A Framework for Integrating Climate Goals into Trade Agreements

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March 2026

Abstract

This paper develops a framework for integrating carbon pricing into international trade agreements, which have traditionally overlooked climate concerns. We begin by showing that countries gaining more from trade agreements impose greater trade-led climate externalities on others, while carbon taxes generate distributive externalities through terms-of-trade changes. To address the cross-externalities that trade and climate policy impose on one another, we formulate an optimal linkage problem that constrains the set of attainable outcomes with institutional, political-feasibility, and informational restrictions. We implement the solution by proposing a Climate Fund as a supplement to the WTO framework that requires members to adopt harmonized carbon pricing and allows a redistribution mechanism to balance the tax burden internationally. Quantitative analysis shows that even a simple redistribution mechanism could support carbon pricing of up to $127 per ton of CO_2 within current trade regimes, achieving more than 50% reduction in global emissions.

1 Introduction

International trade agreements, most notably the World Trade Organization (WTO) and its predecessor, the General Agreement on Tariffs and Trade (GATT), have historically evolved with little consideration for climate change. Likewise, international climate agreements, such as the Paris Climate Accord, have largely left trade policy out of their scope. This disconnect makes both types of agreements less coherent: trade agreements can increase carbon emissions and worsen climate externalities, while climate policies such as carbon pricing can generate distributive externalities by altering the terms of trade between countries. Understanding and addressing the externalities that trade and climate policies generate not only on their own domain (own-externalities) but

*We would like to thank Rodrigo Adao, Treb Allen, Jim Anderson, John Becko, Arnaud Costinot, Matthew Grant, Theodore Papageorgiou, Esteban Rossi-Hansberg and participants in several seminars and conferences for their helpful comments and suggestions. All errors are our own. Email: farid.farrokhi@bc.edu, alashkar@iu.edu, and htaheri@iu.edu.

also on one another (cross-externalities) provides a basis for more comprehensive agreements that allow linkage between the two domains. While the literature on trade and climate policy has recently expanded considerably, as reviewed in Farrokhi, Kortum, and Nath (2025), it has not yet provided a clear understanding of the nature and magnitude of these cross-externalities. This leads to our first question: what theoretical mechanisms shape these cross-externalities, and how large are they quantitatively?

Although existing international climate policies have failed to reduce global emissions, trade agreements have been broadly effective in promoting cooperative trade outcomes for most countries, even amid recent disruptions to the global trading system. The relative success of trade agreements suggests that the institutions underpinning trade cooperation may also provide a basis for climate cooperation. An earlier literature explores such trade-related issue linkages through theoretical analyses (Barrett, 1997; Maggi, 2016), but it offers limited guidance on the practical design and quantitative effects of integrating climate policies into trade agreements. More recent work provides quantitative evaluations, specifically through climate club design (Nordhaus, 2015; Farrokhi and Lashkaripour, 2025), but climate clubs may require an overhaul of the existing world trading system. In contrast, we aim to integrate climate policies into *existing* trade agreements. While our framework applies to a wide range of trade agreements, such as regional trade agreements or customs unions, we focus on the WTO/GATT as a case study given its central role in governing global trade. This leads to our second question: how can international climate policy be integrated into the existing WTO/GATT framework?

We begin by demonstrating that the cross-externalities between trade and climate are systematic and sizable. Using a general equilibrium trade model with detailed fossil-fuel supply chains, we show, both theoretically and quantitatively, that: (1) Trade agreements increase real consumption worldwide, with larger gains accruing to countries that generate higher carbon emissions and thus impose greater "climate externality" on others. (2) Carbon taxes generate substantial distributional effects across countries—which we refer to as a "distributive externality"—through changes in the terms of trade that trade agreements are designed to correct.

Leveraging on these findings, we then develop a framework that expands the scope of the WTO/GATT to incorporate climate policy through harmonized carbon pricing. To this end, we formulate a *constrained-optimal linkage* problem. While the unconstrained optimum may lie anywhere on the globally efficient frontier, our proposed reform introduces institutional, political-feasibility, and informational constraints that restrict attainable outcomes to either a segment of the frontier or its interior. We take the model with our formulation of the linkage problem to data, estimate the parameters governing policy trade-offs, and solve the linkage problem through a proposed "Climate Fund" that uses international transfers to compensate those who would otherwise bear disproportionate losses.

Section 2 presents our theoretical model featuring multiple industries and countries connected through input-output linkages and trade in final goods and intermediate inputs. Our specification

explicitly incorporates fossil fuel supply and demand throughout the global supply chains. Carbon emissions arise from fossil fuel combustion, either as intermediate input use in industrial production or as final consumption by households. These features allow us to assess the trade and climate externalities associated with trade policies and carbon pricing reforms in a unified framework.

Section 3 lays out a *theoretical* evaluation of how trade agreements and carbon pricing affect real consumption and carbon emissions across countries. Our analysis establishes that the cross-externalities between trade and climate possess inherent properties that make them well-suited for policy linkage. Specifically, (1) emissions from trade are positively associated with a country's real consumption gains from trade; (2) carbon pricing generates distributive externalities across countries, with supply-side taxes shifting the real consumption gains from energy importers to energy exporters, and demand-side taxes redistributing the gains toward countries with a comparative advantage in downstream energy-intensive industries; and (3) supply-side and demand-side carbon tax schemes require nearly opposite cross-country transfers to achieve Pareto efficiency.

The unconstrained globally efficient frontier corresponds to outcomes under free trade, a harmonized carbon price equal to the social cost of carbon, and any level of transfers (including none). The unconstrained optimum, however, does not account for political economy constraints that governments face in practice. Section 4 formalizes these as four restrictions. First, *single undertaking*: members must either accept the annexed agreement with carbon pricing obligations in its entirety or reject it, with the disagreement point as the dissolution of existing trade agreements. Second, *consensus*: the agreement must Pareto-dominate the disagreement point. Third, *fiscal feasibility*: transfers must be financed solely through the border-related portion of carbon tax revenues, excluding those levied on purely domestic transactions. Fourth, *minimal information*: transfers must be expressible as a linear function of publicly available and verifiable statistics, such as national accounts or aggregate trade measures. Together, we formulate the constrained optimization problem as one that maximizes the harmonized carbon price subject to these four restrictions.

Section 5 brings our theory to data for a quantitative analysis of the cross-externalities and the linkage problem. We use data on trade, production, and emissions from the 2014 GTAP Database, with our final sample consisting of 23 broadly defined industries, including six fossil-fuel energy industries, across 50 major countries and six aggregated regions made up of neighboring country blocs. Solving the linkage problem also requires counterfactual changes in trade barriers if countries were to defect to the disagreement point, trade elasticities to translate these changes into welfare effects, and governments' valuations of climate change damages. We estimate the impact of the WTO on trade barriers using the recent advances in the empirical gravity literature, estimate sector-level trade elasticities using tariff variation, and infer governments' valuations of climate change damages from their existing climate policies in the spirit of revealed preferences.

Using our model and estimates, Section 6 presents our quantitative policy analyses. We begin

by examining the quantitative impact of trade agreements on climate externality and of carbon pricing on distributive externalities. First, countries that gain more from WTO membership also experience larger increases in carbon emissions, imposing larger climate externalities on others.[1] This correlation suggests that tying market access to carbon pricing could provide a promising path to reducing emissions: countries that benefit most from the WTO also have the most to lose from its dissolution, creating leverage to address climate externalities.

Second, we examine the international incidence of harmonized carbon pricing, showing quantitatively that demand-side and supply-side carbon taxes have substantially opposite distributional effects across countries. Existing climate policies, such as the EU's Emissions Trading System, typically regulate carbon emissions through demand-side taxes or emissions caps. Under these policies, net energy importers experience smaller declines in real consumption and may even benefit, whereas energy exporters incur the largest losses. The opposite pattern holds under supply-side (extraction) carbon taxes, under which energy exporters benefit and energy importers incur the largest losses.

The international incidence of a global carbon tax reflects both *revenue* and *general equilibrium* effects. The revenue effect arises because the tax burden is shared internationally while carbon tax revenues are rebated locally: demand-side taxes mainly benefit high-energy-consuming countries, whereas supply-side taxes benefit major energy producers. In turn, general equilibrium effects operate through changes in global energy prices: demand-side taxes lower energy prices and favor importers over exporters, while supply-side taxes shift the terms of trade in favor of energy exporters. Since carbon pricing reforms create winners and losers through these distributive externalities, an effective linkage design could incorporate international transfers to mitigate these unequal burdens.

Finally, we turn to the optimal linkage problem by proposing a Climate Fund that requires members to adopt a harmonized carbon price as a supplement to the WTO framework. In practice, we focus on demand-side carbon taxes, as existing climate policy institutions are predominantly built around demand-side regulations, making them more readily scalable globally. The Fund facilitates international transfers by collecting *border-related* portions of carbon taxes from member countries and reallocating them according to a formula designed to compensate those bearing disproportionate burdens under demand-side carbon pricing. We explore various allocation rules, each targeting countries that either benefit less from trade agreements or bear higher costs from carbon pricing. Specifically, we consider allocations based on a country's aggregate domestic expenditure share, as a proxy for gains from trade agreements, as well as energy-related statistics such as the domestic expenditure share on energy or only primary energy, which serve as proxies for the distributive losses caused by demand-side carbon pricing.

Without transfers, the maximum feasible carbon price is \$61 per tCO_2, yielding a 38.0% global

[1] On average, real consumption would decline by 2.6% in the absence of the WTO, while global carbon emissions would fall by 1.4%.

emissions reduction. At this price, Venezuela is the marginal country, nearly indifferent between staying in the agreement and exiting, with Nigeria and Russia next in line. With transfers through the Fund, the outcomes improve depending on how the funds are allocated. When allocations are in proportion to each country's aggregate domestic expenditure share, the maximum carbon price rises to $99 and emissions fall by 47.0%. Performance improves further when allocations are based on energy-related statistics, with the most successful results coming from allocations tied to domestic expenditure shares in primary energy. Under this allocation rule, the maximum carbon price reaches $127 and global emissions decline by 51.6%.

We close the paper by evaluating how each of the above-mentioned restrictions limits the effectiveness of the linkage policy outcome. The *minimal information* restriction proves to be the most consequential: the maximum carbon price could rise to $278 if we had detailed knowledge of which countries should receive compensation and in what amounts. The other constraints are significantly less binding. In particular, the highest carbon price that satisfies the *consensus principle* also maximizes global welfare, the global aggregate of governments' objectives, while minimizing global emissions.

Related Literature. This paper contributes to several strands of literature. First, it complements studies on the design of international agreements wherein free trade is contingent on environmental action. Building on the ideas sketched in Barrett (1997), Nordhaus (2015) proposes climate clubs in which import tariffs serve as penalties to incentivize governments to join by raising their local carbon taxes. Iverson (2024) extends this idea to a two-tier climate club, where Tier 2 countries must set their carbon price at a fraction of Tier 1's average or face tariffs. Farrokhi and Lashkaripour (2025) advance the study of climate clubs by characterizing optimal trade penalties in a general equilibrium trade model calibrated to multi-country, multi-industry data. Bourany (2025) examines the optimal climate club that maximizes members' aggregate welfare under participation constraints.[2] This paper complements these studies in three key ways. First, while climate clubs often use trade taxes as an enforcement tool to promote global climate action—a task that may require an overhaul of the current world trade system—we instead examine how climate policy can be integrated into existing trade agreements. In dosing so, we particularly focus on the WTO and use recent advances in gravity equation estimation and local projections to estimate its impact on trade barriers. Second, we propose provisions for incorporating side payments into international agreements, as well as alternative mechanisms that replicate the effects of such transfers. Third, our analysis employs a detailed specification of global fossil fuel supply chains, which is essential for tracing the international incidence of demand- versus supply-side carbon taxation.

In our emphasis on demand- versus supply-side taxes, we also speak to the literature emphasiz-

[2] In addition, see Ederington (2010) for a discussion on incorporating environmental policy into trade agreements, Maggi (2016) for a review of issue linkage in international cooperation, and Harstad (2024) for how contingent trade taxes can help preserve transboundary environmental resources.

ing that the international impact of carbon taxes depends on where they are implemented along the fossil fuel supply chain. Asheim et al. (2019) argue that major fossil fuel exporters may be more receptive to supply-side climate policies, such as forming coalitions to restrict fossil fuel supply. Supporting this view, Asker et al. (2024) find that OPEC's market power has, in fact, reduced emissions to an extent that the resulting environmental benefits outweigh the welfare losses from inefficient production allocation. Garcia-Lembergman, Ramondo, Rodriguez-Clare, and Shapiro (2025) provide detailed carbon accounting at the point of extraction, direct emissions during production, and at the point of consumption. Their analysis estimates fossil fuel supply elasticities and shows that unilateral optimal carbon taxes are most effective when levied at the point of consumption. We, in turn, examine how understanding the international incidence of carbon taxes can inform the design of international agreements on trade and climate in the face of political economy constraints such as fiscal constraints to compensate countries that are disproportionately affected.

Lastly, our work engages with the expanding research on trade and the environment. One strand of this literature examines how trade and trade policy influence environmental outcomes, ranging from local air pollution to global carbon emissions to the depletion of natural resources such as forests, e.g., Antweiler, Copeland, and Taylor (2001), Cristea, Hummels, Puzzello, and Avetisyan (2013), Shapiro (2016), Shapiro (2021), Shapiro and Walker (2018), and Farrokhi, Kang, Pellegrina, and Sotelo (2023) among others. Another strand examines the implications of environmental and energy policies in open economies, e.g., Markusen (1975), Larch and Wanner (2017), Farrokhi (2020), Kortum and Weisbach (2021), Conte, Desmet, and Rossi-Hansberg (2025), Cruz and Rossi-Hansberg (2024), Caliendo, Dolabella, Moreira, Murillo, and Parro (2024) and Ritel et al. (2024) among others. Additionally, see Copeland, Shapiro, and Taylor (2021); Farrokhi, Kortum, and Nath (2025); Desmet and Rossi-Hansberg (2023) for recent reviews of the literature on trade and the environment. Our work contributes to these literatures by highlighting the cross-externalities between the domains of trade and climate—that trade agreements drive carbon emissions, while carbon pricing creates terms-of-trade externalities. We explore designs for international agreements that leverage these cross-externalities to integrate trade and climate objectives into a unified institutional framework.

2 Theoretical Framework

The global economy consists of multiple countries, indexed by $i, j \in \mathbb{N} = \{1, ..., N\}$, and multiple industries divided into primary energy industries $k \in \mathbb{E}_1$ (such as crude oil, natural gas, and coal), secondary energy industries $k \in \mathbb{E}_2$ (such as refined petroleum and electricity), and non-energy industries $k \in \mathbb{F}$ (such as chemicals, electronics, and transportation) with $\mathbb{E} \equiv \mathbb{E}_1 \cup \mathbb{E}_2$ denoting all energy industries and $\mathbb{G} \equiv \mathbb{E} \cup \mathbb{F}$ denoting the entire set of industries. Each country i is endowed by exogenously-given L_i workers and $\{R_{i,k}\}_{k \in \mathbb{E}_1}$ energy reserves, where $R_{i,k}$ is the specific input

required in the production of primary energy $k \in \mathbb{E}_1$. Workers are perfectly mobile across industries but immobile across countries and each worker supplies one unit of labor inelastically. CO_2 emissions are generated by the combustion of primary or secondary energy when they are used as intermediate inputs in industrial production, or when consumed as final goods by households.

Consumers and producers are infinitesimal and so they do not internalize the impact of their consumption or production decisions on climate change.

Households. A representative household in country i has the following utility function that combines the disutility from global carbon emissions with the utility derived from consumption:

$$U_i = C_i \times \Delta_i(Z^{(global)}), \qquad C_i = \mathsf{C}_i \left(\{C_{i,k}^{(H)}\}_{k \in \mathbb{G}} \right) \tag{1}$$

Here, C_i is country i's real consumption, which aggregates over household consumption quantities $C_{i,k}^{(H)}$ of each good $k \in \mathbb{G}$, and $\Delta_i(.)$ is country i's climate-change damage function, which measures the loss from a marginal increase in global carbon emissions, $Z^{(global)}$. Utility maximization delivers household's expenditure share on industry k by

$$\beta_{i,k} = \mathsf{b}_{i,k} \left(\{\tilde{P}_{i,k}^{(H)}\}_{k \in \mathbb{G}}, E_i \right) \tag{2}$$

satisfying $\sum_{k \in \mathbb{G}} \beta_{i,k} = 1$, where $\tilde{P}_{i,k}^{(H)}$ is the household-specific consumer price of good k in country i (the *tilde* notation differentiates them from producer prices), and total expenditure is given by:

$$E_i = \sum_{k \in \mathbb{G}} \tilde{P}_{i,k}^{(H)} C_{i,k}^{(H)} \tag{3}$$

Production: Secondary Energy and Non-energy Industries. Each secondary energy or non-energy industry $k \in \mathbb{E}_2 \cup \mathbb{F}$ in origin i is served by symmetric competitive firms that employ labor and intermediate inputs. Aggregate supply from each industry is represented by a constant-reruns-to-scale production function $\mathrm{F}_{i,k}(.)$,

$$Q_{i,k} = \varphi_{i,k} \, \mathrm{F}_{i,k} \left(L_{i,k}, \left\{ C_{i,gk}^{(I)} \right\}_{g \in \mathbb{G}} \right), \qquad k \in \mathbb{E}_2 \cup \mathbb{F}, \tag{4}$$

where $\varphi_{i,k}$ is total factor productivity, $L_{i,k}$ is labor employment, and $C_{i,kg}^{(I)}$ denotes industry k's use of intermediate good $g \in \mathbb{G}$—including all forms of energy, primary or secondary, and non-energy goods. The output elasticity with respect to each input is defined as

$$\alpha_{i,k}^{(L)} \equiv \frac{\partial \ln \mathrm{F}_{i,k}(.)}{\partial \ln L_{i,k}}, \qquad \alpha_{i,gk}^{(I)} \equiv \frac{\partial \ln \mathrm{F}_{i,k}(.)}{\partial \ln C_{i,gk}},$$

where $\alpha_{i,k}^{(L)} + \sum_g \alpha_{i,gk}^{(I)} = 1$. Faced by the wage rate w_i and (after-tax) consumer prices of intermediate goods for industry k, $\left\{\tilde{P}_{i,gk}^{(I)}\right\}_{g\in\mathbb{G}}$, cost minimization and perfect competition imply the producer price of the variety of industry k in production location i,

$$P_{ii,k} = \frac{c_{i,k}}{\varphi_{i,k}}, \qquad \text{where} \qquad c_{i,k} = \mathsf{c}_{i,k}\left(w_i,\ \left\{\tilde{P}_{i,gk}^{(I)}\right\}_{g\in\mathbb{G}}\right), \qquad k \in \mathbb{E}_2 \cup \mathbb{F}, \tag{5}$$

where $\mathsf{c}_{i,k}(.)$ is a homogeneous-of-degree-one cost function associated with the production function $\mathsf{F}_{i,k}(.)$. Cost minimization equalizes the cost share of each input with its output elasticity.

Supply of Primary Energy. Each primary energy industry ($k \in \mathbb{E}_1$) employs energy reserves, $R_{i,k}$, as specific input, as well as labor, $L_{i,k}$, and intermediate inputs from various industries $g \in \mathbb{G}$, $\left\{C_{i,gk}^{(I)}\right\}_{g\in\mathbb{G}}$, as variable inputs:

$$Q_{i,k} = \varphi_{i,k} \times R_{i,k}^{\alpha_{i,k}^{R}} \times \mathsf{F}_{i,k}\left(L_{i,k}\,,\ \left\{C_{i,gk}^{(I)}\right\}_{g\in\mathbb{G}}\right), \qquad k \in \mathbb{E}_1 \tag{6}$$

where $Q_{i,k}$ is country i's supply of primary energy $k \in \mathbb{E}_1$. The output elasticity with respect to labor and each intermediate good is defined as before, with the only difference that, here, $\mathsf{F}_{i,k}(.)$ is decreasing returns to scale, such that $\alpha_{i,k}^{(R)} \equiv \alpha_{i,k}^{(L)} + \sum_g \alpha_{i,gk}^{(I)} - 1 > 0$. Parameter $\alpha_{i,k}^{R}$ can be thought of as the output elasticity of the specific factor used in extraction of primary energy k. Cost minimization implies an upward-sloping supply curve:

$$P_{ii,k} = \frac{c_{i,k}}{\bar{\varphi}_{i,k}} \times (Q_{i,k})^{\rho_{i,k}}, \qquad \text{with} \qquad \rho_{i,k} \equiv \frac{\alpha_{i,k}^{(R)}}{1-\alpha_{i,k}^{(R)}} > 0;$$

where $c_{i,k} = \mathsf{c}_{i,k}(w_i, \{\tilde{P}_{i,gk}^{(I)}\}_{g\in\mathbb{G}})$ is the cost function associated with $\mathsf{F}_{i,k}(.)$, $\bar{\varphi}_{i,k} \equiv \left(\varphi_{i,k} \times R_{i,k}^{\alpha_{i,k}^{(R)}}\right)^{\alpha_{i,k}^{(R)}-1}$ is a constant, and $\rho_{i,k}$ represents the "inverse supply elasticity" of primary energy $k \in \mathbb{E}_1$. The rents paid for the specific factor equals $\Pi_{i,k} = r_{i,k}R_{i,k}$ where $r_{i,k}$ denotes the rental rate on corresponding energy-specific reserves.

Policy Wedges. There are two types of wedges that can separate producer and consumer prices. These wedges arise from barriers to trade and climate policy, as specified below.

Trade Policy Wedges. Price of good k from origin i shipped to destination j is given by:

$$P_{ij,k} = d_{ij,k}P_{ii,k} \tag{7}$$

where $d_{ij,k}$ denotes the iceberg trade cost. As detailed in Section 5.2.1, we specify $d_{ij,k}$ as a combination of *policy* and *non-policy* components. Specifically, joining trade agreements reduces the

policy component. In our main specification, we interpret this component as non-tariff trade barriers that do not generate revenue.[3]

Carbon Policy Wedges. Country i's government has access to two forms of carbon pricing: *(i)* supply-side taxes, $\tau_{i,k}^{(Q)}$, applied to the output of primary energy $k \in \mathbb{E}_1$ extracted in origin country i regardless of destination; and *(ii)* demand-side taxes, $\tau_{i,kg}^{(I)}$ and $\tau_{i,k}^{(H)}$, applied to the use of primary or secondary energy k in each industry g or the household of purchasing country i regardless of the origin. Specifically, supply-side carbon taxes target CO_2 emissions content of primary energy at the location of extraction, e.g., taxes on coal extraction; and, demand-side carbon taxes target CO_2 emissions content of primary or secondary energy at the location of intermediate use or final consumption, e.g., taxes on coal when used in electricity generation.

Each of these carbon policy wedges may include an additive carbon price ($\tilde{\tau}_{i,k}^{(Q)}$ for the supply side, $\tilde{\tau}_{i,kg}^{(I)}$ and $\tilde{\tau}_{i,k}^{(H)}$ for the demand side) and an ad valorem fossil fuel tax rate ($t_{i,k}^{(Q)}$ for the supply side, $t_{i,kg}^{(I)}$ and $t_{i,k}^{(H)}$ for the demand side),

$$\begin{cases} \tau_{i,k}^{(Q)} = \left(1 + t_{i,k}^{(Q)}\right) + \tilde{\tau}_{i,k}^{(Q)} \frac{Z_{i,k}^{(Q)}}{Y_{i,k}} & k \in \mathbb{E}_1 \\ \tau_{i,kg}^{(I)} = \left(1 + t_{i,kg}^{(I)}\right) + \tilde{\tau}_{i,kg}^{(I)} \frac{Z_{i,kg}^{(I)}}{X_{i,kg}^{(I)}} & k \in \mathbb{E}_1 \cup \mathbb{E}_2 \\ \tau_{i,k}^{(H)} = \left(1 + t_{i,k}^{(H)}\right) + \tilde{\tau}_{i,k}^{(H)} \frac{Z_{i,k}^{(H)}}{X_{i,k}^{(H)}} & k \in \mathbb{E}_1 \cup \mathbb{E}_2 \end{cases} \tag{8}$$

Here, $\frac{Z_{i,k}^{(Q)}}{Y_{i,k}}$ is CO_2 emissions content of primary energy k in country i per dollar of its extracted output,[4] $\frac{Z_{i,kg}^{(I)}}{X_{i,kg}^{(I)}}$ is CO_2 emissions from use of energy k per dollar of its use in industry g and country i, and $\frac{Z_{i,k}^{(H)}}{X_{i,k}^{(H)}}$ is CO_2 emissions from consumption of energy k per dollar of its consumption by the household in country i .[5]

Trade and Price Aggregation. There is a representative *distributor* in each country i that procures international varieties $\{C_{ji,k}\}_i$, at after supply-side tax prices $\left\{\tau_{j,k}^{(Q)} P_{ji,k}\right\}_j$, from suppliers $j = 1, .., N$. The distributor aggregates these varieties into a composite bundle using a CES technology,

$$C_{i,k} = \left(\sum_{j=1}^{N} b_{ji,k}^{\frac{1}{\sigma_k}} C_{ji,k}^{\frac{\sigma_{k-1}}{\sigma_k}}\right)^{\frac{\sigma_k}{\sigma_k - 1}}, \qquad k \in \mathbb{G}, \tag{9}$$

[3] As a robustness, we also consider an alternative specification in which joining trade agreements explicitly reduces import tariffs (Section XXX).

[4] Section 5 explains how to calculate $\{Z_{i,k}^{(Q)}\}$ from $\{Z_{i,kg}^{(I)}, Z_{i,k}^{(H)}\}$.

[5] Note that by construction, $\tau_{i,k}^{(Q)}$ can be different from one only for the supply of primary energy $k \in \mathbb{E}_1$, and $\tau_{i,kg}^{(I)}$ and $\tau_{i,k}^{(H)}$ can be different from one only for the use of secondary or primary energy $k \in \mathbb{E} \equiv \mathbb{E}_1 \cup \mathbb{E}_2$.

where $b_{ji,k}$ is a demand shifter and σ_k is the elasticity of substitution between national varieties within industry k. The distributor's demand pins down the within-industry expenditure share on variety ji,k (origin j–destination i–industry k), $\lambda_{ji,k}$,

$$\lambda_{ji,k} \equiv \frac{\tau_{j,k}^{(Q)} P_{ji,k} C_{ji,k}}{\sum_n \tau_{n,k}^{(Q)} P_{ni,k} C_{ni,k}} = b_{ji,k} \left(\frac{\tau_{j,k}^{(Q)} P_{ji,k}}{P_{i,k}} \right)^{1-\sigma_k}, \qquad k \in \mathbb{G}. \tag{10}$$

where the price of the composite bundle, $P_{i,k}$, is given by:

$$P_{i,k} = \left[\sum_j b_{ji,k} \left[\tau_{j,k}^{(Q)} P_{ji,k} \right]^{1-\sigma_k} \right]^{\frac{1}{1-\sigma_k}}, \qquad k \in \mathbb{G}. \tag{11}$$

The composite bundle is sold to domestic producers as intermediate input and households as final consumption with the addition of a demand-side tax, $\tau_{i,gk}^{(I)}$ and $\tau_{i,k}^{(H)}$, resulting in the following *consumer price*,

$$\tilde{P}_{i,gk}^{(I)} = \tau_{i,gk}^{(I)} P_{i,k}, \quad \tilde{P}_{i,k}^{(H)} = \tau_{i,k}^{(H)} P_{i,k}; \qquad k \in \mathbb{G}. \tag{12}$$

Total Output and Consumption. Country i's aggregate output in industry k, $Q_{i,k}$, given by Equation (6) for primary energy and (4) for other industries, equals its corresponding global demand:

$$Q_{i,k} = \sum_j d_{ij,k} C_{ij,k}, \tag{13}$$

where $C_{ij,k}$ is the consumption of the variety from country i–industry k in market j. In turn, the composite consumption bundle, $C_{i,k}$, that aggregates over $\{C_{ji,k}\}_j$ according to Equation (9), equals the sum of intermediate use by industries and final consumption by households:

$$C_{i,k} = C_{i,k}^{(H)} + \sum_g C_{i,kg}^{(I)} \tag{14}$$

CO_2 Emissions. The use of primary and secondary energy $k \in \mathbb{E} \equiv \mathbb{E}_1 \cup \mathbb{E}_2$ by households and industries generates CO_2 emissions, which are proportional to the quantity of their energy combustion governed by technical coefficients, v, as the emission per unit quantity of energy use, which we treat as exogenous parameters. Specifically, CO_2 emissions associated with energy $k \in \mathbb{E}$ used by final consumers or industry $g \in \mathbb{G}$ in country i sourced from origin country j equal:

$$\begin{cases} Z_{ij,k}^{(H)} = v_{ij,k}^{(H)} C_{ij,k}^{(H)}, & C_{ij,k}^{(H)} = \frac{\lambda_{ji,k} \beta_{i,k} E_i}{\tilde{P}_{i,k}^{(H)}} \\ Z_{ij,kg}^{(I)} = v_{ij,kg}^{(I)} C_{ij,kg}^{(I)}, & C_{ij,kg}^{(I)} = \frac{\lambda_{ji,k} \alpha_{i,kg}^{(I)} P_{ii,g} Q_{i,g}}{\tilde{P}_{i,kg}^{(I)}} \end{cases}, \qquad \text{for energy } k \in \mathbb{E} \tag{15}$$

The technical coefficients, v, convert quantities of fossil fuel energy use into their corresponding CO_2 emissions before energy flows are aggregated into CES bundles, thereby preserving carbon accounting throughout the supply chain.

In each country, the aggregate level of CO_2 emissions generated from the combustion of primary or secondary energy used by industry g as intermediate inputs equals:

$$Z_i^{(I)} = \sum_{k \in \mathbb{E}_1 \cup \mathbb{E}_2} \sum_{g \in \mathbb{G}} Z_{i,kg}^{(I)}; \qquad Z_{i,kg}^{(I)} = \sum_j v_{ji,kg}^{(I)} C_{ji,kg}^{(I)}$$

And similarly, household-level CO_2 emissions amount to:

$$Z_i^{(H)} = \sum_j \sum_{g \in \mathbb{E}_1 \cup \mathbb{E}_2} v_{ji,g}^{(H)} C_{ji,g}^{(H)}$$

By aggregation, national and global emissions are given by:

$$Z_i = Z_i^{(I)} + Z_i^{(H)}, \qquad Z^{(global)} = \sum_{i \in \mathbb{N}} Z_i \tag{16}$$

Tax revenues and the balance of budget. The government of country i collects a total tax revenue, T_i, derived from taxes on production and consumption:

$$T_i = \sum_k \left[(\tau_{i,k}^{(Q)} - 1) P_{ii,k} Q_{i,k} \right] + \sum_k \left[\frac{\tau_{i,k}^{(H)} - 1}{\tau_{i,k}^{(H)}} \beta_{i,k} E_i + \sum_g \frac{\tau_{i,kg}^{(I)} - 1}{\tau_{i,kg}^{(I)}} \alpha_{i,kg}^{(I)} P_{ii,g} Q_{i,g} \right] \tag{17}$$

Assuming that trade is balanced and tax revenues are rebated to households of the tax-imposing country, the balance of budget holds when national expenditure equals national income as the sum of factor rewards and tax revenues:

$$E_i = Y_i \equiv w_i L_i + \sum_{k \in \mathbb{E}_1} [r_{i,k} R_{i,k}] + T_i \tag{18}$$

General Equilibrium. For a given set of taxes $\left\{ t_{i,k}^{(Q)}, t_{i,kg}^{(I)}, t_{i,k}^{(H)}, \tilde{\tau}_{i,k}^{(Q)}, \tilde{\tau}_{i,kg}^{(I)}, \tilde{\tau}_{i,k}^{(H)} \right\}$, a *general equilibrium* is a vector of wage rates $\{w_i\}$ and rental rates on energy reserves $\{r_{i,k}\}_{k \in \mathbb{E}_1}$ such that consumption and production quantities $\left\{ C_i, C_{i,k}, C_{ij,k}, C_{i,k}^{(H)}, C_{i,gk}^{(I)}, Q_{i,k} \right\}$, prices $\left\{ P_{ij,k}, P_{i,k}, \tilde{P}_{i,kg}^{(I)}, \tilde{P}_{i,k}^{(H)} \right\}$, CO_2 emissions $\left\{ Z_{i,k}^{(H)}, Z_{i,gk}^{(I)}, Z_i, Z^{(world)} \right\}$, and aggregate expenditure, income and tax revenues $\{E_i, Y_i, T_i\}$ are satisfied according to Equations 1-18; labor markets clear,

$$w_i L_i = \sum_k \alpha_{i,k}^{(L)} \sum_j \left[\lambda_{ij,k} \left(\frac{1}{\tau_{j,k}^{(H)}} \beta_{j,k} E_j + \sum_g \frac{1}{\tau_{j,kg}^{(I)}} \alpha_{j,kg}^{(I)} P_{jj,g} Q_{j,g} \right) \right], \qquad (i \in \mathbb{N}); \tag{19}$$

and markets of energy reserves clear,

$$r_{i,k}R_{i,k} = \alpha_{i,k}^{(R)} \sum_j \left[\lambda_{ij,k} \left(\frac{1}{\tau_{j,k}^{(H)}} \beta_{j,k} E_j + \sum_g \frac{1}{\tau_{j,kg}^{(I)}} \alpha_{j,kg}^{(I)} P_{jj,g} Q_{j,g} \right) \right], \qquad (i \in \mathbb{N}, k \in \mathbb{E}_1). \tag{20}$$

3 Theoretical Analysis of Trade and Carbon Policy Reforms

In this section, we begin by analyzing the impact of trade and carbon policies on emissions and consumption. We then explore the mechanisms through which trade policies create climate externalities and carbon policies lead to distributive externalities.

3.1 Emission and Consumption Effects of Trade and Carbon Policies

We assume that the production functions, denoted by $F_{i,k}(.)$, follow a Cobb-Douglas specification, which allows for closed-form analytical solutions. Specifically, output in industry k in country i is given by:

$$Q_{i,k} = \varphi_{i,k} \left(\frac{L_{i,k}}{\alpha_{i,k}^L} \right)^{\alpha_{i,k}^L} \left(\frac{R_{i,k}}{\alpha_{i,k}^R} \right)^{\alpha_{i,k}^R} \prod_{g \in \mathbb{G}} \left(\frac{C_{i,gk}^{(I)}}{\alpha_{i,gk}^I} \right)^{\alpha_{i,gk}^I},$$

where $\alpha_{i,k}^R$ is nonzero only for primary energy goods, and $\alpha_{i,k}^L + \alpha_{i,k}^R + \sum_{g \in \mathbb{G}} \alpha_{i,gk}^I = 1$. Similarly, household consumption is governed by a Cobb-Douglas utility aggregator across industries:

$$C_i = \prod_{k \in \mathbb{G}} \left(\frac{C_{i,k}^{(H)}}{\beta_{i,k}} \right)^{\beta_{i,k}}, \qquad \text{with} \qquad \sum_{k \in \mathbb{G}} \beta_{i,k} = 1$$

Our analysis focuses on two key policy changes: (i) trade liberalization and (ii) carbon pricing policies. We model carbon policy changes as modifications to either demand-side or supply-side taxes on energy goods. For expositional purposes, we make the simplifying assumption that demand-side taxes are independent of final use (household vs. industrial) and let $\tau_{i,k}^{(C)} \equiv \tau_{i,kg}^{(I)} = \tau_{i,k}^{(H)}$ denote the common demand-side tax on energy type k. For simplicity, we assume that changes in carbon taxes take the form of ad valorem equivalents. Using the hat-algebra notation, the policy shocks of interest are defined as:

$\{\widehat{\tau}_{i,k}^{(Q)}\}_{i,\, k \in \mathbb{E}_1}$, $\{\widehat{\tau}_{i,k}^{(C)}\}_{i,\, k \in \mathbb{E}_1 \cup \mathbb{E}_2} \sim$ carbon policy shock $\qquad$ $\left\{\hat{d}_{in,g}\right\}_{i,n,g} \sim$ trade policy shock

The change in country i's emissions in response to these policy shocks follows the accounting identity:

$$\hat{Z}_i = \sum_{g \in \mathbb{E}} \left[z_{i,g}^{(H)} \hat{Z}_{i,g}^{(H)} + \sum_{k \in \mathbb{G}} z_{i,gk}^{(I)} \hat{Z}_{i,gk}^{(I)} \right], \tag{21}$$

where $z_{i,gk}^{(I)} \equiv \frac{Z_{i,gk}^{(I)}}{Z_i}$ and $z_{i,g}^{(H)} \equiv \frac{Z_{i,g}^{(H)}}{Z_i}$ represent baseline emission shares. The first summation, indexed over $g \in \mathbb{E}$, reflects that emissions arise solely from energy use, whether primary or secondary. The second summation, indexed over $k \in \mathbb{G}$, captures the fact that all industries consume energy inputs. Aggregating across countries, the change in global emissions is given by the weighted sum of national emission changes:

$$\hat{Z}^{(global)} = \sum_{i \in \mathbb{N}} z_i \hat{Z}_i \qquad \text{where} \qquad z_i \equiv Z_i / Z^{(global)}.$$

Next, we characterize the change in emissions for each energy type and country starting from industrial emissions.

Change in Industrial Emissions. Industrial emissions are proportional to energy input quantity, ($Z_{i,gk}^{(I)} = v_{i,gk}^{(I)} C_{i,gk}^{(I)}$),[6] which per cost minimization are given by $C_{i,gk}^{(I)} = \alpha_{i,gk}^{(I)} \left(w_i \ell_{i,k} L_i / \alpha_{i,k}^{(L)}\right) / \tilde{P}_{i,g}$. Given the constancy of $v_{i,gk}^{(I)}$, $\alpha_{i,k}^{(L)}$, and $\alpha_{i,gk}^{(I)}$, the change in industrial emissions can be stated as

$$\hat{Z}_{i,gk}^{(I)} = \hat{C}_{i,gk}^{(I)} = \hat{\ell}_{i,k} \left(\frac{\hat{\tilde{P}}_{i,g}}{\hat{w}_i} \right)^{-1}, \qquad (\forall g \in \mathbb{E},\ k \in \mathbb{K})$$

Following Appendix B, we can specify the change in the price of energy to labor inputs as a function of the change in domestic expenditures shares, taxes, and employment shares to obtain:

$$\hat{Z}_{i,gk}^{(I)} = \hat{\ell}_{i,k} \times \underbrace{\prod_{k \in \mathbb{G}} \left(\hat{\lambda}_{ii,k}^{\frac{a_{i,kg}}{1-\sigma_k}} \right)}_{\text{trade-related effects}} \times \overbrace{\underbrace{\prod_{k' \in \mathbb{E}} \left(\hat{\tau}_{i,k'}^{-a_{i,k'g}} \right)}_{\text{carbon policy}} \times \underbrace{\prod_{k' \in \mathbb{E}_1} \hat{\ell}_{i,k'}^{-\alpha_{i,k'}^{R} a_{i,k'g}}}_{\text{extraction price}}}^{\text{domestic economy adjsutments}} \qquad (\forall g \in \mathbb{E}), \tag{22}$$

where $\hat{\tau}_{i,k} \equiv \hat{\tau}_{i,k}^{(C)} \hat{\tau}_{i,k}^{(Q)}$ is the composite demand and supply-side tax on energy type $k \in \mathbb{E}$. The term labeled "trade-related effects" accounts for the trade-enabled reduction in the price of traded intermediate inputs used for energy production, making energy input $g \in \mathbb{E}$ more attractive than labor inputs in all energy-consuming industries. For instance, fossil fuel extraction becomes more productive through improved access to extraction equipments, lowering the cots of fossil fuel inputs relative to labor in downstream industries. The remaining two terms represent changes to

[6] In this section, we assume that the technical coefficients (v) are defined at the CES composite level for intermediate use and final consumption, rather than for disaggregated, origin-specific flows of energy. We adopt this assumption only in this section because it helps with analytical tractability.

domestic factor, with the exponents adjusted to account for input-output linkages. The first domestic term is the effective carbon tax on energy type $g \in \mathbb{E}$, accounting for double marginalization through within-energy input-output connections. The second domestic term accounts for the change in the price of primary energy due to diminishing returns to scale in energy extraction. As the demand for energy goes up, this puts upward pressure on the cost of extraction, thereby increasing the price of energy inputs, all else being equal.

Change in Household Emissions. Household emissions are determined by direct household consumption, $C_{i,k}^{(H)}$ of energy goods, $k \in \mathbb{E}$ as shown by Equation 15, resulting in:

$$\hat{Z}_{i,k}^{(H)} = \hat{\kappa}_i \frac{\hat{w}_i}{\hat{\hat{P}}_{i,k}}, \qquad \text{with} \qquad \hat{\kappa}_i \equiv \frac{\hat{Y}_i}{\hat{w}_i}$$

As shown in Appendix B, the change in income-to-wage ratio can be specified by invoking the balanced budget condition. With zero taxes in the baseline equilibrium, this yields

$$\hat{\kappa}_i = \frac{\sum_k \left(\tau_{i,k}^{(Q)} + \sum_g \frac{\alpha_{i,gk}^I}{\tau_{i,g}^{(C)}} \right) \frac{\ell_{i,k} \hat{\ell}_{i,k}}{\alpha_{i,k}^L}}{\left(1 + \sum_k \frac{\alpha_{i,k}^R}{\alpha_{i,k}^L} \ell_{i,k} \right) \sum_k \left(\frac{\beta_{i,k}}{\tau_{i,k}^{(C)}} \right)}. \tag{23}$$

Note that $\tau_{i,g}^{(C)} = 1$ if $g \notin \mathbb{E}$ and $\tau_{i,k}^{(Q)} = 1$ if $k \notin \mathbb{E}_1$ by construction. As before, by specifying $\hat{w}_i / \hat{P}_{i,k}$ in terms of domestic expenditure shares, carbon taxes, and employment shares, we obtain the following expressions for the changes in household emissions from consumption of energy type $k \in \mathbb{E}$:

$$\hat{Z}_{i,k}^{(H)} = \hat{\kappa}_i \prod_{g \in \mathbb{G}} \left(\hat{\lambda}_{ii,g}^{\frac{a_{i,gk}}{1-\sigma_g}} \right) \times \prod_{k' \in \mathbb{E}} \left(\hat{\tau}_{i,k'}^{-a_{i,k'k}} \right) \times \prod_{k' \in \mathbb{E}_1} \left(\hat{\ell}_{i,k'}^{-\alpha_{i,k'}^R a_{i,k'k}} \right) \tag{24}$$

Intuitively, the above expression suggests that household energy consumption rises when energy prices decrease more significantly than household income. Trade liberalization policies can contribute to this effect by providing households with access to cheaper international energy varieties and improving energy production efficiency through better access to traded intermediate inputs in energy production. Conversely, carbon taxes typically have the opposite impact, making energy more expensive and thereby reducing consumption.

Change in Total Emissions. The change in total emissions can be characterized by summing over the changes in industrial and household emissions, as defined by Equation 21. The components of this change, industrial and household emissions, are given by Equations 22 and 24, respectively. This decomposition yields our first proposition, which characterizes how total emissions respond to trade and carbon policy shocks.

Proposition 1. *The change in emissions due to a carbon and trade policy reform,* $\left\{\hat{\tau}_{i,g}, \hat{d}_{in,g}\right\}_{i,n,g}$*, is*

$$\hat{Z}_i = \sum_{k\in\mathbb{G}}\sum_{g\in\mathbb{E}}\left[\left(z_{i,g}^{(H)}\hat{\kappa}_i + z_{i,gk}^{(I)}\hat{\ell}_{i,k}\right) \times \prod_{k'\in\mathbb{G}}\left(\hat{\lambda}_{ii,k'}^{\frac{a_{i,k'g}}{1-\sigma_{k'}}}\right) \prod_{g'\in\mathbb{E}}\left(\hat{\tau}_{i,g}^{-a_{i,g'g}}\right) \prod_{g'\in\mathbb{E}_0}\left(\hat{\ell}_{i,g'}^{-\alpha_{i,g'}^{R}a_{i,g'g}}\right)\right]$$

where $\hat{\ell}_{i,k}$ *and* $\hat{\lambda}_{ii,k}$ *denote the policy-led change in industry-level labor shares and domestic expenditure shares.* $\hat{\kappa}_i = \hat{Y}_i/\hat{w}_i$ *is determined by Equation 23 in terms of policy change, changes in labor shares, and baseline share variables. The global emissions change is then given by:*

$$\hat{Z}^{(global)} = \sum_i z_i \hat{Z}_i,$$

which weights each country's emissions change by its initial emissions share z_i*.*

To interpret these results, note that the above equation expresses emissions changes as a weighted sum of changes in the energy-to-labor input price ratios, $\hat{P}_{i,g}/w_i$, with $g \in \mathbb{E}$. Intuitively, trade and carbon policy reforms modify the relative price of energy to labor inputs, prompting firms to adjust their energy use and associated carbon emissions. The change in energy to labor input prices can be decomposed into three different effects:

(i) $\prod_{k'\in\mathbb{G}}(\hat{\lambda}_{ii,k'}^{\frac{a_{i,k'g}}{1-\sigma_{k'}}})$ captures the efficiency gains from trade liberalization in primary and secondary energy production. The energy sector relies on traded intermediate inputs, and a lower $\lambda_{ii,k'}$ signifies reduced input costs from industry $k' \in \mathbb{G}$. The significance of each input k' is determined by its backward linkages to energy type $g \in \mathbb{E}$, as reflected in the elements $a_{i,k'g}$ of the inverse Leontief matrix.

(2) $\prod_{g'\in\mathbb{E}}(\hat{\tau}_{i,g}^{-a_{i,g'g}})$ represents the direct effect of carbon taxes on energy prices and use. This effect extends through input-output linkages, as energy type $g \in \mathbb{E}$ may use energy type $g' \in \mathbb{E}$ as an intermediate input.

(3) $\prod_{g'\in\mathbb{E}_0}(\hat{\ell}_{i,g'}^{-\alpha_{i,g'}^{r}a_{i,g'g}})$ reflects how changes in the scale of domestic energy extraction influence domestic energy prices. In particular, an increase in primary energy extraction—reflected in higher employment shares—coincides with rising energy prices due to rising cost of reserves. These effects can compound due to input-output linkages within the primary energy sector.

A trade liberalizing policy shock, ($\hat{d}_{in,k} < 1$), affects emissions in each country through two mechanisms: (i) it reallocates labor (and thus value added) across industries, and (ii) it increases emission intensity by lowering the relative cost of energy to labor inputs.[7] While our formula does not

[7] Using Copeland and Taylor's (2004) notation for decomposing aggregate emissions, our first mechanism is closest

identify a clear direction for the contribution of the first effect, it highlights an unambiguous role for second effect. Specifically, holding carbon policy and labor allocation (ℓ) fixed, trade liberalization reduces the relative price of energy to labor inputs across all sectors, leading to greater energy consumption. Since domestic expenditure shares fall ($\hat{\lambda}_{ii,k} < 1$) in response to trade liberalization, Proposition 1 implies that:

$$\hat{Z}^{(global)} \mid \ell = \sum_i \sum_{k \in \mathbb{G}} \sum_{g \in \mathbb{E}} \left[\left(z_{i,g}^{(H)} + z_{i,gk}^{(I)} \right) \prod_{k' \in \mathbb{G}} \hat{\lambda}_{ii,k'}^{\frac{a_{i,k'g}}{1-\sigma_{k'}}} \right] > 1.$$

This result suggests that trade liberalization exacerbates climate externalities by improving the efficiency and availability of energy inputs. However, these potential adverse environmental effects must be weighed against the associated consumption gains. From a policy perspective, the positive effects on consumption also provide an opportunity to design policies that link the benefits of trade to carbon pricing. The next section formalizes the real consumption gains from trade liberalization, setting the foundation for the subsequent policy discussion.

Changes in Real Consumption. Under the Cobb-Douglas parametrization introduced earlier, the change in real consumption for country i is given by:

$$\hat{C}_i = \frac{\hat{Y}_i}{\hat{\hat{P}}_i} = \hat{\kappa}_i \prod_{k \in \mathbb{G}} \left(\frac{\hat{w}_i}{\hat{\hat{P}}_{i,k}} \right)^{\beta_{i,k}}$$

Like before, we can specify the change in wage to priced indexed in terms of changes in domestic expenditure shares, taxes, and employment shares, with derivations detailed in Appendix B. Drawing on this result and our previous expression for $\hat{\kappa}_i$, we characterize $\hat{C}_i$ based on the same set of sufficient statistics that determine emission changes.

Proposition 2. *The change in country i's real consumption in response to a global energy and trade policy shock, $\left\{ \hat{\tau}_{i,g}, \hat{d}_{in,g} \right\}_{i,n,g}$, is given by*

$$\hat{C}_i = \hat{\kappa}_i \times \prod_{k \in \mathbb{G}} \left[\prod_{k' \in \mathbb{G}} \left(\hat{\lambda}_{ii,k'}^{\frac{a_{i,k'k}}{1-\sigma_{k'}}} \right) \prod_{g' \in \mathbb{E}} \left(\hat{\tau}_{i,g}^{-a_{i,g'k}} \right) \prod_{g' \in \mathbb{E}_0} \left(\hat{\ell}_{i,g'}^{-\alpha_{i,g'}^R a_{i,g'k}} \right) \right]^{\beta_{i,k}}$$

where $\hat{\kappa}_i \equiv \hat{Y}_i / \hat{w}_i$ represents the change in the ratio of net income to wage income in country i, which is given by Equation 23.

The above formulation extends the ACR formula by incorporating additional terms that reflect the effects of energy policy, income changes, and price adjustments to fixed inputs in primary en-

in spirit to their composition effect, while our second mechanism most closely aligns with the combined influence of their scale and technique effects. That said, this parallel is only meant to be suggestive because our decomposition does not map one-to-one onto the Copeland and Taylor framework.

ergy extraction. A key insight from this result is that the same mechanisms that reduce the relative price of consumption goods—thereby increasing real consumption—also lower the relative price of energy inputs. This is why trade stimulates greater energy use and emissions while raising real consumption. The next section formally establishes this relationship, exploring its implication for trade and carbon policy reform.

3.2 Three Lessons from Theory

The genesis of this paper lies in the observation that trade policy generates climate externalities, while climate policy, in turn, creates distributive externalities similar to those induced by terms-of-trade changes. Understanding the structure and magnitude of these cross-externalities is essential for designing climate policy reforms that can be effectively integrated into existing trade agreements. In the analysis that follows, we identify two systematic features of these cross-externalities.

(1) *Trade-related emissions are positively linked to a country's consumption gains from trade.*

Recall that trade-related emissions are defined as the excess emissions attributable to trade openness. Propositions 1 and 2 together reveal a systematic relationship between a country's consumption gains from trade and its trade-related emissions. This relationship is most transparent in a simplified setting with a single composite energy input (indexed by 0) that is used solely for industrial production. For additional simplicity, suppose that the labor share, $\alpha_{i,k}^{(L)}$, and engineering constant, $v_{i,k}$, are the same across all activities. Under these simplifying assumptions, the propositions imply that the change in emissions and real consumption following any change to trade costs are[8]

$$\hat{Z}_i = \prod_{g\in\mathbb{G}} \left(\hat{\lambda}_{ii,g}^{\frac{a_{i,g0}}{1-\sigma_g}}\right) \hat{\ell}_{i,0}^{-\alpha_{i,0}^R a_{i,00}}, \qquad \hat{C}_i = \prod_{k\in\mathbb{G}} \left[\prod_{g\in\mathbb{G}} \left(\hat{\lambda}_{ii,g}^{\frac{a_{i,gk}}{1-\sigma_g}}\right) \hat{\ell}_{i,0}^{-\alpha_{i,0}^R a_{i,0k}}\right]^{\beta_{i,k}}$$

The immediate implication is that the consumption gains from trade can be expressed as a function of trade-related emissions:

$$\hat{C}_i = \prod_{k\neq 0} \left[\prod_{g} \left(\hat{\lambda}_{ii,g}^{\frac{a_{i,gk}-a_{i,g0}}{1-\sigma_g}}\right) \hat{\ell}_{i,0}^{-\alpha_{i,0}^r \left(a_{i,0k}-a_{i,00}\right)}\right]^{\beta_{i,k}} \hat{Z}_i$$

This formulation clarifies that the relationship between the consumption gains from trade and trade-related emissions is systematic. And the relationship becomes stronger when the gains from energy trade closely resemble those from trade in other industries.

[8] More specifically, note that $\hat{Z}_i = \sum_{k\in\mathbb{G}} \left[z_{i,k}\hat{\ell}_{i,k}\right] \prod_{g\in\mathbb{G}} \left(\hat{\lambda}_{ii,k'}^{\frac{a_{i,g0}}{1-\sigma_g}}\right) \hat{\ell}_{i,0}^{-\alpha_{i,0}^R a_{i,00}}$, where $\sum_{k\in\mathbb{G}} \left[z_{i,k}\hat{\ell}_{i,k}\right] = 1$ given that $\alpha_{i,k}^{(L)}$ and $v_{i,k}$ are uniform across industries indicating that $z_{i,k} = \ell_{i,k}$.

The intuition behind this result is straightforward: forces reducing the cost of producing consumer goods also lower the cost of energy production. The reduced cost of consumer goods raises welfare by increasing consumption, whereas cheaper energy production raises emissions by encouraging energy use. The term in bracket captures how consumer goods and energy production differ in their reliance on trade-driven intermediate inputs. This term is different from one in all cases, with deviations diminishing as the input-output structure becomes more symmetric.[9]

The above relationship has important implications for the linkage between trade and climate agreements. The rationale for issue linkage is to condition the consumption gains from trade liberalization, $\hat{C}_i$, on a government's commitment to mitigating emissions, Z_i. Since countries with higher trade-related emissions are also among the primary beneficiaries of trade liberalization, making market access contingent on emissions reductions presents a potentially effective reform path. In other words, the systematic link between trade-related emissions and consumption gains strengthens the case for integrating environmental commitments into trade agreements.

(2) *Carbon pricing creates distributive externalities. Supply-side taxes shift income from energy importers to energy exporters, while demand-side taxes redistribute to countries with a revealed comparative advantage in energy-intensive industries.*

We can use our model to showcase that carbon pricing in open economy settings generates two distinct international externalities: (1) a positive non-pecuniary climate externality and (2) a pecuniary distributive externality. To illustrate this, consider a carbon policy reform that raises taxes on energy, both on the extraction side and input demand side:

$$\left\{ \Delta \ln \tau_{i,k}^{(Q)} \, , \, \Delta \ln \tau_{i,k}^{(C)} \right\}_{k \in \mathbb{E}}$$

Starting from an initial equilibrium with no carbon policy ($\tau = 1$) such a reform has no first-order effects on aggregate consumption in a closed economy:

$$\Delta \ln C_i^{(closed)} \mid_{t=0} = 0$$

The intuition is straightforward: absent climate externalities, resource allocation in a closed economy is efficient. Consequently, carbon pricing primarily involves weighing the climate benefits of reduced energy use against the resulting consumption loss from raising τ above the unity. In an open economy, however, the effect on real consumption is nontrivial and can be expressed as[10]

$$\Delta \ln C_i \mid_{\tau=1} = \sum_{k \in \mathbb{G}} \sum_{g \in \mathbb{G}} \frac{a_{i,kg} \beta_{i,g}}{1 - \sigma_g} \Delta \ln \lambda_{ii,g} + \sum_{k \in \mathbb{E}} \sum_{g \in \mathbb{G}} \frac{\mathcal{X}_{i,g}}{Y_i} \left[a_{i,kg} \Delta \ln \tau_{i,k}^{(Q)} + \tilde{a}_{i,kg} \Delta \ln \tau_{i,k}^{(C)} \right],$$

[9] It is important to clarify a crucial nuance. If trade agreements are incomplete and target different sectors to varying degrees, the forces reducing the cost of consumer goods may differ in strength from those lowering the cost of energy production. This can weaken the correlation between the two.

[10] See Appendix B for derivations.

where $\mathcal{X}_{i,g}$ denotes net exports in industry $g \in \mathbb{G}$:

$$\mathcal{X}_{i,g} \equiv P_{ii,g} Q_{i,g} - P_{i,g} C_{i,g} \qquad \text{[net exports]}$$

The first term reflects how energy taxation influences the gains from trade, closely paralleling the ACR formula (Arkolakis et al., 2012). When energy taxes increase the domestic expenditure share in industries with low elasticity of substitution (σ) and strong input-output centrality, captured by the $a_{i,kg}$, they effectively reduce the gains from trade. However, the ACR formulas alone is insufficient here. It does not account for the incidence of energy taxes across international buyers, necessitating a second term.

The second term accounts for international tax burden: a portion of the carbon tax burden falls on foreign consumers via exports. Since energy input k is used across multiple industries, the degree to which the tax is transmitted internationally depends on input-output linkages, $a_{i,kg}$ and $\tilde{a}_{i,kg}$.[11] In export-oriented sectors ($\mathcal{X}_{i,g} > 0$), the energy tax embedded in exports is paid by foreign buyers, shifting the tax burden partially onto foreigners. These payments constitute a pure transfer from foreign economies to the home government.[12] The term $\sum_g \frac{\mathcal{X}_{i,g}}{Y_i} \tilde{a}_{i,kg}$ essentially measures revealed comparative advantage in industries that intensively use energy type k.

Given these effects, unilateral carbon policies can be appealing even when governments prioritize maximizing real consumption with no care for climate change. The optimal design of such policies, however, depends on whether taxation is applied at the supply or demand side of energy markets. Resource-rich countries, whose exports are heavily tied to primary energy, benefit most from taxing primary energy at the extraction stage, as this approach maximizes revenue extraction from foreign buyers. In contrast, countries that import primary energy but export goods with high secondary energy content gain more from demand-side taxes on primary or secondary energy.[13]

To summarize, the incidence of carbon pricing in country i is not borne exclusively by domestic agents but is partially shared with foreign firms and households through trade. Extending this logic, a globally uniform carbon or energy tax would generate asymmetric benefits, disproportionately favoring countries that collect the majority of tax revenues. The design of the carbon tax is therefore a key determinant of its tax incidence. If applied at the point of extraction, the primary beneficiaries would be major fossil fuel-exporting economies, as they would create terms-of-trade

[11] Specifically, let $\mathbf{A}_i = \left[\alpha^I_{i,gk}\right]_{k,g}$ denote the $K \times K$ input-output matrix. Then, $a_{i,kg}$ is the element (k,g) of the inverse Leontief $(\mathbf{I} - \mathbf{A}_i)^{-1}$ and $\tilde{a}_{i,kg}$ is the element (k,g) of the matrix $(I - \mathbf{A}_i)^{-1} \mathbf{A}_i$.

[12] In contrast, for import-competing industries, the standard ACR term tends to overstate the welfare gains from higher imports by treating them *as if* they stemmed from foreign productivity growth or export subsidies. In reality, part of the observed increase in imports (or the decline in $\lambda_{ii,g}$) is due to domestic energy taxation rather than improved terms of trade. Unlike a pure terms-of-trade shift, which the ACR framework captures, these tax effects represent an internal redistribution from domestic energy users to the government. The non-ACR term adjusts the gains implied by the ACR formula, making it compatible with these intra-national transfers.

[13] The benefits arise from two key mechanisms. First, demand-side taxes exert downward pressure on the prices of imported primary energy. Second, the tax burden on secondary energy is partially passed on to foreign consumers who purchase goods manufactured using these energy inputs.

transfers from energy-importing countries to their national economies. Conversely, if the tax is levied at the point of demand, the benefits would accrue disproportionally to industrial economies that import fossil fuel energy and utilize it in the production of traded goods.

The aforementioned asymmetries underscore the necessity of incorporating transfer mechanisms into international carbon agreements to mitigate disparities in tax incidence. We unpack this point next.

(3) *Supply-side and demand-side carbon tax schemes require nearly opposite cross-country transfers to achieve Pareto efficiency.*

Following the logic of the Second Welfare Theorem, an efficient climate policy consists of carbon taxes $\boldsymbol{\tau}$ and lump-sum transfers T that solve the following planning problem

$$\max_{\boldsymbol{\tau}, \boldsymbol{T}} \sum_i \omega_i \ln U_i(\tau, T) \tag{25}$$

subject to equilibrium constraints and the feasibility of transfer, $\sum_i T_i = 0$. Here, $U_i = C_i - \Delta_i(Z^{global})$ denotes country i's welfare (Equation 1) and $\omega_i \in (0, 1)$ is the Pareto weight attached to it. Following Appendix C, the optimal transfers that support the efficient allocation can be expressed as

$$T_i^* = (\omega_i - y_i^*)Y^*$$

where $y_i \equiv Y_i/Y$ represents country i's share of global income inclusive of tax revenues, with Y denoting aggregate global income. This formulation reveals that countries with Pareto weights exceeding their income shares ($\omega_i > y_i$) receive positive transfers, while those with $\omega_i < y_i$ make net contributions.

The direction of efficient transfers, therefore, depends fundamentally on whether taxes are levied on the demand or supply (use or extraction) of fossil fuel markets. Under a demand-side tax regime, energy-importing countries experience a larger share of tax-inclusive global income relative to the supply-side tax regime. This occurs because demand-side taxes generate revenue in the jurisdiction where fossil fuels are consumed. Conversely, under supply-side taxes, energy-exporting countries capture a larger share of global tax-inclusive income, as these taxes effectively allow fossil fuel exporters to extract additional rents from their natural reserves.

These results illuminate a fundamental tension in climate policy design. While both demand-side and supply-side taxes can achieve efficient levels of emissions reductions, they imply diametrically opposed international transfers to ensure Pareto improvements. If an agreement mandates *demand-side* carbon taxation, compensatory transfers are required to offset the redistribution from primary energy importers to exporters. Conversely, under a *supply-side* taxation scheme, transfers must compensate net importers of energy-intensive goods, ensuring that tax revenues are redistributed to countries whose resident's bear a significant share of the tax burden.

4 Constrained-Optimal Linkage Problem

This section applies our theory to evaluate the integration of carbon pricing into international trade agreements. While the proposed framework is general and could be applied to any set of trade agreements—such as regional trade agreements and customs unions—we focus on the WTO as our case study due to its prominent role in regulating the global trade system.

To this end, we formulate the constrained-optimal linkage problem as a reform of the WTO framework that requires the adoption of a harmonized carbon price while satisfying four key feasibility criteria: two institutional restrictions consistent with WTO principles, compatibility with fiscal constraints, and minimal information requirements. We formalize each constraint and present the corresponding optimization problem.

We begin with institutional feasibility. The WTO's annexed agreements are organized under the *Single Undertaking*: the multilateral agreements in Annex 1 form an indivisible package and cannot be selectively accepted or rejected.[14] We capture this institutional feature as follows:

R1 [Single undertaking] Members must either accept the annexed agreement with carbon pricing obligations as a whole or reject it in its entirety.

R1 has direct implications for how we model the disagreement point. In a standard bargaining model over a new obligation, one might take the disagreement point to be the status quo, which is the current WTO framework without a carbon pricing requirement. Under the Single Undertaking, however, rejecting a new core obligation is not *WTO-without-carbon-pricing*, but rather a rejection of the full package itself. Accordingly, we model the reform as presenting governments with a binary choice: accept the WTO with an annexed carbon pricing commitment, or reject the WTO in its entirety. Formally, we consider:

(a) *Disagreement*: an equilibrium *without* carbon pricing obligations or pre-existing WTO trade commitments;

(b) *Agreement*: a counterfactual WTO equilibrium that annexes per unit carbon price requirements ($\tilde{\tau}$) to the existing system, potentially paired with zero-sum transfers ($T \equiv [T_i]$).[15]

This formulation is conservative in its treatment of members' outside options. A stricter alternative, explored in Section 6.3.2, models disagreement as a unilateral defection.[16]

Another feasibility requirement is that the reform be consistent with the WTO's *Consensus Principle*. In practice, decisions are taken by consensus: they are adopted only if no member formally objects, a practice that evolved during the GATT years and was formally incorporated into the

[14] We restrict attention to a multilateral carbon-pricing agreement incorporated into Annex 1A, rather than an Annex 4 plurilateral agreement, because opt-in participation would generate free-riding.

[15] We use $\tilde{\tau}$ to denote the additive equivalent of the multiplicative carbon tax, τ. In other words, $\tilde{\tau}$ is the per unit price of carbon which is harmonized within the agreement.

[16] Under this alternative specification, the cost of noncompliance is generally higher because a defecting country becomes an isolated outsider while other members maintain their WTO access.

WTO Agreement after the Uruguay Round. Consensus effectively gives each member veto power and implies that reforms are incorporated if they constitute a Pareto improvement relative to the disagreement point. We encode this as:

R2 [Consensus] The reform $(\tilde{\tau}, T)$ is institutionally admissible if it Pareto-dominates the disagreement point, labeled by (a):

$$W_i(\tilde{\tau}, T;\, d) \geq W_i(\tilde{\tau}^{(a)}, 0;\, d^{(a)}) \qquad (\forall i).$$

Here, $W_i(\tilde{\tau}, T; d)$ is the government's policy objective in country i given carbon price $\tilde{\tau}$, transfers T, and trade costs $d = [d_{ij,k}]$, which may differ from consumer welfare, U_i.

R2 limits the outcome to points on or within the efficient frontier where the transition from the disagreement point to an annexed agreement aligns with the national interests of all incumbent members.

Our focus on a normative welfare function reflects the fact that individual producers and consumers are atomistic and thus unable to affect aggregate emissions. Only governments can influence emissions through policy. Assumption R2 recognizes that governments' normative welfare measure, W_i, may differ from social welfare, U_i (Equation 1), especially in how climate damages are weighted. In the spirit of revealed preferences, we infer governments' implied valuation of climate damages from observed climate policy (Section 5.2.3) and use these estimates in the main analysis.[17] Accordingly, $W_i^{(a)} \equiv W_i(\tilde{\tau}^{(a)}, 0;\, d^{(a)})$ is country i's objective function evaluated at the disagreement point, characterized by suboptimal carbon taxes $\tilde{\tau}^{(a)}$, zero transfers, and the counterfactual trade barriers $d^{(a)}$ that would prevail in the absence of the WTO, as estimated in Section 5.2.

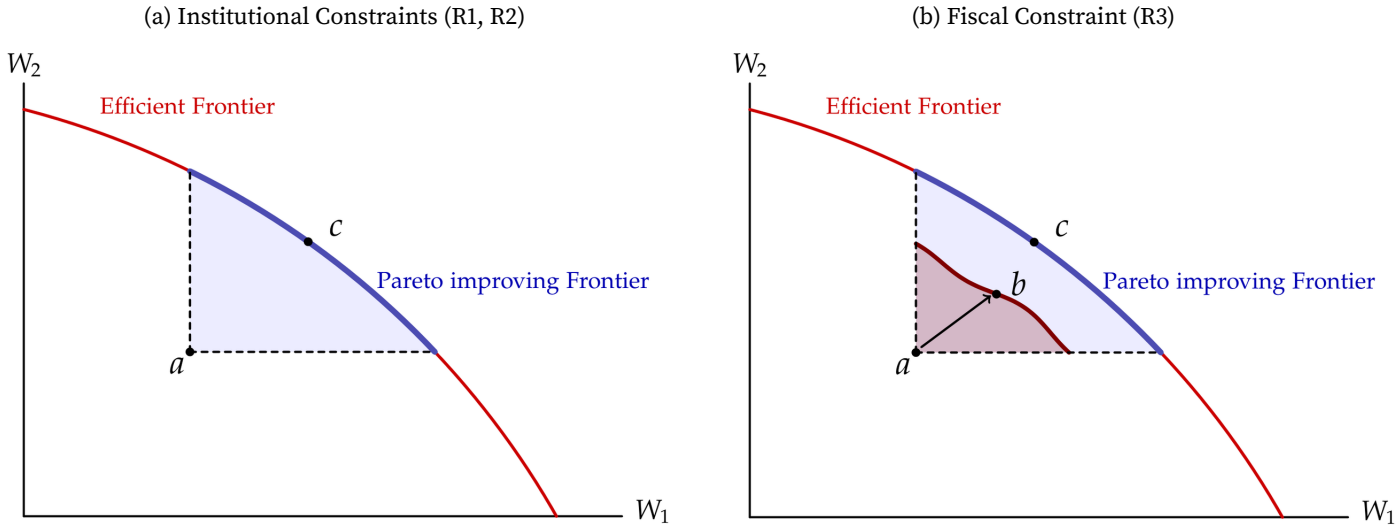
Figure 1 illustrates the consensus principle for the case of two negotiating countries. The efficient frontier consists of the set of allocations that solve the planning problem in Equation 25 for all admissible Pareto weights.[18] Each point on this frontier can be achieved in a decentralized economy with a uniform carbon price, zero border taxes, and an appropriate vector of international transfers. However, only the locus of outcomes within the dashed lines satisfies R2 and is therefore admissible under the Consensus Principle.

Another institutional constraint is fiscal feasibility, which limits the range of transfer schemes that can credibly be implemented. Along the efficient frontier, each outcome is associated with a transfer $T_i^* = (\omega_i - y_i^*)Y^*$, where ω_i is the Pareto weight attached to country i and y_i^* is its income share under the constrained-optimal carbon prices. Implementing these transfers requires tax

[17] To provide a more complete picture, we also calibrate climate change damages, Δ_i, in$U_i \equiv C_i\Delta_i$, using available estimates of country-level social cost of carbon and re-run the analysis under $W_i = U_i$, showing how the results would alter when there was no misalignment. See Section 6.3.2.

[18] The figure defines the efficient frontier in terms of government objectives. Alternatively, the efficient frontier could be defined in terms of social welfare. This distinction, however, does not matter because in our analysis there is no central planner to implement the globally optimal policy.

Figure 1: The locus of feasible outcomes within the efficient frontier



Note: This figure plots policy outcome (W_1,W_2) for two representative WTO members. Point $a = (W_1^{(a)}, W_2^{(a)})$ is the disagreement point implied by the Single Undertaking (WTO dissolution). The red curve is the efficient frontier generated by the planner's problem (Equation 25). The dashed lines impose the Consensus Principle (R2): outcomes must satisfy $W_i \geq W_i^{(a)}$ for each member. Panel (a) highlights the R2-admissible segment of the frontier. Panel (b) adds the fiscal constraint (R3), which truncates the admissible segment by ruling out allocations that require transfers exceeding border-related carbon-tax revenues; outcome c is feasible under R1–R2 but infeasible under R3, and b is the constrained-optimal outcome.

revenue, implying that some jurisdictions finance foreign consumption out of domestic carbon-tax receipts. This is politically demanding unless the tax base is restricted. We therefore constrain transfers to be financed from the border-related component of carbon taxes.

R3 [Fiscal feasibility] *Transfers must be financed by the border-related portion of carbon taxes, rather than those imposed on purely domestic transactions. Moreover, a member's net payment to the transfer scheme cannot exceed its border-related carbon-tax revenue.*

To reiterate, transfers are necessitated by the distributive externalities from carbon pricing. As detailed in Section 3.2, carbon pricing creates international winners and losers, since the tax burden is non-localized but the resulting revenues are rebated locally. To ensure consensus, the reform must make transfers from winners to losers, but R3 puts restrictions on the size of these transfers. Panel (b) in Figure 1 illustrates how R3 truncates the feasible set: fiscal constraints may prevent the large transfers required to implement a frontier allocation such as point c, leaving second-best outcomes such as point b as the best attainable options.

To formalize this constraint, let h_i denote the border-related component of country i's carbon-tax revenue:

$$h_i = \tilde{\tau} \times \sum_{k=\mathbb{E}} \left[(1 - \lambda_{ii,k}(\tilde{\tau}, T)) \times Z_{i,k}(\tilde{\tau}, T) \right],$$

where $(1 - \lambda_{ii,k})$ denotes country i's imported expenditure share on each primary or secondary energy $k \in \mathbb{E} = \mathbb{E}_1 \cup \mathbb{E}_2$, $Z_{i,k}$ is the corresponding CO_2 emissions, and $\tilde{\tau}$ is the harmonized demand-side carbon price adopted by participants in the agreement.[19] We can formally define the politically feasible set of transfer-price pairs $(\tilde{\tau}, T)$ as those that satisfy

$$T_i + h_i(\tilde{\tau}, T) \geq 0 \qquad (\forall i).$$

The above condition states that the magnitude of country i's net contribution *to the transfer scheme* $(-T_i)$ cannot exceed its border-related carbon-tax revenues (h_i).

Our final constraint restricts the *informational* burden of the reform. The informational burden is partially mitigated by our emphasis on harmonized carbon pricing, which is attractive not only on efficiency grounds but also for its simplicity. However, harmonized carbon pricing generates distributive externalities that place disproportionate burdens on certain countries, making it necessary to provide compensatory transfers. Because individual tax burdens cannot be directly observed, the design of the transfer mechanism must balance targeting against informational complexity. This trade-off motivates requirement R4.

R4 [Minimal information] *Transfers must be expressible as a simple function of publicly available and verifiable statistics, such as national accounts or aggregate trade measures, collected in the set $\mathcal{X}$. Formally, the transfer rule for all countries $i = 1, ..., N$ satisfies,*

$$T_i = \alpha_i(x_i, \beta) H_i(\tilde{\tau}, T) - h_i(\tilde{\tau}, T) \qquad with \qquad [x_i] \in \mathcal{X}$$

where $H_i(\tilde{\tau}, T) \equiv \sum_n h_n(\tilde{\tau}, T)$ is the sum of contributions, with the allocation shares satisfying

$$\alpha_i(x_i, \beta) = \beta^T x_i, \qquad \sum_n \alpha_n(x_n, \beta) = 1$$

Note that the fiscal feasibility constraint is automatically satisfied if $\alpha_i(x_i, \beta) \geq 0$, so we encode R3 as a restriction on the sign of the allocation shares.

Having presented all the restrictions, we can now formally state the optimal linkage problem as a constrained optimization problem that maximizes the harmonized carbon price subject to

[19] Here, we have specified carbon prices on the demand side rather than the supply side. This choice reflects the fact that most existing climate policies operate through demand-side pricing, shaped in large part by the European Union's leadership in climate policy. Because these climate policy frameworks are already established at the regional level, it is conceivable that they could be scaled up to a global level.

R1–R4, given $x \subset \mathcal{X}$:

$$\max_{\tilde{\tau},\beta,T} \tilde{\tau} \quad s.t. \quad \begin{cases} W_i(\tilde{\tau}, T;\, d) \geq W_i^{(a)} & (\forall i) \\ T_i = \alpha_i(x_i, \beta) H_i(\tilde{\tau}, T) - h_i(\tilde{\tau}, T) & (\forall i) \\ \alpha_i(x_i, \beta) = \beta^T x_i, \quad [x_i] \subset \mathcal{X} & (\forall i) \\ \alpha_i(x_i, \beta) \geq 0, \quad \sum_i \alpha_i(x_i, \beta) = 1 \end{cases} \tag{26}$$

The first constraint embeds R1 and R2 as incentive compatibility conditions for each country. The next lines collectively encode the fiscal feasibility and informational constraints, R3 and R4. In Section 6.3.1, we will provide a solution to this constrained optimal problem through a "global climate fund" mechanism.

5 Taking the Model to Data

Our quantitative analysis centers on counterfactual equilibrium outcomes under changes in trade and carbon policy. We first outline how we map the model to data to carry out these policy simulations. Solving the linkage problem also requires estimates of key trade-offs, especially the costs of foregone accession and climate change. To obtain these, we use auxiliary historical data to estimate the effect of WTO membership on market access; and, in the spirit of revealed preferences of governments, infer each country's valuation of climate change damages.

5.1 Data and Model Parameters

Quantitative Strategy. Employing the method of exact hat algebra, the set of data and parameters required to calculate counterfactual outcomes are: *(i)* Baseline shares consisting of cost share of labor, energy reserves, and intermediate inputs, $\alpha_{i,k}^{(L)}$, $\alpha_{i,k}^{(R)}$ and $\alpha_{i,gk}^{(I)}$ for all industries $k \in \mathbb{G}$; households' expenditure shares, $\beta_{i,k}$, and international trade shares, $\lambda_{ij,k}$; *(ii)* Baseline aggregates consisting of national expenditure E_i, industry-level sales and expenditures, $Y_{i,g}$ and $X_{i,g}$, national-level wage bills $(w_i L_{i,k})$, rents collected from energy reserves $(r_{i,k} R_{i,k})$, carbon emissions at the level of origin-destination for industries and households $Z_{ij,gk}^{(I)}$, $Z_{ij,k}^{(H)}$—which, by aggregation, imply the national and global emissions; *(iii)* baseline taxes; *(iv)* and trade elasticity parameters $(\sigma_k - 1)$.

Appendix D presents the system of equations that specify equilibrium changes in response to trade and carbon pricing policies. For each policy, the solution to this system determines changes in all equilibrium values, taking in as input the above set of data and parameters.

Parametric Assumptions. In our main specification, we adopt a Cobb-Douglas functional form for the demand aggregator $\mathrm{C}_i(.)$ and production functions $\mathrm{F}_{i,k}(.)$. In Section 6.4, we provide robustness checks using alternative functional forms that allow for lower-than-unity energy demand

elasticity.

Data on Production, Trade and Expenditures. We take information on bilateral trade, gross output and value added, expenditures on intermediate goods and final consumption from the Global Trade Analysis Project (GTAP) database (Aguiar et al., 2019), which reports the global matrix of flows from any origin country-industry pair to any destination country-industry or country-household pair in the year 2014. Our sample covers the largest 50 countries in terms of GDP plus six aggregate regions, each encompassing multiple neighboring countries. Together, our sample covers the global flows of production and trade in their entirety. We divide the space of goods into 23 industries, out of which 3 are primary energy (Coal, Crude Oil, and Natural Gas), 3 are secondary energy (Refined Petroleum, Electricity, and Gas Manufacturing & Distribution), with the remaining 17 industries consisting of Agriculture, Other Mining (aggregation of mining net of primary energy), 11 Manufacturing industries, and 4 Service industries. Tables 1 and 2 report the list of industries and countries along with some of their key characteristics.

The GTAP database provides international trade shares, expenditure shares by households, as well as the cost share of labor and intermediate goods (including primary and secondary forms of energy) for each industry. We additionally observe the value added paid by each industry to natural resources, which are positive for primary energy industries and zero elsewhere. Accordingly, we calibrate the cost share of energy reserves in each primary energy industry $k \in \mathbb{E}_1$, $\alpha_{i,k}^{(R)}$, as the value added paid to natural resources divided by total gross output—which imply inverse energy supply elasticities corresponding to $\rho_{i,k} \equiv \alpha_{i,k}^{(R)}/(1-\alpha_{i,k}^{(R)})$. To avoid potential mis-measurements at the level of individual countries, we set $\alpha_{i,k}^{(R)} = \alpha_{k}^{(R)}$ as a common value for all countries $i \in \mathbb{N}$, based on global averages of the cost share of natural resources. The calibrated values of $\alpha_{k}^{(R)}$ are 0.23, 0.24, and 0.22 respectively for Coal, Crude Oil, and Natural Gas. These values correspond to inverse supply elasticities of 0.29, 0.32, and 0.28, which are close to the inverse supply elasticity estimate of 0.34 for aggregate fossil fuel supply estimated by Garcia-Lembergman et al. (2025) based on data on marginal costs and production of fossil fuels.

Data on CO_2 Emissions. We additionally take from the GTAP database information on CO_2 emissions, associated with the use of each of the six energy goods (primary or secondary) by industries or households. The accounting of the emission flows in the data ensures there is no double counting. These emissions are classified as "direct emissions," meaning they represent emissions generated from burning fossil fuels and not necessarily their use during the production process. For instance, a relatively small portion of crude oil is combusted during its extraction or when it gets processed in the production of refined petroleum, while the majority of the carbon content of petroleum is eventually burned in the form of refined petroleum products by households and in downstream industries such as Chemicals and Transportation.

Carbon Accounting. Our data, as noted above, does not directly provide the CO_2 emission content of primary energy goods. We, however, require this information to specify supply-side carbon taxes—which target the carbon content of primary energy goods at the point of extraction. To ad-

Table 1: Summary of Statistics by Industries

Industry	Share from World			Exports to	Energy	CO_2 Emission
	CO_2 Emission	Output	Exports	Output Ratio	Cost Share	per Output
Coal	0.6%	0.3%	0.9%	0.27	0.05	0.29
Crude Oil	1.1%	1.6%	7.4%	0.50	0.02	0.11
Natural Gas	0.7%	0.4%	1.6%	0.43	0.05	0.29
Refined Petroleum	3.9%	2.6%	4.1%	0.18	0.84	0.26
Electricity	48.3%	1.9%	0.3%	0.02	0.38	4.35
Gas Mfg and Dist	1.1%	0.2%	0.1%	0.07	0.14	0.98
Agriculture	1.5%	2.9%	3.6%	0.11	0.04	0.09
Other Mining	0.6%	0.7%	1.1%	0.28	0.07	0.14
Food	1.3%	4.8%	6.5%	0.12	0.02	0.04
Textile	0.4%	2.1%	6.1%	0.27	0.02	0.03
Wood	0.1%	0.6%	0.5%	0.14	0.02	0.03
Paper	0.7%	1.2%	1.8%	0.15	0.05	0.10
Chemicals	3.4%	3.6%	11.4%	0.33	0.12	0.16
Plastics	0.5%	1.3%	2.3%	0.22	0.04	0.06
Nonmetallic Minerals	5.2%	1.3%	0.6%	0.12	0.10	0.70
Metals	5.3%	5.0%	6.0%	0.23	0.06	0.18
Electronics and Machinery	0.6%	6.9%	13.8%	0.40	0.01	0.01
Motor Vehicles	0.2%	3.5%	7.1%	0.36	0.01	0.01
Other Manufacturing	0.2%	1.2%	2.5%	0.29	0.01	0.03
Construction	0.7%	7.7%	0.1%	0.01	0.01	0.01
Wholesale and Retail	0.6%	7.7%	2.2%	0.03	0.02	0.01
Transportation	19.5%	4.2%	4.7%	0.13	0.22	0.78
Other Services	3.5%	38.3%	15.4%	0.04	0.01	0.02

Note: This table reports for every primary energy, secondary energy, and non-energy industries the share from world industrial CO_2 emission (excluding household-level emission), output and exports, as well as their global exports to output ratio, energy cost shares (total use of primary and secondary energy divided by output), and global CO_2 emission to output ratio (1000 tCO_2 per dollar of output). Reported CO_2 emissions correspond to direct emissions from combustion of primary and secondary fossil fuel energy.

dress this, we have developed an algorithm that uses input-output parameters of the global value chain to trace CO_2 emissions back to their original sources—specifically, to each primary form of energy (coal, crude oil, and natural gas) from each source country. Appendix A.2 describes our algorithm in detail and presents results showing that they closely match those obtained using independent measures of carbon content in primary energy goods. The advantage of our approach is that it is internally consistent with the rest of our data, maintaining the accounting of CO_2 emissions.

Baseline Policy Wedges. We obtain fossil-fuel taxes from the OECD's Environmentally-related Tax Revenues and explicit carbon prices from the OECD's Net Effective Carbon Rates dataset. Appendix A.3 provides details on how we calibrate these policy wedges. We set the explicit carbon prices to zero in our baseline equilibrium, which closely mirrors the policy landscape in 2014,

Table 2: Summary of Statistics by Countries

	Share from World			CO_2 Emission		Energy Cost
Country	CO_2 Emission	Output	Population	per Output	per Capita	Share
United Arab Emirates	0.5%	0.4%	0.1%	146.1	106.9	0.07
Argentina	0.7%	0.6%	0.6%	134.5	28.2	0.09
Australia	1.2%	1.8%	0.3%	82.6	98.1	0.04
Austria	0.2%	0.5%	0.1%	40.1	40.4	0.03
Belgium	0.3%	0.8%	0.2%	45.7	54.5	0.05
Brazil	1.6%	2.7%	2.8%	67.6	14.3	0.06
Canada	1.9%	2.0%	0.5%	108.5	99.6	0.06
Switzerland	0.1%	0.9%	0.1%	17.2	30.4	0.01
Chile	0.3%	0.3%	0.2%	99.3	27.8	0.06
China	26.5%	17.9%	18.9%	172.1	35.9	0.05
Colombia	0.2%	0.4%	0.6%	73.3	9.8	0.04
Czech Republic	0.3%	0.3%	0.1%	100.4	50.2	0.05
Germany	2.3%	4.8%	1.1%	55.5	52.0	0.04
Denmark	0.2%	0.4%	0.1%	52.1	56.7	0.03
Egypt, Arab Rep.	0.6%	0.3%	1.3%	192.0	11.7	0.07
Spain	0.8%	1.7%	0.6%	54.6	31.9	0.05
Finland	0.2%	0.3%	0.1%	56.9	54.7	0.06
France	1.1%	3.2%	0.9%	38.6	29.9	0.03
United Kingdom	1.4%	3.6%	0.9%	46.7	41.0	0.03
Indonesia	1.5%	1.1%	3.5%	156.7	10.7	0.06
India	6.4%	2.7%	17.9%	274.4	9.1	0.13
Ireland	0.1%	0.3%	0.1%	52.6	58.7	0.03
Iran, Islamic Rep.	1.8%	0.5%	1.1%	433.4	42.5	0.17
Israel	0.2%	0.3%	0.1%	73.6	48.3	0.05
Italy	1.1%	2.6%	0.8%	47.0	32.6	0.04
Japan	3.4%	5.9%	1.8%	67.5	50.1	0.06
Kazakhstan	0.8%	0.2%	0.2%	364.8	82.8	0.09
Korea, Rep.	1.7%	2.2%	0.7%	88.3	60.2	0.09
Mexico	1.4%	1.4%	1.7%	115.1	21.6	0.06
Malaysia	0.8%	0.6%	0.4%	155.4	49.9	0.07
Nigeria	0.2%	0.5%	2.4%	56.0	2.3	0.02
Netherlands	0.6%	1.2%	0.2%	55.0	61.5	0.06
Norway	0.2%	0.6%	0.1%	45.9	79.0	0.04
New Zealand	0.1%	0.3%	0.1%	53.6	47.6	0.04
Pakistan	0.5%	0.3%	2.7%	179.8	4.4	0.07
Peru	0.2%	0.3%	0.4%	70.4	10.0	0.05
Philippines	0.3%	0.3%	1.4%	113.5	6.1	0.05
Poland	0.9%	0.7%	0.5%	141.3	42.8	0.06
Portugal	0.2%	0.3%	0.1%	67.9	29.8	0.06
Qatar	0.3%	0.2%	0.0%	146.0	194.9	0.06
Romania	0.2%	0.2%	0.3%	102.4	20.2	0.07
Russian Federation	4.7%	2.4%	2.0%	228.7	60.1	0.14
Saudi Arabia	1.6%	0.8%	0.4%	246.3	95.2	0.15
Sweden	0.1%	0.7%	0.1%	24.3	26.5	0.04
Thailand	0.9%	0.6%	0.9%	172.3	24.8	0.12
Turkey	1.0%	1.0%	1.1%	123.4	24.3	0.06
United States	17.2%	20.0%	4.4%	100.0	100.0	0.05
Venezuela, RB	0.5%	0.5%	0.4%	115.8	32.7	0.03
Vietnam	0.5%	0.3%	1.3%	187.2	9.5	0.05
South Africa	1.4%	0.5%	0.8%	317.1	47.7	0.07
RO Africa	1.5%	1.5%	11.4%	115.3	3.3	0.06
RO Americas	0.8%	0.9%	1.7%	110.5	12.4	0.07
RO Asia and Oceania	2.2%	2.5%	5.0%	99.4	11.0	0.07
RO EU	1.5%	1.3%	1.0%	129.8	39.6	0.08
RO Eurasia	1.6%	0.6%	1.7%	336.8	24.9	0.14
RO Middle East	1.4%	0.7%	1.5%	221.9	23.5	0.15

Note: This table reports for every country the share from world CO_2 emissions, output and population; and CO_2 emissions per capita and per output (each normalized to 100 for the United States), as well as average energy cost share in production (total use of primary and secondary energy divided by output). Reported CO_2 emissions correspond to direct emissions from combustion of primary and secondary fossil fuel energy.

when carbon prices were zero in most countries and minimal even in regions with carbon pricing. In Section 5.2.3, we make use of information on 2023 carbon prices to infer governments' care toward climate change. Using the method of hat algebra, we do not need to know baseline trade costs insofar as they do not generate revenues. However, in estimating trade elasticities, we use import tariffs from Teti (2024).

5.2 Estimating Policy Trade-offs using Event Study Design

A key constraint for the reform is that the transition from the disagreement point (a) to the annexed agreement (b) must be Pareto-improving. Solving the optimal reform problem therefore requires knowing the counterfactual changes in trade barriers if countries were to defect to the disagreement point, as well as the necessary elasticities to convert these changes to welfare effects. We recover these estimates below.

5.2.1 Estimating the impact of WTO membership on market access

We identify the causal effect of WTO accession on bilateral trade barriers and market access using a staggered difference-in-differences design at the country-pair level. The identifying variation comes from cross-country heterogeneity in the timing of accession and the discrete institutional change upon entry for treated units (i.e., being granted MFN status by incumbents). We compare changes in outcomes for country pairs that transition into WTO treatment to contemporaneous changes among country pairs that are never treated or not-yet treated, adopting an estimator that is valid under treatment-effect heterogeneity across cohorts and event time (Baker et al., 2025). Our analysis draws on panel data covering trade flows and trade agreements from the period 1986 to 2019. We use the International Trade and Production Database (Borchert et al., 2022) for industry-level trade data and the Dynamic Gravity Dataset (Gurevich and Herman, 2018) for WTO membership and other gravity variables.

Let $d_{ij,k,t}$ denote the iceberg trade cost between exporter i and importer j in industry k and year t, which embodies policy and technical barriers to trade. We parameterize the trade costs as

$$\ln d_{ij,k,t} = \tilde{\delta}_k^{WTO}\text{WTO}_{ij,t} + \tilde{\delta}_{ij,k} + \delta_k^G \cdot G_{ij,t} + \tilde{\varepsilon}_{ij,k,t}. \tag{27}$$

Substituting this trade cost specification into the CES demand function for international varieties, yields our estimating equation:

$$X_{ij,k,t} = \exp(\, \delta_k^{WTO}\text{WTO}_{ij,t} + \delta_{ij,k} + \delta_{i,k,t} + \delta_{j,k,t} + \delta_k^G \cdot G_{ij,t} + \varepsilon_{ij,k,t}\,). \tag{28}$$

Here, all the coefficients and the error term (previously denoted by tilde) are scaled by a factor $\sigma_k - 1$, e.g., $\delta_k^{WTO} = (1-\sigma_k)\tilde{\delta}_k^{WTO}$. The exporter-industry-year fixed effects ($\delta_{i,k,t}$) absorb all the cost shifters specific to (i,k,t) while the importer-industry-year fixed effects ($\delta_{j,k,t}$) absorb all the

demand shifter specific to market (j, k, t).

Because WTO accessions are staggered and treatment effects may be heterogeneous across cohort and time, the analog of the two-way fixed-effects regression, specified above, can yield biased and misleading estimates for the average treatment affect (Baker et al. (2025)). We therefore implement the extended two-way fixed effect estimator proposed by Wooldridge (2021), which re-weights cohort-specific effects to recover a consistent average treatment effect. This estimator can readily accommodate the rich set of gravity fixed effects and dummies, as discussed by Nagengast and Yotov (2025).[20] Formally, we estimate

$$X_{ij,k,t} = \exp\Big(\sum_{g \in G} \sum_{t'=g}^{T} \delta_{gt',k} D_{gt'} + \delta_{ij,k} + \delta_{i,k,t} + \delta_{j,k,t} + \delta_k^c \cdot x_{ij,t} + \varepsilon_{ij,k,t}\Big)$$

where $D_{gt',k}$ is a dummy that takes the value 1 if the observation ij is part of treatment group g in year t and zero otherwise. The the effect of WTO membership on trade flows is obtained as

$$\hat{\delta}_k^{WTO} = \sum_{g \in G} \sum_{t'=g}^{T} \frac{N_{t'g}}{N_G} \hat{\delta}_{t'g,k}$$

Then, we could recover the effect of WTO membership on trade costs as $\hat{\tilde{\delta}}_k^{WTO} = \hat{\delta}_k^{WTO}/(\sigma_k - 1)$. This approach identifies the casual effect of WTO membership on international market access under the identifying assumptions of no-anticipation with staggered treatment timing and parallel trends for every period and group (i.e., non-treated and non-yet treated).

The results are displayed in Table 3, organized by three broad sectors: Agriculture, Manufacturing, and Energy. The analysis uses a sample of 150 countries, which provides slightly more granularity than our main dataset from GTAP. For each sector, we report results based on two approaches to defining the onset of treatment. In the first approach, we assume an instantaneous onset of WTO accession. In the second, to address concerns about potential violations of the no-anticipation assumption, we implement a design in which treatment begins two years prior to official accession. The findings are consistent with the prevailing view that WTO membership significantly increases market access in the agriculture and manufacturing sectors, while having a less pronounced effect on energy trade. Specifically, with the onset year $t = -2$ which we use in our analysis, WTO membership increases trade values with other member countries by approximately 40% for agricultural goods and almost 80% for manufacturing goods. In contrast, the estimated effects on energy trade are much smaller and statistically insignificant.

[20] We include regional trade agreements as a covariate in our estimation. Since this is a dummy variable, the inclusion does not threaten the *strong overlap assumption*.

Table 3: Estimation results: impact of WTO membership on international market access

	Agriculture & Mining		Manfacturing		Energy	
	(1)	(2)	(3)	(4)	(5)	(6)
$\hat{\delta}_k^{WTO}$	0.534***	0.399***	0.795***	0.792***	0.239	0.150
	(0.131)	(0.132)	(0.140)	(0.148)	(0.179)	(0.184)
On-set year	$t = 0$	$t = -2$	$t = 0$	$t = -2$	$t = 0$	$t = -2$
Observations	280,517	235,407	298,132	260,703	172,779	149,246
Exporters	148	148	147	147	147	147
Importers	148	148	147	147	147	147
Years	34	32	32	30	32	30
Exporter × importer FE	Yes	Yes	Yes	Yes	Yes	Yes
Exporter × year FE	Yes	Yes	Yes	Yes	Yes	Yes
Importer × year FE	Yes	Yes	Yes	Yes	Yes	Yes
Control for RTA	Yes	Yes	Yes	Yes	Yes	Yes
Control for Sanctions	Yes	Yes	Yes	Yes	Yes	Yes

Note: This table reports Poisson pseudo-maximum-likelihood estimates of the effects of regional trade agreements, RTAs, and GATT/WTO membership on bilateral trade flows by broad industry group. The WTO/GATT entries are cohort-weighted average treatment effects from a staggered-adoption event-study design in which treatment is accession to the GATT/WTO; the RTA coefficient is estimated in the same gravity specification as a contemporaneous control. The sample consists of bilateral industry-year observations from 1986 to 2019 from the International Trade and Production Database (Borchert et al., 2022) and WTO membership and gravity variables from the Dynamic Gravity Dataset (Gurevich and Herman, 2018). All regressions include exporter-industry-year, importer-industry-year, and exporter-importer-industry fixed effects. Standard errors, reported in parentheses, are clustered at the exporter-importer-industry level. Dividing an estimated trade-flow coefficient by $\sigma_k - 1$ yields the implied proportional decline in iceberg trade costs.

5.2.2 Estimating Sectoral Trade Elasticities

To translate the estimated effects of WTO membership on trade *values* into corresponding effects on trade *barriers*, it is necessary to estimate trade elasticities. We do so using the local projection instrumental variable (LP-IV) approach developed by Boehm et al. (2023), applying it to new data. For the trade data, we use an extended panel from the International Trade and Production Database, spanning the years 1988 to 2019. We merge this data with the tariff database compiled by Teti (2024). Apart from using different data, we follow the methodology of Boehm et al. (2023) closely. We instrument for the horizon-h tariff change for each partner with the initial MFN tariff change, restricting our sample to non-major partners. Details about the methodology are provided in Appendix A.1.

The results are presented in Table 4. We report the benchmark LP-IV estimates incorporating 5-year and 10-year log differences. For comparison, we also report trade elasticity estimated by regressing trade flows on tariffs in log levels, controlling for multilateral and bilateral fixed effects. This approach closely resembles Fontagné et al. (2022). The LP-IV estimates are larger than the OLS estimates in log levels, hinting at potential tariff endogeneity. Expectedly, the elasticities

Table 4: Trade elasticity estimation results

	Agriculture & Mining			Manufacturing			Energy		
	OLS	LP-IV		OLS	LP-IV		OLS	LP-IV	
	(log levels)	5-year	10-year	(log levels)	5-year	10-year	(log levels)	5-year	10-year
trade elasticity ($\sigma - 1$)	4.25	7.02	13.22	2.35	3.95	6.33	7.81	12.25	12.14
	(0.25)	(2.59)	(3.27)	(0.17)	(1.90)	(2.80)	(0.56)	(4.25)	(5.13)
Observations	477,492	337,182	248,910	339,042	246,852	181,887	360,262	234,113	168,561
Exporters	145	145	145	145	145	143	145	145	145
Importers	145	145	145	145	145	145	145	145	145
Years	32	26	21	32	26	21	32	26	21
Exporter × importer FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter × year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Importer × year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: This table reports sector-level estimates of the trade elasticity, $(\sigma - 1)$, for agriculture and mining, manufacturing, and energy. Columns labeled OLS report coefficients from log-level regressions. Columns labeled LP-IV report local-projection instrumental-variables estimates based on 5-year and 10-year long differences following Boehm et al. (2023). For the LP-IV specifications, the horizon-h tariff change is instrumented with the initial MFN tariff change interacted with minor-partner and MFN-binding indicators, and the sample is restricted to non-major partners. Trade data are from the International Trade and Production Database for Estimation (ITPD-E). Tariff data are from the Global Tariff Database (Teti (2024)). The matched bilateral sector-year panel spans 1988–2019. All specifications include exporter×importer, exporter×year, and importer×year fixed effects. Robust standard errors are reported in parentheses.

based on 10-year log differences are higher than those based on 5-year log-differences. Our LP-IV estimates also exceed those reported by Boehm et al. (2023), possibly due to our use of different data. In our main specification we use the LP-IV estimates based on 5-year log differences.

The estimation results suggest that WTO membership reduces trade barriers by approximately 6% for agricultural products, 20% for manufactured goods, and negligible for energy.[21] In our main specification, we use these estimates as the impact of withdrawal from the WTO on trade costs. We also experiment with tariff changes and find that the results remain close to those in our main specification. (Section 6.4).

5.2.3 Inferring governments' valuation of climate change damages

We infer each government's valuation of climate damage from their existing energy tax and climate policies. This revealed preference approach recognizes that government objectives may not align with social welfare, evidenced by the absence of carbon pricing in many countries facing substantial climate change damages.[22]

[21] We acknowledge that this inference recovers the cost of non-staggered withdrawal by all members from the benefits of staggered accession. Nonetheless, the implied effects are relatively conservative compared with predictions from the strategic trade policy literature. As a rule of thumb, the Nash tariff for a small open economy is inversely proportional to the trade elasticity. In manufacturing, for example, this implies a tariff rate of 25%, compared with 20% in our empirical estimate.

[22] To provide a more complete analysis, we also experiment with an alternative where governments' objectives align with social welfare (Section6.3.2).

To begin, we specify the objective function of country i's government as:

$$W_i^{(\text{gov})} = C_i - \delta_i^{(\text{local})} Z_i - \delta_i^{(\text{global})} Z^{(\text{global})};$$

where C_i is aggregate real consumption in country i, and the two parameters, $\delta_i^{(\text{local})}$ and $\delta_i^{(\text{global})}$, represent the disutility from local and global CO_2 emissions *as perceived by country i's government*. The disutility from local emissions, $\delta_i^{(\text{local})} Z_i$, is a shorthand for non-climate damages in government's evaluation, such as adverse local health effects from air pollutants co-emitted with CO_2 emissions. The disutility from global emissions, $\delta_i^{(\text{global})} Z^{(\text{global})}$, is the climate damage cost from global CO_2 emissions.

Our calibration proceeds in two steps. First, we recover $\delta_i^{(\text{local})}$ from 2014 energy taxes when carbon pricing was virtually absent. Second, we infer $\delta_i^{(\text{global})}$ from the carbon prices adopted in 2023.

In the first step, we focus on our sample in the year 2014 when carbon pricing was virtually nonexistent and assume that in 2014, $\delta_i^{(\text{global})}$ is zero everywhere. Let $\boldsymbol{t}_i \equiv [t_{i,kg}^{(I)}, t_{i,k}^{(H)}]$ denote country i's observed ad valorem energy tax rates for each energy good k when used by industries and households, respectively. We consider the following policy problem for the government in each country i, taking other countries' policies as given:

$$\boldsymbol{t}_i^*(\delta_i^{(\text{local})}) = \arg\max_{\boldsymbol{t}_i} \; C_i - \delta_i^{(\text{local})} Z_i$$

The optimal tax vector $\boldsymbol{t}_i^*(\delta_i^{(\text{local})})$ depends on $\delta_i^{(\text{local})}$ because higher energy taxes reduce local emissions Z_i, which are valued more highly when the government's concern for local damages is greater. We employ a numerical algorithm that uncovers the value of $\delta_i^{(\text{local})}$ for which the observed taxes $\boldsymbol{t}_i$ are unilaterally optimal.[23]

In the second step, we suppose that each country draws a value of $\delta_i^{(\text{global})}$ that reflects its commitment to addressing climate change. Let $\tilde{\tau}_i$ denote the carbon price in country i, which was zero in 2014 but it is now updated to the observed values in 2023 as countries developed concern for climate change. Given the policies of other countries, we now consider the following problem for the government of each country i:

$$p_i^*(\delta_i^{(\text{global})}) = \arg\max_{\tilde{\tau}_i} \; C_i - \delta_i^{(\text{local})} Z_i - \delta_i^{(\text{global})} Z^{(\text{global})}$$

[23] Appendix A presents our numerical algorithm. Two clarifications are worth noting. First, when assessing whether observed taxes are optimal for a given $\delta_i^{(\text{local})}$, we restrict attention to uniform carbon-price perturbations. Specifically, we consider only tax changes implied by a marginal increase or decrease in a carbon price applied uniformly to the carbon content of all fuels across all end users within a country. This reduces the dimensionality of the problem while keeping the focus on carbon pricing, the policy instrument central to our analysis. Second, for some countries, no value of $\delta_i^{(\text{local})}$ rationalizes the observed taxes as an unconstrained optimum. In those cases, we identify the largest $\delta_i^{(\text{local})}$ such that a marginal increase in energy tax rates lowers welfare, even though a marginal decrease would still raise it. This yields a *corner* solution under the additional restriction that deviations in energy taxes are allowed only in one direction: the introduction of a positive carbon price.

Since we have already recovered the values of $\delta_i^{(\text{local})}$, we express the optimal carbon price, $\tilde{\tau}_i^*(.)$, as only a function of $\delta_i^{(\text{global})}$. We compute the value of $\delta_i^{(\text{global})}$ such that, for each country i, the solution $\tilde{\tau}_i^*(\delta_i^{(\text{global})})$ matches the observed carbon price in that country in the year 2023. We assume that any increase in a country's carbon price from 2014 to 2023 is attributable to the introduction of $\delta_i^{(\text{global})}$ into its government's objective function.

Since European countries, including the United Kingdom, largely set their carbon prices jointly, we aggregate them into one "European Union (EU)" region. We use this aggregation in our main quantitative analyses in Section 6.4. Elsewhere, to establish patterns and estimates with a larger number of observations, where we do not need evaluations based on governments' objective functions, we use our disaggregated sample.

Appendix Table A.1 reports the calibrated emission disutility parameters for all countries in our sample, alongside the underlying energy tax and carbon pricing data. Several patterns emerge: First, there is substantial heterogeneity in both local and global damage valuations across countries. Second, several countries, particularly fossil fuel exporters, such as the United Arab Emirates or Saudi Arabia, exhibit negative local disutility parameters, indicating that their energy tax policies reflect objectives beyond environmental damage internalization. Third, explicit carbon pricing remains concentrated among higher-income economies, with the European Union (\$35.3/tCO$_2$) and Canada (\$28.6/tCO$_2$) implementing the highest carbon prices in 2023. Fourth, the global climate concern parameter $\delta_i^{(\text{global})}$ is zero or small for most countries, reflecting the absence of or weak carbon pricing policies, while countries with active carbon pricing show substantial variation in their implied climate valuations, ranging from \$1.8/tCO$_2$ (Chile) to \$48.6/tCO$_2$ (European Union). Lastly, the sum of global damage parameters, $\sum_i \delta_i^{(\text{global})}$, amounts to \$113.9/tCO$_2$, a value that can be different from the global social cost of CO$_2$.

6 Quantitative Policy Analysis

We use our calibrated model along with our estimates of policy trade-offs from Section 5 to conduct three quantitative policy analyses. First, we show that greater trade openness under the WTO increases real consumption across countries, with systematically larger gains in countries that also experience larger increases in emissions. Second, we show that supply-side and demand-side carbon taxes have opposite distributional effects across countries. Building on these results, third and finally, we propose a mechanism for incorporating carbon pricing into the WTO and provide quantitative bounds on the ex ante effectiveness of linking carbon pricing to the existing WTO framework.

6.1 Gains from Trade *vs.* Emissions from Trade

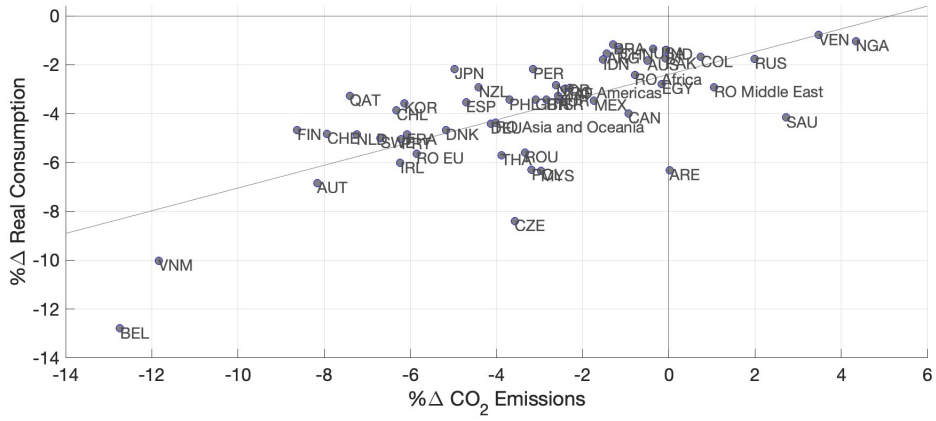
We quantify how greater trade openness under the WTO affects real consumption and CO$_2$ emissions across countries. Our results show that these two metrics are positively and tightly correlated

across countries in our sample. Specifically, we measure the effects of trade openness by simulating counterfactual outcomes in which the WTO is dismantled and members lose preferential market access. This exercise is informed by our causal estimates of the benefits of WTO membership and sector-specific trade elasticities from Section 5.2. We also explore alternative definitions of trade openness and, importantly, demonstrate that the highlighted relationship holds when using a more conventional benchmark of complete autarky.[24]

Figure 2 plots the change in real consumption and CO_2 emissions for all WTO member countries under a counterfactual scenario in which the WTO is dissolved. The change in real consumption is negative across countries, consistent with the textbook principle that the WTO has enhanced real consumption by amplifying the gains from trade. On average, real consumption would decline by 2.6% in the absence of the WTO, while global CO_2 emissions would decrease by 1.4%. Put differently, WTO-enabled emissions constitute 1.4% of global emissions.

Notably, countries that face larger consumption losses from WTO dissolution, positioned in the lower left of Figure 2, also experience greater reductions in CO_2 emissions. In contrast, countries with smaller consumption losses, shown in the upper right of the figure, tend to see more modest declines in emissions or, in some cases, increases. The correlation between losses in real consumption and CO_2 emissions resulting from WTO dissolution is statistically significant, with a correlation coefficient of 0.73.

Figure 2: Consumption and Emission Impacts of Dissolving WTO



Note: This figure shows the percentage change in real consumption and CO_2 emissions across countries resulting from the dissolution of the WTO. Trade costs are increased multilaterally for all countries, based on the estimates in Section 5.2.

As noted earlier, this systematic relationship reflects the structural features of global trade rather than the specific institutional design of the WTO. A similar pattern emerges when we con-

[24] We also consider an alternative in which non-cooperative outcomes are modeled through import tariffs rather than iceberg trade barriers. As Figure 6.4 shows, the positive correlation between real consumption and emissions remains strong under this specification, and the results for the optimal linkage problem, reported in Section 6.4, are close to those in the main specification.

sider a shift to complete autarky: the consumption losses from autarky are strongly and positively correlated with the associated reductions in emissions (see Figure A.4 in the appendix).

Following the decomposition method of Copeland and Taylor (2004) we find that dissolving the WTO reduces global emissions primarily through *scale effect*s—the contraction of global output. The emission reductions achieved through the scale effects are partially offset by *composition effect*s: the dissolution of the WTO directs resources toward countries and industries with higher emission intensities. Meanwhile, *technique effects*, which capture changes in energy use intensity, are quite modest.[25]

As noted in the first takeaway of Section 3.2, a key reason trade-induced consumption gains are correlated with emissions is that forces that lower the costs of producing consumer goods often also reduce the costs of producing energy. To measure the importance of this channel, we recalculate the effects of WTO dissolution in a counterfactual setting where the role of intermediate inputs in energy production is artificially reduced. In particular, for each country i and input-supplying industry g, we adjust the input shares in energy-producing sectors ($k \in \mathbb{E}$) by lowering the intermediate input share $\alpha^I_{i,gk}$ by $x \in (0, 1]$ percentage points for every g, reallocating the corresponding share to labor. Appendix Figure A.6 shows that the correlation declines monotonically in x. And as x approaches one—so that all intermediate input use in energy production is replaced by local labor inputs—the correlation becomes statistically insignificant.

The main takeaway from these results is that the countries that gain the most from WTO membership also account for a disproportionate share of WTO-driven carbon emissions. This finding carries two important implications. First, it speaks directly to a core question raised at the outset of the paper: trade agreements exacerbate climate externalities, and yet they are not designed to internalize these non-pecuniary externalities. Second, the strong positive relationship between consumption gains from WTO membership and associated emissions creates an opportunity for effective linkage design. Countries that stand to loose the most from the dismantling of the WTO are imposing a greater climate externality on partners. As a result, the prospect of losing market access could serve as a credible lever to curb those externalities.

6.2 Carbon Pricing Incidence: Supply-side vs. Demand-Sided Taxes

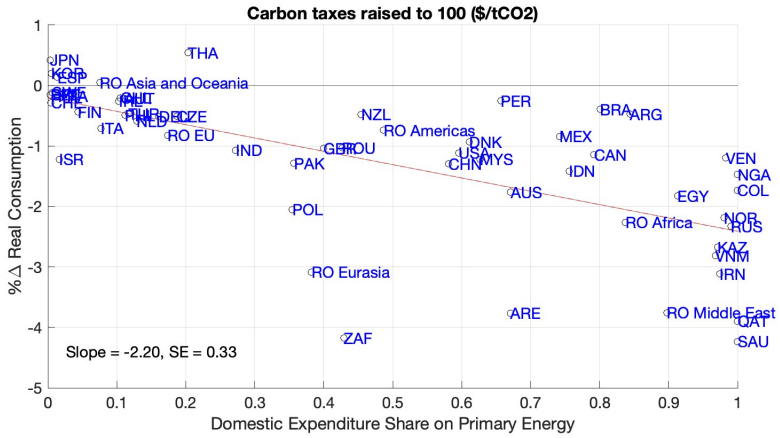
Next, we use the calibrated model to illustrate the unequal incidence of carbon pricing across countries. To this end, we simulate the real consumption effects of a global uniform carbon tax set at 100 ($/tCO$_2$). We compare two implementations of the tax: one applied on the demand side and the other on the supply side. The demand-side tax is levied on the carbon content of primary

[25] When trade costs rise as a result of dissolving the WTO, global industrial emissions (all emissions net of household emissions) fall by 1.4%. Using Copeland and Taylor's approach, this change decomposes into a 2.4 percentage point reduction from the scale effect, a 0.1 p.p. increase from the technique effect, and a 0.9 p.p. increase from the composition effect. The technique effect is modest because WTO-induced changes in energy-sector trade costs are small, so energy intensity adjusts mainly indirectly through reduced trade in non-energy industries. When transitioning to autarky—where trade in both energy and non-energy goods shuts down—the technique effect is much larger.

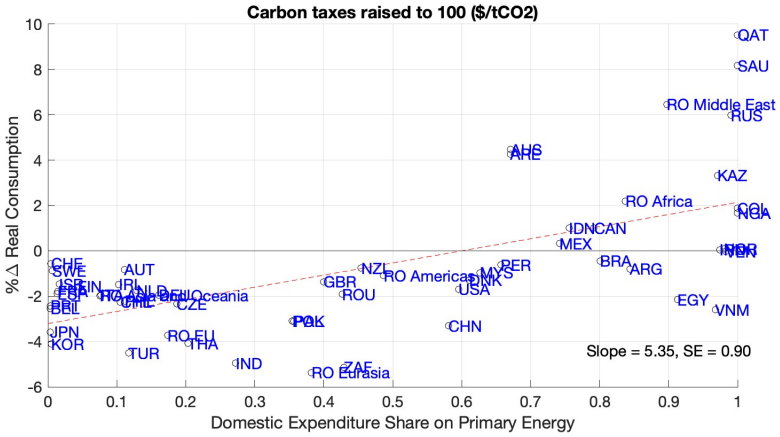
and secondary energy used by households and producers at the point of demand. In contrast, the supply-side tax targets the carbon content of primary energy at the point of extraction. Our goal is to quantitatively assess the conjecture presented in Section 3.2: that the international incidence of carbon taxation diverges under the two tax schemes.

Figure 3: Global Carbon Tax

(a) Demand-side



(b) Supply-side



Note: This figure shows the percentage change in real consumption across countries against their baseline domestic share of expenditure on primary energy, in response to global uniform carbon pricing. Panel (a) shows the results for carbon taxes implemented on the demand side of energy markets, while Panel (b) presents the results for carbon taxes applied on the supply (extraction) side.

The results are presented in Figure 3, which plots the percentage change in real consumption across countries following the implementation of a uniform carbon tax, against each country's domestic expenditure share on primary energy (aggregated over coal, crude oil, and natural gas). This expenditure share serves as a proxy for the size of a country's primary energy reserves and the scale of its extraction activities. Panel (a) displays the results under the demand-side carbon tax scheme, while Panel (b) shows the outcomes under the supply-side tax. While both tax schemes

can achieve the global first-best level of emissions reduction, they produce markedly different distributional effects across countries.

In Panel (a), countries like Japan and Spain, which have near-zero domestic expenditure shares (DES) in primary energy, not only avoid losses but may even gain from demand-side carbon taxes. In contrast, countries such as Saudi Arabia and Russia, with near-unity DES in primary energy, experience the largest losses. These results are reversed under supply-side carbon taxes, as shown in Panel (b). In this case, countries like Japan and Spain face the largest losses from carbon taxation, while countries such as Saudi Arabia and Russia largely benefit from supply-side carbon taxes. The correlation between changes in real consumption and DES in primary energy is strong in both cases, being negative in Panel (a) and positive in Panel (b).

The international incidence of a carbon tax can be understood through the revenue and general equilibrium effects discussed in Section 3.2. The revenue effect stems from the fact that the tax burden is spread internationally and non-localized, while the resulting revenues are rebated locally. Under a demand-side carbon tax, revenues are primarily collected by countries with high energy consumption. In contrast, under a supply-side tax, revenues accrue to major energy-producing countries. The general equilibrium effect arises from changes in global energy prices. A demand-side carbon tax reduces global energy demand, leading to a decline in energy prices. This shift produces terms-of-trade effects that benefit energy-importing countries while disadvantaging exporters. In contrast, a supply-side tax shifts the terms-of-trade to the benefit of energy exporters. Together, these direct and general equilibrium effects generate significant cross-border distributional externalities, as clearly illustrated by the contrasting outcomes in Panels (a) and (b) of Figure 3

Ultimately, while both demand-side and supply-side carbon taxes can achieve the same global emissions targets, their international incidence differs markedly. This finding addresses another core question raised at the outset of the paper: carbon pricing reforms generate winners and losers through trade-related pecuniary externalities, yet existing climate agreements are poorly equipped to manage these distributional consequences. Correspondingly, an effective linkage design should incorporate mechanisms to mitigate such externalities. Without such provisions, the reform would fail to constitute a Pareto improvement and would thus violate the consensus principle discussed earlier.

Revenue vs. GE effects. We next examine whether the unequal incidence of carbon taxes is driven primarily by the revenue effect, based on how tax revenues are rebated geographically, or by the general equilibrium effect, driven by changes in international prices. To this end, Appendix Figure A.7 reproduces our tax incidence figure by comparing the change in real consumption under carbon pricing, $C_i = (Y_i + T_i)/\tilde{P}_i$, with the change in real income excluding tax revenue rebates, $Y_i/\tilde{P}_i$. The difference between these two measures isolates the contribution of general equilibrium price adjustments to tax incidence.

Two main patterns emerge. First, under demand-side taxes, the negative correlation between

a country's primary-energy expenditure share and its real-consumption gains remains largely unchanged, indicating that the revenue effect does not drive the systematic relationship shown in Panel (a) of Figure 3. Second, under supply-side taxes, the positive correlation disappears, implying that the revenue effect is the primary driver of the relationship in Panel (b) of Figure 3. This finding reflects the fact that revenues from supply-side carbon taxes are more geographically concentrated than revenues from demand-side taxes.

6.3 Effectiveness of Integrating Carbon Pricing into the WTO

In this section, we turn to the optimal linkage problem outlined in Section 4. Our analysis here focuses on the integration of *demand-side* carbon taxes into the WTO. This choice is not arbitrary. Existing climate policy frameworks (e.g., carbon taxes, emissions trading systems) are already built around demand-side pricing mechanisms, shaped in large part by the European Union's leadership. It is therefore conceivable to scale them from the regional to the global level.

6.3.1 Implementation through a Global Climate Fund

Our objective is to identify the highest demand-side carbon price subject to constraints R1–R4. Specifically, to implement transfers, we propose the following "Global Climate Fund": all participating countries commit to the same carbon price applied uniformly on the demand side; the Fund collects the border-related portion of the revenues generated by these carbon taxes and allocates them to member countries to compensate those that otherwise lose disproportionately.

Climate Fund Accounting: When a country imports fossil fuels and combusts them locally, the resulting carbon emissions are taxed under the domestic demand-side regime. The fraction of revenue linked to the imported share of that energy is transferred to the Fund.[26] These contributions are then redistributed across participants according to a formula designed to compensate countries that bear disproportionate burdens under the carbon pricing scheme. Formally, the Fund satisfies a global budget balance:

$$\text{Fund} = \sum_i (\text{contribution})_i = \sum_i (\text{allocation})_i$$

$$\text{where} \quad (\text{contribution})_i = (\text{carbon price})_i \times \sum_{k \in \mathbb{E}_1 \cup \mathbb{E}_2} \Big[(\text{imported share of exp})_{i,k} \times Z_{i,k} \Big] .$$

Here, $Z_{i,k}$ is country i's CO_2 emissions associated with the use of primary or secondary energy $k \in \mathbb{E}_1 \cup \mathbb{E}_2$. To put the magnitudes in perspective, under a uniform carbon price of 100 ($/tCO$_2$), only 25.5% of global carbon tax revenues are border-related and allotted to the Fund. Across countries,

[26] As hinted under R3, the motivation behind this design is that if the system instead relied on supply-side taxes, these revenues would be collected by the exporting country rather than the importer.

the share of contributions from total carbon tax receipts ranges from 2% to 71% with an average of 36% (see Figure A.8 in the appendix).[27]

To determine the allocation of transfers, we must first specify the observable statistics, x, on which the allocation is conditioned. While x could, in principle, include multiple variables, we construct the transfers based on one variable at a time, illustrating that even a simple allocation rule can achieve meaningful redistribution. The chosen statistic must provide sufficient flexibility to direct transfers toward marginal participants. Specifically:

(i) countries that gain less from trade agreements;

(ii) countries that suffer more from demand-side carbon pricing.

To effectuate (i), we take note from Arkolakis et al. (2012) who show that the gains from trade relative to autarky are determined by domestic expenditure shares (λ_{ii}). While this measure is not a perfect proxy for the gains from trade agreements, it provides a useful approximation. Based on this insight, our first allocation rule distributes the Fund's resources in proportion to each country's aggregate domestic expenditure share: $x = \{\lambda_{ii}\}_i$.

To effectuate (ii), we note that net energy exporters tend to incur larger welfare losses under demand-side carbon pricing. To compensate these countries, the allocation formula could distribute funds in proportion to the domestic expenditure share in the energy sector, i.e., $x_i = \sum_{\mathbb{E}_1 \cup \mathbb{E}_2} \lambda_{ii,k} e_{i,k}$. Energy-exporting countries receive a larger share under this allocation. We also explore a few variants of this rule: We explore an alternative where transfers are based purely on the *primary* energy domestic expenditures share. We also consider another specification where allocations are determined by each country's share from global energy exports.

To improve the Fund's effectiveness, we incorporate two additional features. First, we define the carbon price as the sum of the explicit carbon price and the implicit price arising from fossil fuel taxes. These implicit prices tend to be higher in countries that both benefit more from trade agreements and place greater weight on climate policy (e.g., the European Union), which further enhances the Fund's effectiveness. Second, we set contributions from low-income countries to zero, following the World Bank income classification.[28] This also improves outcomes at the margin, since some of the low-income countries—most notably India—benefit less from trade agreements while being particularly exposed to energy price increases due to their high expenditure share on energy.

Results. We solve the constrained-optimal linkage problem in Section 4 by finding the maximum carbon price subject to constraints R1-R4, which determines transfers for each choice of x as dis-

[27] Even in countries with minimal domestic primary energy production, the contribution remains limited. This is because a substantial portion of energy demand is met through secondary energy uses, such as electricity, which is produced domestically in power plants that burn coal or natural gas, rather than imported across international borders.

[28] This includes Egypt, Indonesia, India, Nigeria, Pakistan, the Philippines, Vietnam, and the rest of Africa, and it perfectly maps to the ranking of country-level income distribution in our data.

cussed above.[29] Table 5 presents the results. To showcase the role of transfers, we first report the maximum feasible carbon price in the absence of transfers. The maximum tax equals \$61/tCO_2 in this scenario, leading to a 38.0% reduction in global emissions. Moreover, Venezuela is the marginal country that becomes indifferent between staying in and defecting from the agreement, followed by Nigeria (NGA) and Russia (RUS), all of which are large energy-exporting countries.

Table 5: Climate Fund's Outcomes

	Max Carbon Price ($/tCO2)	Reduction in Global Emission	Marginal Countries
No Side Payments	61	38.0%	VEN, NGA, RUS
Side Payments: Allocations from the Fund			
(a) Prop to dom. exp. share in all goods	99	47.0%	RO Middle East, RUS, USA
(b) Prop to dom. exp. share in manufacturing	86	44.4%	RO Middle East, RUS, USA
(c) Prop to dom. exp. share in all energy	112	49.3%	RUS, RO Middle East, USA
(d) Prop to dom. exp. share in primary energy	127	51.6%	RUS, IND, USA
(e) Share of global primary energy exports	107	48.5%	IND, BRA, USA

Note: This table reports, for each specified allocation scheme, the maximum carbon tax at which all existing WTO member countries benefit from staying in the new agreement relative to the dissolution of the agreement.

Activating transfers via the Fund improves outcomes depending on the allocation rule. Allocating funds proportional to the domestic expenditure share on all goods, $x_i = \lambda_{ii}$, raises the maximum carbon price to \$99, with a 47.0% reduction in emissions. The maximum feasible carbon price rises further when allocations use energy-related statistics, with the strongest results obtained when allocations are proportional to the domestic expenditure share in primary energy. Under this allocation rule, the maximum carbon price reaches \$127, and global emissions fall by 51.6%.

6.3.2 The Role of Restrictions R1-R4

We now examine how the institutional constraints R1–R4 limit the effectiveness of integrating carbon pricing into the WTO framework. We relax each constraint in turn, proceeding in reverse order from R4 to R1, while holding the remaining constraints fixed.

R4: Minimal information requirement. Relaxing R4 permits more flexible transfer rules, including arrangements that resemble negotiated side payments across countries. To illustrate one such case, we consider a two-tier iterative procedure for determining relaxed transfers.

In the lower tier, we hold the carbon price fixed and start from an initial transfer allocation. We identify countries that gain and countries that lose, and compute their welfare changes using equivalent variation (EV). When the winners' aggregate gains exceed the losers' aggregate losses,

[29] We consider carbon pricing only for WTO members as of 2014 (our baseline year). This excludes just three countries: Iran, Kazakhstan, and RO Eurasia (a group of countries that were part of the former Soviet Union).

we increase transfers from winners to losers by the minimum amount required to leave losers no worse off, with contributions from winners proportional to their gains. We then re-solve the general equilibrium and repeat the procedure until either all countries are weakly better off or winners' aggregate gains are insufficient to compensate losers.[30] If the lower-tier yields a transfer scheme where all countries are weakly better off, we move to the second tier, in which we raise the carbon price and repeat the procedure. This way, we determine the maximum carbon price that can be supported while ensuring that no country is made worse off.

Using this approach, we obtain a maximum carbon price of \$278 per tCO_2, well above the \$127 achieved under the Global Climate Fund allocation examined earlier. This price also falls within the upper range of recent social cost of carbon estimates, e.g., \$292 from Ricke et al. (2018). We interpret this result as an upper bound on the extent to which transfers can support ambitious international climate cooperation. Achieving this upper bound, however, is information-intensive, as it requires detailed knowledge of which countries should receive compensation and in what amounts. These informational constraints imply that, in practice, less than half of the potential benefits of transfers can be exploited.

R3: Fiscal constraint. Next, we relax R3 by allowing transfers to be financed out of total carbon tax revenues rather than only the border-related portion. Two results follow. First, somewhat unexpectedly, relaxing R3 does not increase the maximum carbon price achievable under the allocation rules we examine. The reason is that the marginal energy-exporting countries, are now required to contribute more to the climate fund, while their allocation does not rise correspondingly under the examined rules. Second, flexible transfers perform better with an expanded fiscal base: the upper bound on the carbon price increases from \$278 in the main specification to \$395. However, realizing this added potential requires different allocation rules than those examined here.

R2: Consensus principle. R2 asserts that the annexed agreement must include all existing WTO members. Relaxing this restriction opens the door to supporting a more ambitious carbon price target, at the cost of excluding some members.[31] Here we examine whether R2 binds the carbon price cap. To this end, we compute outcomes across the full range of carbon prices and report the implied changes in global emissions, global welfare, a global aggregate of governments' objectives, and coalition size. Figure 4 plots these metrics as functions of the carbon price, assuming transfers are allocated to participating countries in proportion to each country's domestic expenditure share on primary energy.[32]

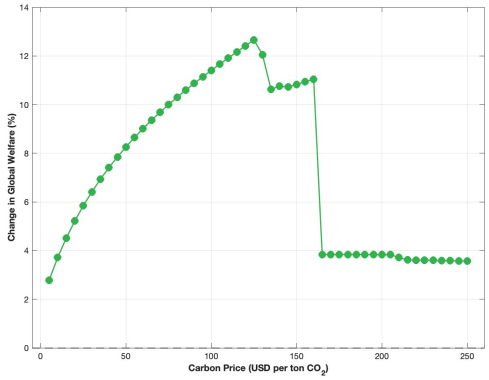
[30] We recompute the equilibrium after each transfer update because transfers affect outcomes through income effects. If preferences were quasi-linear and the linear sector were large and freely traded, income effects would be absent, and recomputing the general equilibrium after each transfer adjustment would be unnecessary.

[31] This analysis relates to Bourany (2025) , who defines the optimal coalition as the one maximizing the joint welfare of its members. In that paper, the optimal agreement does not coincide with maximal participation, and thereby violates R2.

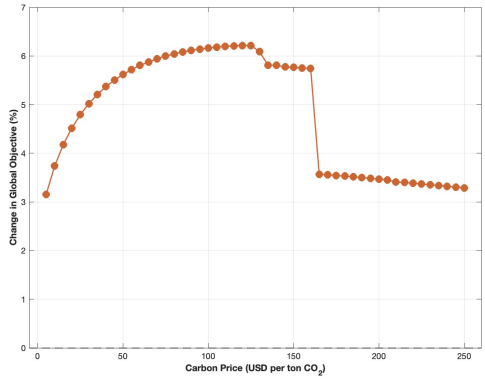
[32] We compute the equilibrium outcome at each carbon price using this iterative procedure: In the first round, we begin with full participation and evaluate each country's decision to remain in the agreement, taking as given that

Figure 4: Coalition Outcomes as a Function of Carbon Price Target

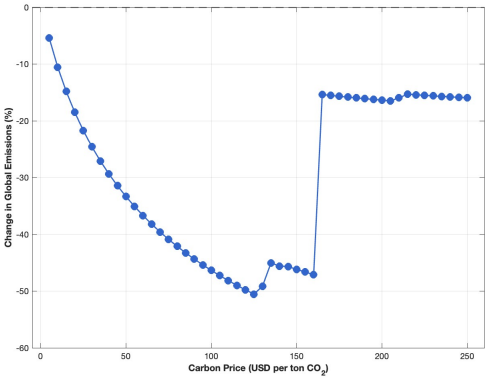
(a) Global Welfare



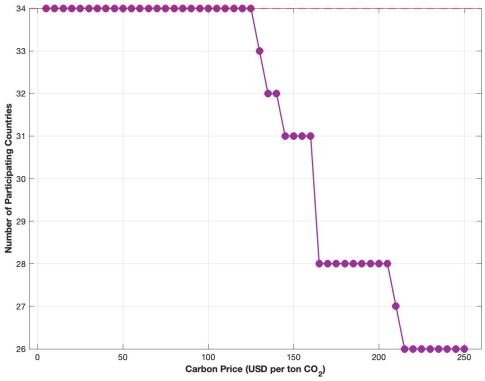
(b) Global Aggregate of Governments' Objectives



(c) Global Emissions



(d) Number of Countries in the Coalition



Note: This figure plots the coalition outcomes through the climate fund with allocations based on each country's domestic expenditure share in primary energy for a wide range of carbon pricing targets. Panel (a) shows percentage changes to global welfare (as the weighted average of welfare of countries with weights proportional to baseline GDP). Panel (b) shows the global weighted value of governments' objectives. Panel (c) shows global emissions, and Panel (d) shows the number of participants in the coalition.

Notably, the highest carbon price that satisfies the Consensus principle (R2) also maximizes global welfare and the global aggregate of governments' objectives, while also minimizing global emissions.[33] This indicates that, at least under the allocation rule that performs best in our analysis, minimizing emissions subject to consensus implies optimality under other commonly-used objectives, such as maximizing global welfare or minimizing global emissions.

Another aspect of R2 is the misalignment between governments' objectives and social welfare. We relax this misalignment by considering an objective function that accords with country-

other countries remain in the agreement. Countries that withdraw in a given round are assumed to remain out in all subsequent rounds. We then repeat the process with the remaining participants until the outcome converges.

[33] Outcomes exhibit a jump at a carbon price of $165. This arises primarily because the United States exits the agreement at that price, which in turn triggers the withdrawal of China and Japan.

specific estimates for climate damage. Specifically, we model the damage function for country i following Shapiro (2021) as

$$\Delta_i(Z^{(global)}) = \left[1 + \mu_i \left(Z^{(global)} - Z_0^{(global)}\right)\right]^{-1}.$$

Here, $Z_0^{(global)}$ and $Z^{(global)}$ denote global emissions in the baseline equilibrium and the counterfactual equilibrium with carbon pricing linkage. The parameter μ_i denotes country i's disutility from increases in global emissions, calibrated using country-level social costs of CO_2 from Ricke et al. (2018). Appendix A.3.4 provides the details of our calibration.

The results under this alternative objective function depend critically on whether the country-level social costs of carbon is allowed to be negative. When negative values are permitted, Russia is consistently the marginal country at relatively low carbon prices. This occurs because Russia's gains from trade agreements are relatively small and Russia largely benefits from climate change. In this case, the most effective allocation rule is the one that provides greater compensation to Russia—namely, transfers based on each country's share of global primary energy exports.

We also consider an alternative in which we re-calibrate country-level social costs of carbon by setting negative values to zero, while keeping the global social cost of carbon unchanged. Under this re-calibration, the maximum carbon price compatible with sustaining the coalition increases sharply, exceeding $200 under the allocation rule based on primary energy export shares. Appendix Table A.2 reports the results.

R1: Single undertaking principle. Finally, we relax R1, which sets the disagreement point to multilateral withdrawal from the WTO. Instead, we consider unilateral deviations: each country evaluates whether to exit the agreement taking as given that all other members remain. We test for such deviations at every annexed carbon price. If no country has an incentive to exit, the outcome constitutes a Nash equilibrium in which all WTO members adopt the harmonized carbon price.

Appendix Table A.3 reports the maximum carbon price sustainable under the unilateral-deviation criterion. Without side payments, limiting deviations to a single country raises the maximum sustainable price to $80 (from $61 under multilateral deviations). With Climate Fund side payments, the highest sustainable price comes from allocating transfers by each country's share of domestic manufacturing expenditure, supporting a maximum price of $132. For this allocation rule, Appendix Figure A.9 shows how global welfare, global emissions, and coalition size change as the carbon price increases further.

Energy price shifts explain why allocation rules perform differently under unilateral versus multilateral deviations. When a single energy exporter defects, the effect on world energy prices is negligible, so the cost of deviation is low. Collective withdrawal, by contrast, depresses global energy demand and drives prices down sharply, making defection far more costly for energy exporters as a group. Consequently, India (a net energy importer) emerges as the marginal country, followed closely by energy exporters such as Russia and Venezuela.

6.4 Sensitivity Analysis

In this section, we examine the robustness of our results by considering a few alternative specifications. First, we experiment with alternative values for energy demand and supply elasticity parameters. In our baseline Cobb-Douglas specification implies that the energy demand elasticity equals one. Here, we let the production and consumption aggregators to take a CES form between an energy bundle and a non-energy bundle, while maintaining a Cobb-Douglas structure within each bundle. We set the substitution elasticity between the energy and non-energy bundles to 0.59, based on the average long-run energy demand elasticity estimates reported in the meta-analysis by Labandeira et al. (2017). In addition, we recalibrate the supply elasticity by setting $\alpha^R_{i,k}$ for primary energy industries $k \in \mathbb{E}_1$ to 0.4 (and proportionally shifting the cost share of labor and intermediate inputs). This reduces the supply elasticity of primary energy to 1.5, consistent with Kotchen (2021). Table A.4 in the appendix shows that the results remain broadly similar to those in our main specification. Under the no-transfer scenario, the maximum carbon price is \$55 (28.9% emissions reduction) while it rises to \$159 when fund allocations are based on countries' domestic expenditure shares in primary energy (46.2% emissions reduction).

Lastly, we consider an alternative specification in which non-cooperative outcomes arise not from higher iceberg trade barriers, but from governments raising revenue-generating import tariffs. We simply set these tariffs to 25%, which approximates non-cooperative tariff rates under a small open economy assumption and a trade elasticity of 4, close to our point estimate for manufacturing. Table A.5 reports the results. Without side payments, the maximum carbon price is \$53, reducing global emissions by 35.5%. Introducing transfers through the Global Climate Fund raises the maximum carbon price up to \$109 and reduces global emissions by 48.8%.

7 Conclusions

International trade and climate agreements have traditionally evolved separately. Yet trade agreements can increase emissions, generating climate externalities, while climate policies such as carbon pricing can create distributive externalities through changes in the terms of trade. To assess the magnitude of these cross-externalities, we use a quantitative trade model with a detailed representation of fossil fuel supply chains. We begin by highlighting two key findings. First, countries that benefit most from trade agreements also tend to generate higher trade-induced emissions. Second, demand-side carbon taxes generate substantial distributional effects, benefiting energy-importing countries at the expense of energy-exporting countries. The first finding suggests that linking market access to carbon pricing through contingent trade reforms could be an effective way to reduce emissions. However, addressing the distributive externalities highlighted in the second finding requires a redistribution mechanism to balance the global tax burden.

To address these cross-externalities, we formulate a constrained-optimal linkage problem that limits the set of feasible outcomes through political-economy constraints. We then implement the

solution by proposing a Climate Fund that requires members to adopt harmonized carbon pricing and redistributes revenues from border-related portion of carbon taxes. Our quantitative analysis demonstrates that simple allocation rules designed to compensate countries facing disproportionate losses can substantially enhance the effectiveness of these agreements.

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Appendix

A Data and Calibration

A.1 Trade Elasticities

This appendix described the data construction and estimation method used to recover trade elasticities. The empirical strategy builds on the local-projection IV framework in Boehm et al. (2023), but the application differs in data source and aggregation level. Our trade flows come from the International Trade and Production Database for Estimation (ITPD-E), Release 2, distributed through the U.S. International Trade Commission Gravity Portal (https://www.usitc.gov/data/gravity/index.htm). Tariffs come from Teti's (2024) Global Tariff Database, version `v_beta1-2024-12` (ISIC Rev. 3.3 bilateral panel, 1988–2021). In this version, weighted tariff variables are BACI-weighted, as stated in the variable definitions.

The unit of observation in the raw trade files is exporter–importer–industry–year. We first map detailed industries into ISIC Rev. 3.3 sector groupings used by the tariff panel and aggregate trade to exporter–importer–sector–year cells. We then merge the bilateral trade panel with the bilateral tariff panel and keep matched observations. The estimating sample is organized into three broad sector blocks. The first block combines agriculture and mining sectors. The second block combines manufacturing sectors. The third block combines energy sectors. Each block is estimated separately to obtain the sector-level trade elasticity.

Let i denote importer, j exporter, s sector, and t year. We define the log trade and tariff factor as

$$\ln X_{ijst} = \ln\bigl(1 + 1000 \cdot \text{trade}_{ijst}\bigr), \qquad \ln \tau_{ijst} = \ln\left(1 + \text{tariff}_{ijst}\right),$$

where trade_{ijst} is trade values in millions of dollars and tariff_{ijst} is the tariff rate, e.g., a 20 percent tariff is $\text{tariff} = 0.2$. We construct horizon-h long differences for $h \in \{0, 5, 10\}$ as

$$\Delta_h \ln X_{ijst} = \ln X_{ijs,t+h} - \ln X_{ijs,t-1}, \qquad \Delta_h \ln \tau_{ijst} = \ln \tau_{ijs,t+h} - \ln \tau_{ijs,t-1}.$$

As in Boehm et al. (2023), the long-difference variables are winsorized at the first and ninety-ninth percentiles.

Identification follows the MFN-based logic in Boehm et al. (2023), adapted to sector-level data. We define an indicator for MFN binding,

$$\text{mfn_binding}_{ijst} = \mathbf{1}\{\text{tariff}_{ijst} = \text{mfn}_{ijst}\},$$

and construct a minor-partner indicator from importer-year bilateral trade ranks. For each importer-year, partners are ranked by bilateral trade in the assembled sample. A partner is coded as minor when its rank is above the tenth percentile threshold among positive-trade partners. Minor-partner indicator are set to one for missing values.

The estimating equation in levels is

$$\ln X_{ijst} = \beta^{OLS} \ln \tau_{ijst} + \alpha_{ist} + \gamma_{jst} + \mu_{ijs} + u_{ijst},$$

with three sets of fixed effects: (1) importer×sector×year, (2) exporter×sector×year, and (3) importer×exporter×sector fixed effects. The local-projection IV equation at horizon $h \in \{0, 5, 10\}$ is

$$\Delta_h \ln X_{ijst} = \beta_h \Delta_h \ln \tau_{ijst} + \alpha_{ist} + \gamma_{jst} + \mu_{ijs} + u_{ijsth},$$

where $\Delta_h \ln \tau_{ijst}$ is instrumented with

$$Z_{ijst} = \Delta_0 \ln \tau_{ijst} \times \text{minor_partner}_{ijt} \times \text{minor_partner}_{ij,t-1} \times \text{mfn_binding}_{ijst} \times \text{mfn_binding}_{ijs,t-1}.$$

The reported elasticity is $\varepsilon_h = -\beta_h$, interpreted as $(\sigma - 1)$ in the output table. Relative to (2023), the key differences are as follows. We use the tariff panel from (2024) rather than TRAINS, we estimate the trade elasticity using trade flow data aggregated at the sector level rather than the HS4 product-country level, and we implement horizons of 0, 5, and 10 years in this specification.

A.2 Carbon Accounting

Our data reports CO_2 flows in the form of "direct emissions," which correspond to where these emissions are generated by burning the carbon content of fuels. As such, our data does not directly report the CO_2 content of primary energy goods, which we are required to specify supply-side carbon taxes. To address this, we have developed an algorithm that uses global value chain input-output data to trace CO_2 flows from "direct emissions" back to each primary energy source (coal, crude oil, and natural gas) by each country.

We specifically use backward linkages to calculate total emissions attributable to each source of primary energy. To explain the algorithm clearly, first consider the case of a closed economy. Gross output of industry k equals intermediate input purchases from all industries $1, ..., K$ and value added payment:

$$Y_k = Y_1 b_{1k} + ... + Y_K b_{Kk} + V_k,$$

where V_k is the valued added in industry k and $b_{sk} = \frac{X_{sk}}{Y_k}$ represents how much industry k purchases intermediate inputs from industry s (X_{sk}) relative to industry k's total output (Y_k)—the fraction of industry k's output that is sourced as input from industry s. In matrix format:

$$\begin{bmatrix} Y_1 & \cdots & Y_K \end{bmatrix} = \begin{bmatrix} Y_1 & \cdots & Y_K \end{bmatrix} \begin{bmatrix} b_{11} & \cdots & b_{1K} \\ \vdots & \ddots & \vdots \\ b_{K1} & \cdots & b_{KK} \end{bmatrix} + \begin{bmatrix} V_1 & \cdots & V_K \end{bmatrix}$$

Or more compactly:

$$\boldsymbol{Y}^\top = \boldsymbol{Y}^\top \boldsymbol{b} + \boldsymbol{V}^\top$$

Hence, the gross output can be calculated from the vector of value added in the following way:

$$\boldsymbol{Y}^\top = \boldsymbol{V}^\top \boldsymbol{G}, \qquad \boldsymbol{G} \equiv (I - \boldsymbol{b})^{-1}$$

where $\boldsymbol{G}$ is referred to in the literature as the inverse "Ghosh matrix" that summarizes backward linkages, namely output allocation coefficients.[34] Next, let V_k^R represent the value added associated with carbon reserves in each industry k, meaning V_k^R is positive only for primary energy industries and zero otherwise. Let $\boldsymbol{V}^R \equiv [V_k^R]$ stack these values. Using the inverse Ghosh matrix, we can now calculate the fraction of the output in each industry that originates from the value added associated with carbon reserves in primary energy industries:

$$\left(\boldsymbol{Y}^R\right)^\top = \left(\boldsymbol{V}^R\right)^\top \boldsymbol{G}$$

From here, total CO_2 emissions attributable to each primary energy industry can be calculated as:

$$Z_s^R = \mu_s^R \times V_s^R, \qquad \mu_s^R = \sum_k G_{sk} \frac{Z_k}{Y_k^R}$$

where Z_k denotes direct emissions in industry k and μ_s^R represents total CO_2 emissions intensity of each primary energy industry. Note that, by construction, Z_s^R is positive only for primary energy industries and zero otherwise. This algorithm preserves the accounting of CO_2 emissions, that is, total emissions assigned to primary energy equals total direct emissions: $\sum Z_s^R = \sum Z_s$.

The same logic extends to the open economy case. Here, each country-industry pair is treated analogously to each industry in the closed economy. The allocation coefficients are now defined as $b_{is,jk} = \frac{X_{is,jk}}{Y_{jk}}$, represents the share of total output from country j, industry k that is purchased as input by country i, industry s. The gross output, value added, and Ghosh matrix are all expanded to account for the country dimension, resulting in a global input-output matrix of backward linkages. The algorithm then traces the value added from primary energy industries in all countries through the global production network, allowing us to attribute CO_2 emissions to the original sources of primary energy by country.

Cross checking with external data. The above calculations have the advantage of delivering an exact carbon accounting, ensuring that the value of global demand-side emissions ($\sum_{i,k} Z_{i,k}$) equals that of supply-side emissions, ($\sum_{i,k} Z_{i,k}^R$). We now compare this with external sources of data on CO_2 emissions of primary energy sources.

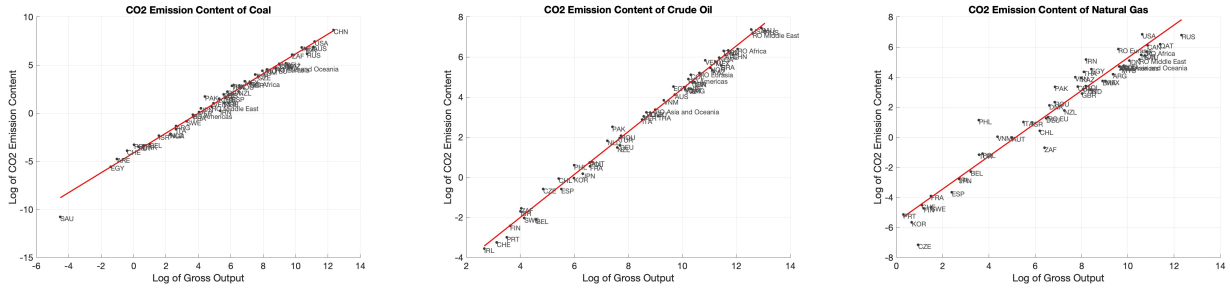
According to the U.S. Energy Information Administration (EIA), CO_2 emissions content of coal, crude oil, and natural gas were 16.4, 11.7 and 6.8 billion tCO_2 in 2014 (the year in our sample). To start, note that these values sum up to 34.9 billion tCO_2 while our data, (directly taken from the GTAP database) sets the level of worldwide CO_2 emissions from fossil fuels at 30.3 billion tCO_2. We, therefore, normalize the EIA data to the global level of CO_2 emissions in our data—equivalently, we compare our results with the EIA data based on *shares* from global emissions. With this point in mind, coal, crude oil, and natural gas

[34] In contrast, the inverse Leontief matrix represents forward linkages, namely input coefficient allocations.

accounted for 47.0%, 33.6%, and 19.4% of total CO_2 emissions. Based on our calibration, these shares at the aggregate of the world are 41.4%, 39.4% and 19.2%, which are slightly lower for coal, slightly higher for crude oil, and about the same for natural gas.

Another advantage of our method is that it delivers CO_2 emissions content of primary energy by source country (rather than only at the level of the world). Figures A.1 shows these values across countries against their gross output for coal, crude oil, and natural gas. As expected, the carbon content within each primary energy across countries appears to be proportional to the gross output. There is, however, notable that there are small variations around the fitted lines reflecting a limited degree of heterogeneity in the carbon intensity within each primary energy across various countries.

Figure A.1: CO_2 emissions content of primary energy by source country



Note: This figure shows CO_2 emissions content of primary energy against their gross output across countries. CO_2 emissions are calculated based on direct emissions from the GTAP database and the author's carbon accounting in tracing them back to their primary energy source using input-output data from the GTAP database.

A.3 Complementary Material for Government Valuation of Climate Change in Policy Objective

A.3.1 Data and Calibration of Fossil Fuel Taxes

For taxes on fossil fuel, we rely on data from the OECD's Environmentally-related Tax Revenues, which reports, for each country, the amount of tax revenue collected from four categories: Energy, Pollution, Resources, and Transport. We use the aggregate measure over these categories because countries differ in how they tax fossil fuels, often relying on one or a combination of these categories. On average, the Energy category accounts for 57% of revenues, Transport for 33%, Resources for 6%, and Pollution for the remaining 4%. We use these data for the year 2014, which is the year of the data used for the baseline calibration of the model.

Let $T_i^{(env)}$ denote the aggregate environmentally-related tax revenues in country i, and let $\boldsymbol{t}_i \equiv [t_{i,kg}^{(I)}, t_{i,k}^{(H)}]$ stack country i's ad valorem energy tax rates for each energy good k across all industries indexed by g ($t_{i,kg}^{(I)}$) and the representative household in country i ($t_{i,k}^{(H)}$). We do not have comprehensive data on these taxes by energy type, but since such taxes are typically levied on fossil fuel utility bills, we allow for non-zero energy tax rates only for Natural Gas, Refined Petroleum, and Gas Manufacturing & Distribution, and set the tax rates to zero for all other energy goods. In addition, we assume that these energy tax rates

are proportional to their emissions intensity:

$$t_{i,kg}^{(I)} = x_i v_{i,kg}^{(I)}, \qquad t_{i,k}^{(H)} = x_i v_{i,k}^{(H)}$$

where x_i is a country-level "as if" tax on each unit of emissions and $v_{i,kg}^{(I)}$ and $v_{i,k}^{(H)}$ are the emissions intensities of each energy good k when used in each industry g or by households. We calibrate the non-zero rates in $\boldsymbol{t}_i$ such that the baseline general equilibrium of the model exactly matches the ratio of the environmentally-related tax revenues to GDP in each country, $T_i^{(rev)}/Y_i$. This calibration problem can be recasted as a non-linear (general equilibrium) system where the problem is to solve for N unknown x_i values for $i = 1, ..., N$, given N observed moments, $T_i^{(rev)}/Y_i$, for $i = 1, ..., N$.

A.3.2 Carbon Prices

We use carbon pricing data from the OECD's Net Effective Carbon Rates dataset. We extract two measures of explicit carbon pricing, both reported in euros per tonne of CO_2-equivalent: the carbon tax (CARBTAX) and the emissions trading system permit price (MPERPRI). A key advantage of this dataset is that both measures are reported as average prices relative to economy-wide CO_2-equivalent emissions, which allows us to aggregate them into a single economy-wide measure of explicit carbon pricing. Accordingly, for each country-year we convert both series to USD per tonne of CO_2-equivalent and sum them to obtain our "carbon price" measure. The most recent available data are for 2023, which we use for calibration.

A.3.3 Calibration of Government Valuation of Climate Change in Policy Objective

As noted in the main text, we specify the objective function of country i's government as:

$$W_i^{\text{(gov)}} = C_i - \delta_i^{\text{(local)}} Z_i - \delta_i^{\text{(global)}} Z^{\text{(global)}}.$$

Here, the disutility from local emissions, $\delta_i^{\text{(local)}} Z_i$, is a shorthand for non-climate damages in government's evaluation, such as adverse local health effects from air pollutants co-emitted with CO_2 emissions. The disutility from global emissions, $\delta_i^{\text{(global)}} Z^{\text{(global)}}$, is the climate damage cost from global CO_2 emissions.

In the first step of our calibration, we recover $\delta_i^{\text{(local)}}$ from energy taxes in 2014 when carbon pricing was virtually absent everywhere. We specifically assume that in 2014, $\delta_i^{\text{(global)}}$ is zero everywhere, meaning that countries have not yet included climate concerns into their objective function. This assumption allows us to pin down $\delta_i^{\text{(local)}}$ from 2014 energy tax data.

In the spirit of revealed preferences of governments, we want observed energy taxes for each country i, $\boldsymbol{t}_i \equiv [t_{i,kg}^{(I)}, t_{i,k}^{(H)}]$, to be optimal when country i's take other countries' policies as given:

$$\boldsymbol{t}_i^* \left(\delta_i^{\text{(local)}}\right) = \arg\max_{\boldsymbol{t}_i} \; C_i - \delta_i^{\text{(local)}} Z_i$$

Since our focus is on carbon pricing policies, we verify optimality by checking only deviations from observed energy taxes that are implied by introducing a uniform carbon price within country i. Specifi-

cally, we seek $\delta_i^{\text{(local)}}$ such that any perturbation $\boldsymbol{t}_i + \Delta\boldsymbol{t}_i$, where $\Delta\boldsymbol{t}_i$ is induced by introducing a positive or negative uniform carbon price, lowers the value of the objective function. Without this constraint, one would need to check the optimality for each element of the vector of taxes—each type of fuel and each end-user in a country. Introducing this constraint simplifies the multi-dimensional problem while focusing on carbon pricing as the policy instrument we focus on.

Our numerical algorithm to find $\delta_i^{\text{(local)}}$ is as follows. We first compute general equilibrium outcomes under energy tax perturbations. We consider a grid of hypothetical uniform carbon prices x_i ranging from -30.0 to +30.0 USD per tonne of CO_2 in increments of 0.1, yielding 601 values. For each x_i, we compute the implied energy tax change $\Delta\boldsymbol{t}_i(x_i)$ and solve for the resulting general equilibrium values $C_i(x_i)$ and $Z_i(x_i)$.

We then find the welfare-maximizing carbon price for each candidate $\delta_i^{\text{(local)}}$. We discretize $\delta_i^{\text{(local)}}$ over a grid from -200 to 200 with step size 0.1. For each candidate value of $\delta_i^{\text{(local)}}$, we evaluate the objective function $C_i(x_i) - \delta_i^{\text{(local)}} Z_i(x_i)$ across all 601 carbon price perturbations and identify the value $x_i^*\left(\delta_i^{\text{(local)}}\right)$ that maximizes this objective.

We next identify the $\delta_i^{\text{(local)}}$ that rationalizes observed taxes. We seek the value of $\delta_i^{\text{(local)}}$ for which $x_i^*\left(\delta_i^{\text{(local)}}\right) = 0$, meaning that the existing energy tax structure (corresponding to $x_i = 0$) is optimal. This procedure typically yields a unique $\delta_i^{\text{(local)}}$, but the discrete grid occasionally produces multiple neighboring values that satisfy this condition. In such cases, we take the average of the smallest and largest qualifying values.

Lastly, for some countries, there is no value of $\delta_i^{\text{(local)}}$ in our grid for which $x_i^*\left(\delta_i^{\text{(local)}}\right) = 0$—that is, no value that rationalizes observed energy taxes as an unconstrained interior optimum. In these cases, we identify all values of $\delta_i^{\text{(local)}}$ for which the objective function $C_i(x_i) - \delta_i^{\text{(local)}} Z_i(x_i)$ is downward sloping at $x_i = 0$. At such values, introducing a positive carbon price would decrease welfare. Among these values, we select the largest $\delta_i^{\text{(local)}}$, which represents an upper bound on the government's valuation of local damages, given the constraint that deviations from observed taxes are restricted to those implied by introducing a positive carbon price. This choice is motivated by two considerations: first, since our subsequent policy analysis focuses on introducing carbon taxes (i.e., positive carbon prices), this corner solution ensures that remaining at current tax levels maximizes welfare under that constraint; second, while arbitrarily negative values of $\delta_i^{\text{(local)}}$ would also satisfy this condition mechanically, the largest qualifying value provides a plausible calibration of government preferences.

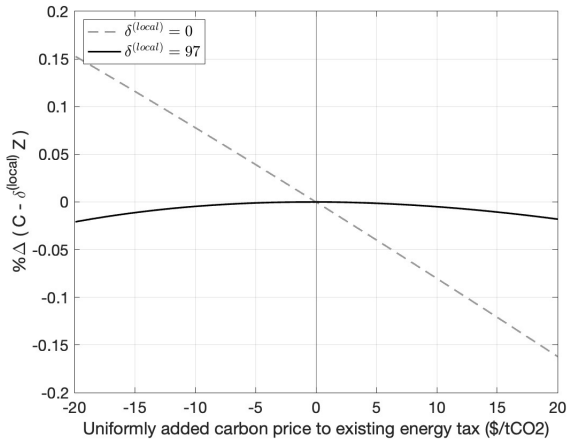
Our numerical algorithm to recover $\delta_i^{\text{(global)}}$ proceeds similarly to the first step but now takes the calibrated values of $\delta_i^{\text{(local)}}$ as given. In this step, we suppose that each country draws a value of $\delta_i^{\text{(global)}}$ that represents its commitment to combating climate change. Let p_i denote the carbon price in country i, which was zero in 2014 but it is now updated to the observed values in 2023 as countries developed concern for climate change.

Here, we first compute general equilibrium outcomes under different carbon pricing scenarios. For each country i, we consider a grid of carbon prices p_i ranging from $p_i^{(observed)} - 20$ to $p_i^{(observed)} + 20$ (per tonne of CO_2) in increments of 0.1, yielding 401 values. For each p_i, we solve for the resulting general equilibrium values $C_i(p_i)$, $Z_i(p_i)$, and $Z^{\text{(global)}}(p_i)$, where the latter reflects changes in global emissions resulting from country i's carbon pricing policy.

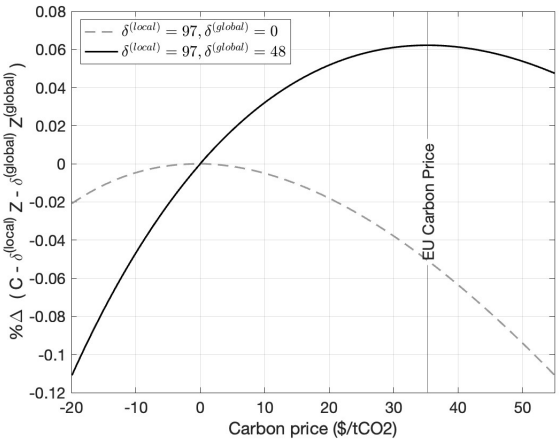
We then find the welfare-maximizing carbon price for each candidate $\delta_i^{\text{(global)}}$. We discretize $\delta_i^{\text{(global)}}$

Figure A.2: Calibration of Emission Disutility Parameters (The EU)

(a) Local Emission Disutility



(b) Global Emission Disutility



over a grid from -200 to 200 with step size 0.1. For each candidate value of $\delta_i^{(\text{global})}$, we evaluate the objective function $C_i(p_i) - \delta_i^{(\text{local})} Z_i(p_i) - \delta_i^{(\text{global})} Z^{(\text{global})}(p_i)$ across all 401 carbon price values and identify the value $p_i^*\left(\delta_i^{(\text{global})}\right)$ that maximizes this objective.

Finally, we identify the $\delta_i^{(\text{global})}$ that rationalizes observed 2023 carbon prices. We seek the value of $\delta_i^{(\text{global})}$ for which $p_i^*\left(\delta_i^{(\text{global})}\right)$ matches the observed carbon price in country i in 2023. This procedure typically yields a unique $\delta_i^{(\text{global})}$, though when the discrete grid produces multiple neighboring values satisfying this condition, we take the average of the smallest and largest qualifying values. Countries identified as corner solutions in the first step all have zero or very small carbon prices in 2023, and we set $\delta_i^{(\text{global})} = 0$ for them. Apart from these countries, New Zealand is the only country in our sample for which no $\delta_i^{(\text{global})}$ rationalizes its observed carbon policy as an optimum. For New Zealand, we instead calibrate $\delta_i^{(\text{global})}$ by considering $C_i(p_i) - \delta_i^{(\text{local})} Z_i(p_i) - \delta_i^{(\text{global})} Z^{(\text{local})}(p_i)$ as their objective function, as if they do not internalize the impact of their policy on global emissions. This approach effectively treats New Zealand as not internalizing the general equilibrium effects of its carbon pricing on other countries' emissions.

To explain how the above procedure works, consider Figure A.2 that illustrates our two-stage calibration for the European Union. Panel *A* shows that when $\delta_i^{(\text{local})} = 97$, the objective function is maximized at zero additional carbon price, indicating that existing 2014 energy taxes optimally internalize local co-pollutant damages. Panel *B* shows that when we incorporate global climate damages at $\delta_i^{(\text{global})} = 48$, the welfare function peaks at a carbon price of \$35/tCO$_2$ – corresponding to the observed 2023 EU carbon price (measured at the economy-wide level). Together, these panels show that the EU's energy policy can be rationalized as reflecting local damage costs of \$97/tCO$_2$ (embedded in energy taxes) and global climate damage costs of \$48/tCO$_2$ (reflected in carbon pricing), where both disutility parameters are measured in carbon-price-equivalent units.

Table A.1 presents the calibrated emission disutility parameters for all countries and regions in our sample, alongside the underlying energy tax and carbon pricing data. Column (1) reports the ad valorem

fossil fuel tax rate in 2014. Column (2) converts these tax rates into an implied carbon price ($/tCO$_2$) based on the carbon content of each fuel, providing a carbon-price-equivalent measure of 2014 energy taxation. Column (3) shows the explicit carbon price implemented in each country by 2023, reflecting the adoption of explicit carbon pricing policies over this period. Columns (4) and (5) report our calibrated parameters: $\delta^{(\text{local})}$ represents the government's valuation of local co-pollutant damages, inferred from 2014 energy taxes, and $\delta^{(\text{global})}$ represents the government's valuation of global climate damages, inferred from 2023 carbon prices. Both parameters are expressed in carbon-price-equivalent units to facilitate interpretation and comparison.

A.3.4 Complementary Material for Calibrating Country-specific Climate Change Damage

We model climate damages using the reduced-form specification in Shapiro (2021). Country i's utility is proportional to real consumption net of climate damages:

$$U_i \;=\; C_i\,\Delta_i\left(Z^{(global)}\right), \qquad \Delta_i(Z) = \left[1+\mu_i\,(Z-Z_0)\right]^{-1}$$

Here Z denotes global emissions in the equilibrium of interest and Z_0 is the reference (baseline) level of global emissions. The parameter μ_i governs how strongly country i is affected by changes in global emissions around the baseline.

To calibrate μ_i, we match the country-level social cost of carbon (CSCC). Differentiating U_i with respect to global emissions and evaluating at the baseline $Z = Z_0$ yields the marginal climate damage for country i in utility units:

$$-\frac{\partial U_i}{\partial Z}\bigg|_{Z=Z_0} = C_i \cdot \frac{\mu_i}{(1+\mu_i)^2}$$

We convert this marginal damage into units of real consumption by dividing by the marginal utility of consumption, which in our model is proportional to the country price index P_i. Define δ_i as the marginal damage in units of real consumption:

$$\delta_i \equiv C_i \cdot \frac{\mu_i}{(1+\mu_i)^2}$$

The implied country-level social cost of carbon is then

$$\text{CSCC}_i \;=\; P_i\,\delta_i.$$

Using $E_i \equiv V_i P_i$ for country i's national expenditure, this relationship can be written compactly as

$$\text{CSCC}_i \;=\; E_i \cdot \frac{\mu_i}{(1+\mu_i)^2}$$

We now solve for μ_i given observed national expenditure, E_i, and the estimates of CSCC$_i$ taken from Ricke et al. (2018). For countries with CSCC$_i > 0$, the calibration chooses μ_i to satisfy

$$\frac{\mu_i}{(1+\mu_i)^2} = \frac{\text{CSCC}_i}{E_i}$$

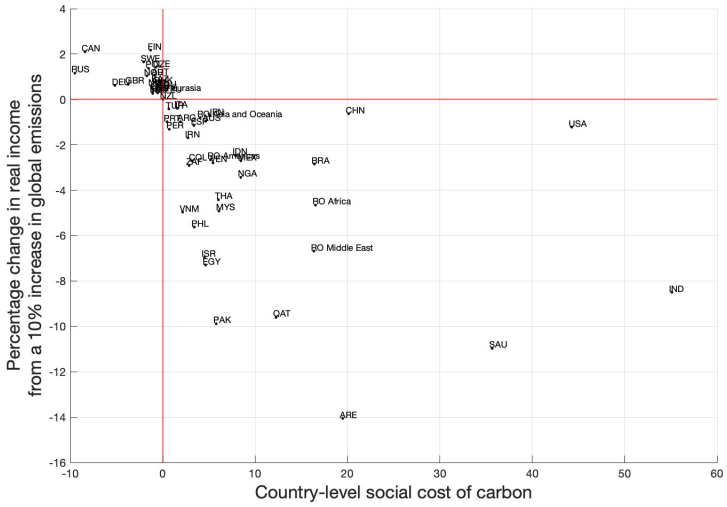
which is equivalent to the quadratic equation

$$\lambda_i \mu_i^2 + \left(2 \times \frac{\text{CSCC}_i}{E_i} - 1\right) \mu_i + \frac{\text{CSCC}_i}{E_i} = 0.$$

This equation generally admits two real roots. We select the root consistent with the branch where marginal damages are increasing in μ_i. This corresponds to choosing the smaller root if $\text{CSCC}_i \geq 0$ and the largest root if $\text{CSCC}_i < 0$.

Figure A.3 reports the calibration results, which are easier to interpret in terms of the implied climate costs. Specifically, using the calibrated μ_i, the figure plots the percentage change in real income resulting from a 10% increase in global emissions, $100 \times \left(\left[1 + \mu_i \times 0.1 \times Z_0^{(global)}\right]^{-1} - 1\right)$, against each country's social costs of carbon, CSCC_i. The income loss varies between -2.2 for Russia (that gains from increases in emissions) to 13.9% for the UAE, with an average of 2.0% across countries in the sample.

Figure A.3: Climate damage costs versus country-level social cost of carbon



Note: This figure shows the

B Proofs and Derivations

Changes in Aggregate Price Indexes

Recall from Section 3, the expression for the price index of the industry k composite:

$$\hat{\tilde{P}}_{i,k} = \hat{\tau}_{i,k}\, \hat{w}_i^{\left(\alpha_{i,k}^L + \alpha_{i,k}^R\right)} \hat{\ell}_{i,k}^{\alpha_{i,k}^R} \hat{\lambda}_{ii,k}^{\frac{1}{1-\sigma_k}} \prod_{g \in \mathbb{G}} \hat{\tilde{P}}_{i,g}^{\alpha_{i,gk}^I}.$$

Taking logs from the above equation and writing it in vector notation, yields

$$\ln \hat{\tilde{\boldsymbol{P}}}_i = \ln \hat{\boldsymbol{\tau}}_i + (\mathbf{I} - \mathbf{A}_i)\, \mathbf{1} \ln w_i + \mathbf{B}_i + \mathbf{A}_i \ln \hat{\tilde{\boldsymbol{P}}}_i$$

where $\mathbf{A}_i = \left[\alpha^I_{i,gk}\right]_{k,g}$ is the $K \times K$ input-output matrix; $\mathbf{B}_i \equiv \left[\alpha^R_{i,k} \ln \hat{\ell}_{i,k} + \frac{1}{1-\sigma_k} \ln \lambda_{ii,k}\right]_k$ is a $K \times 1$ vector; and $\mathbf{1}$ and $\mathbf{I}$ are respectively $K \times 1$ column vector of ones and the $K \times K$ identity matrix. Inverting the above equation, delivers:

$$\ln \hat{\tilde{\boldsymbol{P}}}_i = \mathbf{1} \ln w_i + (\mathbf{I} - \mathbf{A}_i)^{-1} \left[\ln \hat{\boldsymbol{\tau}}_i + \mathbf{B}_i\right]$$

Letting $a_{i,gk}$ denotes the entry (k, g) of the inverse Leontief matrix, the above equation delivers the following expression for the change in the industry-level price index:

$$\hat{\tilde{P}}_{i,k} = \hat{w}_i \times \prod_{g \in \mathbb{G}} \left(\hat{\lambda}_{ii,g}^{\frac{a_{i,gk}}{1-\sigma_g}}\right) \times \prod_{k' \in \mathbb{E}} \left(\hat{\tau}_{i,k'}^{a_{i,k'k}}\right) \times \prod_{k' \in \mathbb{E}_1} \left(\hat{\ell}_{i,k'}^{\alpha^R_{i,k'} a_{i,k'k}}\right)$$

Change in Industrial Emissions. To characterize the change in industrial emissions, $\hat{Z}^{(I)}_{i,gk}$, we appeal to the proportionality condition, $Z_{i,gk} = v_{i,gk} C_{i,gk}$, which links emissions for each energy transaction to the quantity of energy inputs, where the conversion factor, $v_{i,gk}$, is an engineering constant. Considering the Cobb-Douglas production function with country and industry-specific weights, we can specify the unit input cost as

$$c_{i,k} = w_i^{\alpha^L_{i,k}} r_{i,k}^{\alpha^R_{i,k}} \prod_{g \in \mathbb{G}} \left(\tilde{P}_{i,g}^{\alpha^I_{i,gk}}\right),$$

Note that the share of reserves in production is only non-zero in primary energy sectors and zero otherwise, i.e., $\alpha^R_{i,k} > 0$ if $k \in \mathbb{E}_1$ and $\alpha^R_{i,k} = 0$ for all $k \notin \mathbb{E}_1$. The intermediate input price index, $\tilde{P}_{i,g} = \left(1 + t^{(I)}_{i,g}\right) P_{i,g}$, is the after-tax price of input bundle g, where the tax $t^{(c)}_{i,g}$ is revised only for energy inputs ($g \in \mathbb{E}$). Base on cost minimization,

$$Z^{(I)}_{i,gk} = v^{(I)}_{i,gk} C^{(I)}_{i,gk} = v_{i,gk} \frac{\alpha^{(I)}_{i,gk}}{\tilde{P}_{i,g}} \frac{w_i \ell_{i,k} L_i}{\alpha^{(L)}_{i,k}}.$$

Given the constancy of $v^{(I)}_{i,gk}$, $\alpha^{(I)}_{i,gk}$, $\alpha^{(L)}_{i,k}$, and L_i, we can use the above equation to specify he change in industrial emissions as

$$\hat{Z}^{(I)}_{i,gk} = \hat{C}^{(I)}_{i,gk} = \hat{\ell}_{i,k} \left(\frac{\hat{\tilde{P}}_{i,g}}{\hat{w}_i}\right)^{-1}, \qquad (\forall g \in \mathbb{E},\ k \in \mathbb{K})$$

The above equation equates the change in emissions associated with energy use in a given industry with the changes in the relative price of energy to labor inputs, $\hat{\tilde{P}}_{i,g}/\hat{w}_i$, and the change in employment $\hat{\ell}_{i,k}$.

Next, we must characterize the change in the relative price of labor-to-energy in terms of changes in observable share variables. Invoking the constant elasticity import demand system, $\lambda_{ii,g} = \left((1 + t^{(Q)}_{i,g}) P_{ii,g}/P_{i,g}\right)^{1-\sigma_k}$, we can write the change in the after-tax price $\tilde{P}_{i,k} = (1 + t^{(I)}_{i,k}) P_{i,k}$ of the energy composite as

$$\hat{\tilde{P}}_{i,g} = \hat{\tau}^{(Q)}_{i,g}\, \hat{\tau}^{(C)}_{i,g}\, \hat{P}_{ii,g} \hat{\lambda}_{ii,g}^{\frac{1}{1-\sigma_g}}$$

Considering our parametric specification for $c_{i,k}$, the change in the producer price of the variety (i, i, k)

in response to the policy shocks is

$$\begin{aligned}\hat{P}_{ii,k} = \hat{c}_{i,k} &= \hat{w}_i^{\alpha^L_{i,k}}\, \hat{r}_i^{\alpha^R_{i,k}} \prod_{g\in\mathbb{G}} \hat{\tilde{P}}_{i,g}^{\alpha^I_{i,gk}} \\ &= \hat{w}_i^{\left(\alpha^L_{i,k}+\alpha^R_{i,k}\right)}\, \hat{\ell}_{i,k}^{\alpha^R_{i,k}} \prod_{g\in\mathbb{G}} \hat{\tilde{P}}_{i,g}^{\alpha^I_{i,gk}},\end{aligned}$$

where the last line follows from cost minimization, whereby $r_{i,k}R_{i,k} = \alpha^R_{i,k} w_i \ell_{i,k} L_i / \alpha^L_{i,k}$, which yields $\hat{r}_{i,k} = \hat{w}_i \hat{\ell}_{i,k}$ given the constancy of $\alpha^R_{i,k}$,$\alpha^L_{i,k}$, and $R_{i,k}$. To make the notation more compact, we integrate the carbon policy change, which channels through changes to energy-specific consumption and supply-side taxes as

$$\hat{\tau}_{i,k} \equiv \hat{\tau}^{(Q)}_{i,g}\, \hat{\tau}^{(C)}_{i,g}$$

Appealing to the expression for $\hat{P}_{ii,k}$ and using the compact notation for energy taxes, we can specify the change in the after-tax price of composite energy input $k \in \mathbb{E}$ as

$$\hat{\tilde{P}}_{i,k} = \hat{\tau}_{i,k}\, \hat{w}_i^{\left(\alpha^L_{i,k}+\alpha^R_{i,k}\right)} \hat{\ell}_i^{\alpha^R_{i,k}}\, \hat{\lambda}_{ii,k}^{\frac{1}{1-\sigma_k}} \prod_{g\in\mathbb{G}} \hat{\tilde{P}}_{i,g}^{\alpha^I_{i,gk}}\,.$$

The system of equations specified above implicitly determines $\left\{\hat{\tilde{P}}_{i,k}\right\}_k$ in terms of $\left\{\hat{w}_i, \hat{r}_i, \hat{\tau}_{i,k}, \hat{\ell}_{i,k}, \hat{\lambda}_{ii,k}\right\}$. Inverting this system and performing some algebraic simplifications yields

$$\hat{\tilde{P}}_{i,k} = \hat{w}_i \times \prod_{g\in\mathbb{G}} \left(\hat{\lambda}_{ii,g}^{\frac{a_{i,gk}}{1-\sigma_g}}\right) \times \prod_{k'\in\mathbb{E}} \left(\hat{\tau}_{i,k'}^{a_{i,k'k}}\right) \times \prod_{k'\in\mathbb{E}_1} \left(\hat{\ell}_{i,k'}^{\alpha^R_{i,k'} a_{i,k'k}}\right)$$

Rearranging the above equation specified the $\hat{\tilde{P}}_{i,k}/w_i$ for each energy variety, which when plugged back into our initial expression for $\hat{Z}^{(I)}_{i,gk}$, yields

$$\hat{Z}^{(I)}_{i,gk} = \hat{\ell}_{i,k} \times \underbrace{\prod_{k\in\mathbb{G}} \left(\hat{\lambda}_{ii,k}^{\frac{a_{i,kg}}{1-\sigma_k}}\right)}_{\text{trade-related effects}} \times \overbrace{\underbrace{\prod_{k'\in\mathbb{E}} \left(\hat{\tau}_{i,k'}^{-a_{i,k'g}}\right)}_{\text{carbon policy}} \times \underbrace{\prod_{k'\in\mathbb{E}_1} \hat{\ell}_{i,k'}^{-\alpha^R_{i,k'} a_{i,k'g}}}_{\text{extraction price}}}^{\text{domestic economy adjsutments}} \qquad (\forall g \in \mathbb{E}) \qquad \textbf{(B.1)}$$

To give intuition, the term labelled as "trade-related effects" encompasses the information about how trade impacts the relative price of labor-to-energy inputs via the domestic expenditure shares. The remaining three terms represent adjustments to domestic variables. All these effects are adjusted by the role of input-output linkages. Also note that since energy production uses non-energy inputs, adjustment to non-energy prices influence the price of energy inputs.

Changes in Income to Wage Ratio

Total income in country i is the sun of primary factor rewards and energy tax revenues. Namely,

$$Y_i = w_i L_i + \sum_k r_{i,k} R_{i,k} + \sum_k \left[(\tau_{i,k}^{(Q)} - 1) P_{ii,k} Q_{i,k} \right] + \sum_k \frac{\tau_{i,k}^{(C)} - 1}{\tau_{i,k}^{(C)}} \left[\beta_{i,k} Y_i + \sum_g \alpha_{i,kg}^I P_{ii,g} Q_{i,g} \right]$$

Rearranging the above equation yields

$$Y_i = \frac{w_i L_i + \sum_k r_{i,k} R_{i,k} + \sum_k \left[(\tau_{i,k}^{(Q)} - 1) P_{ii,k} Q_{i,k} \right] + \left[\sum_k \frac{\tau_{i,k}^{(C)} - 1}{\tau_{i,k}^{(C)}} \sum_g \alpha_{i,kg}^I P_{ii,g} Q_{i,g} \right]}{1 - \sum_k \frac{\tau_{i,k}^{(C)} - 1}{\tau_{i,k}^{(C)}} \beta_{i,k}}$$

Next we specify industry-wide sales in terms of wage payments, by noting that

$$r_{i,k} R_{i,k} = \frac{\alpha_{i,k}^R}{\alpha_{i,k}^L} w_i \ell_{i,k} L_i, \qquad P_{ii,k} Q_{i,k} = \frac{1}{\alpha_{i,k}^L} w_i \ell_{i,k} L_i.$$

Based on the above equation, we can express the payments to energy reserves as

$$\sum_k r_{i,k} R_{i,k} = \sum_k \left[\frac{\alpha_{i,k}^R}{\alpha_{i,k}^L} \ell_{i,k} \right] w_i L_i$$

and the energy tax income as

$$\begin{aligned} \sum_k \left[(\tau_{i,k}^{(Q)} - 1) P_{ii,k} Q_{i,k} \right] + \left[\sum_k \frac{\tau_{i,k}^{(C)} - 1}{\tau_{i,k}^{(C)}} \sum_g \alpha_{i,kg}^I P_{ii,g} Q_{i,g} \right] \\ = \left(\sum_k \left[(\tau_{i,k}^{(Q)} - 1) \frac{\ell_{i,k}}{\alpha_{i,k}^L} \right] + \left[\sum_k \frac{\tau_{i,k}^{(C)} - 1}{\tau_{i,k}^{(C)}} \sum_g \alpha_{i,kg}^I \frac{\ell_{i,g}}{\alpha_{i,g}^L} \right] \right) w_i L_i. \end{aligned}$$

Plugging the above equations back into our last expression for Y_i yields

$$Y_i = \frac{1 + \sum_k \left[\frac{\alpha_{i,k}^R}{\alpha_{i,k}^L} \ell_{i,k} + (\tau_{i,k}^{(Q)} - 1) \frac{\ell_{i,k}}{\alpha_{i,k}^L} + \frac{\tau_{i,k}^{(C)} - 1}{\tau_{i,k}^{(C)}} \sum_g \alpha_{i,kg}^I \frac{\ell_{i,g}}{\alpha_{i,g}^L} \right]}{1 - \sum_k \frac{\tau_{i,k}^{(C)} - 1}{\tau_{i,k}^{(C)}} \beta_{i,k}} w_i L_i,$$

which immediately implies the expression for the income to wage ration presented in the main text:

$$\kappa_i \equiv \frac{Y_i}{w_i L_i} = \frac{1+\sum_k \left(\alpha^R_{i,k} + (\tau^{(Q)}_{i,k}-1) + \sum_g \frac{\tau^{(C)}_{i,k}-1}{\tau^{(C)}_{i,k}}\alpha^I_{i,gk}\right)\frac{\ell_{i,k}}{\alpha^L_{i,k}}}{1-\sum_k \frac{\tau^{(C)}_{i,k}-1}{\tau^{(C)}_{i,k}}\beta_{i,k}}.$$
$$= \frac{1+\sum_k \left(-\alpha^L_{i,k} + \tau^{(Q)}_{i,k} - \sum_g \frac{\alpha^I_{i,gk}}{\tau^{(C)}_{i,k}}\right)\frac{\ell_{i,k}}{\alpha^L_{i,k}}}{1-\sum_k \frac{\tau^{(C)}_{i,k}-1}{\tau^{(C)}_{i,k}}\beta_{i,k}} = \frac{\sum_k \left(\tau^{(Q)}_{i,k} - \sum_g \frac{\alpha^I_{i,gk}}{\tau^{(C)}_{i,k}}\right)\frac{\ell_{i,k}}{\alpha^L_{i,k}}}{\sum_k \frac{\beta_{i,k}}{\tau^{(C)}_{i,k}}}$$

The change in the income-to-wage ratio starting from a baseline of zero taxes, follows immediately from the fact that $\alpha^R_{i,k}$, $\alpha^L_{i,k}$, and $\beta_{i,k}$ are constant implying that

$$\kappa'_i = \frac{\sum_k \left(\tau^{(Q)}_{i,k} - \sum_g \frac{\alpha^I_{i,gk}}{\tau^{(C)}_{i,k}}\right)\frac{\ell_{i,k}\hat{\ell}_{i,k}}{\alpha^L_{i,k}}}{\sum_k \frac{\beta_{i,k}}{\tau^{(C)}_{i,k}}}, \qquad \kappa_i\,|_{\boldsymbol{\tau}=1} = 1 + \sum \frac{\alpha^R_{i,k}}{\alpha^L_{i,k}}\ell_{i,k},$$

which in turn delivers the expression for $\hat{\kappa}_i$ presented in the main text:

$$\hat{\kappa}_i \equiv \frac{\kappa'_i}{\kappa_i} = \frac{\sum_k \left(\tau^{(Q)}_{i,k} - \sum_g \frac{\alpha^I_{i,gk}}{\tau^{(C)}_{i,k}}\right)\frac{\ell_{i,k}\hat{\ell}_{i,k}}{\alpha^L_{i,k}}}{\left(1+\sum \frac{\alpha^R_{i,k}}{\alpha^L_{i,k}}\ell_{i,k}\right)\sum_k \frac{\beta_{i,k}}{\tau^{(C)}_{i,k}}}$$

Consumption Effects of Carbon Pricing Reform

Our goal is to characterize the effect of the carbon tax shock, $\left\{d\ln\tau^{(C)}_{i,k}, d\ln\tau^{(Q)}_{i,k}\right\}_k$, on real consumption $C_i = \mathrm{V}_i\left(Y_i, \tilde{\boldsymbol{P}}_i\right)$. Here, Y_i denotes income, which is the sum of factor rewards and tax revenues. In particular,

$$Y_i = \tilde{w}_i L_i + \sum_k (\tau^{(Q)}_{i,k}-1)P_{ii,k}Q_{i,k} + \sum_k (\tau^{(C)}_{i,k}-1)P_{i,k}C_{i,k} \tag{B.2}$$

where $C_{i,k} \equiv C^{(H)}_{i,k} + \sum_g C^{(I)}_{i,kg}$ and $\tilde{w}_i L_i$ is a short-hand for primary factor compensation, which includes labor and energy reserves. Taking derivatives from $C_i = \mathrm{V}_i\left(Y_i, \tilde{\boldsymbol{P}}_i\right)$, yields

$$\mathrm{d}C_i = \frac{\partial \mathrm{V}_i(.)}{\partial Y_i}\mathrm{d}Y_i + \sum_k \sum_n \frac{\partial \mathrm{V}_i(.)}{\partial \ln \tilde{P}_{ni,k}}\mathrm{dln}\tilde{P}_{ni,k},$$

Since $\tau^{(C)}_{i,k}$ is applied to all demanded goods in industry k, the change in the variety-specific price $\mathrm{dln}\tilde{P}_{ni,k}$ can be expressed as

$$\mathrm{dln}\tilde{P}_{ni,k} = \mathrm{d}\ln\tau^{(C)}_{i,k} + \mathrm{dln}P_{ni,k}.$$

Plugging he above equation back into the welfare expression, delivers

$$\mathrm{d}C_i = \frac{\partial \mathrm{V}_i(.)}{\partial Y_i}\mathrm{d}Y_i + \sum_k \sum_n \frac{\partial \mathrm{V}_i(.)}{\partial \ln \tilde{P}_{ni,k}}\left(\mathrm{d}\ln\tau^{(C)}_{i,k} + \mathrm{dln}P_{ni,k}\right).$$

We can invoke Roy's identity $\frac{\partial \mathrm{V}_i(.)}{\partial \tilde{P}_{ni,k}} = \frac{\partial \mathrm{V}_i(.)}{\partial Y_i} C^{(H)}_{ni,k}$ to simplify this equation as

$$\begin{aligned} \mathrm{d}C_i &= \frac{\partial \mathrm{V}_i(.)}{\partial Y_i}\left[\mathrm{d}Y_i - \sum_k \sum_n P_{ni,k} C^{(H)}_{ni,k}\left(\mathrm{d}\ln \tau^{(C)}_{i,k} + \mathrm{d}\ln P_{ni,k}\right)\right] \\ &= \frac{\partial \mathrm{V}_i(.)}{\partial Y_i}\left[\mathrm{d}Y_i - Y_i \sum_k \sum_n \beta_{i,k}\lambda_{ni,k}\left(\mathrm{d}\ln \tau^{(C)}_{i,k} + \mathrm{d}\ln \tilde{P}_{ni,k}\right)\right] \end{aligned}$$

To further simplify the above equation, we note that $\mathrm{d}\ln P_{ni,k} = \mathrm{d}\ln \tilde{P}_{ii,k} + \frac{1}{\sigma_k - 1}\left(\mathrm{d}\ln \lambda_{ni,k} - \mathrm{d}\ln \lambda_{ii,k}\right)$, and follow the ACR logic to write the above equation as

$$\mathrm{d}C_i = \frac{\partial \mathrm{V}_i(.)}{\partial Y_i}\left[\mathrm{d}Y_i - Y_i \sum_k \beta_{i,k}\left(\mathrm{d}\ln \tau^{(C)}_{i,k} + \mathrm{d}\ln \tilde{P}_{ii,k} + \frac{1}{\sigma_k - 1}\mathrm{d}\ln \lambda_{ii,k}\right)\right] \tag{B.3}$$

Noting that $\tilde{P}_{ii,k} = \tau^{(Q)}_{i,k} P_{ii,k}$, we can specify domestic price changes as as

$$\mathrm{d}\ln \tilde{P}_{ii,k} = \mathrm{d}\ln \tau^{(Q)}_{i,k} + \alpha^{(\tilde{L})}_{i,k} d\ln \tilde{w}_i + \sum_g \alpha^{(I)}_{i,gk}\tilde{P}_{i,g},$$

where $\alpha^{(\tilde{L})}_{i,k} \equiv \left[1 - \sum_g \alpha^{(I)}_{i,gk}\right]$ denotes the primary factor input share. Considering that $\tilde{P}_{i,g} = \tau^{(c)}_{i,g}\,\tilde{P}_{ii,g}\lambda^{\frac{1}{\sigma_k - 1}}_{ii,k}$ can be reformulated as

$$\mathrm{d}\ln \tilde{P}_{ii,k} = \mathrm{d}\ln \tau^{(Q)}_{i,k} + \alpha^{(\tilde{L})}_{i,k} d\ln \tilde{w}_i + \sum_g \alpha^{(I)}_{i,gk}\left(\mathrm{d}\ln \tau^{(C)}_{i,g} + \mathrm{d}\ln \tilde{P}_{ii,g} + \frac{1}{\sigma_g - 1}\mathrm{d}\ln \lambda_{ii,g}\right)$$

The above equation can be alternatively represented in vector notation as

$$\mathrm{d}\ln \tilde{\boldsymbol{P}}_{ii} = \mathrm{d}\ln \boldsymbol{\tau}^{(Q)}_i + \left(\mathbf{I} - \mathbf{A}_i\right)\mathbf{1}\mathrm{d}\ln \tilde{w}_i + \mathbf{A}_i\left(\mathrm{d}\ln \boldsymbol{\tau}^{(C)}_i + \mathrm{d}\ln \tilde{\boldsymbol{P}}_{ii} + \frac{1}{\sigma - 1} \circ \mathrm{d}\ln \boldsymbol{\lambda}_{ii}\right)$$

Inverting the above system we get

$$\mathrm{d}\ln \tilde{P}_{ii,k} = \mathrm{d}\ln \tilde{w}_i + \sum_g a_{i,kg}\mathrm{d}\ln \tau^{(Q)}_{i,g} + \sum_g \tilde{a}_{i,kg}\left[\mathrm{d}\ln \tau^{(C)}_{i,g} + \frac{1}{\sigma_g - 1} d\ln \lambda_{ii,g}\right] \tag{B.4}$$

where $a_{i,kg}$ is the element (k,g) of the inverse Leontief $\left(\mathbf{I} - \mathbf{A}_i\right)^{-1}$ and $\tilde{a}_{i,kg}$ is the element (k,g) of the matrix $\left(I - \mathbf{A}_i\right)^{-1}\mathbf{A}_i$. Noting that $\left(\mathbf{I} - \mathbf{A}_i\right)^{-1}\mathbf{A}_i = \left(\mathbf{I} - \mathbf{A}_i\right)^{-1} - \mathbf{I}$, we get

$$\tilde{a}_{i,kg} = \begin{cases} a_{i,kg} - 1 & k = g \\ a_{i,kg} & k \neq g \end{cases},$$

Considering the above equation, we can plug Equation B.4 into Equation B.3 to obtain:

$$\mathrm{d}C_i = \frac{\partial \mathrm{V}_i\left(.\right)}{\partial Y_i}\left[\mathrm{d}Y_i - Y_i\left\{\mathrm{d}\ln\tilde{w}_i + \sum_k\sum_g a_{i,kg}\beta_{i,g}\left(\mathrm{d}\ln\tau_{i,g}^{(Q)} + \mathrm{d}\ln\tau_{i,g}^{(C)} + \frac{1}{\sigma_g - 1}\mathrm{d}\ln\lambda_{ii,g}\right)\right\}\right]. \quad \text{(B.5)}$$

Next we characterize the change in income by taking derivative from Equation B.2, which delivers

$$\begin{aligned}\mathrm{d}Y_i = \tilde{w}_i L_i \mathrm{d}\ln w_i &+ \sum_{k\in\mathbb{E}}\left[\tau_{i,k}^{(Q)}P_{ii,k}Q_{i,k} + (\tau_{i,k}^{(Q)} - 1)\frac{\partial\left(P_{ii,k}Q_{i,k}\right)}{\partial\ln\tau_{i,k}^{(Q)}}\right]d\ln\tau_{i,k}^{(Q)} \\ &+ \sum_{k\in\mathbb{E}}\left[\tau_{i,k}^{(C)}P_{i,k}C_{i,k} + (\tau_{i,k}^{(C)} - 1)\frac{\partial\left(P_{i,k}C_{i,k}\right)}{\partial\ln\tau_{i,k}^{(C)}}\right]d\ln\tau_{i,k}^{(C)}\end{aligned}$$

In the neighborhood of $\boldsymbol{\tau} = 1$, the above equation simplifies to

$$\mathrm{d}Y_i\mid_{\boldsymbol{t}=0} = Y_i\mathrm{d}\ln w_i + \sum_{k\in\mathbb{E}}\left[P_{ii,k}Q_{i,k}d\ln\tau_{i,k}^{(Q)}\right] + \sum_{k\in\mathbb{E}}\left[P_{ii,k}C_{i,k}d\ln\tau_{i,k}^{(C)}\right]$$

To evaluate the above equation, we use the market clearing condition whereby total expenditure on good k equals the final demand expenditure $P_{i,k}C_{i,k}^H = \beta_{i,k}Y_i$ and the intermediate input expenditure. Namely,

$$P_{i,k}C_{i,k} = \beta_{i,k}Y_i + \sum_g \alpha_{i,kg}^{(I)}P_{ii,k}Q_{i,k}$$

In a closed economy, the sales equals expenditure per industry, $P_{ii,k}Q_{i,k} = P_{i,k}C_{i,k}$. Hence, we can write the above equation in vector notation as $\boldsymbol{P}_{ii}\circ\boldsymbol{Q}_i = \boldsymbol{\beta}_i Y_i + \mathbf{A}_i\boldsymbol{P}_{ii}\circ\boldsymbol{Q}_i$, which after basic inversion implies:

$$\frac{P_{ii,k}Q_{i,k}}{Y_i} = \frac{P_{i,k}C_{i,k}}{Y_i} = \sum_g a_{i,kg}\beta_{i,g} \qquad \text{[closed economy]}$$

The open economy counterpart of this equation can be stated as

$$P_{i,k}C_{i,k} = \beta_{i,k}Y_i + \sum_g \alpha_{i,kg}^{(I)}P_{i,k}C_{i,k} + \sum_g \alpha_{i,kg}^{(I)}\chi_{i,g}$$

where $\mathcal{X}_{i,k} \equiv P_{ii,k}Q_{i,k} - P_{i,k}C_{i,k}$ is net exports in industry k. In vector notation, $\boldsymbol{P}_i\circ\boldsymbol{C}_i = \boldsymbol{\beta}_i Y_i + \mathbf{A}_i\boldsymbol{P}_i\circ\boldsymbol{C}_i + \mathbf{A}_i\boldsymbol{X}_i$, which after inversion yields:

$$\frac{P_{i,k}C_{i,k}}{Y_i} = \sum_g a_{i,kg}\beta_{i,g} + \sum_g \tilde{a}_{i,kg}\frac{\mathcal{X}_{i,g}}{Y_i}$$

Alternatively, we can write the accounting equation as $P_{i,k}Q_{ii,k} = \chi_{i,k} + \beta_{i,k}Y_i + \sum_g \alpha_{i,kg}^{(I)}P_{ii,k}Q_{i,k}$, which after inversion delivers

$$\frac{P_{i,k}Q_{ii,k}}{Y_i} = \sum_g a_{i,kg}\beta_{i,g} + \sum_g a_{i,kg}\frac{\mathcal{X}_{i,g}}{Y_i}.$$

Plugging the expressions for $\frac{P_{i,k}C_{i,k}}{Y_i}$ and $\frac{P_{i,k}Q_{ii,k}}{Y_i}$ into the equation representing $\mathrm{d}Y_i \mid_{\boldsymbol{\tau}=1}$, we obtain:

$$\mathrm{d}Y_i \mid_{\boldsymbol{\tau}=1} = Y_i \left\{ \mathrm{d}\ln w_i + \sum_{k\in\mathbb{E}} \sum_{g} \left[\left(a_{i,kg}\beta_{i,g} + a_{i,kg}\frac{\mathcal{X}_{i,g}}{Y_i} \right) d\ln \tau_{i,k}^{(Q)} + \left(a_{i,kg}\beta_{i,g} + \tilde{a}_{i,kg}\frac{\mathcal{X}_{i,g}}{Y_i} \right) d\ln \tau_{i,k}^{(C)} \right] \right\}$$

Plugging the above expression for $\mathrm{d}Y_i$ into the Equation B.5 delivers:

$$\mathrm{d}C_i \mid_{\boldsymbol{\tau}=1} = \sum_{k\in\mathbb{E}} \sum_{g\in\mathbb{G}} \frac{\mathcal{X}_{i,g}}{Y_i} \left[a_{i,kg}\mathrm{d}\ln \tau_{i,k}^{(Q)} + \tilde{a}_{i,kg}\mathrm{d}\ln \tau_{i,k}^{(C)} \right] + \sum_{g\in\mathbb{G}} \sum_{k\in\mathbb{G}} \frac{a_{i,kg}\beta_{i,g}}{\sigma_g - 1} \mathrm{d}\ln \lambda_{ii,g}$$

C Required Transfers under Globally Optimal Carbon Pricing

Environment. Country i faces a (possibly distorted) domestic consumer price vector $\tilde{\mathbf{P}}_i \in \mathbb{R}^K_{++}$, and we write $\tilde{\mathbf{P}} = (\tilde{\mathbf{P}}_i)_{i\in\mathbb{N}}$. World producer prices are analogously $\mathbf{P}$. Global emissions are $Z \coloneqq Z^{(global)} \geq 0$. Country i's indirect utility is $V_i(E_i, \tilde{\mathbf{P}}_i)$ where E_i is nominal expenditure (income after transfers) at the domestic consumer prices $\tilde{\mathbf{P}}_i$. Welfare of i is

$$W_i \;=\; V_i(E_i, \tilde{\mathbf{P}}_i)/\Delta_i(Z), \tag{C.1}$$

where $\Delta_i : \mathbb{R}_+ \to \mathbb{R}_{++}$ is a *damage index*. The above formalization assumes separability between the indirect utility from consumption and the disutility from climate damage. It also assumes that countries have symmetric exposure proportional to real consumption, as measured by $V_i(.)$.

Pareto weights and transfers. Fix Pareto weights $(\omega_i)_{i\in\mathbb{N}}$ with $\omega_i > 0$ and $\sum_{i\in\mathbb{N}} \omega_i = 1$. Transfers are encoded by expenditure shares $\alpha = (\alpha_i)_{i\in\mathbb{N}}$ on the simplex,

$$\Lambda^N \equiv \Big\{ \alpha \in \mathbb{R}^N_+ : \sum_{i\in\mathbb{N}} \alpha_i = 1 \Big\},$$

with national expenditure levels satisfying

$$E_i \;=\; \alpha_i\, Y, \tag{C.2}$$

where Y is global income, which is the sum of factor income and tax revenues as specified below. Explicit transfers are, thus, $T_i = E_i - Y_i$, where Y_i is country i's pre-transfer income.

Policies and income. A policy consists of prices of goods including energy goods with embedded carbon $\tilde{\mathbf{P}}$ and transfers α. Global income is the factor income and tax revenues:

$$Y \;=\; \tilde{\mathbf{w}} \cdot \mathbf{L} \;+\; (\tilde{\mathbf{P}} - \mathbf{P}) \cdot \mathbf{C}, \tag{C.3}$$

Here, $\tilde{\mathbf{w}} \cdot \mathbf{L}$ denotes world factor income, $\mathbf{C} = (\mathbf{C}_i)_{i\in\mathbb{N}}$ is the vector of quantities on which goods-price wedges reflected in $\tilde{\mathbf{P}}$ are levied.

Assumptions. Throughout we impose the following regularity conditions.

A1. (*Homotheticity and Differentiability*) For each i, $V_i(\cdot, \tilde{\mathbf{P}}_i)$ is homogeneous of degree one in E_i, which entails that $V_i(E_i, \tilde{\mathbf{P}}_i) = v_i(\tilde{\mathbf{P}}_i)E_i$. Equivalently,

$$\frac{\partial \ln V_i(E_i, \tilde{\mathbf{P}}_i)}{\partial \ln E_i} = 1 \quad \text{for all } (E_i, \tilde{\mathbf{P}}_i). \tag{C.4}$$

Moreover, V_i is C^1 and strictly increasing in E_i; Δ is C^1 and strictly increasing in Z.

A3. (*Utility maximization*) For each $k \in \mathbb{K}$, Roy's identity implies

$$\frac{\partial \ln V_i(E_i, \tilde{\mathbf{P}}_i)}{\partial \tilde{P}_{i,k}} \;=\; -\frac{\partial \ln V_i(E_i, \tilde{\mathbf{P}}_i)}{\partial E_i}\, C_{ik}^{(H)}. \tag{C.5}$$

A4. (*Cost minimization*) If producers input choices follow cost minimization, Shephard's Lemma entails that the induced change in global income from a marginal change in the after-tax prices of goods or emissions $\mathscr{P} \in \tilde{\mathbf{P}}$, is

$$\frac{dY}{d\mathscr{P}} \;=\; (C_{ik} - C_{ik}^{(I)})\mathbb{1}_{\mathscr{P}=\tilde{P}_{i,k}} \;+\; (\tilde{\mathbf{P}} - \mathbf{P}) \cdot \frac{d\mathbf{C}}{d\mathscr{P}},$$

where $C_{ik} - C_{ik}^{(I)} = C_{ik}^{(H)}$ by construction.

A5. (*Rank condition*) The Jacobian $D_{\tilde{\mathbf{P}}}\mathbf{C}$ has full rank at the optimum.

Eisenberg–Gale program. The globally efficient allocation (for Pareto weights ω) solves the reduced-form Eisenberg–Gale objective

$$\max_{\tilde{\mathbf{P}},\, \alpha \in \Lambda^N} \sum_{i \in \mathbb{N}} \omega_i \ln W_i \;=\; \sum_{i \in \mathbb{N}} \omega_i \ln V_i(E_i, \tilde{\mathbf{P}}_i) \;-\; \sum_{i \in \mathbb{N}} \omega_i \ln \Delta_i(Z), \qquad \text{subject to } E_i = \alpha_i Y. \tag{C.6}$$

Transfers are implicitly determined by α via (C.2).

Optimal policy schedule. Under **A1–A**4, any interior solution $(\tilde{\mathbf{P}}^*, \alpha^*)$ to (C.6) satisfies

$$\tilde{\mathbf{P}}^* - \mathbf{P} = \sum_n \left[\omega_n \frac{d \ln \Delta_n(Z)}{dZ}\right] D_{\tilde{\mathbf{P}}} Z(\tilde{\mathbf{P}}^*, \alpha_i^*), \tag{C.7}$$

$$\alpha_i^* = \omega_i \quad \forall i \in \mathbb{N}, \qquad \text{so that } T_i^* = \omega_i Y^* - Y_i. \tag{C.8}$$

Optimal Policy Derivation. We proceed in three steps.

Step 1 (optimal prices). By homotheticity **A1**, write $V_i(E_i, \tilde{\mathbf{P}}_i) = E_i\, v_i(\tilde{\mathbf{P}}_i)$ for some $v_i(\cdot) > 0$. Using (C.1), (C.2), and $\sum_i \omega_i = 1$ we can write the planner's objective as

$$\sum_i \omega_i \ln W_i = \ln Y \;+\; \sum_i \omega_i \ln v_i(\tilde{\mathbf{P}}_i) \;-\; \sum_i \omega_i \ln \Delta_i(Z) \;+\; \sum_i \omega_i \ln \omega_i,$$

Fix (i,k) and differentiate the objective in (C.6) with respect to $\tilde{P}_{i,k}$. Using $\sum_j \omega_j = 1$ and (C.4),

$$\frac{1}{Y}\frac{dY}{d\tilde{P}_{i,k}} + \omega_i \frac{\partial \ln v_i}{\partial \tilde{P}_{i,k}} - \sum_n \left[\omega_n \frac{d\ln \Delta_n(Z)}{dZ}\right] \frac{dZ}{d\mathbf{C}} \frac{d\mathbf{C}}{d\tilde{P}_{i,k}} = 0. \tag{C.9}$$

By **A3–A1**, the second term in the above equation becomes, $\omega_i \, \partial \ln v_i / \partial \tilde{P}_{ik} = -\frac{\omega_i}{\alpha_i} C_{ik}^{(H)}/Y$. Substituting this and the envelop condition implied by cost minimization (Assumption 3) into (C.9), obtains

$$\begin{aligned} 0 &= \frac{1}{Y}\left[(C_{ik} - C_{ik}^{(I)}) + (\tilde{\mathbf{P}} - \mathbf{P}) \cdot \frac{d\mathbf{C}}{d\tilde{P}_{i,k}}\right] - \frac{C_{ik}^{(H)}}{Y} - \sum_n \left[\omega_n \frac{d\ln \Delta_n(Z)}{dZ}\right] \frac{dZ}{d\mathbf{C}} \frac{d\mathbf{C}}{d\tilde{P}_{i,k}} \\ &= \frac{1}{Y}\left[(C_{ik} - C_{ik}^{(I)}) - C_{ik}^{(H)}\right] + \frac{1}{Y}\left(\tilde{\mathbf{P}} - \mathbf{P} - \sum_n \left[\omega_n \frac{d\ln \Delta_n(Z)}{dZ}\right] \frac{dZ}{d\mathbf{C}}\right) \cdot \frac{d\mathbf{C}}{d\tilde{P}_{ik}}. \end{aligned}$$

Noting that $C_{ik} - C_{ik}^{(I)} - C_{ik}^{(H)} = 0$ by construction, the first-order condition reduces to

$$\left[(\tilde{\mathbf{P}}^* - \mathbf{P}) - \sum_n \left[\omega_n \frac{d\ln \Delta_n(Z)}{dZ}\right] D_{\tilde{\mathbf{P}}} Z(\tilde{\mathbf{P}}^*, \boldsymbol{\alpha}^*)\right] \cdot D_{\tilde{\mathbf{P}}} \mathbf{C}(\tilde{\mathbf{P}}^*, \boldsymbol{\alpha}^*) = 0 \qquad \forall (i,k). \tag{C.10}$$

Under the rank condition **A5** (after normalization), the only solution is $\tilde{\mathbf{P}}^* - \mathbf{P} = \sum_n \left[\omega_n \frac{d\ln \Delta_n(Z)}{dZ}\right] D_{\tilde{\mathbf{P}}} Z(\tilde{\mathbf{P}}^*, \boldsymbol{\alpha}^*)$, establishing (C.7).

Step 2 (optimal transfers). Holding $\tilde{\mathbf{P}}$ fixed, the choice of α in (C.6) is

$$\max_{\alpha \in \Delta^N} \sum_i \omega_i \ln \alpha_i + \ln \mathrm{Y}(\tilde{\mathbf{P}}^*, \boldsymbol{\alpha}) + \sum_i \omega_i \ln v_i(\tilde{\mathbf{P}}_i^*) - \sum_i \omega_i \ln \Delta_i(\mathrm{Z}(\tilde{\mathbf{P}}, \boldsymbol{\alpha})).$$

The Lagrangian is

$$\mathcal{L}(\alpha, \lambda) = \sum_i \omega_i \ln \alpha_i + \ln \mathrm{Y}(\tilde{\mathbf{P}}, \alpha^*) + - \sum_i \omega_i \ln \Delta_i(\mathrm{Z}(\tilde{\mathbf{P}}, \alpha^*)) + \lambda(1 - \sum_i \alpha_i)$$

Following Assumption 3, the first-order condition w.r.t. α_i becomes

$$(\frac{\omega_i}{\alpha_i} - \lambda) + \left[(\tilde{\mathbf{P}}^* - \mathbf{P}) - \sum_n \left[\omega_n \frac{d\ln \Delta_n(Z)}{dZ}\right] D_{\tilde{\mathbf{P}}} Z(\tilde{\mathbf{P}}^*, \boldsymbol{\alpha}^*)\right] \cdot D_{\boldsymbol{\alpha}} \mathbf{C}(\tilde{\mathbf{P}}^*, \boldsymbol{\alpha}^*) = 0$$

The second part of the expression is zero if consumer prices are set optimally according to $C.7$. Thus, the first-order optimality condition entails that $\omega_i/\alpha_i = \lambda$ for all i, so $\alpha_i = \omega_i/\lambda$. Summing over i and using $\sum_i \alpha_i = \sum_i \omega_i = 1$ gives $\lambda = 1$ and thus $\alpha_i^* = \omega_i$. Combining Steps 1–2yields (C.8) and completes the proof. □

Decentralization (Eisenberg–Gale). Given ω, the program (C.6) is a Nash (log) product maximization. Under standard convexity conditions, its optimality conditions coincide with the optimality and budget conditions of a competitive equilibrium with prices $\tilde{\mathbf{P}}^*$ and lump-sum transfers $(T_i^*)_i$ implementing $E_i^* =$

$\omega_i Y^*$, so the efficient allocation is supported as a decentralized equilibrium.

D Equilibrium in Changes

This section introduces the system of equations used to solve equilibrium changes in response to trade and carbon policy shocks. Trade shocks can arise from changes in iceberg trade costs, denoted as $d_{ij,k}$, or from adjustments to trade taxes, import tariffs ($\tau_{ij,k}^{(M)} = 1 + t_{ni,k}^{(M)'}$) or export taxes ($\tau_{ij,k}^{(X)} = 1 + t_{ij,k}^{(X)}$). Carbon policy shocks, on the other hand, involve changes to supply-side taxes ($\tau_{i,k}^{(Q)}$) that target carbon emissions at the point of primary energy extraction $k \in \mathbb{E}_1$, and/or demand-side taxes that target carbon emissions at the consumption location of primary or secondary energy $k \in \mathbb{E}_1 \cup \mathbb{E}_2$. These demand-side taxes are applied to industries ($\tau_{i,kg}^{(I)}$) or households ($\tau_{i,k}^{(H)}$).

Note that in the main body of the paper, we did not explicitly model import tariffs and export taxes ($t_{ij,k}^{(M)}, t_{ij,k}^{(X)}$) on the trade policy side and additive carbon prices ($p_{i,k}^{(Q)}$, $p_{i,kg}^{(I)}$ and $p_{i,k}^{(H)}$) on the climate policy side. Here, we include them for completeness. In addition, to maintain generality in the model specification, below we assume that the household consumption aggregator follows a CES structure between energy (*E*) and non-energy (*N*) goods with substitution elasticity η_H, with a Cobb-Douglas structure within the energy and non-energy categories. Similarly, production technologies are modeled as CES between energy (*E*) and non-energy (*N*) with substitution elasticity η_I, with Cobb-Douglas structures within each category. In our main specification, however, we have adopted a simpler functional form with $\eta_H \to 1$ and $\eta_I \to 1$—which corresponds to a Cobb-Douglas aggregation also over energy (*E*) and non-energy (*N*) goods.

To express equilibrium responses to trade and climate policy changes, we adopt the exact hat algebra notation. For any generic variable z that denotes the value of z in the status quo equilibrium, we use z' to denote its value in the counterfactual equilibrium, with $\hat{z} \equiv z'/z$ representing the change from status quo to the counterfactual value.

Consider a policy change that adjust trade policy parameters to $\{d'_{ij,k}, t_{ij,k}^{(M)'}, t_{ij,k}^{(X)'}\}$ and carbon policy instruments to $\{t_{i,k}^{(Q)'}, t_{i,kg}^{(I)'}, t_{i,k}^{(H)'}, p_{i,k}^{(Q)'}, p_{i,kg}^{(I)'}, p_{i,k}^{(H)'}\}$.

Prices along the supply chain include producer prices at the location of supply, landed prices inclusive of production, export, and import taxes, distribution-level prices that aggregate over landed price in each destination, and consumer prices that additionally include demand-side taxes. In our notation below, the cost share parameter of natural resources, $\alpha_{i,k}^R$, is non-zero in the primary energy industries and zero in

all other industries. The change to prices along the supply chain is as follows:

$$\begin{cases} \widehat{P}_{ij,k} = \widehat{d}_{ij,k}\widehat{c}_{i,k} & \text{a) producer price} \\ \widehat{c}_{i,k} = \widehat{r}_{i,k}^{\alpha_{i,k}^R}\left(s_{i,k}^e\left(\hat{\tilde{P}}_{i,k}^E\right)^{1-\eta_I} + \left(1-s_{i,k}^e\right)\left(\hat{\tilde{P}}_{i,k}^N\right)^{1-\eta_I}\right)^{\frac{1-\alpha_{i,k}^R}{1-\eta_I}} & \text{b) marginal cost} \\ \hat{\tilde{P}}_{i,k}^E = \prod_{g\in\mathbb{E}}\hat{\tilde{P}}_{i,kg}^{\alpha_{i,kg}^I},\quad \hat{\tilde{P}}_{i,k}^N = \hat{w}_i^{\alpha_{i,k}^L}\prod_{g\in\mathbb{F}}\hat{\tilde{P}}_{i,kg}^{\alpha_{i,kg}^I} & \\ \widehat{\tilde{P}}_{ji,k} = \widehat{\tau_{ji,k}^{(M)}}\widehat{\tau_{ji,k}^{(X)}}\widehat{\tau_{j,k}^{(Q)}}\widehat{P}_{ji,k} & \text{c) landed price} \\ \widehat{\tilde{P}}_{i,k} = \left[\sum_n \lambda_{nj,k}\hat{\tilde{P}}_{nj,k}^{1-\sigma_k}\right]^{\frac{1}{1-\sigma_k}} & \text{d) distribution-level price} \\ \widehat{\tilde{P}}_{i,kg}^{(I)} = \widehat{\tau_{i,kg}^{(I)}}\widehat{\tilde{P}}_{i,g},\quad \widehat{\tilde{P}}_{i,g}^{(H)} = \widehat{t_{i,g}^{(H)}}\widehat{\tilde{P}}_{i,g} & \text{e) consumer price} \end{cases} \tag{D.1}$$

The change to international expenditure shares follow from the CES gravity structure:

$$\widehat{\lambda}_{ij,k} = \left(\widehat{\tilde{P}}_{ij,k}/\widehat{\tilde{P}}_{j,k}\right)^{1-\sigma_k} \tag{D.2}$$

On the side of factor employment and intermediate input use, industries' input cost shares are as follows:

$$\begin{cases} \hat{\alpha}_{i,k}^N = \left(\frac{\hat{\tilde{P}}_{i,k}^N}{\widehat{c}_{i,k}}\right)^{1-\eta_I} \\ \hat{\alpha}_{i,k}^E = \left(\frac{\hat{\tilde{P}}_{i,k}^E}{\widehat{c}_{i,k}}\right)^{1-\eta_I} \end{cases} \tag{D.3}$$

On the final consumption side, households' final expenditure shares are given by:

$$\begin{cases} \hat{\beta}_i^N = \left(\frac{\hat{\tilde{P}}_i^N}{\widehat{\tilde{P}}_i}\right)^{1-\eta_H} & \hat{\tilde{P}}_i^N = \prod_{k\in\mathbb{F}}\left(\hat{\tilde{P}}_{i,k}\right)^{\beta_{i,k|N}} \\ \hat{\beta}_i^E = \left(\frac{\hat{\tilde{P}}_i^E}{\widehat{\tilde{P}}_i}\right)^{1-\eta_H} & \hat{\tilde{P}}_i^E = \prod_{k\in\mathbb{E}}\left(\hat{\tilde{P}}_{i,k}\right)^{\beta_{i,k|E}} \end{cases} \tag{D.4}$$

where $\beta_{i,k|N}$ and $\beta_{i,k|E}$ denote cost shares within the input bundles of non-energy and energy use. Changes to total sales, $Y_{i,k} = P_{ii,k}Q_{i,k}$, in primary energy industries and secondary and non-energy industries can be express as:

$$\begin{cases} \widehat{Y}_{i,k} = \frac{1}{\hat{\alpha}_{i,k}^L}\widehat{r}_{i,k} & k\in\mathbb{E}_1 \\ \widehat{Y}_{i,k} = \frac{1}{\hat{\alpha}_{i,k}^L}\widehat{\ell}_{i,k}\widehat{w}_i & k\in\mathbb{E}_2\cup\mathbb{F} \end{cases} \tag{D.5}$$

where $\ell_{i,k} = L_{i,k}/L_i$ denotes the employment share of industry k in country i. In the post-policy equilibrium, total expenditures, inclusive or net of production and trade taxes, are equal to:

$$\begin{cases} \tilde{X}'_{i,k} = \frac{1}{\tau_{i,k}^{(H)'}}\hat{\beta}_{i,k}\beta_{i,k}\widehat{E}_i E_i + \sum_{g\in\mathbb{E}_2\cup\mathbb{F}}\frac{1}{\tau_{i,kg}^{(I)'}}\hat{\alpha}_{i,gk}^I\alpha_{i,gk}^I\widehat{Y}_{i,g}Y_{i,g}, \\ \tilde{X}'_{ij,k} = \tilde{P}'_{ij,k}C'_{ij,k} = \hat{\lambda}_{ij,k}\lambda_{ij,k}\tilde{X}'_{i,k} \\ X'_{ij,k} = P'_{ij,k}C'_{ij,k} = \frac{\tilde{X}'_{ij,k}}{\tau_{ij,k}^{(M)'}\tau_{ij,k}^{(X)'}\tau_{i,k}^{(Q)'}} \\ X'_{j,k} = \sum_i X'_{ij,k} \end{cases} \tag{D.6}$$

Using the changes in sales, expenditures, and prices, we can write the changes in CO_2 emissions. Specifically, emissions changes at different levels of aggregation are as follows:

$$\begin{cases} \widehat{Z}_{i,gk}^{(I)} = \frac{\hat{\alpha}_{i,kg}^{I}\hat{Y}_{i,k}}{\hat{\tilde{P}}_{i,gk}^{(I)}} & \text{a) industry emission } (i,k; \quad g \in \mathbb{E}) \\ \widehat{Z}_{i,g}^{(H)} = \frac{\hat{\beta}_{i,g}\hat{E}_i}{\hat{\tilde{P}}_{i,g}^{(H)}} & \text{b) household emission } (i; \quad g \in \mathbb{E}) \\ \widehat{Z}_{i}^{(I)} = \frac{1}{Z_i^{(I)}}\sum_k \sum_{g\in\mathbb{E}} \widehat{Z}_{i,gk}^{(I)} Z_{i,gk}^{(I)} & \text{c) industrial emission, } (i) \\ \widehat{Z}_{i}^{(H)} = \frac{1}{Z_i^{(H)}}\sum_{g\in\mathbb{E}} \widehat{Z}_{i,g}^{(H)} Z_{i,g}^{(H)} & \text{d) household emission, } (i) \\ \widehat{Z}_i = \frac{1}{Z_i}\left(\widehat{Z}_i^{(I)} Z_i^{(I)} + \widehat{Z}_i^{(H)} Z_i^{(H)}\right) & \text{e) national emission} \\ \widehat{Z}^{(global)} = \sum_{i=1}^{N}\left[\left(Z_i/Z^{(global)}\right) \times \widehat{Z}_i\right] & \text{f) global carbon emission} \end{cases}$$

Labor market clearing conditions equate the demand and supply of labor at both the industry level and the national level, expressed in terms of post-policy equilibrium values:

$$\begin{cases} \hat{\ell}_{i,k}\ell_{i,k}w_i\bar{L}_i = \hat{\alpha}_{i,k}^{L}\alpha_{i,k}^{L}\sum_j X'_{ij,k} & \text{a) LMC } (i,k \in \mathbb{K}) \\ \sum_{k=1}^{K}\hat{\ell}_{i,k}\ell_{i,k} = 1 & \text{b) National LMC } (i) \end{cases} \tag{D.7}$$

$$\hat{r}_{i,k}r_{i,k}R_{i,k} = \left(1 - \hat{\alpha}_{i,k}^{l}\alpha_{i,k}^{l}\right)\sum_j X'_{ij,k}, \qquad (i,k \in \mathbb{E}_1) \tag{D.8}$$

Lastly, the balance of budget requires that total final expenditure equals the payments to factors of production plus the taxes that are rebated to households:

$$\widehat{E}_i E_i = \widehat{Y}_i Y_i + T'_i, \qquad \widehat{Y}_i Y_i = \widehat{w}_i w_i L_i + \sum_{k\in\mathbb{E}_1}\left[\widehat{r}_{i,k}r_{i,k}\bar{R}_{i,k}\right]$$

where taxes consist of taxes at the points of local production, exports, imports, and local demand

$$T'^{(\text{demand})}_i = \sum_{k\in\mathbb{E}_1\cup\mathbb{E}_2}\left[\frac{\tau_{i,k}^{(H)'} - 1}{\tau_{i,k}^{(H)'}}\hat{\beta}_{i,k}\beta_{i,k}\widehat{E}_i E_i + \sum_{g\in\mathbb{E}_2\cup\mathbb{F}}\frac{\tau_{i,kg}^{(I)'} - 1}{\tau_{i,kg}^{(I)'}}\hat{\alpha}_{i,g}^{k}\alpha_{i,g}^{k}\widehat{Y}_{i,g}Y_{i,g}\right]$$

$$T'^{(\text{imports})}_i = \sum_k\sum_{n\neq i}\left[\frac{\tau_{ni,k}^{(M)'} - 1}{\tau_{ni,k}^{(M)'}}\tilde{X}'_{ni,k}\right]$$

$$T'^{(\text{exports, supply})}_i = \sum_k\sum_n\left[\frac{\tau_{i,k}^{(Q)'}\tau_{in,k}^{(X)'} - 1}{\tau_{i,k}^{(Q)'}\tau_{in,k}^{(X)'}\tau_{in,k}^{(M)'}}\tilde{X}'_{in,k}\right]$$

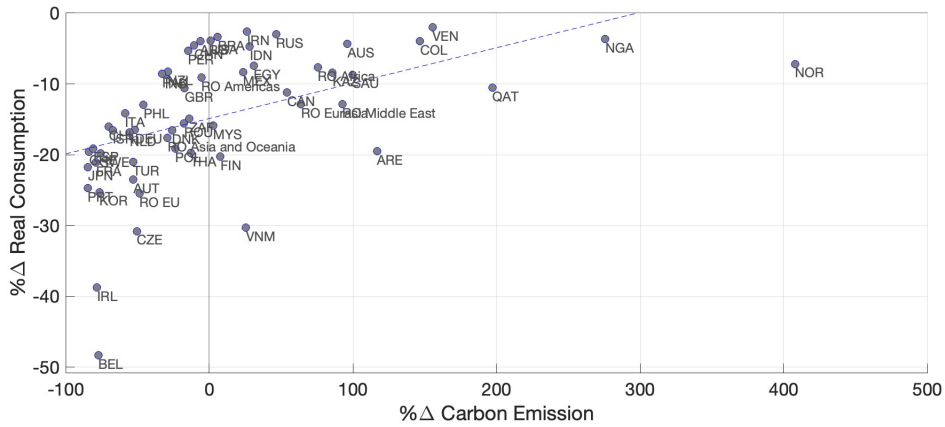
$$T'_i = T'^{(\text{demand})}_i + T'^{(\text{imports})}_i + T'^{(\text{exports, supply})}_i \tag{D.9}$$

where composite carbon tax rates, $\left\{\tau_{i,k}^{(Q)'}, \tau_{i,kg}^{(I)'}, \tau_{i,k}^{(H)'}\right\}$ consist of additive and multiplicative terms follow-

ing equation 8 (evaluated at the post-policy equilibrium).

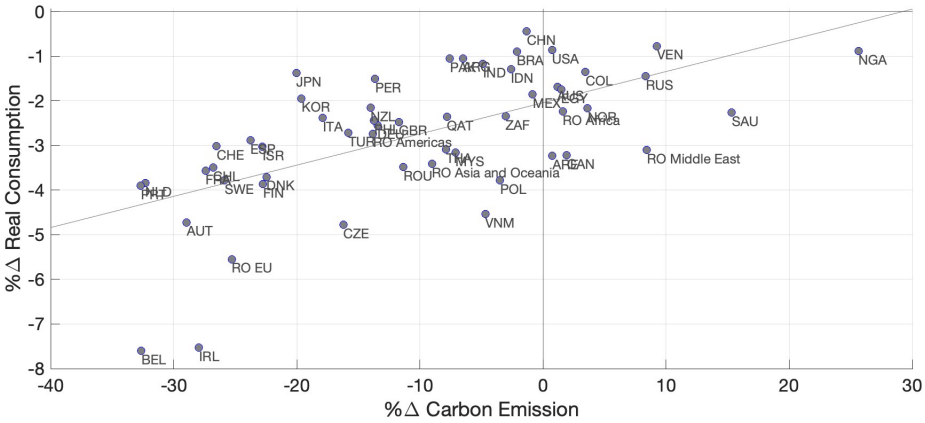
E Additional Tables and Figures

Figure A.4: Consumption and Emission Impacts of Moving to Autarky



Note: This figure shows the impact of moving to autarky on real consumption and emissions across countries.

Figure A.5: Consumption and Emission Impacts of Raising Import Tariffs



Note: This figure shows the impact of raising import tariffs to 25% on real consumption and emissions across countries.

Table A.1: Carbon Prices and Disutility Parameters

Country	(1) Implied Carbon Price from Fossil Fuel Taxes in 2014	(2) Explicit Carbon Price in 2023	(3) Emission Disutility	(4)
			Local $\left(\delta^{local}\right)$	Global $\left(\delta^{global}\right)$
European Union	100.3	35.3	91.6	48.6
United Arab Emirates	0.0	0.0	-14.9	0.0
Argentina	44.2	0.7	18.5	2.0
Australia	82.1	4.7	84.2	7.6
Brazil	30.6	0.0	9.1	0.0
Canada	25.8	28.6	-9.5	26.7
Chile	32.3	1.5	14.1	1.8
China	10.6	2.1	15.0	2.5
Colombia	38.7	1.3	20.8	1.3
Egypt, Arab Rep.	3.0	0.0	-3.0	0.0
Indonesia	0.0	0.0	-24.9	0.0
India	10.3	0.0	-1.3	0.0
Iran, Islamic Rep.	0.0	0.0	-3.0	0.0
Israel	60.0	0.0	62.8	0.0
Japan	33.7	1.5	-0.9	2.8
Kazakhstan	0.0	0.4	-18.8	0.2
Korea, Rep.	40.4	6.0	26.7	8.8
Mexico	3.6	1.5	-20.0	0.0
Malaysia	0.0	0.0	-19.9	0.0
Nigeria	1.3	0.0	-16.2	0.0
New Zealand	129.9	14.6	124.2	7.7
Pakistan	12.3	0.0	6.0	0.0
Peru	12.7	0.0	-7.0	0.0
Philippines	8.3	0.0	-6.4	0.0
Qatar	0.0	0.0	4.0	0.0
Russian Federation	0.0	0.0	-10.7	0.0
Saudi Arabia	0.0	0.0	-5.3	0.0
Thailand	0.0	0.0	-25.1	0.0
United States	18.3	2.2	11.3	2.5
Venezuela, RB	0.0	0.0	-3.2	0.0
Vietnam	3.1	0.0	-5.1	0.0
South Africa	15.5	0.9	20.1	0.6
RO Africa	25.4	0.0	12.1	0.1
RO Americas	28.3	0.3	7.7	0.8
RO Asia and Oceania	5.5	0.7	-34.6	0.0
RO Eurasia	6.4	0.3	-6.2	0.0
RO Middle East	0.0	0.0	-23.1	0.0

Note: This table reports for every region the average economy-wide *implied* carbon prices from fossil fuel taxes in 2014, explicit carbon prices in 2023 as the sum of carbon tax and emission permit, and calibrated values of government evaluation of local and global emission disutility. For details, see Sections 5.1 and 5.2.3 in the main text and A.3 in the appendix.

Table A.2: Fund's Outcomes—Based on Climate Adjusted Welfare

Social cost of carbon, $\sum_i \text{CSCC}_i$	292	156	292	156
Impose $\text{CSCC}_i \geq 0$	No	No	Yes	Yes
No Side Payments	12	23	81	81
Side Payments: Allocations from the Fund				
(a) Prop to domestic expenditure share	13	24	93	93
(b) Prop to domestic expenditure share in all energy	13	25	99	99
(c) Prop to domestic expenditure share in primary energy	13	26	114	114
(d) Share of Global Primary Energy Exports	18	51	270	225

Note: This table reports the results when R4 is relaxed – corresponding to a specification in which there is no misalignment between governments' objectives and the social welfare. The climate damages are based on our calibration in Section **??**. For each specified allocation scheme, the table reports the maximum carbon tax at which all current WTO members benefit to stay in the new agreement relative to the multilateral breaking point of the agreement.

Table A.3: Fund's Outcomes—Unilateral Breaking Point

	Max Carbon Price ($/tCO2)	Reduction in Global Emission	Marginal Countries
No Side Payments	80	42.8%	IND, VEN, RUS
Side Payments: Allocations from the Fund			
(a) Prop to dom. exp. share in all goods	125	51.1%	IND, RUS, BRA
(b) Prop to dom. exp. share in manufacturing	132	52.1%	IND, RUS, BRA
(c) Prop to dom. exp. share in all energy	122	50.7%	IND, RUS, BRA
(d) Prop to dom. exp. share in primary energy	101	47.2%	IND, RUS, BRA
(e) Share of global primary energy exports	85	42.6%	IND, BRA, PAK

Note: This table reports the results when R1 is relaxed – corresponding to an alternative specification where we consider unilateral deviations: each country evaluates whether to leave the agreement taking as given that all other countries remain. For each specified allocation scheme, the table reports the maximum carbon tax at which all countries benefit to stay in the agreement relative to the unilateral deviation from the agreement.

Table A.4: Fund's Outcomes—Alternative Energy Demand and Supply Elasticities

	Max Carbon Price ($/tCO2)	Reduction in Global Emission	Marginal Countries
No Side Payments	55	28.9%	NGA, VEN, IDN
Side Payments: Allocations from the Fund			
(a) Prop to dom. exp. share in all goods	105	39.8%	RO Middle East, RUS, USA
(b) Prop to dom. exp. share in manufacturing	88	36.4%	RO Middle East, RUS, USA
(c) Prop to dom. exp. share in all energy	124	42.1%	RO Middle East, RUS, USA
(d) Prop to dom. exp. share in primary energy	159	46.2%	IND, USA, RO Middle East
(e) Share of global primary energy exports	128	42.5%	IND, USA, CHN

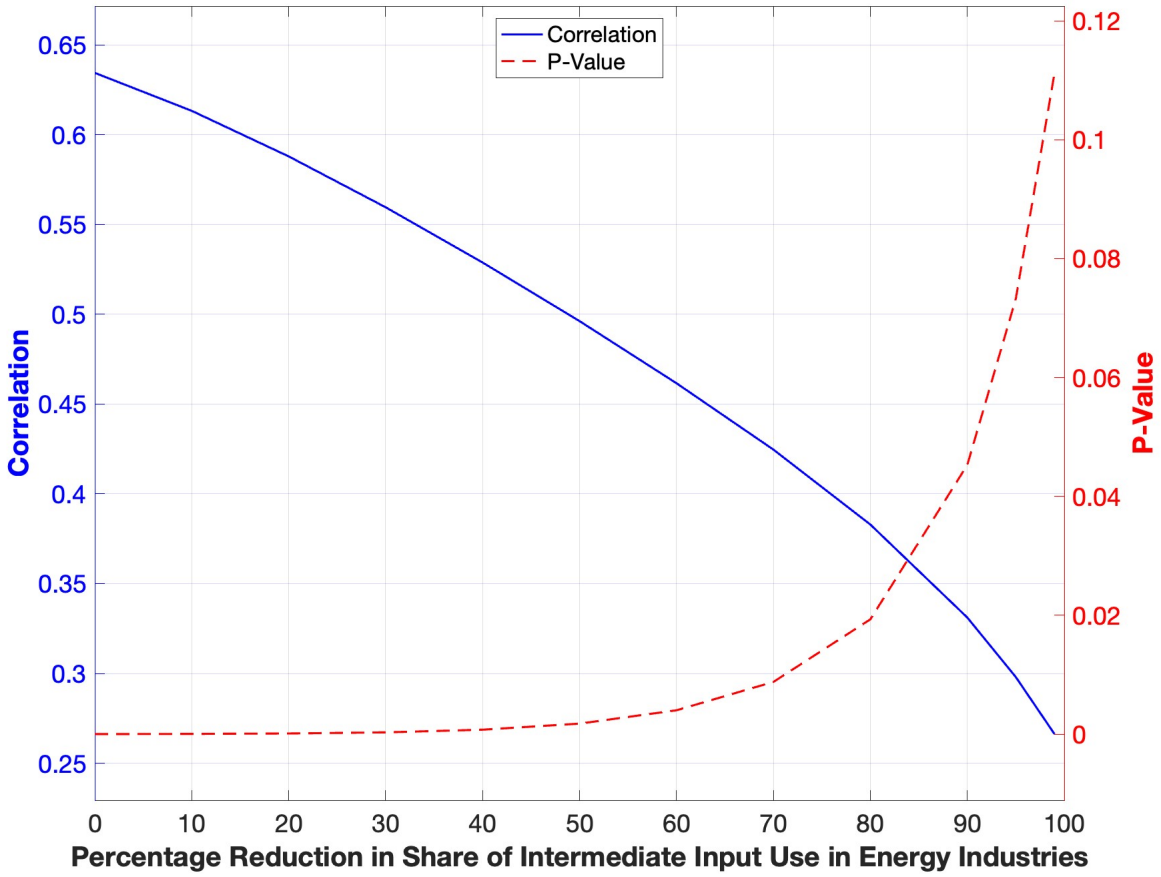
Note: This table reports the results for alternative parameters values of energy supply and demand elasticities in line with the description in Section 6.4. For each specified allocation scheme, the table reports the maximum carbon tax at which all countries benefit to stay in the agreement relative to the multilateral breaking point of the agreement.

Table A.5: Fund's Outcomes—Alternative Specification with Import Tariffs

	Max Carbon Price ($/tCO2)	Reduction in Global Emission	Marginal Countries
No Side Payments	53	35.5%	SAU, NGA, IDN
Side Payments: Allocations from the Fund			
(a) Prop to dom. exp. share in all goods	86	44.4%	SAU, RUS, CHN
(b) Prop to dom. exp. share in manufacturing	76	42.1%	SAU, RUS, CHN
(c) Prop to dom. exp. share in all energy	104	47.9%	RUS, CHN, SAU
(d) Prop to dom. exp. share in primary energy	109	48.8%	CHN, USA, IND
(e) Share of global primary energy exports	95	46.3%	IND, CHN, PAK

Note: This table reports the results for alternative specification where the change in trade costs are modeled as changes to import tariffs, in line with the description in Section 6.4. For each specified allocation scheme, the table reports the maximum carbon tax at which all countries benefit to stay in the agreement relative to the multilateral breaking point of the agreement.

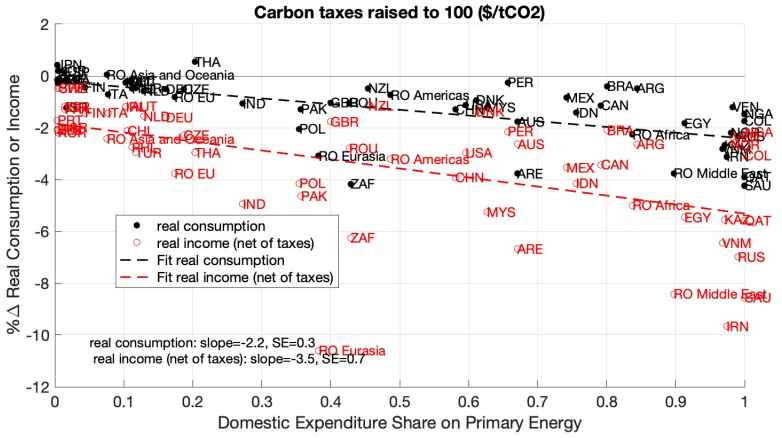
Figure A.6: Correlation between Consumption Gains and Emissions from Trade



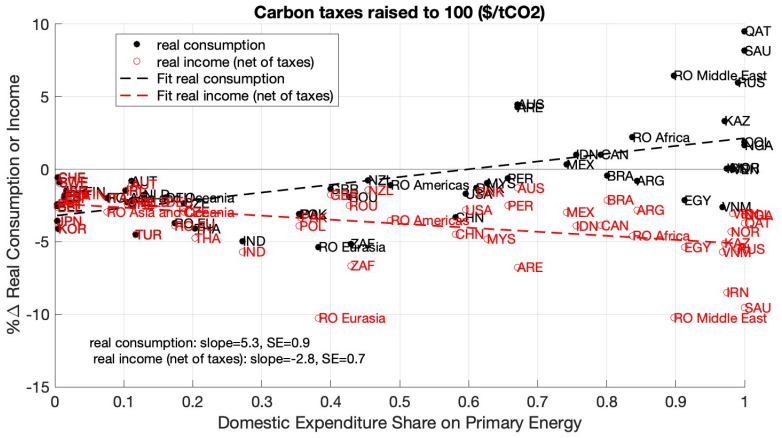
Note: This figure reports the correlation (in solid blue) between the change to consumption and emissions across countries under counterfactual scenarios where a percentage of payments to intermediate inputs in production of energy are replaced with equal payments to local labor. That is, in each country and industry and for each $x \in [0,1]$, $\alpha^I_{i,gk}$ (for $g \in \mathbb{E}$) and $\alpha^L_{i,k}$ are replaced by $x\alpha^I_{i,gk}$ and $(1-x)\alpha^L_{i,k}$. When x approaches one, the entire intermediate input use in energy production is replaced by local labor services. The dashed red plot shows the p-value of the correlation.

Figure A.7: Global Carbon Tax (Real Consumption $vs.$ Real Income)

(a) Demand-side

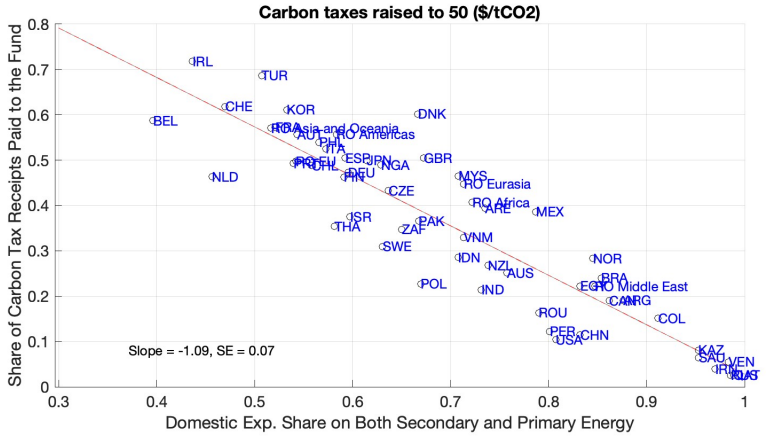


(b) Supply-side



Note: This figure shows the percentage change in real consumption, $(Y_i + T_i)/\tilde{P}_i$, and real income, $Y_i/\tilde{P}_i$, across countries against their baseline domestic share of expenditure on primary energy, in response to global uniform carbon pricing. Panel (a) shows the results for carbon taxes implemented on the demand side of energy markets, while Panel (b) presents the results for carbon taxes applied on the supply (extraction) side.

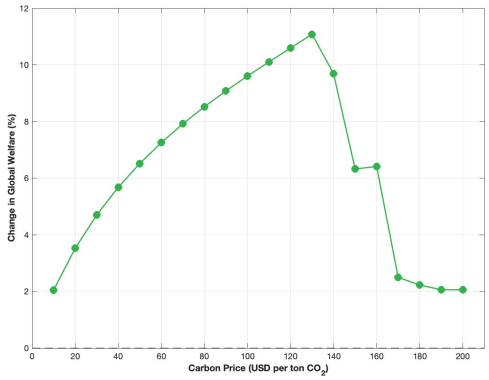
Figure A.8: Ratio of Contributions to the Fund Relative to Carbon Tax Receipts



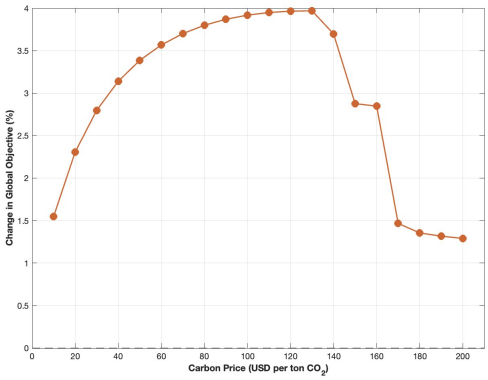
Note: This figure plots the ratio of each country's contribution to the Fund relative to its total carbon tax receipts on the y-axis, against the domestic expenditure share in primary and secondary energy on the x-axis. The calculations are based on a uniform demand-side carbon price of $100/tCO2.

Figure A.9: Coalition Outcomes as a Function of Carbon Price Target - Unilateral Deviations

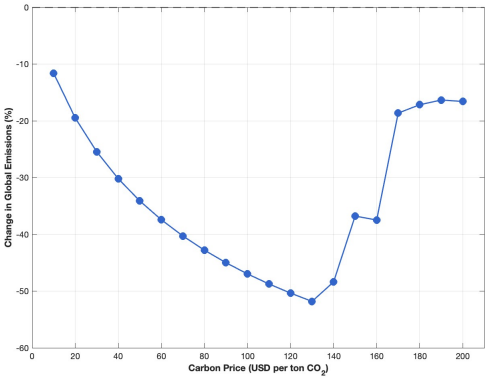
(a) Global Welfare



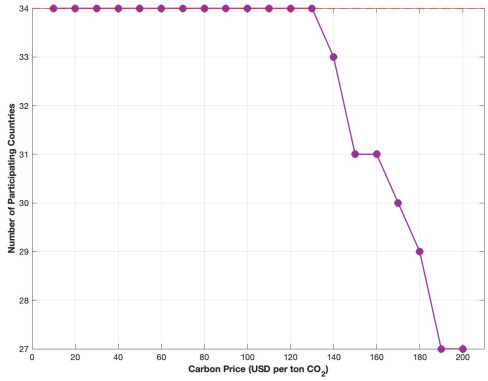
(b) Global Aggregate of Governments' Objectives



(c) Global Emissions



(d) Number of Countries in the Coalition



Note: This figure plots the coalition outcomes under a wide range of carbon pricing targets. Panel (a) shows percentage changes to global welfare (as the weighted average of welfare of countries with weights proportional to baseline GDP). Panel (b) shows the global weighted value of governments' objectives. Panel (c) shows global emissions. and Panel (d) shows the number of participants in the coalition.