The Distributional Effects of Carbon Pricing: A Global View of Common but Differentiated Responsibilities *

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Abstract

We use a quantitative international trade model with climate policies to explore the idea of Common but Differentiated Responsibilities (CBDR), a leading principle of climate action. The principle recognizes that low- and middle-income countries are most affected by climate change despite their lower contributions to its causes. We ask what are the consequences for global equity of policies that ignore CBDR and explore the efficiency and feasibility of various policy schemes that comply with it. Our analysis delivers three main results. First, efficient climate policies that ignore CBDR strongly exacerbate between-country inequality. Second, equity can still be achieved with efficient climate policies when they are paired with realistic international transfers that either equalize carbon tax costs or consider historical emissions, with minimal impact on high-income countries. Third,carbon tax schemes that rely on heterogeneous pricing with lower taxes for low and middle-income countries do not necessarily lead to fairer outcomes.

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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. For instance, much to the frustration of low- and middle-income countries, CBDR was notably absent from the final text of the 2023 COP meeting in Doha, due to opposition from high-income nations.[2]

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, as well as their political viability. To structure the analysis, we first establish a benchmark that asks what are the consequences

[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).

[2]According to the website Carbon Brief in their discussion about the outcomes of the COP meeting in Doha, "Many developing countries wanted to acknowledge the [CBDR] principle in the Global Goal on Adaptation (GGA) talks. (...) High-Income countries, on the other hand, completely opposed its inclusion." GGA is a "a "framework" that is meant to guide nations in their efforts to protect their people and ecosystems from climate change." (Brief, 2023)

of climate policies that disregard geopolitical considerations and, more specifically, the CBDR principle. 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 standpoint and also a popular proposal among policymakers and experts. 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).[3,4] 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 in the spirit of CBDR. 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).[5] 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 recently gained traction in the policy debate: (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

[3] A global carbon tax is also a popular proposal in the policy sphere. For example, the Director-General of the World Trade Organisation recently launched a global carbon price task force to elaborate a unified taxation scheme that could simplify and replace the multitude of currently existing ones (Reuters, 2023).

[4] 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.

[5] 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.

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).[6] 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 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.[7]

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 key 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.

[6]We work with a multi-sector Armington model with input-output linkages. Since the work of Arkolakis et al. (2012), it is well understood that an Armington framework yields the same aggregate predictions as other quantitative trade models, such as Eaton and Kortum (2002).

[7]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.

Given that some countries experience a real income gain while others face a real income loss, there is a role for international transfers inspired by the CBDR principle 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 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 such as a climate club and the recent IMF carbon taxation proposal may be politically more feasible due to the need for policy coordination among fewer countries, they do not necessarily lead to fairer outcomes. We show that this is the case of a climate club formed by key global players necessary to deliver meaningful reductions in emissions.[8] Despite 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.[9] In all configurations, the ICPF can never deliver both lower transfer requirements together with a more efficient climate policy when compared to a global policy benchmark. 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.

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))[10].

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).

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

[9] 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.

[10] 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)

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 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-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).[11]

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 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 production emission intensity of production of good s' in country i.[12,13]

[11] 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.

[12] 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:

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

[13] We also investigate our main results in a version of the model in which the carbon tax is instead paid in the origin country by producers. Results are similar and the main conclusions of the paper remain unchanged.

2.2 Demand

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

$$U_j = \prod_{s'} U_{s'j}{}^{\beta_{s'j}}$$

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

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:

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

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:

$$m_{is'js} = b_{is's}[p_{is'}\tau_{is'j}(1+t^e_{is'j})]^{-\eta_{s's}} E_{s'js} \overset{\pi}{P}_{s'js}^{(\eta_{s's}-1)} \tag{2}$$

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:

$$p_{is'} = \frac{(w_i)^{\gamma_{i,Ls'}}}{A_{is'}} \prod_k (\overset{\pi}{P}_{kis})^{\gamma_{kis}} \tag{3}$$

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:

$$I_j = \sum_s w_j L_{js} + \sum_{i,s',s} p_{is'j} m_{is'js} t^e_{is'j} + D_j \tag{4}$$

in which D_j is an exogenous and fixed deficit for each country, with $\sum_j D_j = 0$.[14]

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:

[14] Notice that carbon taxes obtained from imports of final goods are absent from the expression (4) as they are both paid by consumers and rebated lump-sum to them.

$$E_{js} = \sum_i \left(p_{jsi} \left(q_{jsi} + \sum_{s'} m_{jsis'} \right) \right) \tag{5}$$

By summing (4) and (5) we obtain the country trade balance, where taxes cancel out because they are domestic:

$$\sum_{i,s'} p_{is'j} q_{is'j} + \sum_{i,s',s} p_{is'j} m_{is'js} = D_j + \sum_{i,s} \left(p_{jsi} \left(q_{jsi} + \sum_{s'} m_{jsis'} \right) \right) \tag{6}$$

Last, labor market clearing in each country implies that:

$$\sum_s \gamma_{j,Ls} \frac{E_{js}}{w_j} = L_j \tag{7}$$

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 (1), (2), (3), (4) and (5) 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:

$$\widetilde{q}_{is'j} = \widetilde{I}_{s'j} [\widetilde{p}_{is'}(1 + t^e_{is'j})]^{-\sigma_{s'}} \; \overset{c}{\widetilde{P}}_{s'j}^{\,(\sigma_{s'}-1)} \tag{8}$$

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

$$\widetilde{m}_{is'js} = \widetilde{E}_{s'js}[\widetilde{p}_{is'}(1+t^e_{is'j})]^{-\eta_{s's}} \; \widetilde{P}^{\pi \; (\eta_{s's}-1)}_{s'js} \tag{10}$$

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

$$\widetilde{p}_{js} = \widetilde{w}_j^{\gamma_{j,Ls}} \prod_{s'} \widetilde{P}^{\pi \; \gamma_{s'js}}_{s'js} \tag{12}$$

Changes in the market clearing conditions are given by:

$$\widetilde{I}_{s'j} = \sum_s \widetilde{w}_j \widetilde{L}_{js}(w^B_j L^B_{js}) + \sum_{i,s',s} \widetilde{p}_{is'} \widetilde{m}_{ijs's} t^e_{ijs'}(p^B_{is'j} m^B_{is'js}) + D^B_j \tag{13}$$

$$\widetilde{E}_{js} = \sum_i \left(\widetilde{p}_{js} \widetilde{q}_{jsi}(p^B_{jsi} q^B_{jsi}) + \sum_{s'} \widetilde{p}_{js} \widetilde{m}_{jsis'}(p^B_{jsi} m^B_{jsis'}) \right) \tag{14}$$

$$\sum_s \frac{\widetilde{E}_{js}}{\widetilde{w}_j} L^B_{js} = L_j \tag{15}$$

In Appendix B, 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 aim at delivering climate justice.

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 and detail how we design the quantification routine to account for the main concerns of the principle of Common but Differentiated Responsibilities.

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:

$$\tilde{W}_j = \frac{\widetilde{I}_j}{\Pi_{s'} \widetilde{P}^{\beta_{s'j}}_{s'j}} \tag{16}$$

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 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:

$$T_j = H_j \frac{\sum_j G_j}{\sum_j H_j} - G_j \tag{17}$$

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 (17) as a fixed point to the algorithm described in Appendix B 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:

$$T_j = H_j - G_j + \Omega_j^B H_j \frac{\sum_j (G_j - H_j)}{\sum_j \Omega_j^B H_j} \tag{18}$$

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:

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

To back out transfers in this case, we add expressions (18) and (19) as a fixed point to the algorithm described in the Appendix B.[15]

3 Data

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

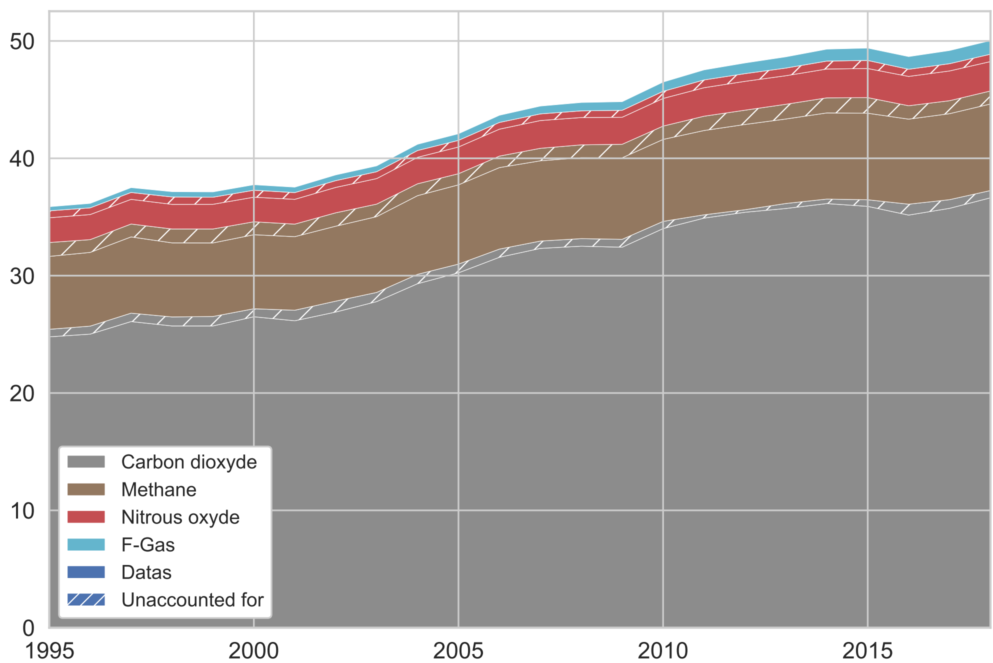
3.1 Data sources

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

[15] 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 17, 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.

Figure 1: Emissions by Gas



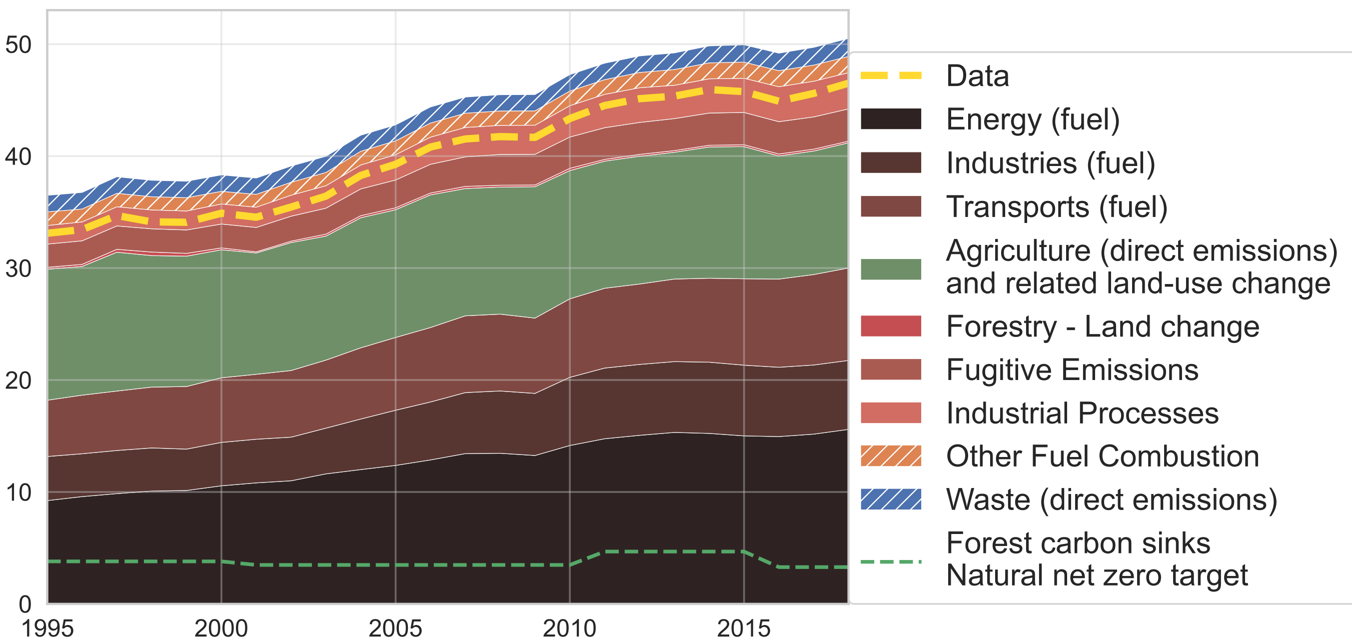
datasets: the OECD Carbon Dioxide Emissions Embodied in International Trade dataset (TECO2) (OECD, 2021), the FAOSTAT Domain Emission Totals (FAO, 2023), and the European Commission's Emissions Database for Global Atmospheric Research (EDGAR) (European Commission, 2023). The TECO2 dataset is constructed 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 agriculture, forestry, and land-use,[16] and the EDGAR database[17] 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.

Figure 1 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

[16]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.

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

Figure 2: Emissions by Source



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 2 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.

Now we turn to the emissions by sector in Figure 3. 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 emissions intensity of a sector in tons of CO_2e across countries. There are two main takeaways: Looking at the y-axis, there is large variation in emissions across sectors. Water and air transport, the agricultural sector, the mining sectors, energy, and raw materials are among the most polluting sectors. Looking at the x-axis, there is a large variation in emission intensities across different countries.[18]

[18] Plotting the density of the emissions intensity in % deviation from the sectoral mean in Figure 31 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 3: Sectoral Emissions

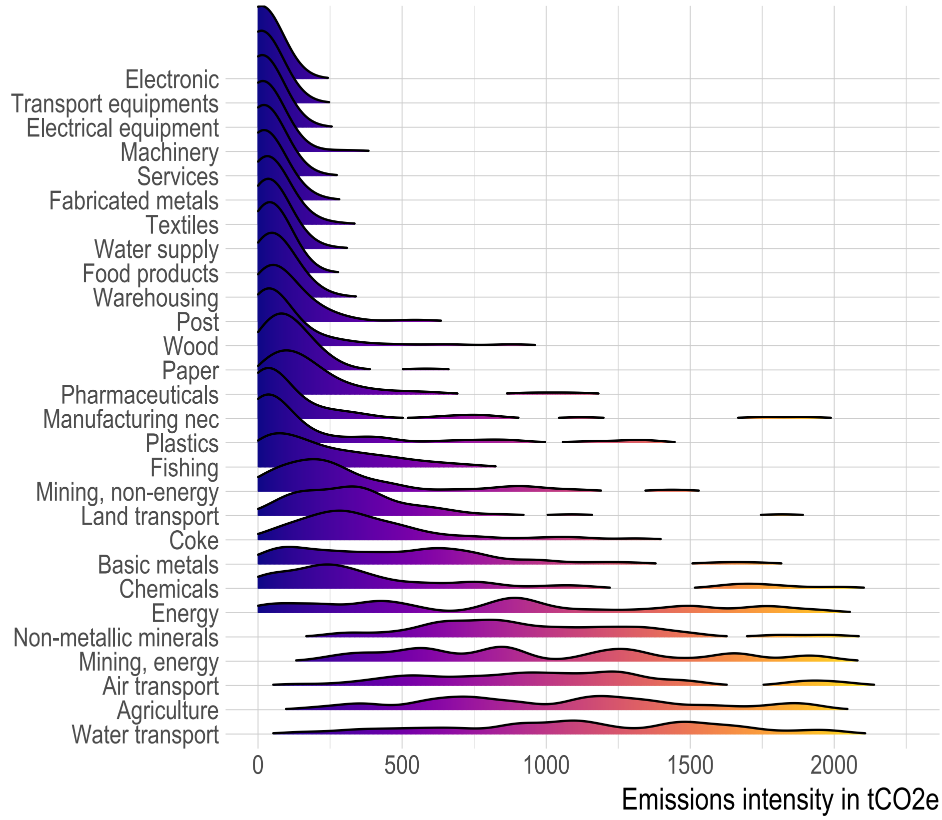


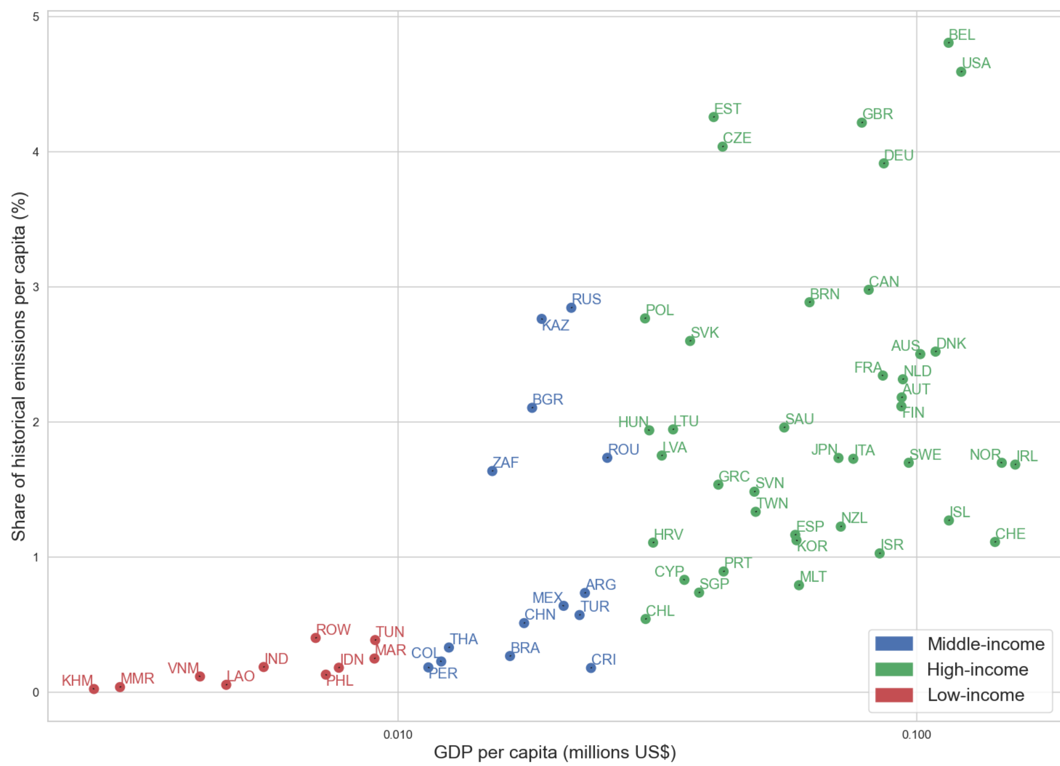
Figure 4 shows the historical cumulative emissions per capita for each country, based on data from Ritchie (2019). The countries with the largest GDP per capita are also responsible for the largest share of historical emissions per capita. Low-income countries have historically contributed very little to emissions. Additionally, Figure 32 in the Appendix shows that the U.S. accounts for around 25% of cumulative historical emissions. China is on second place, with a share of around 14%.

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, we address the elasticity of substitution across origins in consumption and intermediate input use. We assume $\sigma_{s'} = \eta_{s's} = \eta_{s'}$, following the method described by (Caliendo and Parro, 2015). To ensure robustness, we provide two alternative specifications: one based on estimates from Fontagné et al. (2022), and another using the elasticities provided by Fontagné et al. (2022), mapped to our industry

Figure 4: Historical Emissions



Note: Source: Ritchie (2019)

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 $\gamma_{j,Ls}$ and $\gamma_{s'js}$ are calibrated from the data as the ratio of intermediate input expenditures to gross output. Additionally, the labor share parameter $\gamma_{j,Ls}$ is calibrated as the value added in gross output.

4 Results

4.1 Carbon taxes

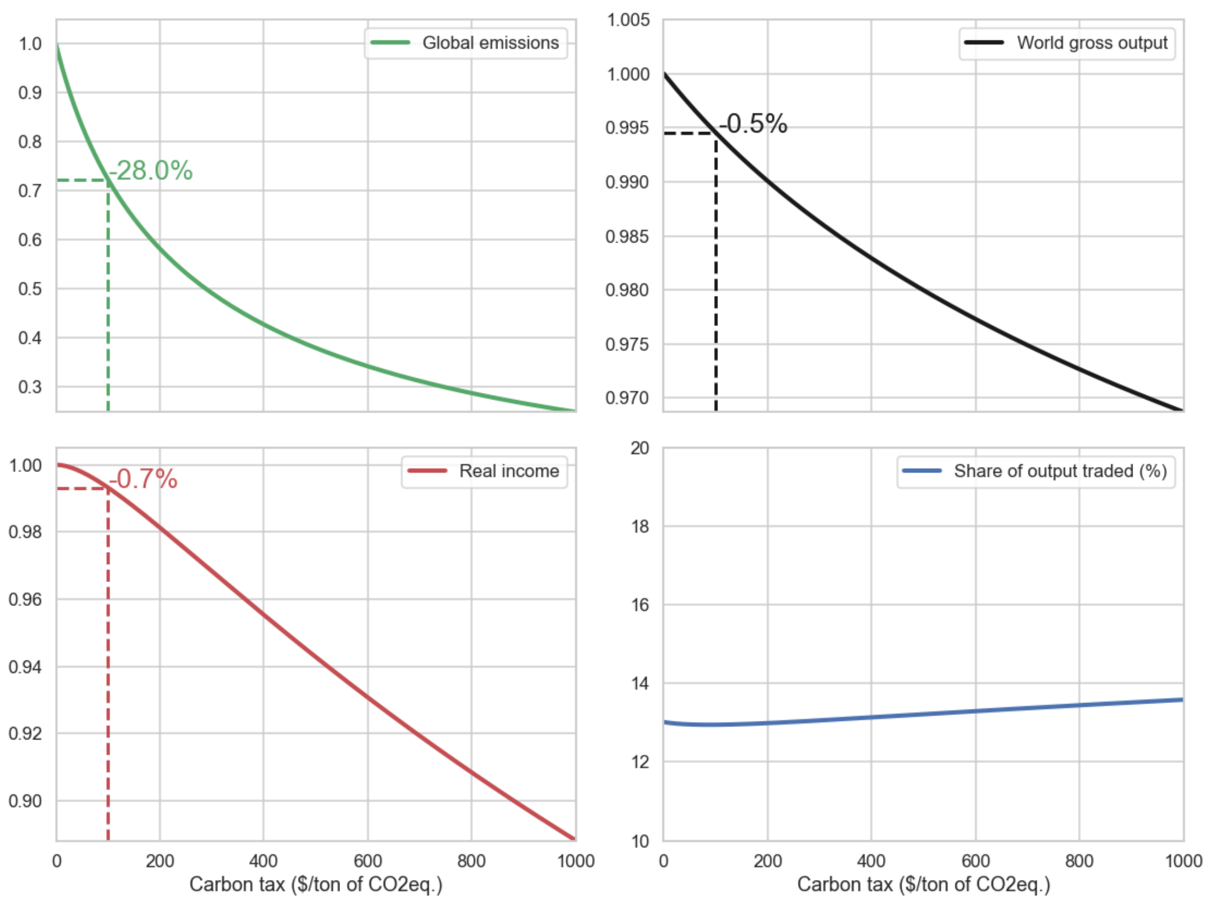
Figure 5 shows the macro effects of carbon taxes. The x-axis shows different levels of taxes and the y-axis shows the change in outcomes compared to the baseline without taxes. The upper left panel depicts global emissions and the bottom left panel shows associated changes in real income. Emissions are very responsive to carbon taxation, but notice that for higher taxes this comes at a large economic cost. World gross output in the upper right panel decreases as well as a response to higher carbon taxes. Interestingly, the share of output traded in the bottom right panel stays relatively constant, even for high levels of taxes. This suggests that there is still a role for international trade, even at very high levels of taxes. Focusing on a carbon tax of 100 USD/tCO_2e, a carbon tax seems to be very effective. We obtain a decrease in emissions of 28% for a decrease in real incomes of 0.7% and a decrease in world gross output of 0.5%.

4.1.1 Country effects

The macro effects mask substantial heterogeneity across countries. Figure 6 shows the real income change for each country and their GDP per capita. The graph reveals that most low- and middle-income countries experience a strong decrease in real incomes, while most high-income countries even experience a real income gain. This result stem from a higher carbon tax burden in low and middle-income markets. Figure 7 shows the effective tax rate, which we calculate as the total tax paid by the producers and consumers in a country divided by the total expenditure of a country. It shows that most high-income countries pay tax rates of around 1-2%, while low-income countries pay up to 8%.

We investigate further the impact of the tax on different countries in two ways. First, we look at the reallocation of economic output across different countries. Second, we investigate the consequent labor force reallocation. For the first exercise, Figure 8 shows the net change of output together with the reallocated output in percent. 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 low- and middle-income countries not only experience the largest decrease in net output, but they also

Figure 5: Macro effects of carbon taxes

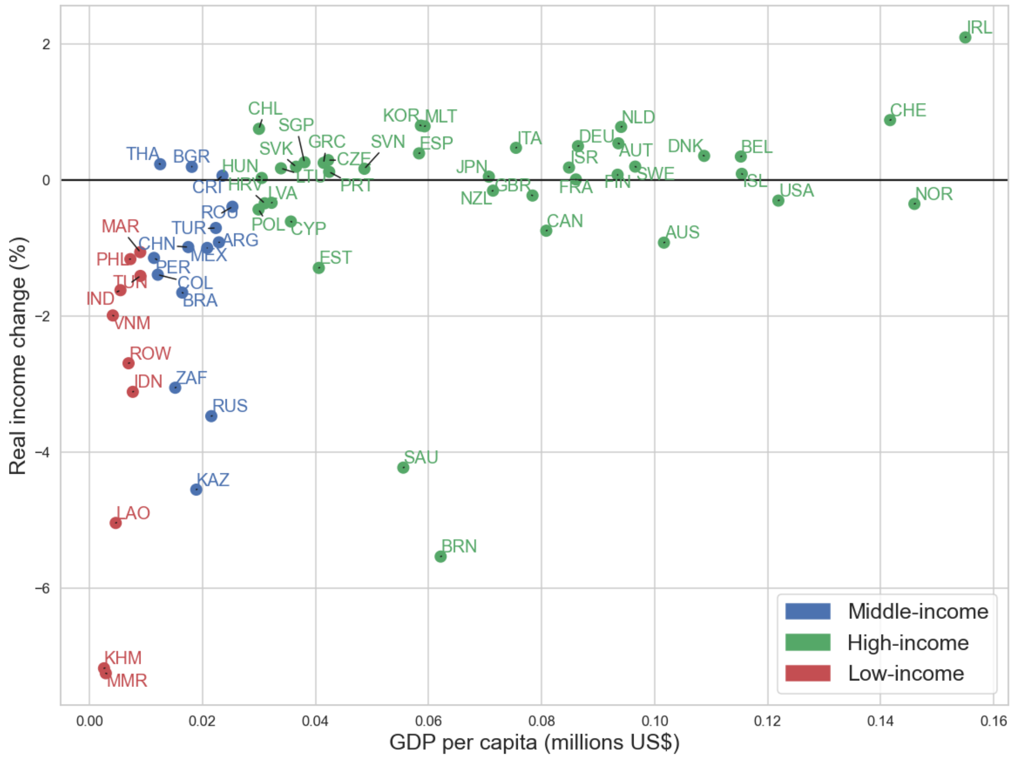


Note: This figure shows the macroeconomic effects of varying levels of carbon taxes on global outcomes. It tracks changes in global emissions, real income, and gross output as the tax rate increases from USD 0 (which we consider as the approximate state of the world in 2018) to USD1000/ton of CO_2e.

exhibit a larger reallocation of their output. We find a decrease in gross output for most of the low- and middle-income countries in our sample, and net zero changes or net gains for high-income economies. Large reallocation effects reveal that low- and middle-income countries' sectoral mix is less effective in terms of environmental comparative advantage (Le Moigne et al., 2024), so a carbon tax will impose a larger adjustment for these countries not only in terms of income but also in terms of resources.

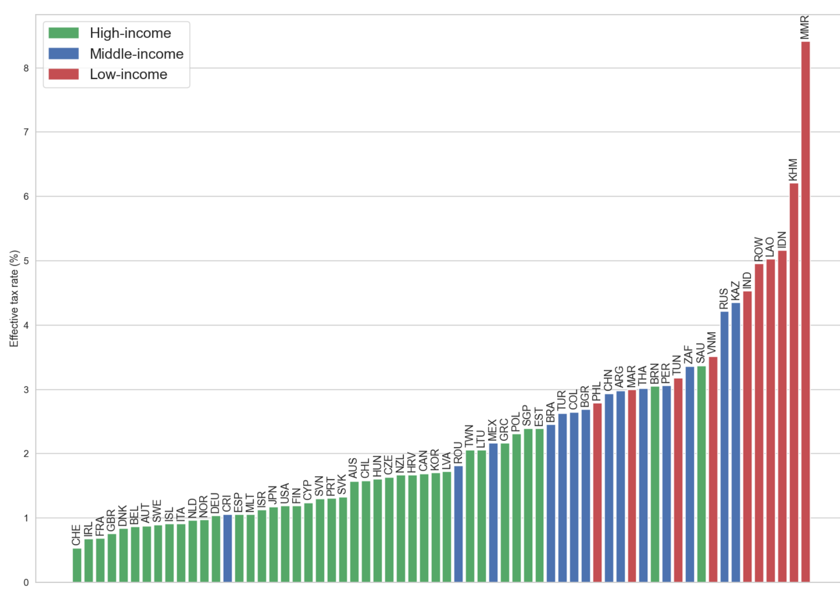
For the second exercise, we investigate the reallocation of labor. Figure 9 shows the percentage of the workforce that has to move to a different sector as a response to the carbon tax. Since labor is immobile across countries, each country will have the same amount of workers in the new equilibrium. These workers might have to work in different sectors, though. Here again, low- and middle-income countries experience the largest reallocation of their workforce.

Figure 6: Real income changes



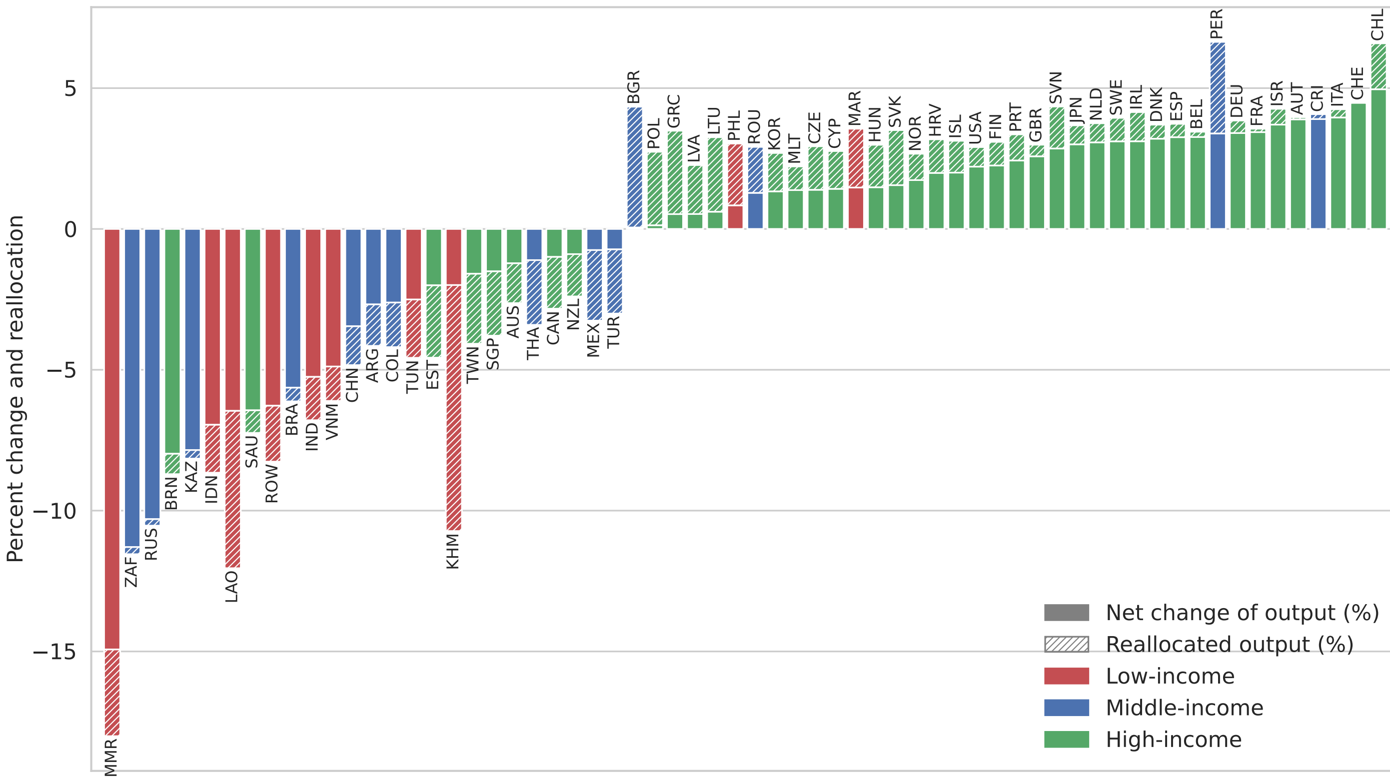
Note: This figure illustrates the changes in real income across countries following the implementation of carbon taxes, categorized by GDP per capita levels.

Figure 7: 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.

Figure 8: Within Country Output Reallocation

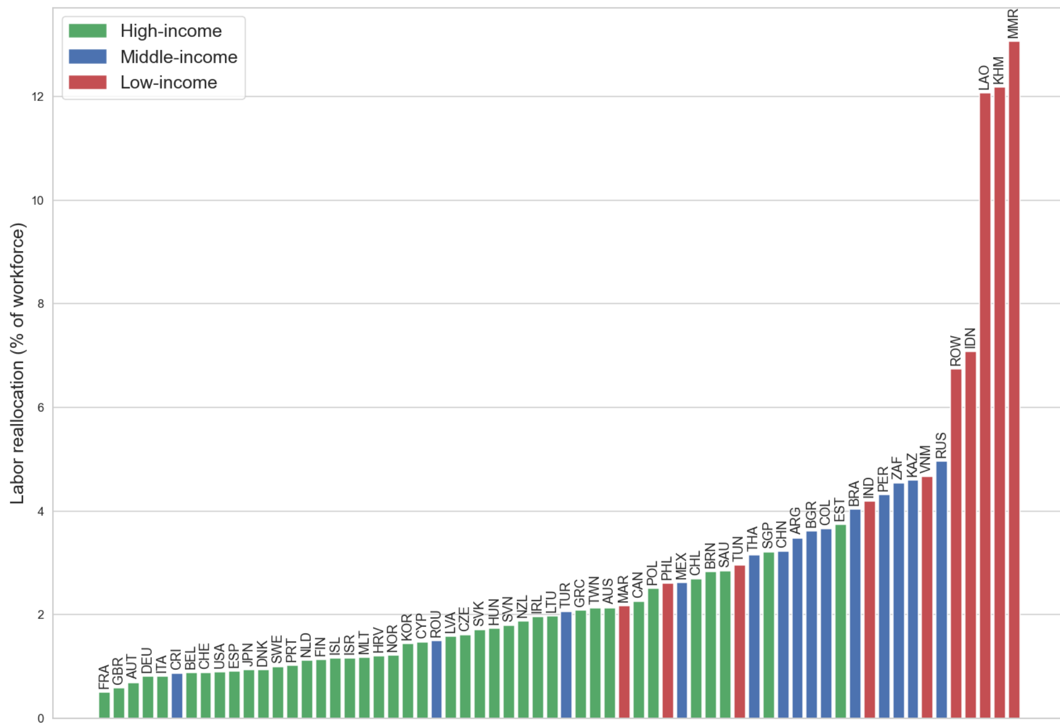


Note: This figure illustrates the economic impact of carbon taxes on different countries, categorized by their income levels. It displays the net change in output as well as the reallocation of output across sectors within each country. The sum of the two bars represents the total output decrease in 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.

4.1.2 Sectoral effects

Carbon taxes promote substantial changes in the cross-country and cross-sector pattern of production and international trade. We illustrate this point in Figures 10,11, 12 and 13, where we depict changes in production and trade flows across countries for specific sectors. 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

Figure 9: Labor reallocation



Note: This figure presents the percentage of the workforce that needs to transition to different sectors in response to carbon taxes, highlighting the labor mobility demands across different income levels (low, middle, high). Each bar represents the percentage of the total workforce in each country category that moves to a new sector in response to the carbon tax.

and relative to the median.

Figure 10 shows the changes in trade patterns for all sectors. Overall, trade in high-income countries (US, Europe, and Japan, for example) increase relatively to the median change in trade patterns as a response to the carbon tax, while it decreases in low- and middle-income countries (China for example). There are some deviations from this general trend for different sectors, though. For instance, Figure 11 shows the trade patterns for the energy sector. Notice that the US export less in total and export less to Canada specifically, while Canada increase production and exports to the US. Agriculture in China presents another deviation, as shown by Figure 12, with a relative increase in exports in the country. Notice also that there is a strong red arrow from Brazil to China. Given that Brazil has relatively high emission intensities, its exports to China decrease. Last, Figure 13 shows a fourth example from the basic metals sector 13. Observe that Chile and Peru are relatively green and display a relative increase

Figure 10: Micro effects of carbon taxes: All sectors

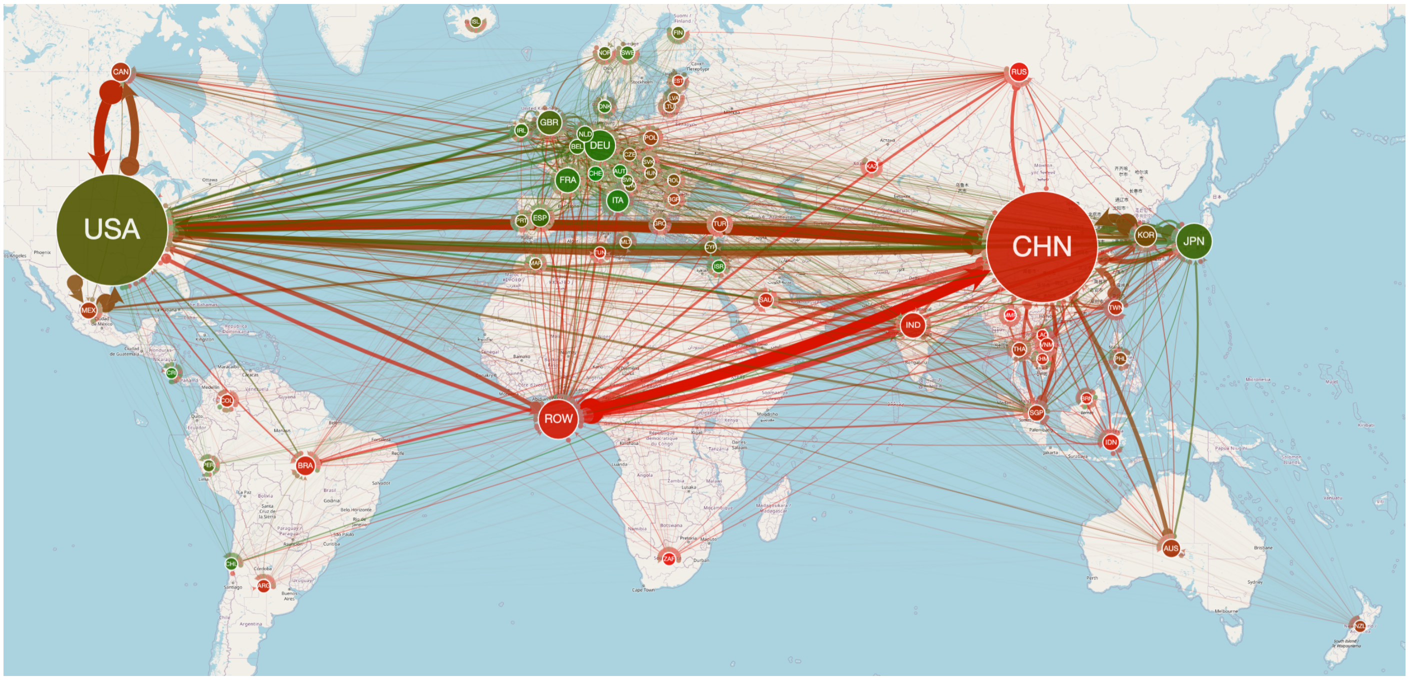


Figure 11: Micro effects of carbon taxes: Energy sector

in their exports. All in all, these figures show that while low- and middle-income countries do suffer the most from climate policy, there are certain subsectors in which they observe gains, with an expansion of production and exports.

Production can be reallocated across countries for a specific sector as seen in the previous graphs. Figure 14 shows how much of production is reallocated across countries for each sector. For each sector,

Figure 12: Micro effects of carbon taxes: Agricultural sector

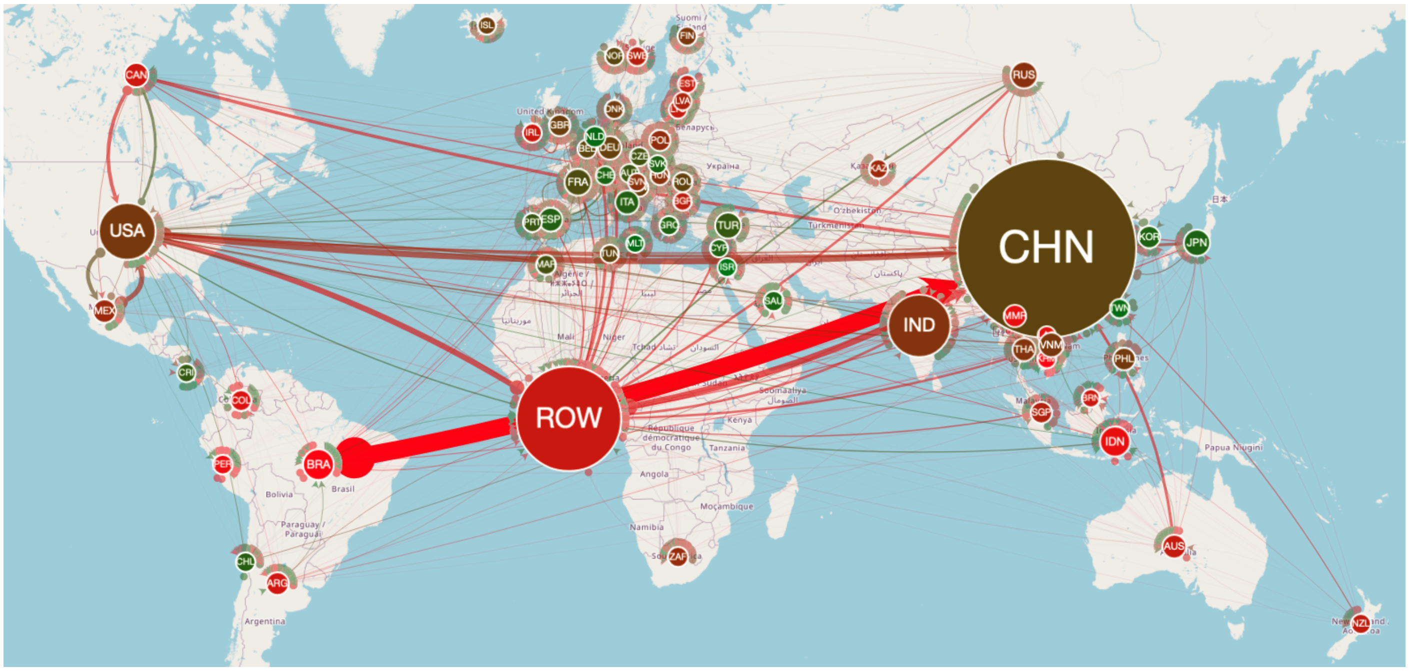
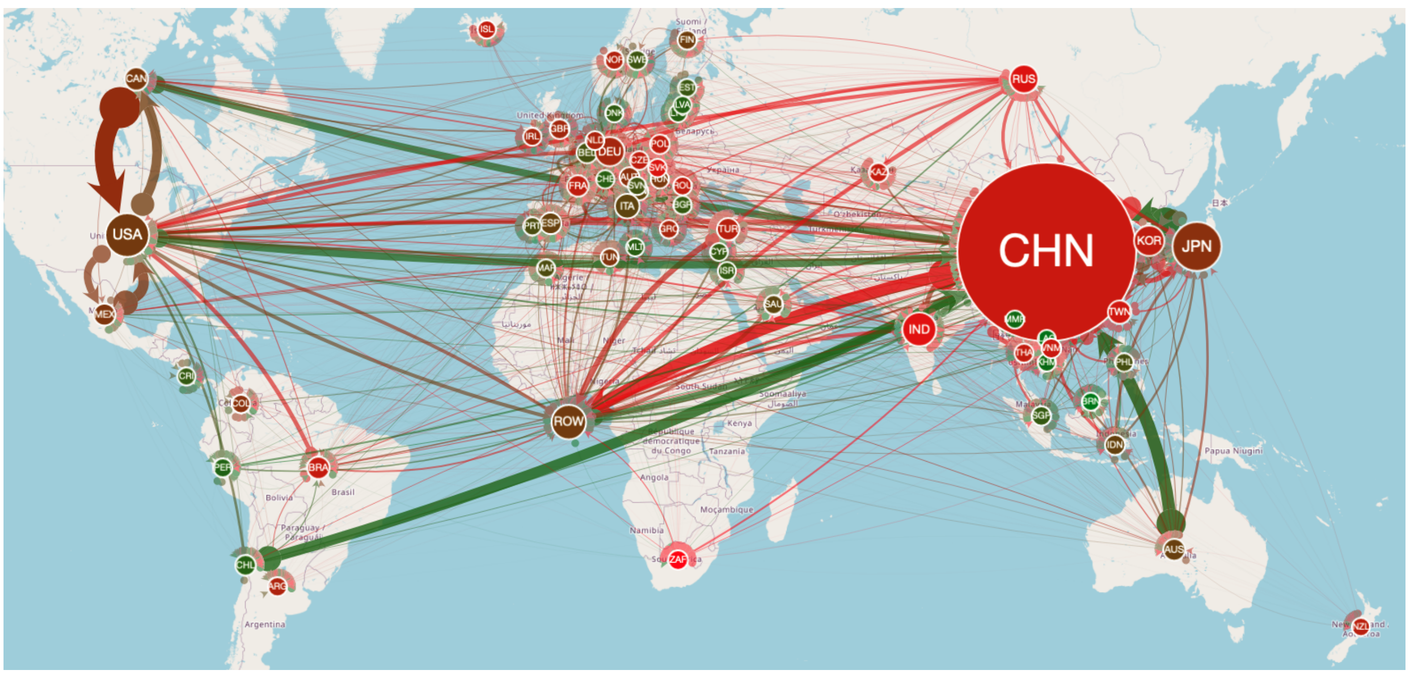
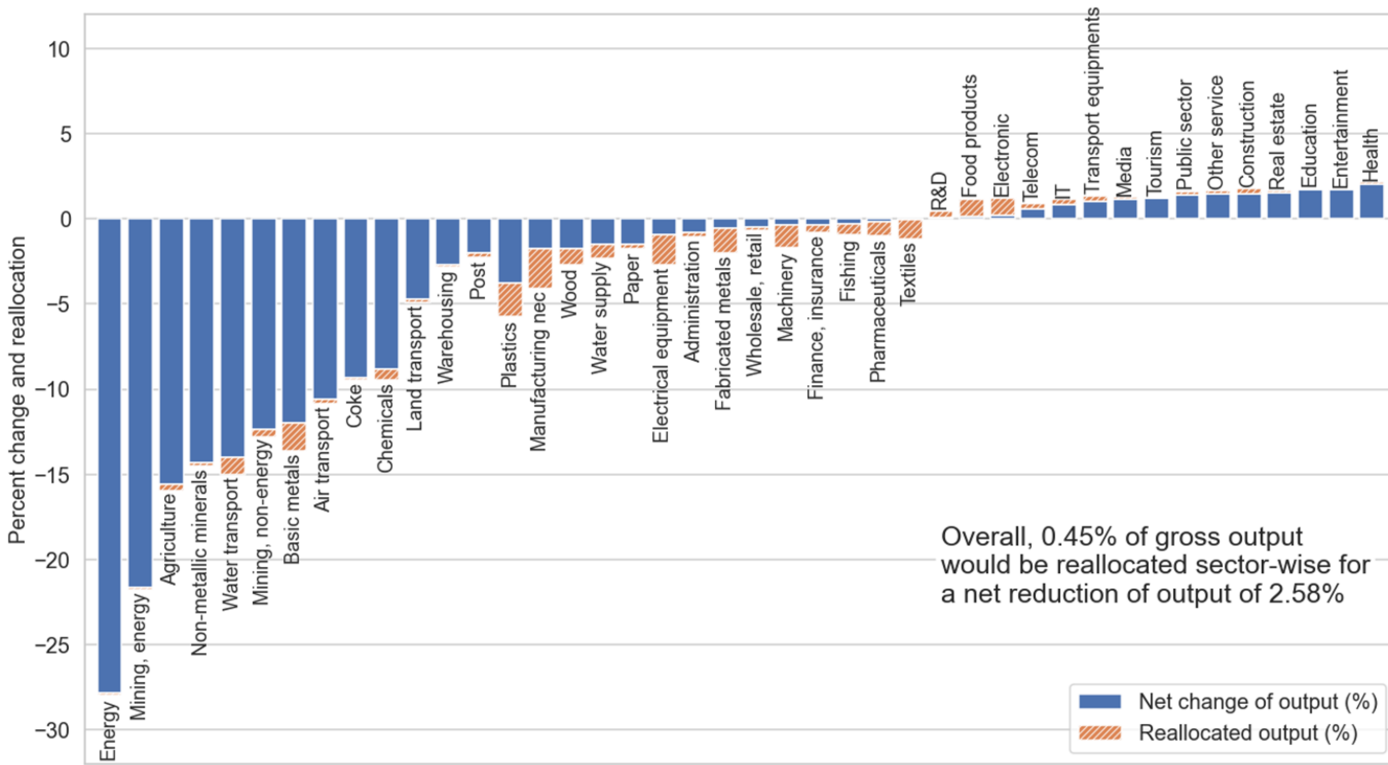


Figure 13: Micro effects of carbon taxes: Basic metals sector



the bars represent the percent change in a sector's gross output (across all producing countries) between the realized data in 2018 and the economy with a USD100/tCO_2e carbon tax. The filled blue bars represent the net change in output, whereas the hatched orange sections represent how much of a sector's output is produced in an origin different than previously. Unsurprisingly, the most polluting sectors (energy, agriculture, mining) experience the largest decrease in output. The services sectors instead show

Figure 14: Production Reallocation Across Countries



Note: This figure shows how much of production is reallocated across countries for each sector. For each sector, the bars represent the percent change in a sector's gross output (across all producing countries) between the realized data in 2018 and the economy with a USD100/tCO_2e carbon tax. The filled blue bars represent the net change in output, whereas the hatched orange sections represent how much of a sector's output is produced in an origin different than in the baseline.

an increase in output. While water transport and air transport were among the most polluting sectors looking at their emissions intensity in Figure 3, these sectors do not experience the largest decrease in production. This is a feature of our general equilibrium model. In a partial equilibrium world, we would expect more polluting sectors to show a larger decrease in emissions. In our setting, we observe a larger decrease in sectors that are relatively high up in the supply chain, as this have trickle-down effects on the entire economy. These net effects hide potential reallocations across countries within sectors, that are represented by the hatched bars. This reallocation effect or "green sourcing effect" can be quite large (Le Moigne et al., 2024), and sometimes even larger than the resulting net change. That means that in a given sector, the amount of production simply displaced from a dirty origin to a cleaner one is higher than the number of production capacities destroyed (in the case of a negative change) or created (in the case of a positive change). This phenomenon occurs in a wide range of sectors, from manufacturing equipment to fishing and food products to R&D.

4.2 Transfers

In this section, we explore international transfer schemes aimed at delivering climate justice. Recall that transfers are needed because the costs associated with the implementation of climate change mitigation policies are disproportionately borne by developing countries. As we show next, moderate monetary transfers across countries can remedy this fact.

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. 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.

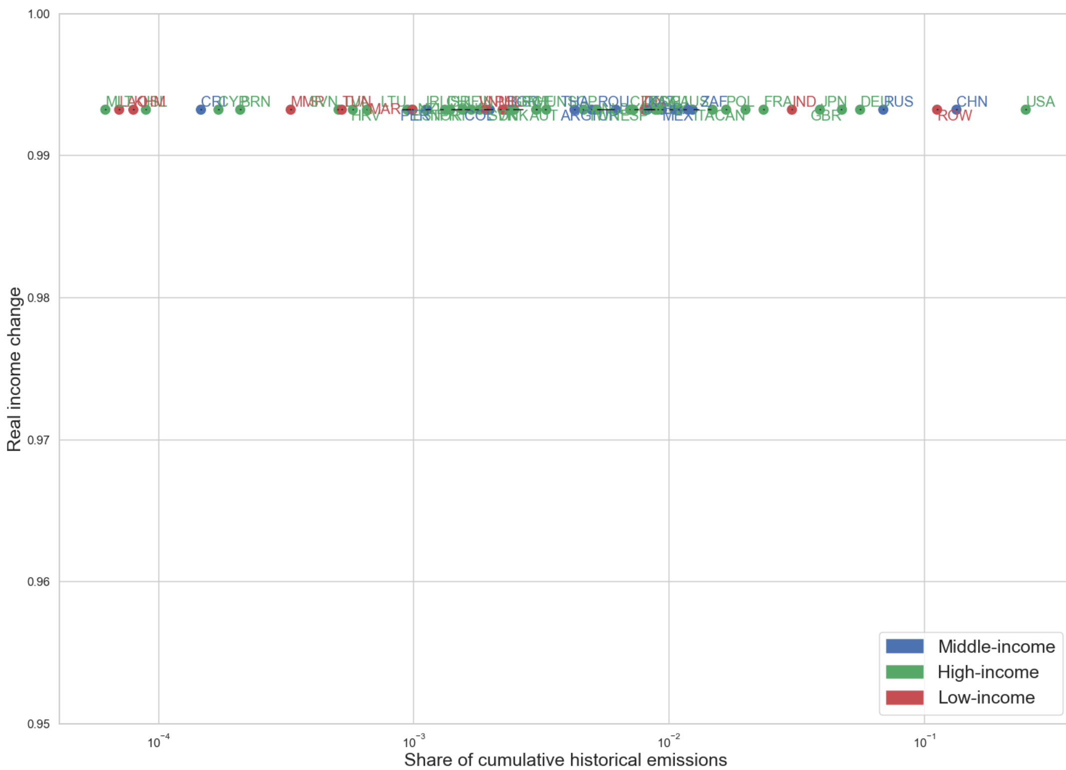
Results show that the overall impact of the global common carbon tax paired with monetary transfers is de facto smoother than without transfers: the reduction of global emissions achieved is the same (–28%) for identical aggregated real income costs (–0.7%). In addition, the gross-output decline is lower (–2.1% compared with –2.6% previously). Figure 15 shows the mechanism behind these results: changes in real income are all negative, lower than 1% and equally borne by all countries irrespective of their relative contribution to the climate crisis.

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 16, 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,[19] the figure reveals that high-income countries in general have to pay a monetary transfer to low- and middle-income countries in order to equalize the economic cost of a global carbon tax. The largest payers are European countries and the U.S., while the largest receivers are 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

[19] 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.

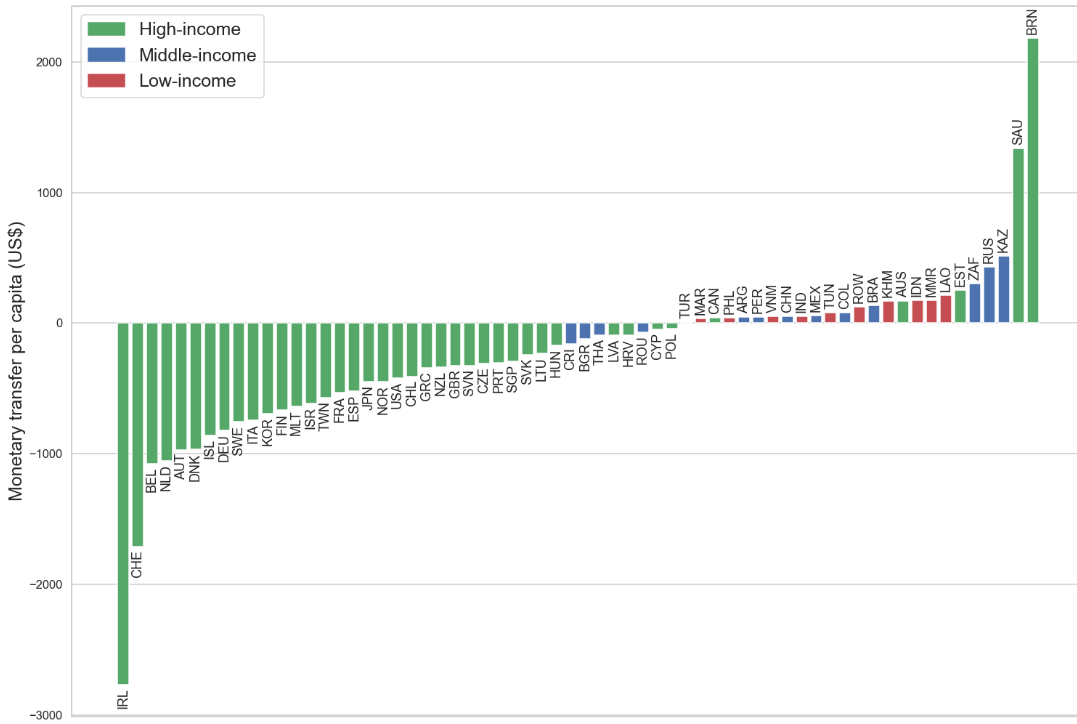
Figure 15: Equal Cost Transfers: Changes in Real Income by Country



the 15th Conference of Parties (COP15) of the UNFCCC in Copenhagen in 2009, high-income countries committed to a collective goal of mobilizing \$100 billion per year by 2020. The goal was formalized at the COP16 in Cancun, and, at the COP21 in Paris, it was reiterated and extended to 2025. 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 the comparison with the "USD 100 billion per year" pledge of the successive COPs, our model suggests that in the presence of a global carbon tax, the transfers needed to equalize the economic costs of climate action across countries amount to USD 272 billion. While this is substantially larger than the latest pledge achieved (by a factor of 3), the impact this would have on the population of developed countries is in fact relatively modest. The highest transfers need to be paid by Ireland in the amount of \$2,000 per person per year, and by Switzerland in the range of \$1,400 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 \$1,000. Note that because poor countries tend to have larger populations, the

Figure 16: Equal Cost Transfers by Country

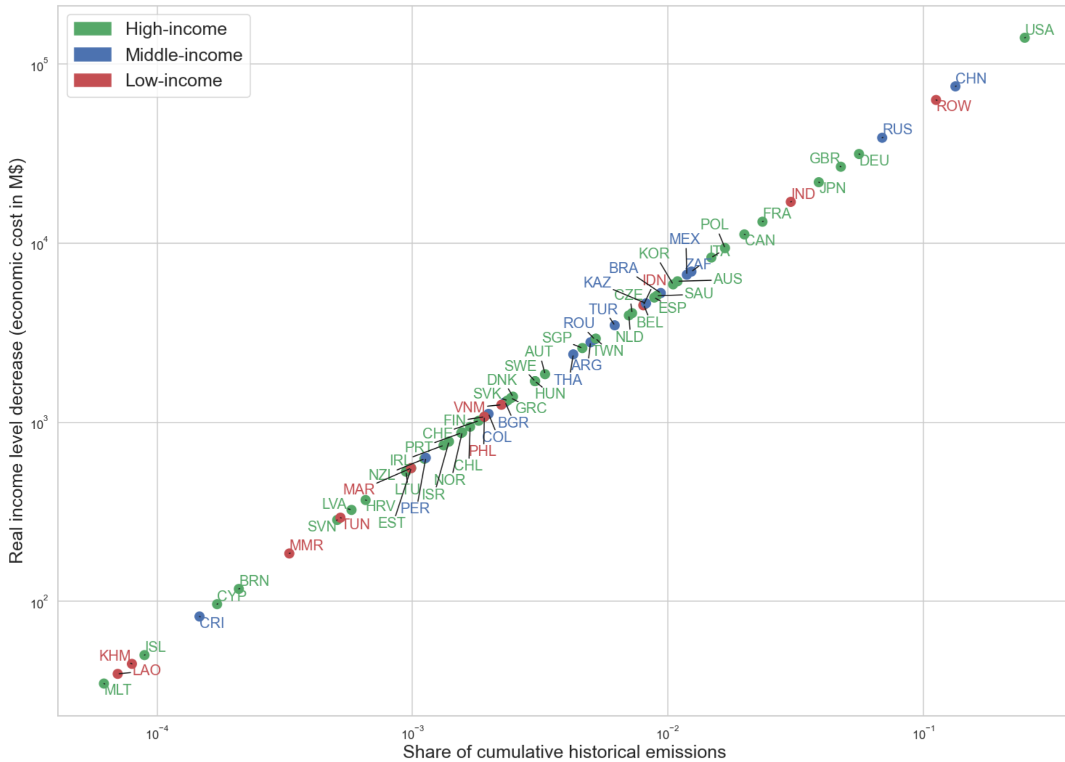


effective transfers received per capita are lower (e.g., \$600 per capita for Kazakhstan, less than \$200 for Laos and Indonesia). The equal-costs scenario therefore suggests that in absence of any geopolitical consideration, socio-economic equality in the face of optimal climate action can be achieved with modest transfers.

4.2.2 Historical Polluter-Pays Transfers

We now turn to the international monetary transfers associated with a polluter-pay scheme. Recall that our polluter-pay scheme is designed to make sure that the realized real-income cost borne by a country is proportional to its historical contribution to global cumulative emissions. Figure 17 shows that the transfers successfully achieve that. In practice, this means, for instance, that the economic cost of the global carbon tax for the U.S. needs to be 25% of the aggregate economic costs, the economic cost for China 13%, and the economic cost of Brazil 1%, as those are the relative contributions of each country to total emissions of greenhouse gases. Similar to the equal-costs case, the overall impact of the

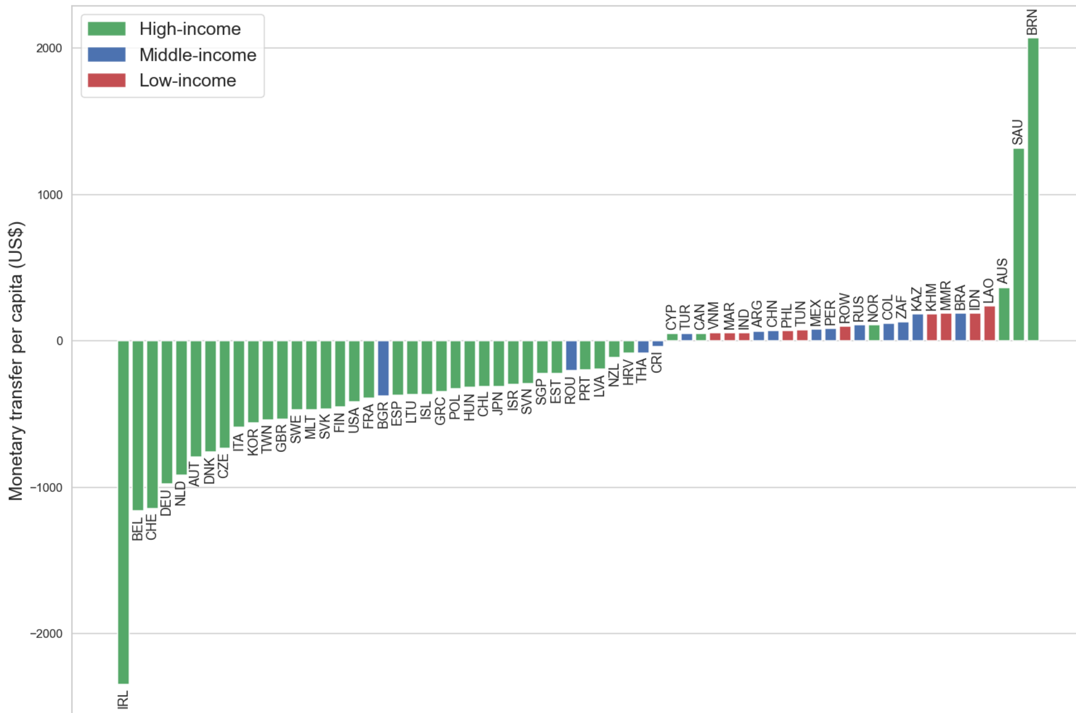
Figure 17: Historical Polluter Pays Transfers: Changes in Real Income by Country



polluter-pays scenario is also smoother than climate action without redistribution: the global reduction of emissions remains at –28%, the global real income cost remains at –0.7%, and the decline in gross output remains lower at –2.1%.

In terms of transfers, three important facts can be emphasized. First, the total amount of transfers required is slightly lower than in the equal-cost scenario at USD 255.7 billion. This is because the equal-costs scenario is focused solely on redistributing economic costs equally, whereas the polluter-pays scenario allows for unequal economic costs based on historical responsibility. As a result, per-capita transfers will also be lower, the maximum amount required being now less than $2,000 per person per year (still paid by Ireland). Second, the distribution of transfers across countries still implies that high-income countries should pay and low- and middle-income countries should receive, as shown by Figure 18. There is a clear positive correlation between current per-capita GDP and historical contribution to global cumulative emissions. This should not be particularly surprising as countries that benefited from the Industrial Revolution started to emit CO_2 during the 19th century and have now the highest levels

Figure 18: Historical Polluter Pays Transfers by Country



of development.

Third, the differences in the distribution of transfers implied by the equal-costs and by the polluter-pays scenarios (comparing Figures 16 and 18) 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 7, 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 ask what heterogeneous carbon pricing schemes in which countries adopt different levels of carbon taxation would imply for fairness in climate action. Such schemes are often seen as more politically feasible, as they eliminate the need for coordination among all countries, as well as fairer, as they reduce the depth of carbon taxation in low and middle-income countries. We investigate the following two policy options, which feature prominently in the policy debate: (i) a unilateral carbon pricing scheme amongst a selected "club" of countries paired with a carbon border mechanism, as is currently being implemented in the European Union, and (ii) heterogeneous carbon prices based on income levels following a recent proposal 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? To answer this question we compare the proposed policy with a clear benchmark: a counterfactual world generating the same emissions reduction as in the scenario analyzed through the adoption of a global carbon tax paired with "equal costs" transfers. By keeping the reduction in emissions fixed, we can isolate the effects of price heterogeneity both in delivering fairness, by comparing transfers in the two cases, as well as in delivering efficiency, by comparing the associated real income costs.

5.1 Climate Club with a Carbon Border Adjustment Mechanism

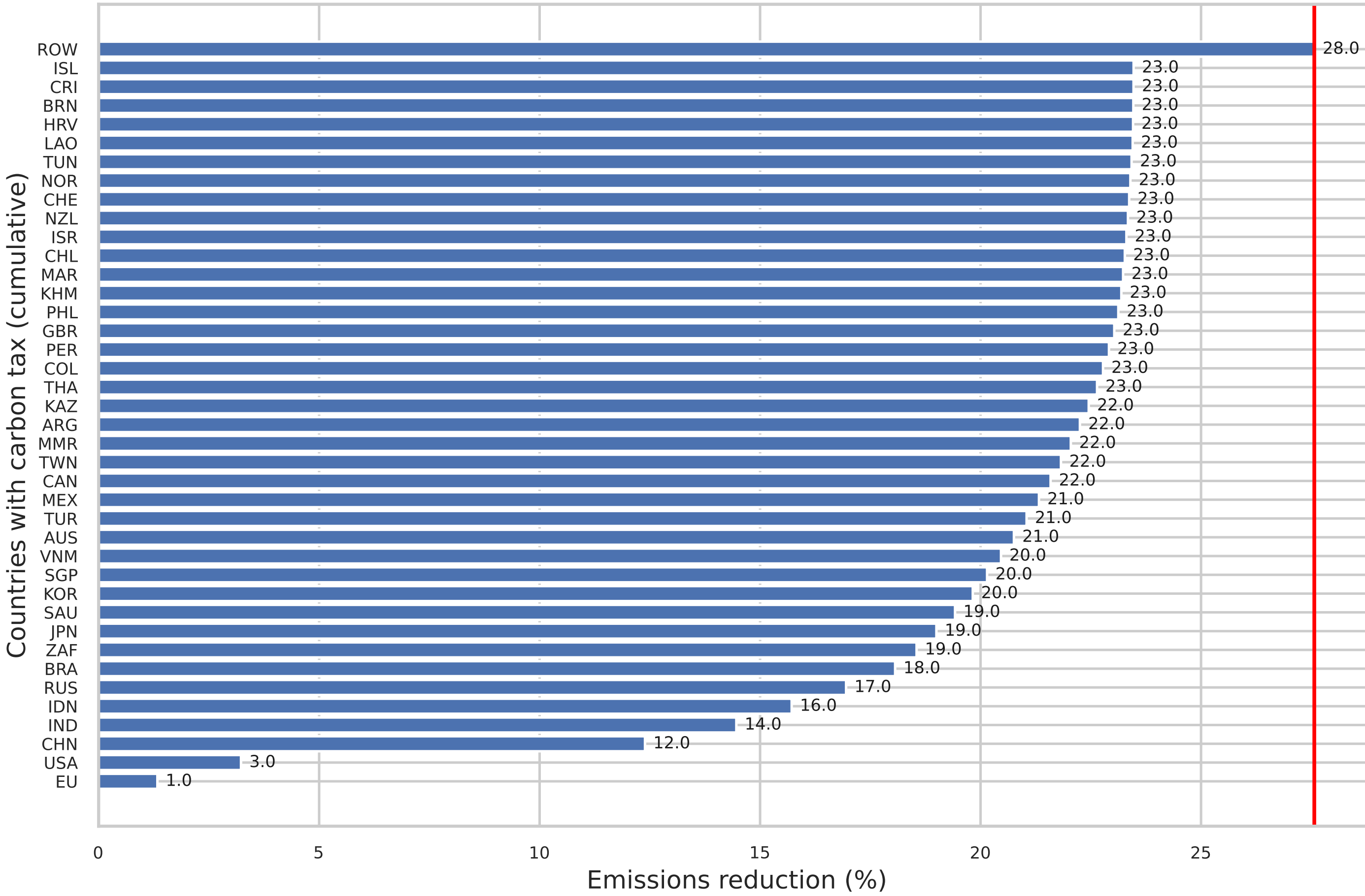
To model the scenario of a climate club with a carbon border adjustment, we build on the design of the European Union's Emissions Trading Scheme (ETS) and Carbon Border Adjustment Mechanism (CBAM). The EU CBAM has been imagined in response to the EU ETS to allow European companies to remain competitive in a world where the EU imposes a unilateral carbon price on its producers. In simple terms, one can consider the EU ETS as a carbon producer tax: any European producer must pay for a right to emit GHG emissions over the course of their production process. This makes the price of their output relatively more expensive, and therefore less attractive than foreign goods produced with no carbon tax. To restore the competitiveness of these producers within the EU, the CBAM imposes a similar carbon price on the consumption of foreign goods imported into the EU if no carbon tax has been applied on them prior to entry.

To understand what domestic carbon taxation paired with a border adjustment mechanism would imply for fairness in climate action, we simulate the creation of a club with a critical mass of countries from the Global North and South: members of the EU, the U.S., China, India, Indonesia, Russia, Brazil, and South Africa. Members of the club impose a carbon tax of $100/tCO2eq on their producers, while simultaneously imposing a consumption tax on all imports coming in. We selected this group of countries because they are some of the "key players" driving down emissions in the uniform carbon tax scenario. This is shown by Figure 19, which displays the cumulative emissions reduction as more countries impose a carbon tax (moving from the bottom to the top of the figure). When the key players are the only ones adopting a USD 100/tCO2eq tax, an 18.5% reduction of global emissions is achieved, that is, already two-thirds of the maximum achievable with widespread adoption. Notice that also in this scenario a carbon price is not adopted by the majority of low and middle-income countries, which is important for our discussion of the distributional consequences of the climate club.[20]

Results show that a climate club with "key players" would imply a global welfare cost 10.6% larger than the scenario of a uniform global carbon tax, assuming that carbon is priced at a level such that the obtained global emissions reduction is identical (in this case, equivalent to -19%). This corresponds to a world with a carbon price of USD 60/tCO2eq. In other words, such a climate club is relatively less

[20]We also simulate a similar climate club configuration with only EU countries. In this case, the emissions reduction is only 1.4% of global emissions. This can be explained by the fact that production is already relatively clean in Europe compared to the rest of the world, and that trade within the EU is relatively strong.

Figure 19: Incremental Carbon Taxes

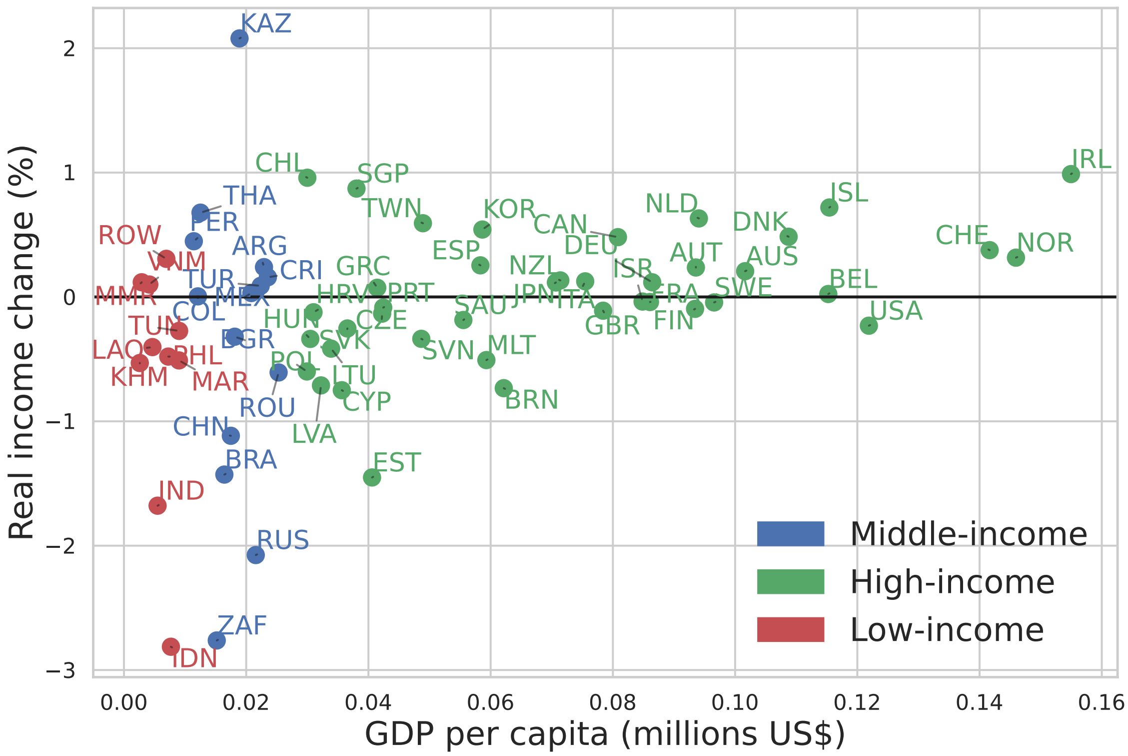


Note: This figure depicts emissions reduction when imposing a uniform carbon tax of USD100/ton of CO_2 on an incrementally larger set of countries. The x-axis depicts the emissions reduction, while the y-axis indicates which country is newly added to the scenario (from the bottom to the top).

efficient than a uniform global carbon tax. Figure 20 shows the real income changes associated with the creation of the climate club. Interestingly, low and middle-income countries still disproportionately bear the costs of the policy, even though many of them do not actively participate on it. This highlights the importance of accounting for international trade and global supply chains when discussing the distributional effects of carbon policies as income effects are determined by cross-country linkages.

But what would our definition of the climate club imply in terms of fairness? Comparing North-South transfers needed to equalize the real-income cost of carbon pricing for all countries with our climate club to our benchmark of a uniform global carbon tax with "equal-cost" transfers, we find that the climate club is in fact less fair, to the extent that it requires transfers of the order of USD 201 billions, that is 36% more than in our benchmark scenario. Hence, the argument according to which heterogeneous carbon pricing would be fairer does not hold here. Figure 21 further displays the associated transfers. The majority of transfers is still made by high income countries, although many of them now feature

Figure 20: Real Income Changes by Country - Climate Club

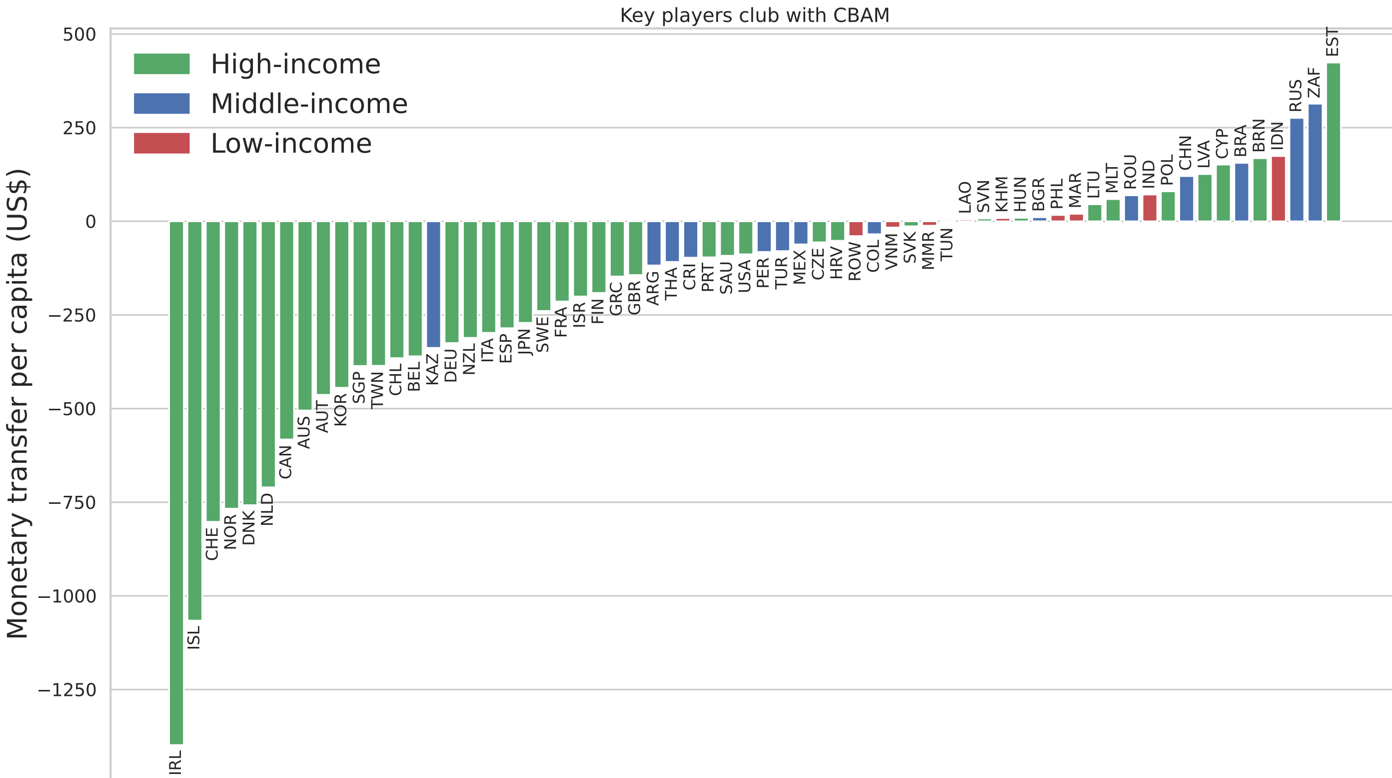


as receivers. Compared to the uniform tax case (in Figure 16), it is clear that the climate club changes the correlation between transfers and income status. This happens because different from our global tax benchmark this policy does not correctly target cross-country and cross-sector variation in emission intensities, which, as we have seen, are strongly correlated with income levels.

5.2 IMF International Carbon Price Floor

International Carbon Price Floor (ICPF) is a proposal made by the IMF in June 2021 with the key ambition to match near-term climate goals with credible policy actions (Parry et al., 2021). To paraphrase the proposal, the scheme would rely on two key ingredients: (i) a small number of key large emitting countries would be the core "club" negotiating it, and (ii) the negotiation would focus on the minimum carbon price that each country must put on their CO_2 emissions. The argument in favor of a core "club" of members is to simplify negotiations by limiting the size of the initial set-up. Candidates retained in the original proposal are either a group composed of Canada, China, the European Union, Great Britain, India, and the United States, or the whole of the G20. Focusing the negotiations on the floor prices is in essence proposing a compromise between a global uniform carbon tax as advertised by the economists, and a climate club scenario similar to what we studied above. In their calibration,

Figure 21: Equal Cost Transfers by Country - Climate Club



the IMF proposes three floor prices: \$75/tCO2eq for advanced countries, \$50/tCO2eq for high-income emerging economies (EME), and \$25/tCO2eq for low-income EMEs.

In our simulations, 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 a scenario with our "key players" (as in our climate club scenario), as well as another one in which all countries are participating of the ICPF according to their income level.[21] Again, we compare the welfare cost and the 'equal cost' transfers in the ICPF scenarios with the same metrics of a global tax with transfers scenario achieving the same emissions reduction. Our analysis shows that the IMF's ICPF scenario, which includes 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. In comparison, including the G20 countries in the ICPF leads to a need for transfers that are 1.2% higher than the uniform tax benchmark. The ICPF applied to "key players" and all countries results in lower transfer requirements, decreasing by 3.4% and 5.5%, respectively, compared to the uniform carbon tax scenario. Figures 22, 23, 24 and 25 display the transfers in each scenario. Similar

[21] To outline this scenario we follow the World Bank allocation of countries to different income levels, which can be found at: https://datatopics.worldbank.org/world-development-indicators/the-world-by-income-and-region.html. See Figure 33 in Appendix E for a description of how GDP per capita relates to heterogeneous carbon prices in this case.

to the climate club case, transfers are still paid by high income countries, but the correlation with income status is not so pronounced even when all countries are included in the policy scheme. Again, this happens because the policy doesn't directly target the cross-country and cross-sector variation in emission intensities.

What about efficiency? The IPCF scheme on the restricted group of countries proposed by the IMF (Canada, China, the European Union, Great Britain, India, and the United States) is not only the least fair but also the least efficient of these schemes, with a measured welfare cost 1.3 times larger than for a uniform carbon tax (132%). The scheme with G20 countries has 50% higher real income costs, while the scenario with key players and all countries have costs that are 67% and 12% higher, respectively. Hence, none of the studied scenarios appear more efficient than their uniform "fair" tax benchmark, although it is clear that the more countries included in the scheme, the lower the inefficiency. To sum it up, it is unclear whether the IMF proposal would be so much fairer than a simple global uniform carbon tax paired with North-South transfers. In the best-case scenario, in which all countries participate, the slightly lower transfers come at a higher real income cost.[22]

6 Robustness

6.1 Elasticities

In this section, we test the robustness of our results for different values of the trade elasticity. The main part of the paper estimates the elasticities using the method in Caliendo and Parro (2015). Additionally, we examine the result for two other sets of elasticities: First, we take the elasticities in Fontagné et al. (2022) and aggregate them to our sectoral definition. Second, we use the method in Fontagné et al. and estimate the elasticities with our data, combining it with tariff data from Fontagné et al.. More details on how the elasticites are estimated can be found in Appendix C.

Figure 26 shows the changes in real income for each country for all three sets of elasticities. The overall picture is very similar: high-income countries gain, while low- and middle-income countries lose. The actual percentage change for the real income change is slightly different for each elasticity and depends on which sectors the countries specialize in. Saudi-Arabia for example will have a lower real

[22] Figures 34, 35, 36, 37 in the Appendix show the changes in real income by country in each scenario.

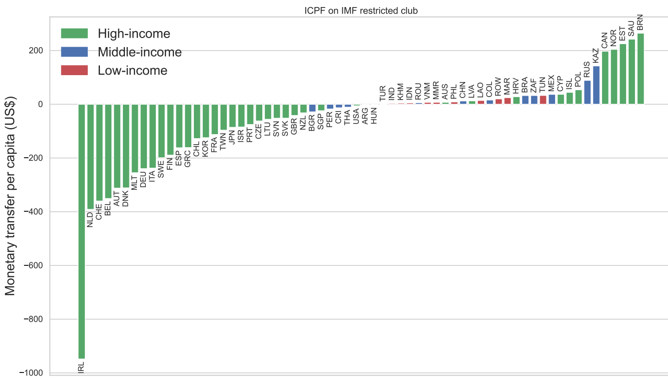


Figure 22: Equal Cost Transfers by Country - IMF Proposal - Restricted Club

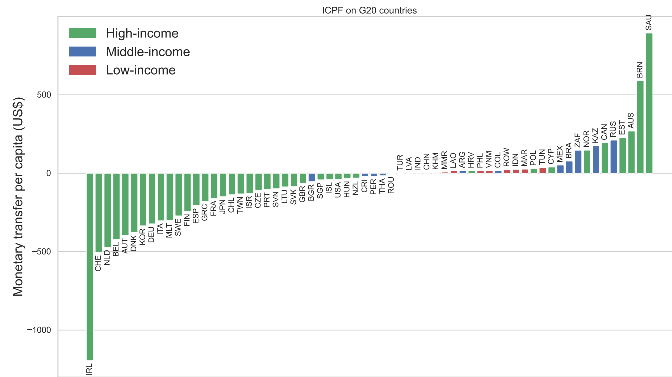


Figure 23: Equal Cost Transfers by Country - IMF Proposal - G20 Countries

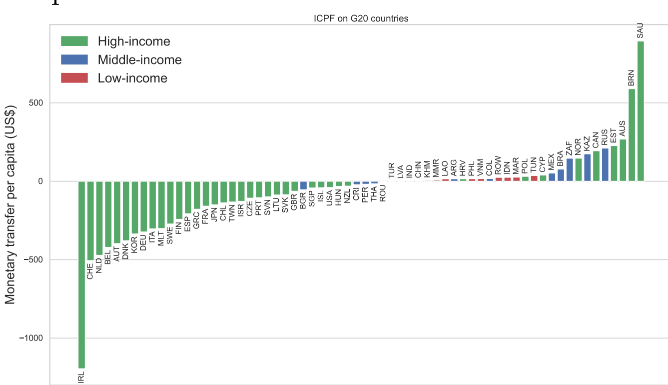


Figure 24: Equal Cost Transfers by Country - IMF Proposal - All Countries

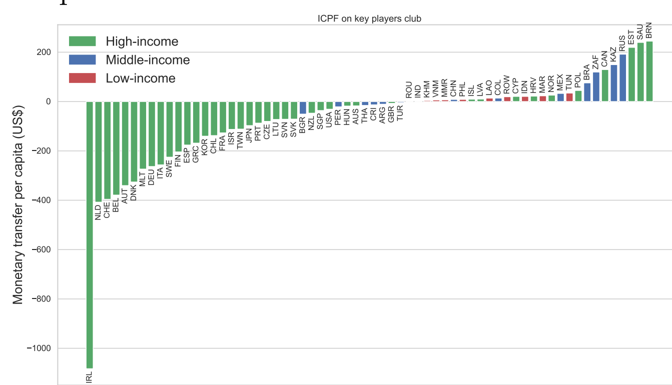
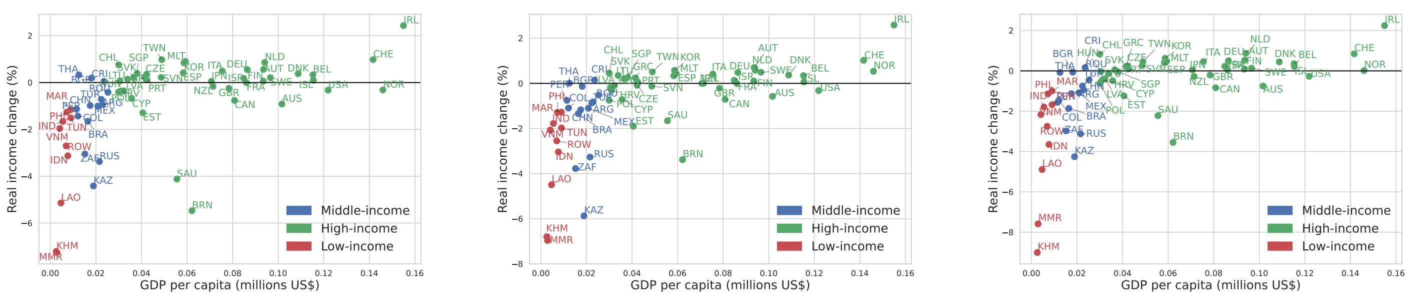


Figure 25: Equal Cost Transfers by Country - IMF Proposal - Key Players



(a) Caliendo-Parro estimation

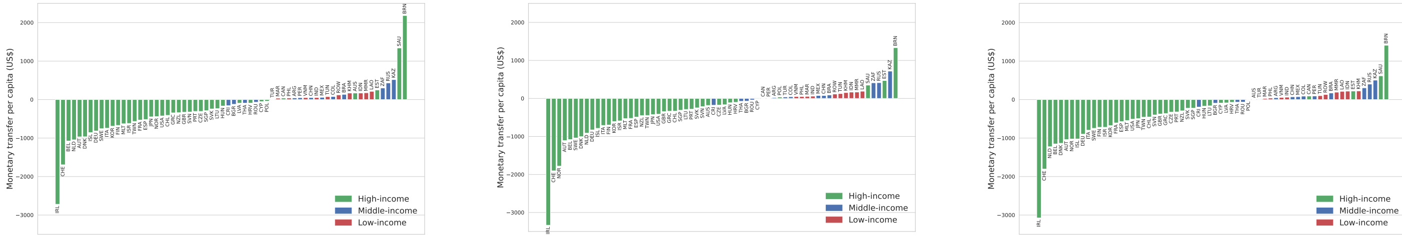
(b) Aggregated elasticities

(c) Fontagne estimation

Figure 26: Real income Changes by Elasticity

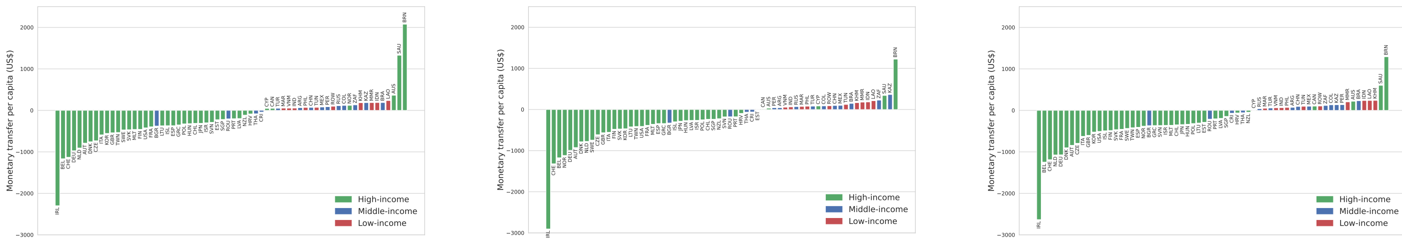
income decrease with the aggregated and the Fontagne elasticities. The reason is that the elasticities for mining are much higher for those two methods, so that a carbon tax induces a larger reallocation from that sector since they are more substitutable. Figure 27 shows the results for the equal cost transfers for each elasticity. Figure 28 shows the results for the polluter pays transfers for each elasticity.

Observe that the magnitude of the transfers may vary with the different estimation methods. For instance, transfers received by Bahrain 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,



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

Figure 27: Equal Cost Transfers by Elasticity



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

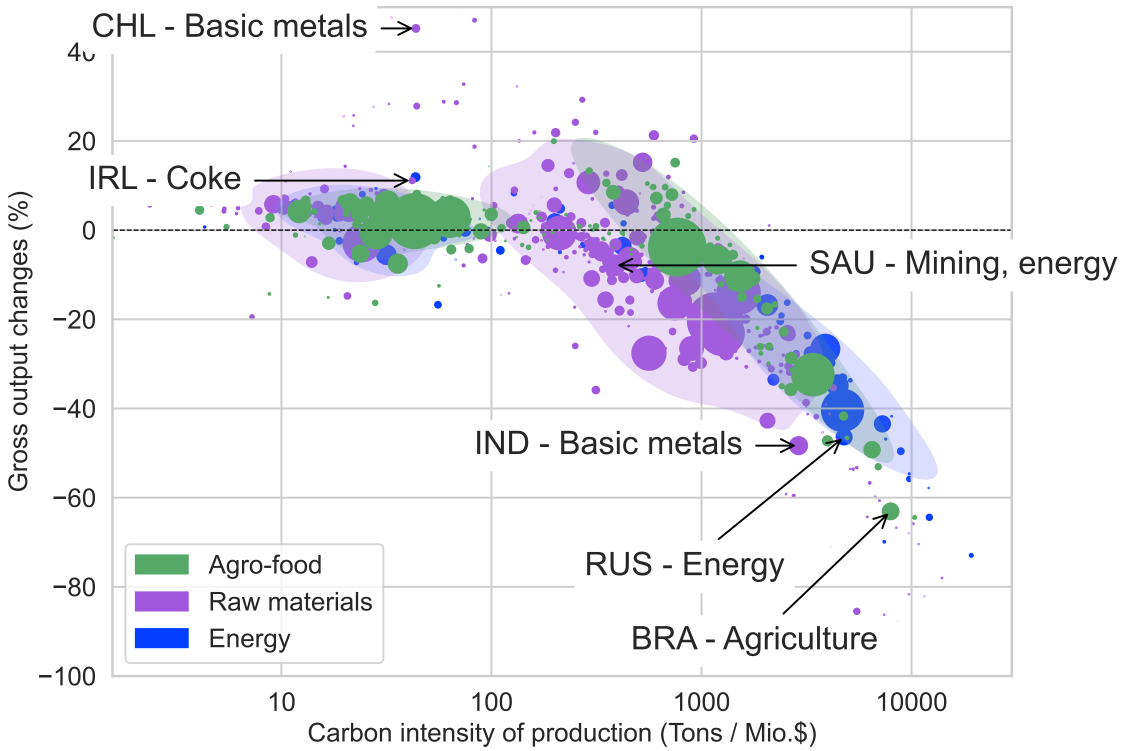
Figure 28: Polluter Pays Transfers by Elasticity

this happens because the Caliendo and Parro elasticity in the Mining and Energy sector, which is disproportionally important for these two countires, 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 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 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 29 shows the changes in gross output in percent and the carbon intensity of production for country-sector pairs as a result of the carbon tax. 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 highest increases in production predicted by the model are around 40%, which does not seem too far from what

Figure 29: 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.

would be possible in reality.

7 Conclusion

In this paper, we conduct a quantitative analysis of the principle of Common but Differentiated Responsibilities (CBDR), recognizing that low- and middle-income countries are most vulnerable to climate hazards despite their minimal contributions to climate change. We utilize a modern, multi-country, multi-sector quantitative trade model to assess how policies non-compliant with CBDR affect the Global South and explore alternative transfer schemes that could render optimal climate policy politically feasible. Furthermore, we examine the fairness of policy proposals relying on heterogeneous pricing, which are prominently debated in policy circles.

Our findings indicate that while a uniform carbon tax effectively reduces global emissions, it disproportionately impacts low- and middle-income countries, exacerbating economic inequalities between nations. These countries bear less historical responsibility for emissions and are more susceptible to climate impacts, yet they face real income losses up to 7%, in stark contrast to the potential income gains observed in high-income countries. Our analysis suggests that redistribution mechanisms designed to socialize the costs of climate action or to account for historical GHG emission patterns could mitigate this disparity. Implementing such mechanisms would require tripling current climate finance levels, representing a relatively modest per capita cost for high-income countries. Additionally, we find that heterogeneous pricing schemes, such as a climate club or the recent IMF carbon taxation proposal, while arguably politically more feasible, do not necessarily lead to fairer outcomes compared to global policies.

This study opens several avenues for future research. An exploration of how technological innovation or diffusion, particularly in clean energy driven by carbon taxation, could alter the impact of climate action on inequality would be valuable. Further research could also investigate the heterogeneity in climate damages in light of CBDR by relating our findings to estimations of the social costs of carbon by individual countries.

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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.[23] The remaining observations are then aggregated into the 64 countries with the ROW aggregate and are assigned to the 'Agriculture' sector.

[23]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.[24] 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.[25] This procedure results in disaggregated emissions as presented in Figure 1.

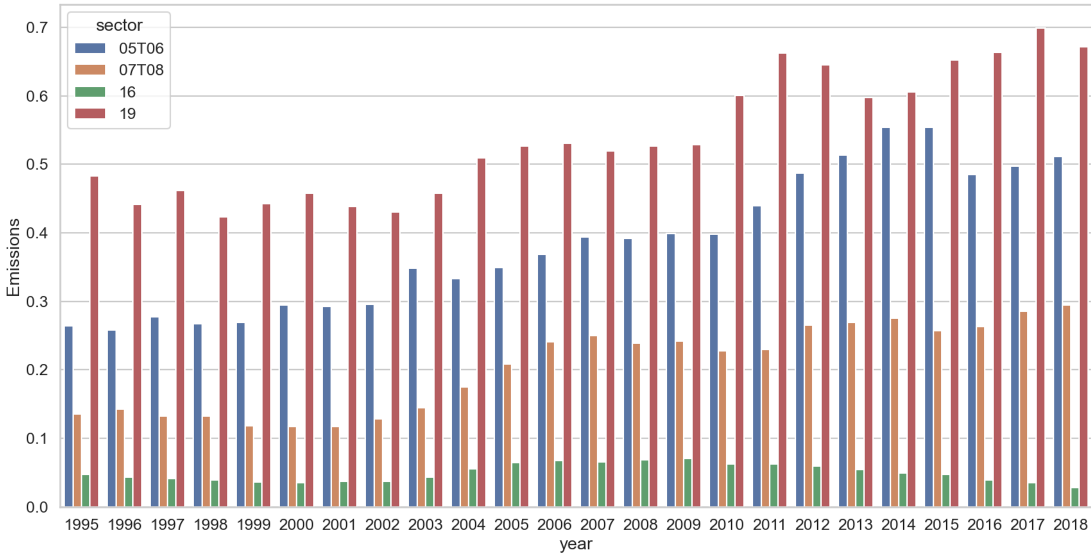
Notes on data uncertainty

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).

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

[25]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 30: Sectoral emission disaggregation



B 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 (8) and (9) imply that :

$$\widetilde{q}_{is'j} = \widetilde{I}_j \widetilde{q}_{is'j}{}^{\circ} \tag{20}$$

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 (10) together with $\widetilde{E}_{s'js} = \widetilde{E}_{js}$ imply that :

$$\widetilde{m}_{is'js} = \widetilde{E}_{js} \widetilde{m}_{is'js}{}^{\circ} \tag{21}$$

where $\widetilde{m}_{is'js}{}^{\circ} = [\widetilde{p}_{is'}(1+t^e_{is'j})]^{-\eta_{s's}} \overset{\pi}{\widetilde{P}}_{s'js}{}^{(\eta_{s's}-1)}$ 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 (15) with $\widetilde{E}_{js} = \widetilde{Y}_{js}$ to compute the wages change under a change of spending of the producer:

$$\widetilde{w}_j = \frac{\sum_s \widetilde{E}_{js} L^B_{js}}{L_j} \tag{22}$$

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 :

$$\widetilde{I}_j I^B_j = \sum_s \widetilde{E}_{js} L^B_{js} w^B_j + \sum_{i,s'} \widetilde{I}_j \widetilde{p}_{is'} t^e_{is'j} \widetilde{q}_{is'j}{}^{\circ}(p^B_{is'j} q^B_{is'j}) + \sum_{i,s',s} \widetilde{E}_{js} \widetilde{p}_{is'} t^e_{is'j} \widetilde{m}_{is'js}{}^{\circ}(p^B_{is'j} m^B_{is'js}) + D^B_j \tag{23}$$

$$\widetilde{E}_{is'} E^B_{is'} = \sum_j \widetilde{I}_j \widetilde{p}_{is'} \widetilde{q}_{is'j}{}^{\circ}(p^B_{is'j} q^B_{is'j}) + \sum_{j,s} \widetilde{E}_{js} \widetilde{p}_{is'} \widetilde{m}_{is'js}{}^{\circ}(p^B_{is'j} m^B_{is'js}) \tag{24}$$

We then use (23) in (24):

$$\begin{aligned}\widetilde{E}_{is'} E^B_{is'} = \widetilde{p}_{is'} \Bigg(\sum_{j,s} \widetilde{E}_{js} \Bigg[& \widetilde{q}_{is'j}{}^{\circ}(p^B_{is'j} q^B_{is'j}) \frac{L^B_{js} w^B_j + \sum_{i,s'} \widetilde{m}_{is'js}{}^{\circ} \widetilde{p}_{is'} t^e_{is'j}(p^B_{is'j} q^B_{is'j})}{I^B_j - \sum_{i,s'} \widetilde{q}_{is'j}{}^{\circ} \widetilde{p}_{is'} t^e_{is'j}(p^B_{is'j} q^B_{is'j})} + \widetilde{m}_{is'js}{}^{\circ}(p^B_{is'j} m^B_{is'js}) \Bigg] \\ & + \sum_j \frac{D_j \widetilde{q}_{is'j}{}^{\circ}(p^B_{is'j} q^B_{is'j})}{I^B_j - \sum_{i,s'} \widetilde{p}_{is'} t^e_{is'j} \widetilde{q}_{is'j}{}^{\circ}(p^B_{is'j} q^B_{is'j})} \Bigg)\end{aligned} \tag{25}$$

$$\widetilde{p}_{js} = \left(\sum_{s'} \widetilde{E}_{js'} \frac{L^B_{js'}}{L_j} \right)^{\gamma_{j,Ls}} \prod_{s'} \overset{\pi}{\widetilde{P}}_{s'js}{}^{\gamma_{s'js}} \tag{26}$$

with the last equation expressing the cost of production from the solution of the cost minimization of the production costs of the producer (12). We have thus reduced the equations to a system of two non-linear equations (25) and (26) 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.

$$\widetilde{X}_{\text{numeraire}} = 1 \tag{27}$$

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 :

$$\sum_{s'} \widetilde{E}_{USA,s'} \frac{L^B_{USA,s'}}{L_{USA}} = 1 \tag{28}$$

So we can solve for any solution $(\widetilde{E}_{\text{sol}}, \widetilde{p}_{\text{sol}})$ of (25) and (26) and construct :

$$\left(\frac{\widetilde{E}_{\text{sol}}}{\sum_{s'} \left(\widetilde{E_{\text{sol}}}_{USA,s'} \frac{L^B_{USA,s'}}{L_{USA}} \right)}, \frac{\widetilde{p}_{\text{sol}}}{\sum_{s'} \left(\widetilde{E_{\text{sol}}}_{USA,s'} \frac{L^B_{USA,s'}}{L_{USA}} \right)} \right) \tag{29}$$

that is the unique solution that respects (25), (26) and (28). Our results are robust to other choices of numéraire, such as global GDP or total global output.

C 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.

D Additional Figures

Figure 31: Density of emissions intensity

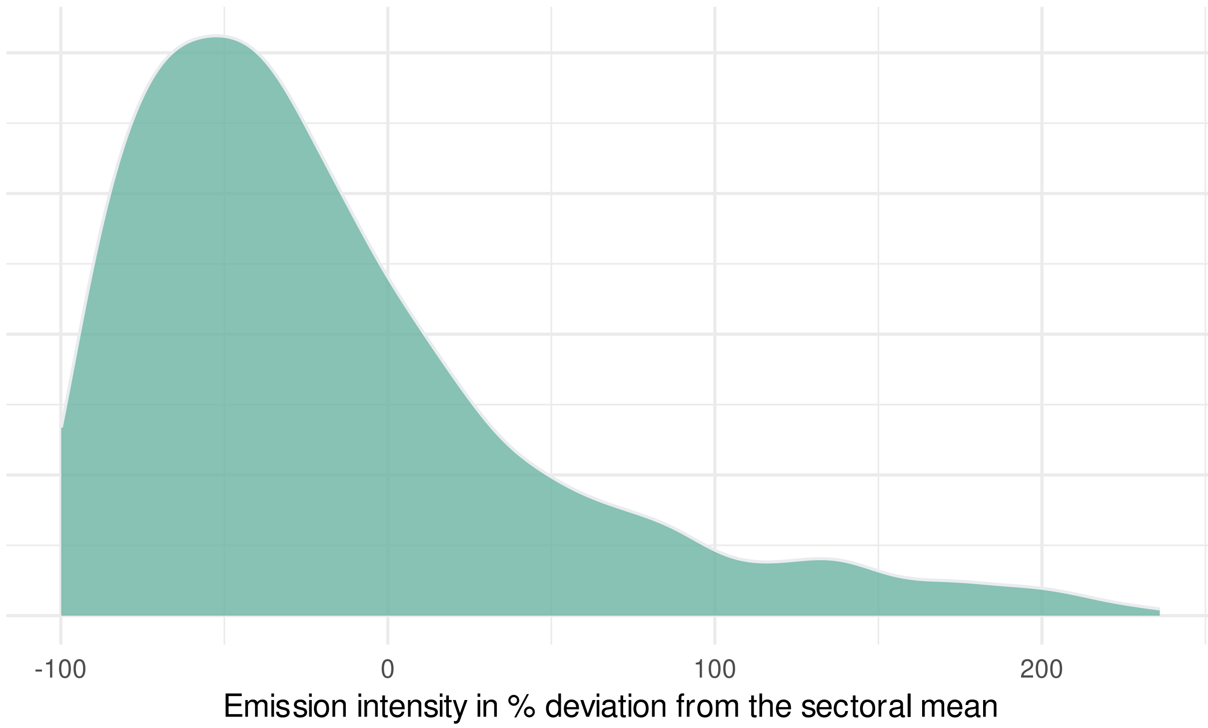


Figure 32: Cumulative Historical Emissions

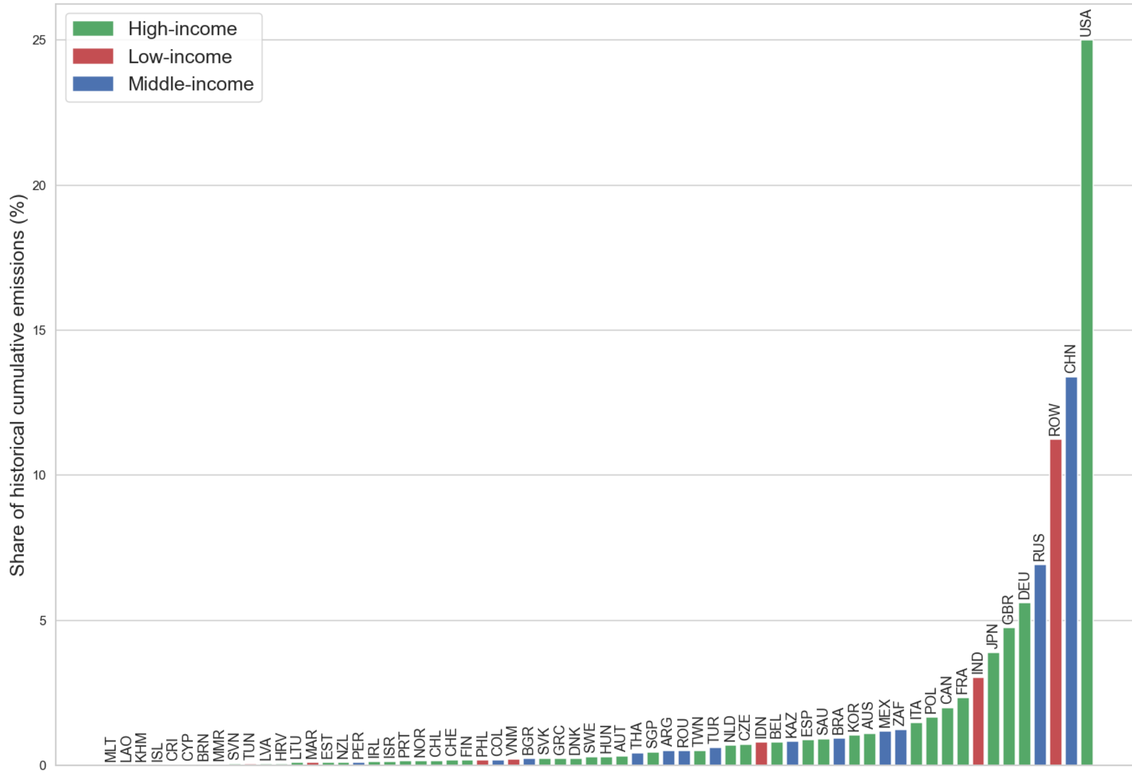


Figure 33: IMF Proposal

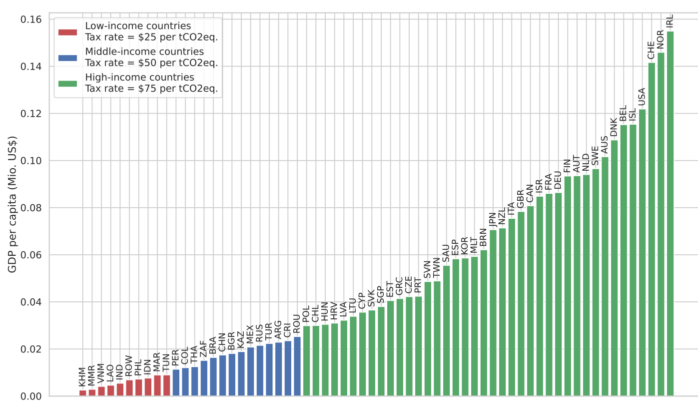


Table 1: Elasticities

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.

Figure 34: Real Income Changes - IMF Proposal - Restricted Club

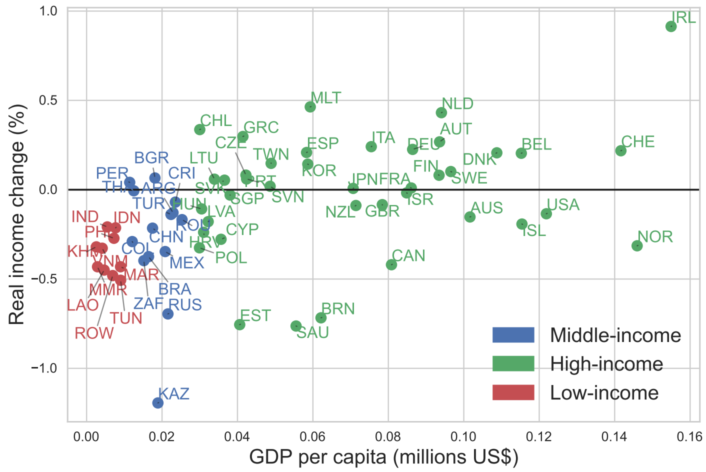


Figure 35: Real Income Changes - IMF Proposal - G20

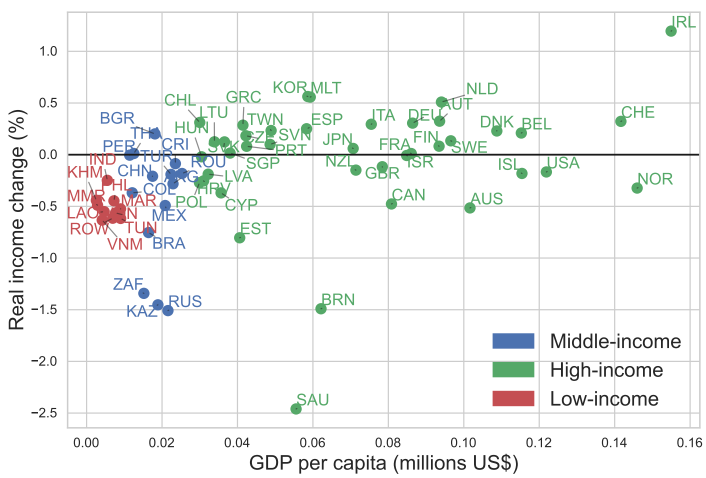


Figure 36: Real Income Changes - IMF Proposal - Key Players

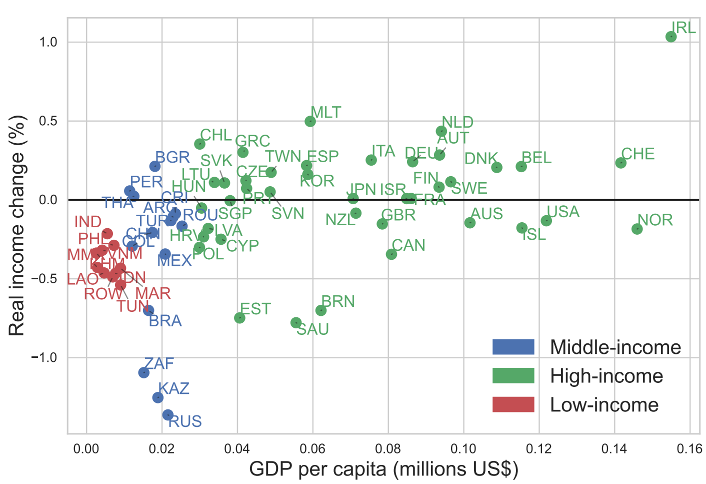


Figure 37: Real Income Changes - IMF Proposal - All Countries