	Health	3.49	NA	4.95	NA	3.05
90T93	Entertainment	2.29	0.11	3.22	0.56	4.71
94T98	Other service	3.49	NA	4.95	NA	3.05

* This table shows different versions of the elasticity of substitution across origins. The sectors correspond to the OECD ICIO sectoral classification. We replace insignificant, negative, and nonestimable elasticities with the mean. These elasticities have no standard error.

Table 2: Pollution Elasticities

Shapiro and Walker Sector	**OECD ICIO Sector**	**Elasticity** ($\gamma_{j,Zs}$)
Food, beverages, tobacco	01T02: Agriculture	0.0040
Food, beverages, tobacco	03: Fishing	0.0040
Coke, refined petroleum, fuels	05T06: Mining, energy	0.0212
Coke, refined petroleum, fuels	07T08: Mining, non-energy	0.0212
Food, beverages, tobacco	10T12: Food products	0.0040
Textiles, apparel, fur, leather	13T15: Textiles	0.0022
Wood products	16: Wood	0.0103
Paper and publishing	17T18: Paper	0.0223
Coke, refined petroleum, fuels	19: Coke, petroleum	0.0212
Chemicals	20: Chemicals	0.0205
Chemicals	21: Pharmaceuticals	0.0205
Rubber and plastics	22: Plastics	0.0048
Other non-metallic minerals	23: Non-metallic minerals	0.0303
Basic metals	24: Basic metals	0.0557
Fabricated metals	25: Fabricated metals	0.0019
Office, computing, electrical	26: Electronic	0.0023
Office, computing, electrical	27: Electrical equipment	0.0023
Machinery and equipment	28: Machinery	0.0015
Motor vehicles, trailers	29T30: Transport equipment	0.0016
Other transport equipment	29T30: Transport equipment	0.0019
Furniture, other, recycling	31T33: Manufacturing nec	0.0047
	41T43: Construction	0.011
	45T47: Wholesale, retail	0.011
	49: Land transport	0.011
	50: Water transport	0.011
	51: Air transport	0.011
	52: Warehousing	0.011
	53: Post	0.011
	55T56: Tourism	0.011
	58T60: Media	0.011
	61: Telecom	0.011
	62T63: IT	0.011
	64T66: Finance, insurance	0.011
	68: Real estate	0.011
	69T75: R&D	0.011
	77T82: Administration	0.011
	84: Public sector	0.011
	85: Education	0.011
	86T88: Health	0.011
	90T93: Entertainment	0.011
	94T98: Other service	0.011

Note: Elasticities for services sectors are equal to the average elasticity of other sectors.

Figure 32: Cumulative Historical Emissions

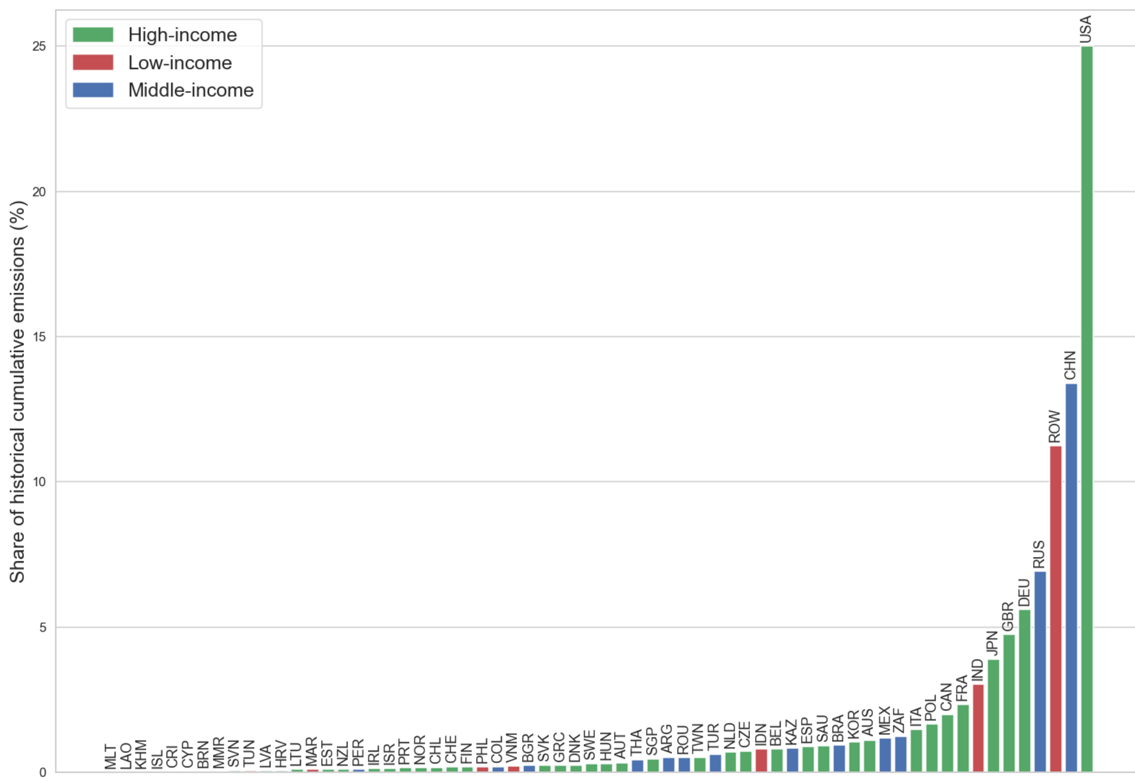


Figure 33: Historical Polluter Pays Transfers: Changes in Real Income by Country

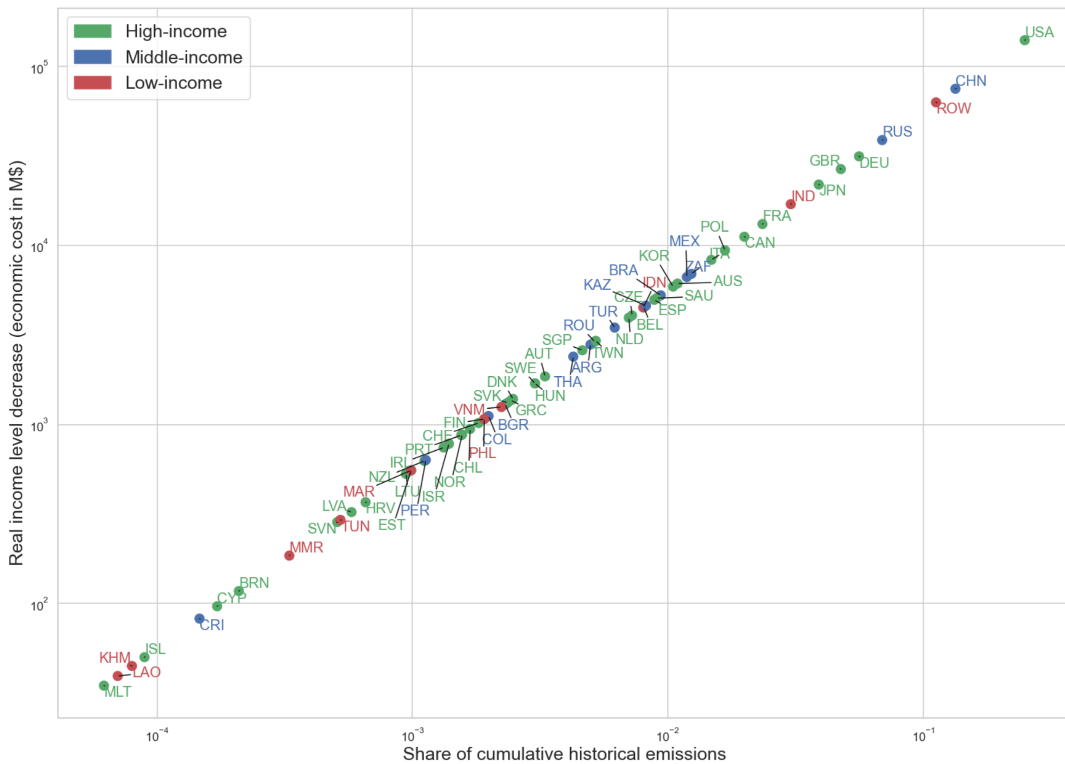


Figure 34: IMF Proposal

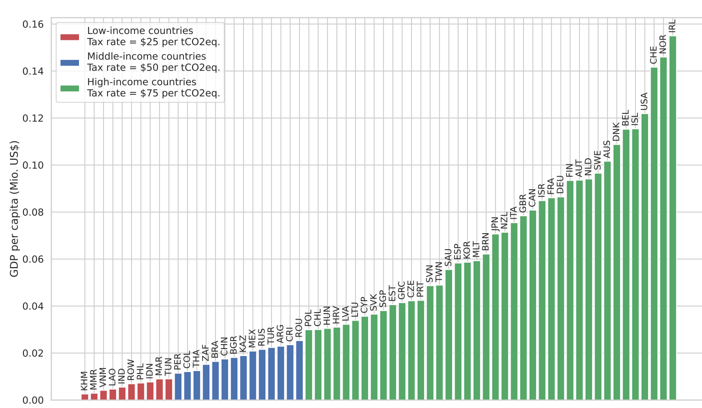


Figure 35: Real Income Changes - IMF Proposal - Restricted Club

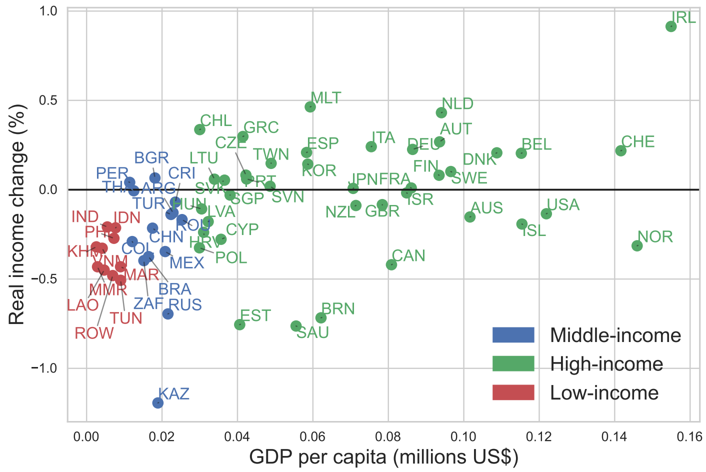


Figure 36: Real Income Changes - IMF Proposal - G20

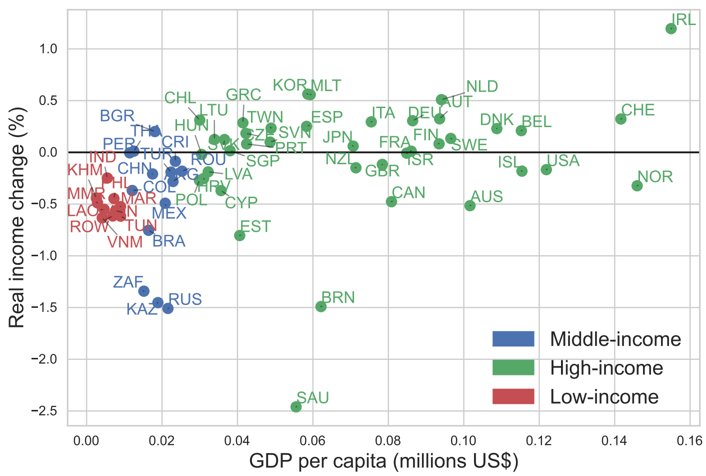


Figure 37: Real Income Changes - IMF Proposal - Key Players

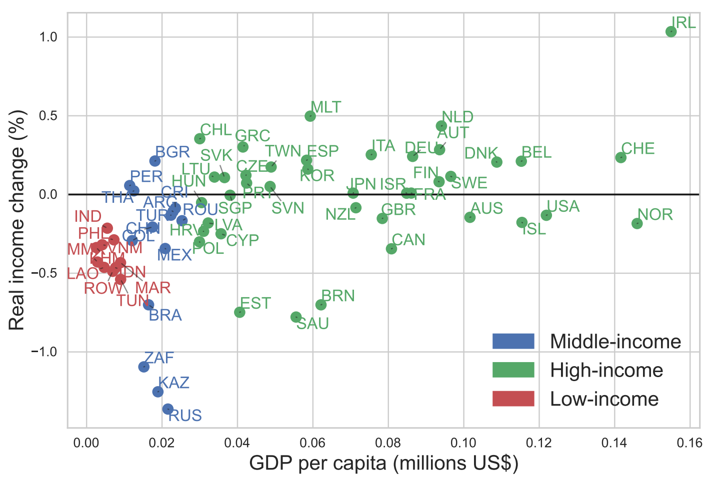


Figure 38: Real Income Changes - IMF Proposal - All Countries