NBER WORKING PAPER SERIES

ARE CARBON TARIFFS CLIMATE POLICY?

Gregory Casey
Kyle C. Meng
Ivan Rudik

Working Paper 35307
http://www.nber.org/papers/w35307

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
June 2026

We thank Jonathan Dingel for productive conversations during the early stages of this project. We thank Joe Aldy, Juanma Castro-Vincenzi, Farid Farrokhi, Joe Shapiro, Jim Stock, Catherine Wolfram, and seminar participants at Duke, Harvard, and Peterson Institute. Minwoo Hyun and Jordan Wingenroth provided excellent research assistance. This paper was supported by the Alfred P. Sloan Foundation grant G-2025-25307. Code review and paper proofreading were done with AI assistance using Claude, ChatGPT, and Refine.ink. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

NBER working papers are circulated for discussion and comment purposes. They have not been peer-reviewed or been subject to the review by the NBER Board of Directors that accompanies official NBER publications.

© 2026 by Gregory Casey, Kyle C. Meng, and Ivan Rudik. All rights reserved. Short sections of text, not to exceed two paragraphs, may be quoted without explicit permission provided that full credit, including © notice, is given to the source.

Are carbon tariffs climate policy?
Gregory Casey, Kyle C. Meng, and Ivan Rudik
NBER Working Paper No. 35307
June 2026
JEL No. F18, H23, Q5, Q58

ABSTRACT

Carbon import tariffs, traditionally considered a complement to domestic climate policy, are increasingly proposed as standalone policies. We build a quantitative trade model to compare U.S. carbon tariffs with and without a domestic carbon tax, each applied to a set of carbon-intensive, trade-exposed sectors. We find three main results. First, a U.S. carbon tariff increases U.S. emissions, lowers foreign emissions, and on net achieves half the global emissions reductions of the combined policy, which lowers both U.S. and foreign emissions. Second, both approaches increase U.S. GDP and welfare, but the combined policy has a larger effect due to terms of trade improvements. Third, global emissions reductions from multilateral tariff-only agreements are modest and do not increase monotonically with greater membership, whereas under combined policies they scale considerably with membership.

Gregory Casey
Williams College
Department of Economics
gpc2@williams.edu

Ivan Rudik
Cornell University
and NBER
irudik@cornell.edu

Kyle C. Meng
University of California, Santa Barbara
Department of Economics
and NBER
kmeng@bren.ucsb.edu

1 Introduction

In recent years, policymakers in the United States and elsewhere have been increasingly interested in standalone carbon tariffs. These proposals depart from textbook unilateral climate policy by excluding domestic policy.[1,2] Standalone carbon tariffs appear to offer a politically attractive compromise. They promise global emissions reductions without the economic costs of domestic carbon policy. Indeed, the two leading U.S. climate bills both include carbon tariffs, but differ on one key point. The Foreign Pollution Fee Act (FPFA) would impose carbon tariffs alone, while the Clean Competition Act (CCA) would combine carbon tariffs with domestic policy. Whether standalone carbon tariffs achieve global emissions reductions, and whether pairing them with domestic carbon policy leads to economic costs are ultimately quantitative questions. We tackle this by developing a multi-country, multi-sector trade model to quantify the economic and environmental consequences of U.S. carbon tariffs with and without a domestic carbon tax.

Global emissions may rise or fall under a unilateral carbon tariff. A carbon tariff shifts domestic demand for the targeted sector from foreign to domestic producers, increasing domestic emissions while lowering foreign emissions (Brunel and Levinson, 2024). The net global impact depends on the relative cleanliness of domestic and foreign production, the substitution patterns induced by the tariff, and the structure of the global production network. Adding a domestic carbon tax to a carbon tariff further lowers domestic emissions and increases foreign emissions, with an unclear net global emissions impact.

The domestic GDP and welfare effects of standalone carbon tariffs, or of tariffs combined with a domestic policy, are also theoretically ambiguous. When baseline tariffs are low, a carbon tariff can increase domestic GDP by improving its terms of trade as suggested by the optimal tariff literature (Bickerdike, 1907; Costinot and Rodríguez-Clare, 2014; Ossa, 2014). In a closed economy, a domestic carbon tax unambiguously lowers GDP by raising production costs. In a large open economy, however, part of the tax incidence falls on foreign purchasers while the benefits of the tax revenue are retained locally. This is akin to terms of trade effects from the optimal tariff literature, where the domestic carbon tax serves as an export tax, potentially increasing GDP (Conte, Desmet and Rossi-Hansberg, 2025).[3] Since

[1] Optimal unilateral climate policy combines domestic carbon pricing with border carbon adjustments applied to all sectors (Markusen, 1975; Hoel, 1991; Copeland, 1996; Farrokhi and Lashkaripour, 2025). Together, these instruments address leakage and competitiveness concerns by raising costs for both domestic and foreign producers.

[2] We use carbon throughout as a shorthand for CO_2-equivalent (CO_2e) emissions, which includes all greenhouse gases weighted by their global warming potential. Our quantitative analysis examines CO_2e emissions.

[3] As shown in this literature, export taxes can be optimal, because they are a mechanism for a country with market power to withhold supply and raise global prices. Production taxes can function like export

the absolute and relative effects on GDP and global emissions are ambiguous under both policies, whether a standalone carbon tariff or a combined carbon tariff and tax policy is better for domestic welfare will be ambiguous as well.

Our quantitative trade model includes multiple sectors, endogenous carbon abatement via input switching, and input-output linkages across sectors. We analyze the impact of carbon tariffs with and without a domestic carbon tax on economic and environmental outcomes. We calibrate the model to detailed input-output, trade, and emissions data available from Exiobase3 (Stadler et al., 2018). This fine-sectoral resolution allows us to consider carbon tariffs and taxes targeting specific carbon-intensive, trade-exposed (CITE) sectors, as done in current policy proposals.[4]

Our analysis of unilateral policy reveals two key findings. First, a unilateral U.S. carbon tariff valued at \$60 per tCO_2e on CITE sectors increases U.S. emissions and lowers foreign emissions. The net effect is a decrease in global emissions because the U.S. is relatively clean in the targeted sectors. Adding a domestic carbon tax to the carbon tariff leads to 2.6 times more global emissions reductions. Second, both a tariff-only and a combined policy increase U.S. GDP and welfare, where welfare accounts for the external benefits of reduced emissions. The GDP and welfare gains are larger for the combined policy, with welfare increasing 2.1 times more under the combined policy than under the carbon tariff alone.

Why does the combined policy do better in terms of GDP? In the data, U.S. CITE sectors are heavily exported, so a modest domestic carbon tax on these sectors improves U.S. terms of trade and raises GDP. Larger GDP gains and emissions reductions generate greater U.S. welfare gains under the combined policy versus a tariff alone. This quantitative exercise shows there may not be a trade-off between global emissions reductions and aggregate U.S. GDP and welfare when comparing combined carbon tariff and tax policies with standalone carbon tariffs. With a few exceptions, these results broadly hold across different carbon price values, CITE sector definitions, and other policy design considerations.

Achieving significant global emissions reductions will require climate policy implementation beyond the U.S. Building on our unilateral policy results, we also compare the global emissions impact of standalone carbon tariffs and combined tariff-domestic taxation policies in multilateral coalitions. In these coalitions, member countries impose tariffs only on non-members. For a tariff-only coalition, emissions reductions are non-monotonic in the number

taxes when the taxed sector is heavily exported. This is tightly related to the argument for optimal tariffs, because Lerner symmetry implies that tariffs and export taxes can yield identical outcomes.

[4]We do not explicitly model all the features of the CCA and FPFA as there are sufficient design differences between the two bills, such as tariff schedules and covered sectors, that would complicate the comparison. Instead, we focus on the main conceptual difference between CCA and FPFA, whether a carbon import tariff is paired with a domestic carbon price.

of participating countries. As membership grows, carbon tariffs place increasing pressure on ever fewer non-member countries, so global emissions reductions initially rise but then fall. For example, a \$60 per tCO_2e tariff-only coalition with OECD countries, Brazil, China, Indonesia, and India reduces global emissions by 0.5%, but this reduction shrinks as other Asian and South and Central American countries join the coalition. In the limit, a coalition with universal membership produces zero emissions reduction and is identical to a world without climate policy: there are no tariffs and no domestic policy. In contrast, multilateral coalitions that require domestic policy achieve greater emissions reductions as membership increases. For example, a \$60 per tCO_2e combined policy coalition with OECD countries, Brazil, China, Indonesia, and India reduces global emissions by 10.3%, while a coalition involving all countries lowers global emissions by 13.2%.

Our paper contributes to the existing literature on trade and the environment by comparing standalone carbon tariffs to combined carbon tariffs and domestic carbon taxes. Our focus on comparing real-world policy proposals complements the long literature studying the joint role of a domestic carbon tax and border adjustments in optimal unilateral climate policy in two-country models (Markusen, 1975; Hoel, 1991; Copeland, 1996; Kortum and Weisbach, 2021; Weisbach et al., 2023) and more recently in multi-region, multi-sector, quantitative models (Farrokhi and Lashkaripour, 2025; Farrokhi, Lashkaripour and Taheri, 2025; Bourany, 2025; Fan et al., 2025; Garcia-Lembergman et al., 2025; Clausing et al., 2025; Wolfram et al., 2026). Our work also complements the existing literature using computable general equilibrium models in sub-optimal settings, which often focuses on quantifying emissions leakage rates (see Böhringer, Balistreri and Rutherford (2012) and Böhringer et al. (2022) for summaries). Our methodological approach draws on standard tools in the quantitative trade literature (see Costinot and Rodríguez-Clare (2014) for a review). Our findings highlight the role of carbon taxes in affecting the terms of trade, an observation stressed by Conte, Desmet and Rossi-Hansberg (2025) in the context of the E.U.

The paper is organized as follows. Section 2 details our theoretical framework. Section 3 covers the data used to calibrate our model and presents summary statistics. Section 4 presents our results. Section 5 provides a concluding discussion.

2 Model

This section presents our multi-sector general-equilibrium trade model with input-output linkages, domestic carbon taxes, and carbon tariffs. There are M sectors that are indexed by m or n, and N countries that are indexed by i or j.

2.1 Households

There is a representative household in each country that inelastically supplies L_j units of labor and has utility function

$$U_j = \ln\left(\prod_{m=1}^{M} (Q_{j,m})^{\alpha_{j,m}}\right) - Z \ln E, \tag{1}$$

where $Q_{j,m}$ is the quantity of the sector-m final good consumed by the household, $\alpha_{j,m}$ is the expenditure share on sector m by households in country j where $\sum_{m=1}^{M} \alpha_{j,m} = 1 \ \forall j$, E is total global emissions, and Z is the utility cost of emissions.[5] The representative household takes emissions as given.

For simplicity, we refer to $C_j \equiv \prod_{m=1}^{M} (Q_{j,m})^{\alpha_{j,m}}$ as aggregate consumption in country j. Given the utility function, this implies the consumption price index in country j is

$$P_j = \prod_{m=1}^{M} \alpha_{j,m}^{-\alpha_{j,m}} P_{j,m}^{\alpha_{j,m}}, \tag{2}$$

where $P_{j,m}$ is the price of the sector-m final good in country j.

Labor cannot cross country borders, but it is perfectly mobile between sectors, implying that there is a unique wage rate w_j for country j. Total household labor income in country j is then $w_j L_j$. In addition to wage income, the representative household receives a per-person lump-sum transfer from the government of amount T_j funded by tariff revenue and an amount $\mathcal{T}_j$ funded by carbon tax revenue. The total household transfer income in country j from tariffs and carbon taxes is $(T_j + \mathcal{T}_j)L_j$. Total household income in j is then $(w_j + T_j + \mathcal{T}_j)L_j$, which is equal to total expenditure on consumption $P_j C_j$. Total expenditure is in turn equal to total final expenditure on all goods, X_j^F.

2.2 Production

Each country-sector produces a tradable intermediate good using local labor and a bundle of materials inputs. A local composite good producer in each country sources sectoral intermediates from all countries and produces a sectoral composite purchased by firms for use as materials and by households for consumption. We model the domestic carbon tax as an ad-valorem tax on the use of energy inputs in production.

[5] Since this is a static model, we do not distinguish between cumulative and flow emissions. We calibrate Z to recent estimates of the social cost of carbon, which is designed to estimate the cost of future flow emissions.

2.2.1 Sectoral Intermediates

Sectoral intermediate goods are produced by competitive firms operating Cobb-Douglas technologies. Gross output of sector m in country j is:

$$q_{j,m} = \chi_{j,m} L_{j,m}^{\eta_{j,m}} \prod_{n=1}^{M} (M_{j,nm})^{(1-\eta_{j,m})\omega_{j,nm}}, \tag{3}$$

where $\chi_{j,m}$ is country-sector productivity, $\eta_{j,m}$ is the labor share, and $\omega_{j,nm}$ is the share of the sector-n composite used in the materials input bundle of sector m in country j.[6] The materials input $M_{j,nm}$ is the quantity of the sector-n composite used in production by sector m in country j. The materials input shares satisfy $\sum_{n=1}^{M} \omega_{j,nm} = 1$ for each (j, m).

When producers use fossil fuel materials, CO_2 is emitted. Let $\mathcal{E} \subset \{1, \ldots, M\}$ denote the set of fossil fuel intermediate sectors. Define emissions from sector m using fossil fuel input n in country j as:

$$E_{j,nm} \equiv \upsilon_{j,m} \upsilon_n M_{j,nm}, \qquad n \in \mathcal{E},$$

where $\upsilon_{j,m}$ is country-sector emissions intensity, and υ_n is fuel-specific emissions intensity.[7] We assume $\upsilon_{j,m}$ and υ_n are invariant to policy. Firms have two margins of endogenous abatement. They can substitute from higher- to lower-intensity fossil fuels or away from fossil fuels entirely.

We model a domestic carbon tax as an input-specific ad-valorem wedge on fossil fuel materials used by producers. Let $\psi_{j,nm}$ denote the wedge faced by a producer in (j, m) when purchasing input n. We parameterize the wedge as

$$\psi_{j,nm} = 1 + \delta_{j,m} \upsilon_{j,m} \upsilon_n \quad \forall n \in \mathcal{E}, \qquad \psi_{j,nm} = 1 \quad \forall n \notin \mathcal{E},$$

where $\delta_{j,m}$ is the carbon price, measured in dollars per ton CO_2e, used to construct the ad-valorem-equivalent tax.

The carbon tax-inclusive materials price index in (j, m) is:

$$P_{j,m}^{M} \equiv \prod_{n=1}^{M} (\psi_{j,nm} P_{j,n})^{\omega_{j,nm}}.$$

[6] This Cobb-Douglas production structure implies an elasticity of substitution of one across inputs. This relatively high elasticity is consistent with long-run evidence on substitution between energy and non-energy inputs in production (e.g., Atkeson and Kehoe, 1999; Hassler, Krusell and Olovsson, 2021). The model results, therefore, should be interpreted as capturing the long-run effects of these policies.

[7] $\upsilon_{j,m}$ captures, among other features, process emissions and heterogeneity in energy efficiency across country-sectors.

Cost minimization and perfect competition imply the factory-gate price is:

$$p_{j,m} = \frac{1}{\chi_{j,m}} \tilde{\eta}_{j,m} \, w_j^{\eta_{j,m}} \left(P_{j,m}^M \right)^{1-\eta_{j,m}}, \tag{4}$$

where $\tilde{\eta}_{j,m} \equiv \eta_{j,m}^{-\eta_{j,m}} (1-\eta_{j,m})^{-(1-\eta_{j,m})}$.

Under the firm's cost minimization problem, tax-inclusive expenditure on each composite input is a constant share of revenue, which implies that pre-tax material expenditure satisfies:

$$X_{j,nm}^I = \omega_{j,nm}(1-\eta_{j,m}) \frac{Y_{j,m}}{\psi_{j,nm}},$$

where $Y_{j,m} \equiv p_{j,m} q_{j,m}$ is sectoral revenue at producer prices.

Carbon tax revenue per capita in country j can be written as:

$$\mathcal{T}_j = \frac{1}{L_j} \sum_{m=1}^{M} \sum_{n \in \mathcal{E}} \left(\psi_{j,nm} - 1 \right) X_{j,nm}^I = \frac{1}{L_j} \sum_{m=1}^{M} \sum_{n \in \mathcal{E}} \frac{\psi_{j,nm} - 1}{\psi_{j,nm}} \omega_{j,nm}(1-\eta_{j,m}) Y_{j,m}. \tag{5}$$

2.2.2 Local Sectoral Composite Good

A local sectoral composite good $Q_{j,m}$ is produced as a CES aggregate of country-sector intermediates. This composite is used locally both for final household consumption and as a materials input. The representative composite good producer in sector m in country j combines intermediate goods sourced from each country i to produce:

$$Q_{j,m} = \left(\sum_{i=1}^{N} a_{ij,m}^{\frac{1}{\sigma_m}} q_{ij,m}^{\frac{\sigma_m - 1}{\sigma_m}} \right)^{\frac{\sigma_m}{\sigma_m - 1}}, \tag{6}$$

where $a_{ij,m}$ is a share parameter, σ_m is the elasticity of substitution between country-specific goods, and $q_{ij,m}$ is the quantity of i's sector m good used by the producer in j.

Cost minimization yields a CES demand function for the intermediate good from country i:

$$q_{ij,m} = a_{ij,m} p_{ij,m}^{-\sigma_m} P_{j,m} Q_{j,m} P_{j,m}^{\sigma_m - 1},$$

where $p_{ij,m}$ is the price of country i's sector-m good in country j and $P_{j,m}$ is the CES price index for the local composite good in sector m.

2.3 Trade

Shipments of intermediate goods incur trade costs and are subject to import tariffs. Trade costs take the iceberg form such that $\tau_{ij,m} \geq 1$ units of the sector m intermediate good

must be shipped from country i to country j for one unit to be delivered. We normalize $\tau_{jj,m} = 1 \; \forall j, m$. Imports of sector m goods from country i are subject to ad valorem tariffs $t_{ij,m}$, imposed by the government of country j. The price of country j procuring a sector m intermediate good from country i is its factory-gate price times the bilateral trade cost, scaled by the import tariff:

$$p_{ij,m} = p_{i,m}\tau_{ij,m}(1 + t_{ij,m}). \tag{7}$$

We let $\varphi_{ij,m} \equiv (1 + t_{ij,m})$ be the tariff wedge to simplify later expressions. Inserting this expression for price into the demand function for the local sectoral composite yields equilibrium trade flows:

$$X_{ij,m} = a_{ij,m} \left[p_{i,m}\tau_{ij,m}\varphi_{ij,m}\right]^{1-\sigma_m} X_{j,m} \left[P_{j,m}\right]^{\sigma_m - 1} = \frac{a_{ij,m} \left[p_{i,m}\tau_{ij,m}\varphi_{ij,m}\right]^{1-\sigma_m}}{\sum_{l=1}^{N} a_{lj,m} \left[p_{l,m}\tau_{lj,m}\varphi_{lj,m}\right]^{1-\sigma_m}} X_{j,m},$$

where $X_{j,m}$ is total expenditures by j on sector m goods, including both final household and firm materials demand. The second equality uses the fact that the price index can be expressed as:

$$P_{j,m}^{1-\sigma_m} = \sum_{l=1}^{N} a_{lj,m} \left[p_{l,m}\tau_{lj,m}\varphi_{lj,m}\right]^{1-\sigma_m}. \tag{8}$$

The resulting sectoral trade shares are:

$$\lambda_{ij,m} \equiv \frac{X_{ij,m}}{X_{j,m}} = \frac{a_{ij,m} \left[p_{i,m}\tau_{ij,m}\varphi_{ij,m}\right]^{1-\sigma_m}}{\sum_{l=1}^{N} a_{lj,m} \left[p_{l,m}\tau_{lj,m}\varphi_{lj,m}\right]^{1-\sigma_m}}. \tag{9}$$

Total tariff revenue per capita in country j is:

$$T_j = \frac{1}{L_j} \sum_{m=1}^{M} \sum_{i=1}^{N} t_{ij,m}\varphi_{ij,m}^{-1} X_{ij,m} = \frac{1}{L_j} \sum_{m=1}^{M} \bar{\tau}_{j,m} X_{j,m}, \tag{10}$$

where $\bar{\tau}_{j,m} \equiv \sum_i \lambda_{ij,m}\, t_{ij,m}/\varphi_{ij,m}$ is the import-share-weighted tariff wedge. The division by $\varphi_{ij,m} = 1 + t_{ij,m}$ ensures the taxes on imports in the model are levied on pre-tax producer prices.

2.4 Market clearing and equilibrium

Recall X_j^F is total final expenditure in country j, $X_{j,mn}^I$ is total expenditure by sector n on sector m in country j, and $X_{j,m}$ is total gross expenditure in country j on the sector-m composite. Final demand for sector m in country j is given by:

$$X_{j,m}^F = \alpha_{j,m} X_j^F.$$

Materials demand for sector m in country j is the sum of input purchases across all producing sectors:

$$X_{j,m}^I \equiv \sum_{n=1}^{M} X_{j,mn}^I.$$

Market clearing in the composite good markets requires

$$X_{j,m} = X_{j,m}^F + X_{j,m}^I = \alpha_{j,m} X_j^F + \sum_{n=1}^{M} X_{j,mn}^I. \tag{11}$$

Goods market clearing for each origin country-sector requires that total sales at producer prices equal total revenues from all destinations net of tariffs:

$$Y_{i,m} = \sum_{j=1}^{N} \varphi_{ij,m}^{-1} X_{ij,m}. \tag{12}$$

Labor market clearing requires that labor income in a country-sector is a constant share of sectoral revenue:

$$w_i L_{i,m} = \eta_{i,m} Y_{i,m} = \eta_{i,m} \sum_{j=1}^{N} \varphi_{ij,m}^{-1} X_{ij,m}. \tag{13}$$

Labor market clearing also requires that the labor allocation is feasible:

$$\sum_m L_{j,m} = L_j. \tag{14}$$

Below we will use $\Gamma_{i,m} \equiv \frac{w_i L_{i,m}}{\sum_k w_i L_{i,k}}$ to denote the share of labor income in country i that is earned in sector m.

The budget constraint for consumers in country j is that total final expenditure equals the sum of labor income and net domestic transfers:

$$X_j^F = (w_j + T_j + \mathcal{T}_j) L_j. \tag{15}$$

A competitive equilibrium is given by the following definition.

Definition 1. *Given preferences* $\{\alpha_{j,m}, a_{ij,m}, \sigma_m\}$*, technologies* $\{\chi_{j,m}, \eta_{j,m}, \omega_{j,nm}\}$*, bilateral trade costs* $\{\tau_{ij,m}\}$*, labor endowments* $\{L_j\}$*, and policy wedges* $\{t_{ij,m}, \psi_{j,nm}\}$*, a* competitive equilibrium *is a set of prices* $\{w_j, p_{j,m}, P_{j,m}, P_{j,m}^M, P_j\}$*, allocations* $\{L_{j,m}, Y_{j,m}, X_j^F, X_{j,mn}^I, X_{j,m}, X_{ij,m}\}$*, and per-capita transfers* $\{T_j, \mathcal{T}_j\}$ *such that all agents optimize and equations* (5)*,* (9)*,* (10)*,* (11)*,* (12)*,* (13)*,* (14) *and* (15) *are satisfied.*

Our definition of an equilibrium does not include emissions, which are byproducts of production that are relevant for welfare. We compute emissions and welfare separately from

finding the equilibrium. This requires the additional preference parameter Z.

2.5 Counterfactuals

We solve counterfactuals using exact hat algebra. The solution algorithm is detailed in Appendix A. Let hats denote relative changes from the baseline equilibrium: $\hat{x} \equiv x'/x$. We define a policy scenario as a set of changes in the carbon tax and tariff wedges, $\{\hat{\psi}_{j,nm}, \hat{\varphi}_{ij,m}\}$, for CITE sectors $m \in \mathcal{C}$. We describe how we define the CITE sectors subject to the policies in Section 3.3. Given these counterfactual changes, a counterfactual equilibrium is defined by the set of endogenous hat variables $\{\hat{w}_j, \hat{P}^M_{j,m}, \hat{p}_{j,m}, \hat{P}_{j,m}, \hat{\lambda}_{ij,m}, \hat{X}^F_j, \hat{Y}_{j,m}\}$.

We use $\delta_{j,m}$ to denote the baseline carbon price that applies to sector m in country j and $\delta'_{j,m}$ to denote the counterfactual carbon price. In the quantitative implementation, these carbon price values are reference values used to construct ad-valorem-equivalent taxes. A carbon tax and carbon import tariff are defined accordingly.

Carbon tax. An ad-valorem carbon tax imposed on sector $m \in \mathcal{C}$ is implemented as:

$$\psi_{j,nm} = 1 + \delta_{j,m}\upsilon_{j,m}\upsilon_n, \qquad \psi'_{j,nm} = 1 + \delta'_{j,m}\upsilon_{j,m}\upsilon_n, \qquad \hat{\psi}_{j,nm} = \frac{\psi'_{j,nm}}{\psi_{j,nm}},$$

The domestic carbon tax covers direct emissions generated in the production of a good, and does not account for upstream emissions generated in the creation of inputs. It is greater than one only for fossil fuel materials.

Carbon import tariff. An ad-valorem carbon tariff imposed by country j on imports from country i on sector $m \in \mathcal{C}$ is:

$$t^C_{ij,m} = \delta'_{j,m}\, e_{i,m},$$

where $e_{i,m} = \frac{E_{i,m}}{Y_{i,m}}$ is the *baseline* direct GHG intensity of output, not accounting for upstream emissions generated in the creation of (i,m) inputs. Since $e_{i,m}$ is defined as the baseline intensity, it does not respond endogenously in the counterfactual. Therefore, $t^C_{ij,m}$ does not adjust if foreign firms reduce their counterfactual emissions intensity, making it act like a typical tariff but where the scale is set by baseline emissions intensity. These carbon tariffs are in addition to existing tariffs. A carbon import tariff wedge is implemented as:

$$\varphi_{ij,m} = 1 + t_{ij,m}, \qquad \varphi'_{ij,m} = 1 + t_{ij,m} + t^C_{ij,m}, \qquad \hat{\varphi}_{ij,m} = \frac{\varphi'_{ij,m}}{\varphi_{ij,m}}.$$

Under this formulation, a country implements a carbon tax on the emissions content of inputs and a carbon tariff on the emissions content of outputs. This implies that domestic firms can reduce their carbon tax exposure by substituting away from fossil fuel inputs, while foreign firms cannot. This difference reflects real-world constraints in how carbon taxes and tariffs are implemented.[8] Governments have greater visibility into production that occurs within their own borders. In particular, while firm-level outcomes may be observable domestically, they are much harder to observe and verify internationally. As a result, carbon tariffs are often applied at the sector level rather than the firm level. In a setting with many firms, this implies that each firm takes the relevant emissions intensity as given. Foreign firms therefore have no direct incentive to substitute away from fossil fuels in response to the tariff. This is equivalent to facing a fixed tariff on output at the sector level, which also does not create incentives for input substitution.[9]

Our benchmark model imposes a carbon import tariff on direct emissions. Some policy proposals consider applying a carbon tariff also to indirect emissions embodied in materials inputs and from services like transportation. We consider this approach in a robustness check.

3 Data and Calibration

In this section, we first describe and present data sources. We then describe how these data are used to calibrate our model.

3.1 Data sources

The primary source for production and trade data is Exiobase3 (Stadler et al., 2018), a global multi-region, multi-sector, input-output (MRIO) database that provides bilateral trade flows, domestic input-output tables, and satellite accounts for greenhouse gas emissions. It covers 200 sectors for 49 countries and a rest-of-world aggregate. This fine sectoral resolution is particularly advantageous for examining carbon tariff proposals, because many Exiobase3 sectors match those targeted in current carbon tariff proposals.[10] We aggregate E.U. mem-

[8] This feature appears in the E.U. CBAM, as well as in the U.S. FPFA and CCA bills.

[9] In addition, governments do not observe foreign sector-level emissions at high frequency. As a result, even if foreign firms did adjust their input mix in response to the tariff, there would likely be a long lag before importing governments could credibly observe this change and update the tariff in response.

[10] Other environmentally-extended MRIO datasets tend to have coarser sectoral definitions. For example, Global Trade Analysis Project 11 (GTAP11), the global input-output database used in many prior papers, has 65 sectors with cement and glass grouped as part of non-metallic minerals, while aluminum is part of non-ferrous metals that also include copper and nickel. Likewise, the World Input Output Database (WIOD), another commonly used global input-output database, has 56 sectors and includes aluminum among all metals

ber countries into a single region, resulting in 23 country-regions (see Table E.1). We use Exiobase3 data for 2020.[11]

Bilateral tariff rates are from the World Integrated Trade Solution (WITS) database for 2022 (World Bank, 2022), matched to our country-sector classification using concordance tables between HS6 product codes and Exiobase sectors. Effective carbon prices by country are from the OECD Effective Carbon Rates database for 2021 (OECD, 2023). Fossil fuel energy sectors are based on the KLEMS accounting framework from Timmer et al. (2007) with fossil fuel combustion GHG emission factors obtained from IPCC (2006). All monetary values are adjusted to 2025 USD.

3.2 Calibration

The model in Section 2 and the exact-hat solution algorithm in Appendix A assume balanced trade, whereas actual trade data are unbalanced. In Appendix B, we detail a procedure that balances our trade data, extending the approach of Ossa (2014).

For sector trade elasticities, σ_m, we match Exiobase's 200 sectors to sector-specific trade elasticities estimated by Ossa (2015), as shown in Table E.2.[12] Appendix C describes the calibration of other primitives $\{\alpha_{j,m}, \eta_{j,m}, \omega_{j,nm}, \upsilon_{j,m}, \upsilon_n, Z\}$ and baseline data objects $\{\lambda_{ij,m}, Y_{j,m}, X_j^F, \varphi_{j,nm}, \varphi_{ij,m}\}$.[13] Because much of this calibration is standard for quantitative trade models, we focus here on the calibration of emissions factors, $\upsilon_{j,m}$ and υ_n, and climate damages, Z, which are specific to our application. Our calibration is summarized in Table E.4.

We calibrate υ_n, the emissions intensity for fossil fuel sectors $\mathcal{E}$ in tCO_2e/MMBtu, using combustion emission factors from IPCC (2006), matched to the corresponding Exiobase3 energy sectors. Table E.3 lists these fossil fuel materials and their values for υ_n. Exiobase provides country-sector emissions, $E_{j,m}$, and materials expenditures, $X^I_{j,nm}$. Because we do not observe $M_{j,nm}$, the real quantity of the sector-n composite used in production by sector

while cement and glass are a part of other non-metallic mineral products. By contrast, Exiobase3 has 200 sectors that match specific sectors targeted in current carbon tariff proposals. Given sectoral heterogeneity in emissions intensities and trade patterns, such coarse sectoral definitions may result in inaccurate modeling results.

[11] We use Exiobase v3.9.6 for year 2020. At the time of this writing, Exiobase3 had been updated to v4.10.2 with 2022 trade data, but it had substantial inconsistencies for GHG intensities in some sectors.

[12] Ossa (2015) estimates trade elasticities for 33 3-digit SITC sectors. Of the 200 Exiobase sectors, 105 sectors can be directly matched to 3-digit SITC sectors in Ossa (2015). If the match is one-to-many, we take the average global trade share-weighted trade elasticity across matched 3-digit SITC sectors. Each of our benchmark CITE sectors falls in this category. The remaining 95 unmatched Exiobase sectors are primarily service and non-traded goods that either do not have a matched 3-digit SITC code or are not estimated in Ossa (2015) because of low trade volume. For these sectors, we follow Ossa (2015) and assign them the average trade elasticity across traded sectors estimated by Ossa (2015), a value of 3.63.

[13] The primitives $a_{ij,m}$ and $\chi_{j,m}$ drop out of the solution algorithm and need not be calibrated.

m in country j, we assume that one unit of input n equals one baseline dollar of expenditure on that input such that $M_{j,nm} = X^I_{j,nm}$. This enables us to calibrate the country-sector energy intensity $\upsilon_{j,m}$ as

$$\upsilon_{j,m} = \frac{E_{j,m}}{\sum_{n \in \mathcal{E}} \upsilon_n X^I_{j,nm}}.$$

The resulting parameter $\upsilon_{j,m}$ has units of MMBtu per dollar. Combined with the baseline carbon price, this is sufficient to set the baseline domestic carbon tax.[14] In Appendix C.3, we detail how to construct emissions intensities that incorporate direct emissions and indirect emissions embodied in materials inputs, which we use for alternative policy scenarios.

How reliable are Exiobase GHG intensities? In Figure D.1, we compare country-level GHG intensities for aluminum and iron and steel against intensities calculated by the E.U. Joint Research Centre (Vidovic et al., 2023). These calculations inform the implementation of the E.U. carbon tariff under its emissions trading system, known also as the E.U. Carbon Border Adjustment Mechanism (CBAM).[15] We find that Exiobase GHG intensities are strongly correlated with this alternative GHG intensity measure for aluminum and iron and steel.[16]

Finally, to measure the welfare impacts of climate policies, we calibrate Z to match the U.S.-specific domestic social cost of carbon (SCC) of \$55.47 (2025 USD) obtained from Kopits et al. (2025) (see Appendix C.7).[17] This assumes that individuals in the U.S. ignore the impact of emissions on people living outside the U.S. The welfare benefits of emissions reductions would be larger if policy was set using the global SCC.

[14] By using expenditure rather than physical units to calibrate $\upsilon_{j,m}$, our measurement approach adds the extra assumption that emissions per unit of carbon content are proportional to expenditure on fossil fuels, rather than BTUs, in the baseline. Alternatively, we could assume that emissions per unit of carbon content are proportional to *physical quantities* of fossil fuels. In practice, this would require a reliable measure of relative prices across fuels in each country to implement the physical quantity approach. As far as we are aware, no such data source exists.

[15] Country-sector emissions intensity constructed from Exiobase is:

$$e_{j,m} = \frac{E_{j,m}}{Y_{j,m}} = \frac{\upsilon_{j,m} \sum_{n \in \mathcal{E}} \upsilon_n X^I_{j,nm}}{Y_{j,m}}.$$

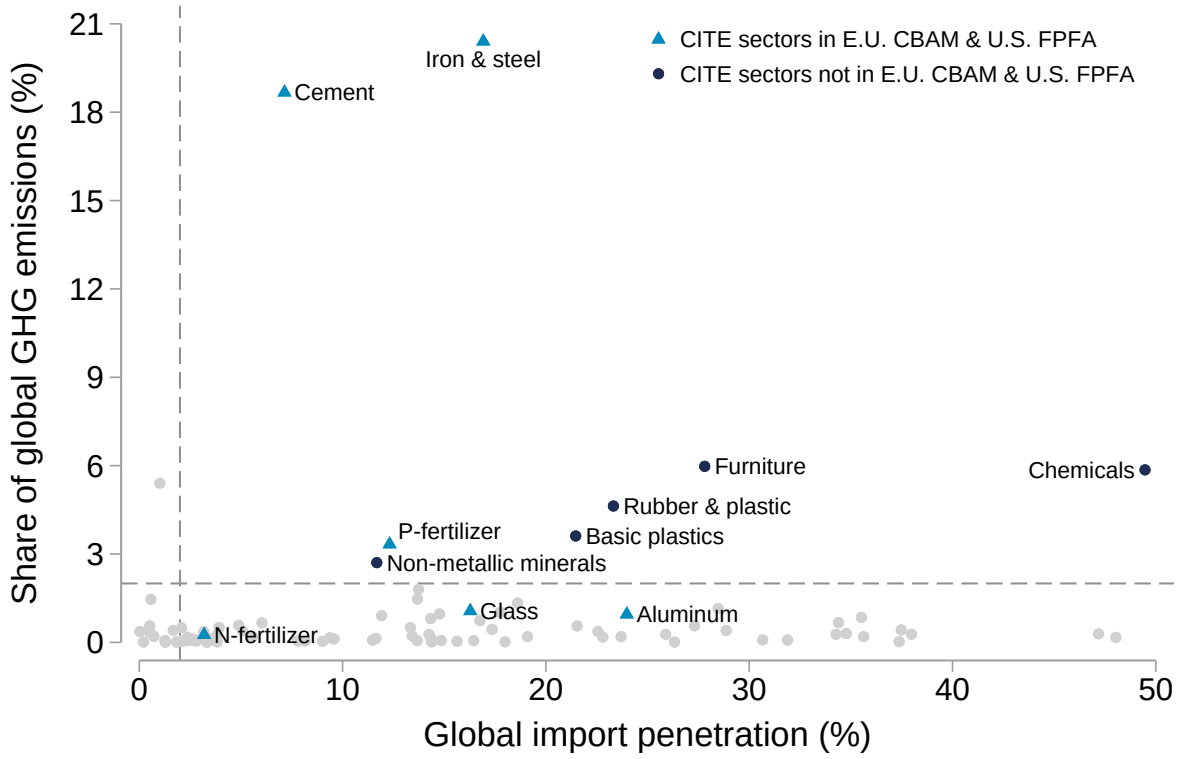
[16] JRC GHG intensities are measured in terms of metric tons of CO_2e per ton output. To convert Exiobase GHG intensities from CO_2e per dollar output to per ton output, we apply 2022 country-sector export prices from UN Comtrade. There are also differences in the scope of GHG measurement. Exiobase covers direct emissions. JRC covers direct and electricity-related indirect emissions.

[17] We take the average U.S.-specific social cost of carbon from Table 6 of Kopits et al. (2025) and adjust it to the cost of GHGs emitted in 2025 and in 2025 dollars.

3.3 Defining carbon-intensive trade-exposed sectors

Carbon tariff policies typically apply to a subset of sectors that both contribute a large share of GHG emissions and are globally traded. Figure 1 assesses these two dimensions using Exiobase data. For each sector, it plots its share of global GHG emissions against global import penetration, defined as total imports summed across countries divided by total consumption summed across countries. The dashed lines indicate 2% thresholds for each dimension. Sectors marked as light blue triangles are eligible for carbon tariffs under the E.U. CBAM and the U.S. FPFA. Dark blue circles indicate sectors that are not covered by the E.U. CBAM or U.S. FPFA but still have a global emissions share and global import penetration above 2%.

Figure 1: Carbon-intensive trade-exposed sectors



Notes: Vertical axis shows sector-level share of global GHG emissions among globally traded, non-fossil fuel goods. Horizontal axis shows global import penetration, defined as the ratio of total global imports over total global consumption, using 2020 values. Light blue triangles indicate sectors covered under E.U. CBAM and U.S. FPFA. Dark blue circles indicate sectors with global share of GHG emissions and global import penetration above 2% that are not covered under E.U. CBAM and U.S. FPFA. Gray indicates the remaining Exiobase sectors, excluding three with import penetrations greater than 50% for visual compactness.

We call the union of these two sets carbon-intensive, trade-exposed (CITE) sectors. These 11 sectors contribute 67.5% of global GHG emissions and 19.3% of global output in 2020 among globally traded, non-fossil fuel goods (see Table E.5). This definition combines policy

relevance with potential carbon tariff impact according to our data. In our analysis, we also consider alternative sectoral eligibility definitions by lowering the global emissions share and import penetration thresholds, as well as examining just the E.U. CBAM and U.S. FPFA sectors. Figure D.2 shows the distribution of GHG intensities across countries and regions for each CITE sector and across CITE sectors.

4 Results

This section presents our modeling results, which show the impacts of a standalone carbon import tariff and the combination of a carbon import tariff and a domestic carbon tax. Section 4.1 examines our benchmark policy, which values carbon tariffs and the U.S. domestic tax at \$60 per ton CO_2e, the value considered in the U.S. Clean Competition Act. It applies these policies to the set of CITE sectors displayed in Figure 1. Section 4.2 examines these impacts under alternative policy designs, varying carbon prices, CITE sector definitions, and coverage of GHG emissions. Section 4.3 considers the emissions consequences of multilateral policies.

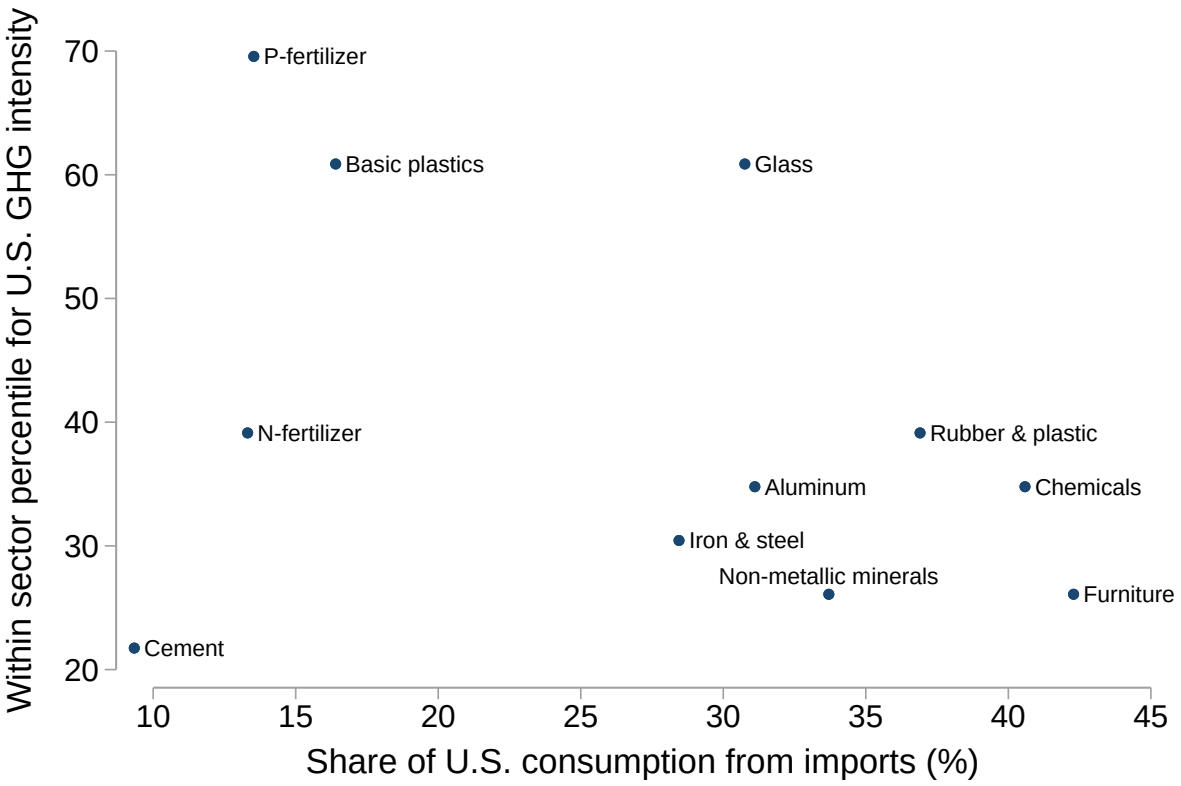
4.1 Benchmark unilateral U.S. policies

Figure 2 shows baseline data that previews our sector-level results. For each CITE sector, the vertical axis in Figure 2 shows the U.S. GHG intensity percentile within the global distribution for each sector. Lower percentiles indicate that the U.S. has lower GHG intensity, and is thus cleaner, compared to other countries and regions in that sector (see also the GHG intensity distributions in Figure D.2). The horizontal axis shows the share of U.S. consumption in that sector from imports, with higher values indicating greater import dependence. To a first approximation, unilateral U.S. carbon tariffs should have greater global emissions reductions in sectors for which the U.S. is relatively less carbon intensive and more reliant on imports. Together, these 11 CITE sectors contribute 36.0% of U.S. GHG emissions and 17.3% of U.S. output in 2020 (see Table E.5).

Table 1 reports sectoral and aggregate outcomes under a unilateral standalone U.S. carbon import tariff (Panel A) and a unilateral combined U.S. carbon import tariff and carbon tax (Panel B). Both policies price carbon at \$60 per ton CO_2e. A standalone carbon tariff lowers U.S. imports, and in most CITE sectors, raises U.S. output.[18] As a consequence, U.S.

[18]The negative output effects for a handful of CITE sectors occur because of input-output linkages. Table E.6 replicates Panel A of Table 1 but with input-output linkages shut off. Without input-output linkages, carbon tariffs increase U.S. output in every CITE sector. Without input-output linkages represented, global emissions reductions, real GDP, and welfare gains are all of smaller magnitudes.

Figure 2: U.S. GHG intensity and import penetration for CITE sectors



Notes: Figure shows the sector-level U.S. GHG intensity percentile among countries and regions (lower values indicate relatively lower GHG intensity) plotted against U.S. import penetration, defined as the ratio of total imports over consumption, for CITE sectors.

CITE emissions rise while non-U.S. emissions fall. Comparing the results with Figure 2 suggests these effects are indeed strongest in CITE sectors in which the U.S. is relatively cleaner (e.g., cement), or cleaner and more import dependent (e.g., iron and steel, non-metallic minerals, furniture). But in all CITE sectors, global emissions fall, because the decrease in non-U.S. emissions more than offsets the increase in U.S. emissions. In the aggregate, global GHG emissions drop by 70.7 million tons, of which 0.8 million tons are U.S. increases and 71.5 million tons are non-U.S. reductions.

A combined tariff and tax policy also lowers U.S. imports, though to a lesser extent, because the domestic tax offsets some of the advantage to U.S. CITE producers. The combined policy lowers U.S. output in many, though not all, CITE sectors because the domestic tax raises domestic production costs. In contrast to the tariff-only policy, the combined policy lowers U.S. emissions in all CITE sectors, even in the furniture sector, which experiences an output increase. In the aggregate, the drop in global emissions under the combined policy is 2.6 times that of a tariff-only policy, totaling 183.5 million tons in reductions, of which 113.2 million tons are from the U.S. and 70.3 million tons from other countries.

Table 1: Impact of U.S. carbon tariffs with and without U.S. carbon tax

A. Carbon import tariff, valued at $60 per tCO2e

Sector:	U.S. economic impacts: Imports	U.S. economic impacts: Output	GHG impacts: U.S.	GHG impacts: Other	GHG impacts: Global
	% chg		% (mil. tons CO2e) chg		
Aluminum	−1.5	−0.3	−0.0 (−0.0)	−0.2 (−0.3)	−0.2 (−0.3)
Iron and steel	−4.2	0.4	0.7 (0.3)	−0.1 (−3.1)	−0.1 (−2.8)
Non-metallic minerals	−1.8	0.6	0.7 (0.0)	−0.2 (−0.6)	−0.2 (−0.5)
Cement	−25.0	2.4	2.7 (1.6)	−1.5 (−32.5)	−1.3 (−30.9)
Chemicals	−1.6	0.1	0.2 (0.1)	−0.3 (−2.2)	−0.3 (−2.1)
Basic plastics	−1.9	0.2	0.3 (0.1)	−0.1 (−0.3)	−0.1 (−0.2)
Rubber and plastic	−2.2	0.2	0.4 (0.1)	−0.4 (−2.3)	−0.4 (−2.3)
N-fertilizer	−15.4	2.0	2.2 (0.0)	−1.6 (−0.5)	−1.5 (−0.5)
P-fertilizer	−1.9	−0.2	0.3 (0.1)	−0.1 (−0.4)	−0.1 (−0.3)
Furniture	−4.5	2.5	2.6 (0.3)	−3.7 (−25.9)	−3.6 (−25.6)
Glass	−2.2	−0.5	−0.4 (−0.1)	−0.2 (−0.3)	−0.2 (−0.3)
Aggregate:	Tariff rev.	Tax rev.	U.S.	Other	Global
	(bil. USD)		% (mil. tons CO2e) chg		
	13.9	0.0	0.0 (0.8)	−0.2 (−71.5)	−0.2 (−70.7)
			Real U.S. GDP (% chg):		0.012
			Climate impact-inclusive U.S. welfare (% chg):		0.030

B. Carbon tax + carbon import tariff, valued at $60 per tCO2e

Sector:	U.S. economic impacts: Imports	U.S. economic impacts: Output	GHG impacts: U.S.	GHG impacts: Other	GHG impacts: Global
	% chg		% (mil. tons CO2e) chg		
Aluminum	−1.2	−1.6	−41.6 (−2.6)	−0.2 (−0.2)	−2.5 (−2.8)
Iron and steel	−2.9	−2.6	−47.8 (−20.3)	−0.1 (−2.1)	−0.9 (−22.4)
Non-metallic minerals	−1.4	−1.2	−31.3 (−1.7)	−0.2 (−0.5)	−0.7 (−2.2)
Cement	−22.5	−1.4	−53.3 (−32.4)	−1.4 (−31.6)	−2.8 (−64.0)
Chemicals	−0.8	−1.7	−6.7 (−4.0)	−0.2 (−1.0)	−0.7 (−5.0)
Basic plastics	−0.0	−3.2	−34.2 (−15.6)	0.1 (0.4)	−3.5 (−15.3)
Rubber and plastic	−1.5	−1.3	−5.7 (−1.0)	−0.3 (−1.8)	−0.5 (−2.8)
N-fertilizer	−13.7	−1.0	−13.7 (−0.1)	−1.5 (−0.4)	−1.7 (−0.5)
P-fertilizer	1.3	−7.8	−47.9 (−19.9)	−0.0 (−0.1)	−4.9 (−20.0)
Furniture	−4.2	2.1	−15.2 (−1.7)	−3.6 (−25.7)	−3.8 (−27.4)
Glass	−1.1	−3.5	−27.4 (−4.2)	−0.1 (−0.1)	−3.3 (−4.3)
Aggregate:	Tariff rev.	Tax rev.	U.S.	Other	Global
	(bil. USD)		% (mil. tons CO2e) chg		
	14.1	14.9	−2.8 (−113.2)	−0.2 (−70.3)	−0.5 (−183.5)
			Real U.S. GDP (% chg):		0.015
			Climate impact-inclusive U.S. welfare (% chg):		0.063

Notes: Panel A (B) shows modeled results for a U.S. carbon tariff-only (carbon tariff and domestic carbon price) policy valued at $60 per ton CO_2e (in 2025 USD). Each panel shows for each CITE sector modeled, sector-level change in U.S. import, output (%); U.S., non-U.S., and global GHG emissions (% and mil. tons CO_2e). Aggregate outcomes include carbon tariff and tax revenue (bil. 2025 USD); U.S., non-U.S., and global GHG emissions (% and mil. tons CO_2e); real GDP and climate impact-inclusive welfare (%).

U.S. welfare impacts combine these emissions effects with changes in real GDP. A unilateral U.S. carbon tariff at \$60 per tCO_2e raises \$13.9 billion in tariff revenue and raises real U.S. GDP by 0.012%. The increase in GDP is due to terms-of-trade improvements as in the optimal tariff literature. Incorporating the avoided climate damages from GHG reductions, this implies an increase in U.S. consumption-equivalent welfare by 0.030%.

A combined policy includes additional effects that allow it to boost GDP and welfare relative to a standalone carbon tariff. In a closed economy, a carbon tax lowers GDP by raising production costs. But in a large open economy, a domestic production tax can raise GDP provided that the taxed product is sufficiently exported and revenue from the tax is recycled back to the domestic economy. This is the case with U.S. CITE sectors, for which the baseline emissions-weighted export share of output is 24.4% (see Table E.5).[19]

The combined policy raises \$14.9 billion in tax revenue, doubling the total revenue from a standalone tariff. GDP increases by 0.015% under the combined policy, slightly more than under the standalone carbon tariff. Together with the larger global emissions reductions, this leads to a 0.063% increase in welfare, or 2.1 times that of the tariff-only policy. Our quantitative exercise demonstrates there need not be a trade-off between emissions reductions and domestic economic outcomes and that a U.S. combined policy can achieve better outcomes on both dimensions than a standalone U.S. carbon tariff.

One possibility is that our results are sensitive to the trade elasticities employed in our model, which were obtained from Ossa (2015). Figure D.4 shows how our results change when we multiply sector-specific trade elasticities by 0.8, 0.9, 0.95, 1.0 (benchmark), 1.05, 1.1, and 1.2. The figure shows U.S.-wide aggregate results for GHG emissions (Panel A), U.S. government revenue (Panel B), U.S. real GDP (Panel C), and U.S. welfare (Panel D) under a standalone U.S. carbon tariff (in blue) and a combined carbon tariff and domestic tax policy (in red). Global emissions reductions remain substantially larger under a combined policy than a standalone tariff, while U.S. GDP and welfare changes are also higher in a combined policy.

4.2 Alternative unilateral U.S. policy designs

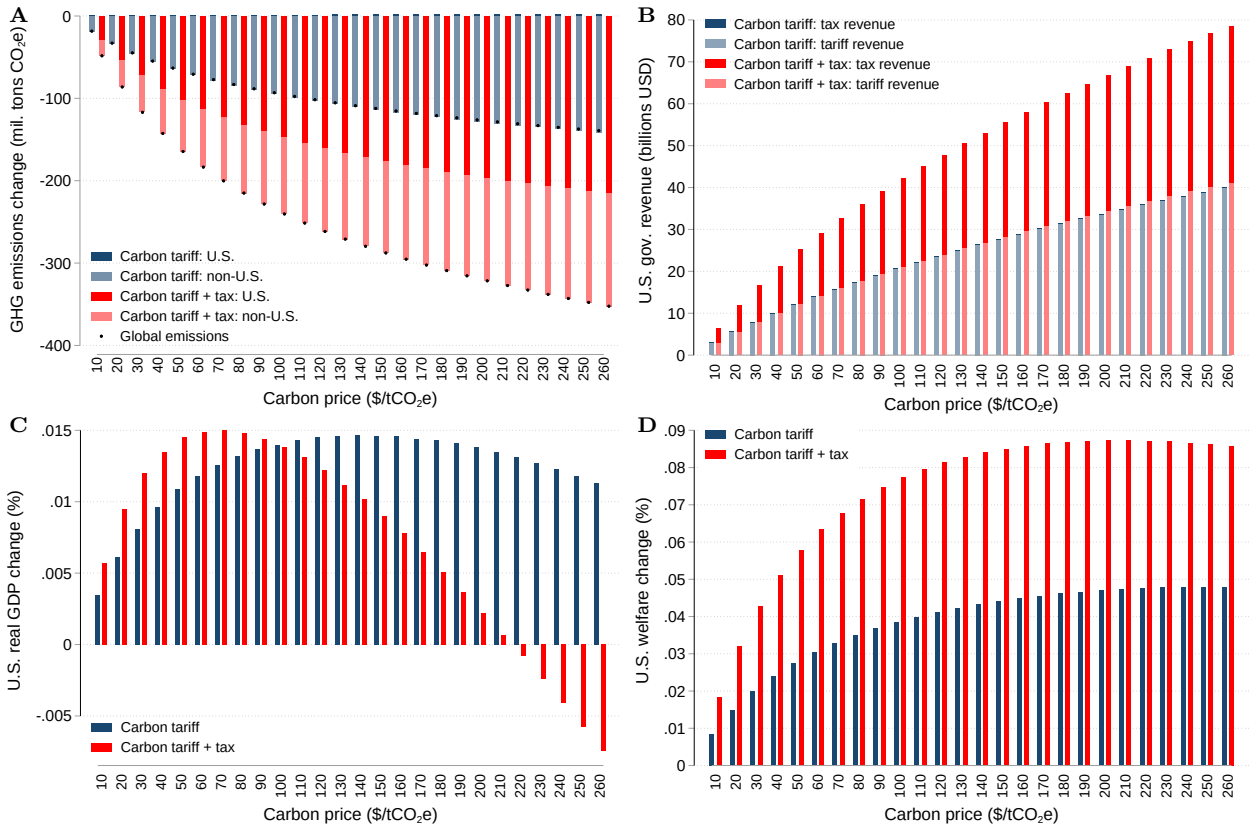
To examine the robustness of our results, we compare standalone U.S. carbon tariffs and combined policies when varying four design considerations: the policies' reference carbon price, the CITE sector definition, whether indirect GHG emissions from upstream in the

[19] Let the export share of output in country i sector m be $\mu_{i,m} = \frac{\sum_{\ell \neq i} X_{i\ell,m}}{Y_{i,m}}$. The emissions-weighted export share of output aggregated across CITE sectors in $\mathcal{C}$ is $\mu_i^{\mathcal{C}} = \frac{\sum_{n \in \mathcal{C}} E_{i,n} \mu_{i,n}}{\sum_{n \in \mathcal{C}} E_{i,n}}$, which is shown as the last column in Table E.5 for different CITE sector definitions.

supply chain are covered under a carbon tariff, and whether the domestic tax incentivizes endogenous abatement by shifting away from dirty inputs.

Carbon prices Figure 3 plots aggregate outcomes under carbon price values ranging from \$0 to \$260, the 2025 value of U.S. EPA's central global social cost of carbon estimate during the Biden Administration (EPA, 2023). Panel A shows GHG emissions under a standalone carbon tariff (blue) and a combined policy (red) for the U.S. (dark shading) and other countries (light shading). Across carbon prices, a standalone carbon tariff marginally increases U.S. emissions and substantially lowers non-U.S. emissions, yielding net global emissions reductions. Combined policies have similar non-U.S. emissions reductions but add more substantive U.S. reductions, resulting in net global reductions that are consistently more than double those under tariff-only policies. This difference also rises with the carbon price. Panel B shows that total U.S. government revenue under the combined policy is also consistently double that of the tariff-only policy due to additional carbon tax revenue.

Figure 3: Robustness check: Aggregate impacts under varying carbon prices



Notes: Modeled aggregate results for U.S. carbon tariff-only policy (in blue) and combined carbon tariff and domestic tax policy (in red) under different carbon price values. Panel A shows change in U.S. and non-U.S. GHG emissions (mil. tons CO_2e). Panel B shows change in U.S. government tariff and carbon tax revenues (bil. 2025 USD). Panel C shows U.S. real GDP change (%). Panel D shows U.S. welfare change (%).

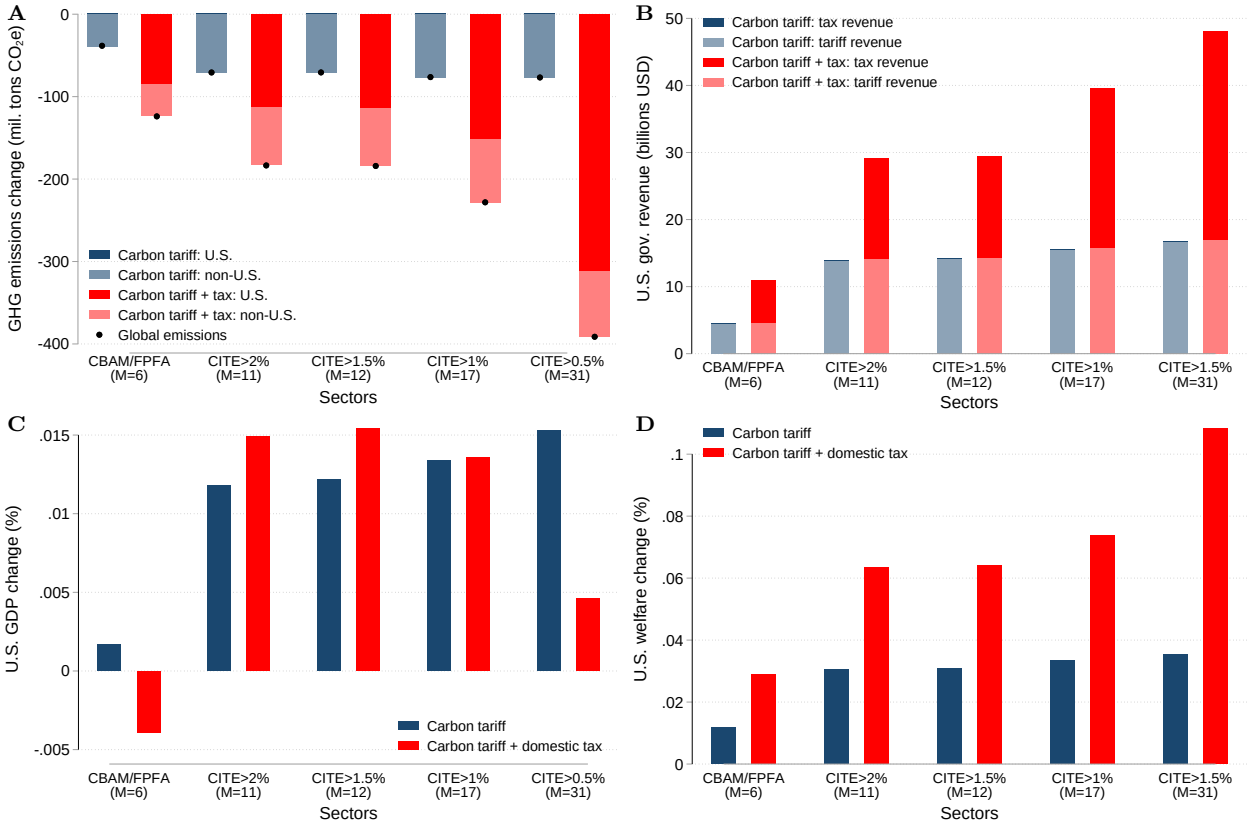
Panel C shows how real GDP varies with different carbon prices for each policy. It shows the characteristic inverse-U-shaped relationship between tariffs and real GDP for the standalone tariff. Interestingly, the real GDP response under a combined policy also exhibits an optimum, but that optimum occurs at a lower carbon price and yields higher real GDP than under a standalone carbon tariff. The domestic tax adds two further effects. It distorts production choices away from privately-optimal levels, which pushes GDP down. It also improves U.S. terms of trade. Since the U.S. exports output of CITE sectors, a domestic tax has elements of an export tax, implying that some of the tax incidence falls on foreign buyers. This pushes GDP up. In our setting, the net effect of these two forces leads to a higher GDP peak. For welfare (Panel D), which includes avoided climate damage from lowered global emissions, a combined policy exhibits positive welfare effects up to the $260 global SCC. This welfare effect is consistently double that from a tariff-only policy with greater global emissions reductions offsetting negative GDP effects at higher carbon prices.

CITE sector definitions Figure 4 follows a similar structure to Figure 3 but examines different CITE sector definitions. In addition to our benchmark CITE definition based on E.U. CBAM and U.S. FPFA sectors plus sectors with global emissions share and global import penetration rates above 2%, we also model policies that additionally include sectors with global emissions shares and import penetration above 1.5%, 1%, and 0.5%. We also apply policies to the more limited set of sectors eligible under the E.U. CBAM and U.S. FPFA. Table E.5 shows summary global and U.S. statistics for these alternative CITE sector definitions.

In general, global emissions reductions under combined policies are more than double those of tariff-only policies, with the emissions difference between the policies rising with the number of targeted sectors (Panel A). U.S. government revenues also increase from increasing carbon tax revenues (Panel B). Panel C shows real GDP impacts are more mixed, reflecting different export shares across CITE sector definitions. In general, CITE sectors for which the aggregate emissions-weighted export share of output is larger (see Table E.5) exhibit greater terms-of-trade improvements from a carbon tax and therefore more positive real GDP impacts. Despite this, the greater GHG reductions under combined policies consistently result in double the welfare improvement than under tariff-only policies, with the difference between policies increasing with greater sectoral coverage (Panel D).

Indirect emissions Figure 5 shows the impacts of changing GHG coverage to include indirect, upstream emissions, as has been debated for the E.U. CBAM and U.S. climate and trade proposals. The left columns are our benchmark where carbon tariffs and taxes

Figure 4: Robustness check: Aggregate impacts under alternative CITE sectors

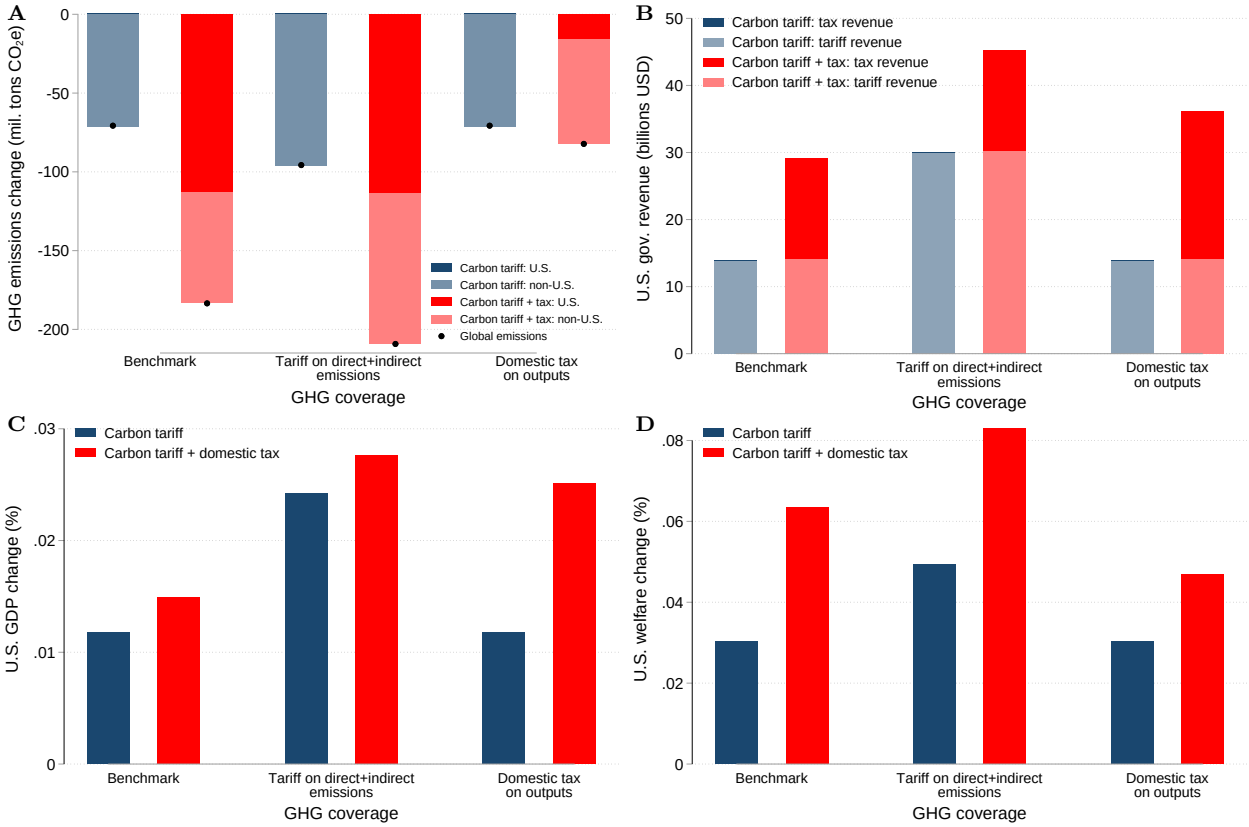


Notes: Modeled aggregate results for U.S. carbon tariff-only policy (in blue) and combined carbon tariff and domestic tax policy (in red) for E.U. CBAM and U.S. FPFA sectors (M=6), CITE sectors defined as CBAM/FPFA sectors plus sectors with global import penetration and share of global emissions above 2% (M=11), 1.5% (M=12), 1% (M=17), and 0.5% (M=31). Policies valued at \$60 per ton CO_2e (in 2025 USD). Panel A shows change in U.S. and non-U.S. GHG emissions (mil. tons CO_2e). Panel B shows change in U.S. government tariff and carbon tax revenues (bil. 2025 USD). Panel C shows U.S. real GDP change (%). Panel D shows U.S. welfare change (%).

are applied to GHG emissions emitted directly from each sector, without accounting for the indirect emissions from the upstream inputs used in that sector. The middle columns further cover indirect emissions when applying the carbon tariff. Both modeling choices appear in current policy proposals. Including indirect emissions expands the base of non-U.S. emissions covered by the carbon tariff, thus increasing the reduction in non-U.S. emissions (Panel A). However, the relative difference between a combined policy and a standalone carbon tariff remains similar to the benchmark results, with U.S. real GDP and welfare improvements from a combined policy larger than those of a standalone carbon tariff (Panels C and D). These results are also shown in Table E.7.

Endogenous input substitution In our benchmark analysis, we model the domestic tax as an input-specific tax on emissions, which allows for endogenous GHG abatement both

Figure 5: Robustness check: Aggregate impacts under alternative GHG coverage



Notes: Modeled aggregate results for U.S. carbon tariff-only policy (in blue) and combined carbon tariff and domestic tax policy (in red) under (i) benchmark GHG coverage, (ii) when carbon tariff is applied to direct and indirect GHG emissions, and (iii) when domestic carbon tax is applied to outputs and not inputs. Policies valued at \$60 per ton CO_2e (in 2025 USD). Panel A shows change in U.S. and non-U.S. GHG emissions (mil. tons CO_2e). Panel B shows change in U.S. government tariff and carbon tax revenues (bil. 2025 USD). Panel C shows U.S. real GDP change (%). Panel D shows U.S. welfare change (%).

through input substitution and output reduction. We model the carbon tariff as an output tax on emissions, which only allows for abatement through output reductions within a given sector. As noted earlier, there is a fundamental asymmetry in how policy proposals treat domestic carbon taxes and carbon import tariffs.

The right columns of Figure 5 show the impact of treating the domestic tax as an output tax, effectively shutting down abatement via input substitution. Relative to the combined policy with input substitution in the left benchmark columns, U.S. emissions reductions shrink by over 80% (Panel A). Indeed, Figure D.5 shows that the domestic input tax leads to lower expenditures for more carbon-intensive fuels, whereas that relationship is much weaker under the domestic output tax, indicative of the domestic input tax inducing greater fuel substitution than the domestic output tax. Despite lower emissions reductions, global emissions reductions from a combined policy still exceed those from a standalone tariff (Panel

A). Smaller U.S. emissions reductions imply higher revenue from the domestic tax (Panel B) than in the benchmark model. Increases in real GDP and welfare remain larger under the combined policy than under a standalone tariff (Panels C and D). These results are also shown in Table E.8.

4.3 Multilateral policies

Prior literature has emphasized the important role of carbon tariffs as part of global climate policy architecture. We examine the emissions consequences of multilateral climate and trade policies. As with unilateral policies, we model two types of multilateral policies: one built on a carbon import tariff without a domestic carbon price, and another built on a combined carbon tariff and domestic carbon price. The latter policy is related to the climate club framework proposed by Nordhaus (2015) and more formally studied in Farrokhi and Lashkaripour (2025), though for just the subset of CITE sectors. In that arrangement, countries within a club adopt similar domestic carbon taxes, waive carbon import tariffs among club members, and jointly impose carbon import tariffs on non-club countries. When modeling multilateral policy based on just carbon tariffs, we maintain the same structure of carbon tariffs on non-members and waivers for members, but without members adopting domestic carbon taxes.[20]

Table 2 examines GHG consequences of different coalitions of multilateral climate policies built on carbon tariffs alone (Panel A) and combined with a domestic carbon tax (Panel B), valued at \$60 per tCO_2e (in 2025 USD) applied to benchmark CITE sectors. We reproduce our unilateral U.S. policy results and then incrementally expand membership by adding (i) the E.U., (ii) the remaining OECD countries, (iii) Brazil, China, Indonesia, and India, (iv) the rest of Asia, (v) the rest of the Americas, and (vi) the rest of the world (see Table E.1 for region definitions).

Two forces are at play under a tariff-only policy as membership grows. First, the costs imposed on non-club countries grow as an increasing number of their trade partners impose carbon tariffs on non-club country exports. This leads to rising global emissions reductions. Second, as club membership expands, there are fewer non-club countries to impose carbon tariffs on. Membership expansion reduces the emissions base subject to tariffs, inducing smaller global emissions reductions. These two opposing forces, on net, lead global emissions reductions to rise initially and then fall as membership expands. For example, global

[20]Our analysis does not consider incentives to join a club and thus whether specific coalitions are stable. As such, we focus on reporting emissions impacts and not other outcomes. Also, we do not consider broad tariffs that are meant to enforce the coalitions and focus only on tariffs tied to carbon emissions. For climate club games using a quantitative trade framework see (Farrokhi and Lashkaripour, 2025; Bourany, 2025).

Table 2: Impacts of multilateral carbon tariffs with and without domestic carbon tax

Club membership	GHG impacts			
	U.S.	Club members	Non-members	Global
	% change (mil. tons CO2e change)			
A. Carbon import tariff, valued at $60 per tCO2e				
US	0.0 (0.8)	−− (−−)	−0.2 (−71.5)	−0.2 (−70.7)
US+EU	0.0 (0.8)	0.1 (3.5)	−0.4 (−107.6)	−0.3 (−104.1)
OECD	0.0 (0.2)	0.1 (6.6)	−0.6 (−156.8)	−0.4 (−150.2)
OECD+BR+CN+ID+IN	0.0 (0.5)	0.1 (30.8)	−2.1 (−202.1)	−0.5 (−171.3)
OECD+BR+CN+ID+IN+Asia	0.0 (0.3)	0.1 (22.8)	−2.0 (−149.2)	−0.3 (−126.4)
OECD+BR+CN+ID+IN+Asia+Am.	0.0 (0.3)	0.1 (22.6)	−2.2 (−147.4)	−0.3 (−124.9)
World	0.0 (0.0)	0.0 (0.0)	−− (−−)	0.0 (0.0)
B. Carbon import tariff + carbon tax, valued at $60 per tCO2e				
US	−2.8 (−113.2)	−− (−−)	−0.2 (−70.3)	−0.5 (−183.5)
US+EU	−2.8 (−113.9)	−3.9 (−253.7)	−0.4 (−107.0)	−1.0 (−360.6)
OECD	−2.9 (−116.0)	−5.4 (−553.8)	−0.6 (−153.9)	−1.9 (−707.8)
OECD+BR+CN+ID+IN	−2.9 (−119.4)	−13.2 (−3540.6)	−2.5 (−243.1)	−10.3 (−3783.7)
OECD+BR+CN+ID+IN+Asia	−3.0 (−119.5)	−13.3 (−3875.3)	−2.5 (−188.4)	−11.1 (−4063.7)
OECD+BR+CN+ID+IN+Asia+Am.	−3.0 (−120.4)	−13.2 (−3942.0)	−2.8 (−184.3)	−11.3 (−4126.3)
World	−3.0 (−121.1)	−13.2 (−4831.3)	−− (−−)	−13.2 (−4831.3)

Notes: Panel A (B) shows modeled results for a U.S. carbon tariff-only (carbon tariff and domestic carbon tax) policy valued at $60 per ton CO_2e (in 2025 USD) for different coalitions of countries. Each panel shows modeled change in U.S. GHG emissions, non-U.S. coalition GHG emissions, non-coalition GHG emissions, and global GHG emissions (all in mil. tons CO_2e). BR=Brazil. CN=China. ID=Indonesia. IN=India. Asia=Rest of Asia. Am=Rest of South and Central America. See Table E.1 for regional definitions.

emissions drop by 171.3 million tons or 0.5% when membership includes the OECD countries and Brazil, China, Indonesia, and India. Global reductions then start falling as other Asian and South and Central American countries join the coalition. And in the limit where membership is universal, a tariff-only approach returns the world to where it is today; there are no carbon tariffs, no additional domestic policy, and no global emissions reductions.

By contrast, under multilateral agreements that require member adoption of a domestic carbon tax, global GHG reductions increase monotonically with expanding membership, driven primarily by increased adoption of domestic pricing. Under combined policies valued at $60 applied to benchmark CITE sectors, we model that a multilateral coalition involving countries in the OECD, Brazil, China, Indonesia, and India reduces global emissions by 3783.7 million tons, or 10.3%. That reduction is not only substantially larger than a tariff-only coalition, but continues to increase as membership grows further. When all countries are part of the coalition, global GHG emissions fall by 4831.3 million tons or 13.2%. This occurs despite CITE sectors contributing only 67.5% of baseline global emissions among globally traded, non-fossil fuel goods.

5 Discussion

We build a multi-region, multi-sector quantitative trade model with input-output linkages and endogenous GHG abatement to evaluate the GHG emissions and economic impacts of two U.S. policies designed to match currently proposed legislation. We study a standalone carbon tariff in the spirit of the Foreign Pollution Fee Act and a policy that combines carbon tariffs with domestic carbon taxes in the spirit of the Clean Competition Act.

We find that both policies reduce emissions, but the combined policy reduces emissions by twice as much. Both policies increase U.S. GDP, but the combined policy has a larger impact under most specifications. Thus, there may not be a trade-off between global emissions reductions and U.S. GDP. Our results suggest that combined policies generate greater improvements along both margins and therefore lead to greater improvements in welfare.

In multilateral coalitions, carbon tariffs alone do not lead to monotonic increases in global emissions reductions as coalition membership grows. Instead, as more countries join the coalition, carbon tariffs place increasing pressure on fewer non-member countries such that global reductions eventually fall. In the limit where all countries join, there are no emissions reductions and the world returns to a state of no carbon tariffs and no additional domestic policy. In contrast, multilateral coalitions that require domestic policy achieve greater emissions reductions as membership increases.

Returning to this paper's title, should policymakers view standalone carbon tariffs as climate policy? Our results suggest that standalone carbon tariffs are ineffective climate policy at best. They do reduce global GHG emissions, which is not theoretically guaranteed. However, these emissions reductions are much smaller than those achieved under an approach that combines carbon tariffs with domestic policy. As a result, the combined policy leads to a much larger increase in U.S. welfare. Furthermore, tariff-only policies do not yield meaningful global emissions reductions in multilateral coalitions. As such, standalone carbon tariffs are not a foundation for global climate policy.

Our analysis can be extended along several dimensions. First, our assumptions on production structure might be relaxed to better capture firm-level abatement responses. In our model, we assume that production is Cobb-Douglas in all sectors, so the elasticity of substitution is one across all inputs. This elasticity governs the degree of abatement that occurs in response to the domestic climate policy. Extensions may introduce a more flexible functional form, such as CES, to capture a wider range of substitution possibilities. In addition, existing research suggests that elasticities vary with time horizon (e.g., Atkeson and Kehoe, 1999; Hassler, Krusell and Olovsson, 2021), which could be incorporated into a dynamic extension of our model.

Second, as our aim is to inform ongoing discussions of U.S. climate and trade policy, one can refine our model to incorporate design features currently under consideration. For example, the CCA has a carbon tax applied only to domestic firms that are more carbon-intensive than the domestic average for that sector. Modeling such a performance standard would require a model with firm heterogeneity in emissions intensity and firm-specific emissions intensity data in order to calibrate that heterogeneity. While that data is not readily available, future model extensions could incorporate firm-level emissions intensities constructed from administrative data sources, both from the U.S. and elsewhere. Introducing this heterogeneity would allow for analyses of domestic performance standards.

References

Atkeson, Andrew, and Patrick J Kehoe. 1999. "Models of energy use: Putty-putty versus putty-clay." *American Economic Review*, 89(4): 1028–1043.

Bickerdike, Charles F. 1907. "Review of A. C. Pigou's Protective and Preferential Import Duties." *The Economic Journal*, 17(65): 98–102.

Böhringer, Christoph, Carolyn Fischer, Knut Einar Rosendahl, and Thomas Fox Rutherford. 2022. "Potential impacts and challenges of border carbon adjustments." *Nature Climate Change*, 12(1): 22–29.

Böhringer, Christoph, Edward J Balistreri, and Thomas F Rutherford. 2012. "The role of border carbon adjustment in unilateral climate policy: Overview of an Energy Modeling Forum study (EMF 29)." *Energy Economics*, 34: S97–S110.

Bourany, Thomas. 2025. "The Optimal Design of Climate Agreements: Inequality, Trade, and Incentives for Climate Policy." mimeo.

Brunel, Claire, and Arik Levinson. 2024. "Carbon Tariffs 101." National Bureau of Economic Research Working Paper 33024.

Clausing, Kimberly A, Jonathan M Colmer, Allan Hsiao, and Catherine Wolfram. 2025. "The Global Effects of Carbon Border Adjustment Mechanisms." National Bureau of Economic Research Working Paper 33723.

Conte, Bruno, Klaus Desmet, and Esteban Rossi-Hansberg. 2025. "On the Geographic Implications of Carbon Taxes." *The Economic Journal*.

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

Costinot, Arnaud, and Andrés Rodríguez-Clare. 2014. "Trade theory with numbers: Quantifying the consequences of globalization." In *Handbook of international economics*. Vol. 4, 197–261. Elsevier.

EPA. 2023. "EPA Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances." *Supplementary Material for the Regulatory Impact Analysis for the Final Rulemaking, "Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review"*. US Environmental Protection Agency Washington, DC.

Fan, Haichao, Yuan Mei, Tong Ni, and Huanhuan Wang. 2025. "Carbon Border Adjustment Mechanism and Trade Policy: A Quantitative Analysis." *Available at SSRN 6003654*.

Farrokhi, Farid, Ahmad Lashkaripour, and Homa Taheri. 2025. "A Framework for Integrating Climate Goals into Trade Agreements." Mimeo.

Farrokhi, Farid, and Ahmad Lashkaripour. 2025. "Can Trade Policy Mitigate Climate Change?" *Econometrica*, 93(5): 1561–1599.

Garcia-Lembergman, Ezequiel, Natalia Ramondo, Andrés Rodríguez-Clare, and Joseph S. Shapiro. 2025. "Carbon Emissions in the Global Economy."

Hassler, John, Per Krusell, and Conny Olovsson. 2021. "Directed technical change as a response to natural resource scarcity." *Journal of Political Economy*, 129(11): 3039–3072.

Hoel, Michael. 1991. "Global environmental problems: the effects of unilateral actions taken by one country." *Journal of environmental economics and management*, 20(1): 55–70.

IPCC. 2006. "Chapter 2: Stationary combustion."

Kopits, Elizabeth, Daniel Kraynak, Bryan Parthum, Lisa Rennels, David Smith, Elizabeth Spink, Charles Griffiths, Joseph Perla, Nshan Burns, and Michael Howerton. 2025. "Economic Damages from Climate Change to U.S. Populations: Integrating Evidence from Recent Studies." U.S. EPA.

Kortum, Samuel S, and David A Weisbach. 2021. "Optimal unilateral carbon policy."

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

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

OECD. 2023. "Pricing Greenhouse Gas Emissions Through Taxes and Emissions Trading."

Ossa, Ralph. 2014. "Trade Wars and Trade Talks with Data." *American Economic Review*, 104(12): 4104–46.

Ossa, Ralph. 2015. "Why trade matters after all." *Journal of International Economics*, 97(2): 266–277.

Stadler, Konstantin, Richard Wood, Tatyana Bulavskaya, Carl-Johan Södersten, Moana Simas, Sarah Schmidt, Arkaitz Usubiaga, José Acosta-Fernández, Jeroen Kuenen, Martin Bruckner, Stefan Giljum, Stephan Lutter, Stefano Merciai, Jannick H. Schmidt, Michaela C. Theurl, Christoph Plutzar, Thomas Kastner, Nina Eisenmenger, Karl-Heinz Erb, Arjan de Koning, and Arnold Tukker. 2018. "EXIOBASE 3: Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input-Output Tables." *Journal of Industrial Ecology*, 22(3): 502–515.

Timmer, Marcel, Ton Moergastel, Edwin Stuivenwold, Mary O'Mahony, and Mari Kangasniemi. 2007. "EU KLEMS Growth and Productivity Accounts Version 1.0."

Vidovic, D., A. Marmier, L. Zore, and J. Moya. 2023. "Greenhouse gas emission intensities of the steel, fertilisers, aluminium and cement industries in the EU and its main trading partners." , (KJ-NA-31-653-EN-N (online)).

Weisbach, David A, Samuel Kortum, Michael Wang, and Yujia Yao. 2023. "Trade, leakage, and the design of a carbon tax." *Environmental and Energy Policy and the Economy*, 4(1): 43–90.

Wolfram, Catherine, Joseph Aldy, Candido Bracher, Gregory Casey, Kimberly Clausing, Vaibhav Chaturvedi, Carolyn Fischer, Christian Gollier, Allan Hsiao, Frank Jotzo, Marcelo Medeiros, Kyle Meng, Athiphat Muthitacharoen, Axel Ockenfels, Mari Pangestu, Marilyn Pereboom, Arathi Rao, Ivan Rudik, Daouda Sembene, Naomi Shimberg, E. Somanathan, Dustin Tingley, and Jennifer Winter. 2026. "Building a Scalable Climate Coalition for Heavy Industry." Mimeo.

World Bank. 2022. "World Integrated Trade Solution (WITS)." Accessed 2022.

Appendices

A Theory appendix

This appendix derives the exact hat-algebra system and solution algorithm for our model in Section 2. Throughout, hats denote relative changes in variables: $\hat{x} \equiv x'/x$.

A.1 Exact hat algebra

In this subsection we derive a set of equations in terms of counterfactual variables relative to baseline variables to solve our model in changes using standard exact hat algebra techniques. Everything that follows assumes iceberg trade costs and country-level labor endowments are fixed so that $\hat{\tau}_{ij,m} = 1$ and $\hat{L}_j = 1$. Tariff changes $\hat{\varphi}_{ij,m}$ are exogenous policy shocks constructed from changes in carbon prices. Domestic carbon tax changes $\hat{\psi}_{j,nm}$ are exogenous policy shocks constructed from policy carbon prices and the input-specific emissions factors $(\upsilon_{j,m}, \upsilon_n)$. Preference parameters (α, σ) and technology shares (η, ω) are held fixed.

The materials unit-cost index in (j, m) is given by:

$$P_{j,m}^M = \prod_{n=1}^{M} \left(\psi_{j,nm} P_{j,n}\right)^{\omega_{j,nm}}.$$

Expressing this in hat terms gives:

$$\widehat{P}_{j,m}^M = \prod_{n=1}^{M} \left(\hat{\psi}_{j,nm} \hat{P}_{j,n}\right)^{\omega_{j,nm}}. \tag{A.1}$$

For fossil fuel inputs $n \in \mathcal{E}$, we parameterize the ad-valorem carbon tax as:

$$\psi_{j,nm} = 1 + \delta_{j,m}\upsilon_{j,m}\upsilon_n, \qquad \psi'_{j,nm} = 1 + \delta'_{j,m}\upsilon_{j,m}\upsilon_n, \qquad \hat{\psi}_{j,nm} = \frac{\psi'_{j,nm}}{\psi_{j,nm}}$$

Non-fossil fuel sectors $n \notin \mathcal{E}$ are not taxed and so we set $\psi_{j,nm} = \psi'_{j,nm} = \hat{\psi}_{j,nm} = 1$.

Equation (4) yields the factory-gate price:

$$p_{j,m} = \chi_{j,m}^{-1} \tilde{\eta}_{j,m}\, w_j^{\eta_{j,m}} \left(P_{j,m}^M\right)^{1-\eta_{j,m}}.$$

In hat terms this simplifies to:

$$\hat{p}_{j,m} = \hat{w}_j^{\eta_{j,m}} \left(\widehat{P}_{j,m}^M\right)^{1-\eta_{j,m}} \tag{A.2}$$

since productivity is held fixed. The local composite price index is given by equation (8):

$$P_{j,m}^{1-\sigma_m} = \sum_{i=1}^{N} a_{ij,m} \left(p_{i,m}\tau_{ij,m}\varphi_{ij,m}\right)^{1-\sigma_m}.$$

Take the ratio of counterfactual and baseline, then multiply and divide each term by its baseline contribution to destination-sector expenditure:

$$\hat{P}_{j,m}^{1-\sigma_m} = \sum_{i=1}^{N} \frac{a_{ij,m}(p_{i,m}\tau_{ij,m}\varphi_{ij,m})^{1-\sigma_m}}{P_{j,m}^{1-\sigma_m}} \left(\hat{p}_{i,m}\hat{\varphi}_{ij,m}\right)^{1-\sigma_m}.$$

Using the baseline trade share $\lambda_{ij,m} = \frac{a_{ij,m}(p_{i,m}\tau_{ij,m}\varphi_{ij,m})^{1-\sigma_m}}{P_{j,m}^{1-\sigma_m}}$, we obtain the hat version:

$$\hat{P}_{j,m} = \left(\sum_{i=1}^{N} \lambda_{ij,m} \left[\hat{p}_{i,m}\hat{\varphi}_{ij,m}\right]^{1-\sigma_m}\right)^{\frac{1}{1-\sigma_m}}. \tag{A.3}$$

Equations (A.1)–(A.3) define the algorithm's inner fixed point in prices: materials costs depend on destination composite prices, and destination composite prices depend on source factory-gate prices.

From equation (9) trade shares are given by:

$$\lambda_{ij,m} = \frac{a_{ij,m}\left(p_{i,m}\tau_{ij,m}\varphi_{ij,m}\right)^{1-\sigma_m}}{\sum_{l=1}^{N} a_{lj,m}\left(p_{l,m}\tau_{lj,m}\varphi_{lj,m}\right)^{1-\sigma_m}}.$$

Following a similar procedure to the local composite price index gives the hat version:

$$\hat{\lambda}_{ij,m} = \frac{\left[\hat{p}_{i,m}\hat{\varphi}_{ij,m}\right]^{1-\sigma_m}}{\sum_{l=1}^{N} \lambda_{lj,m}\left[\hat{p}_{l,m}\hat{\varphi}_{lj,m}\right]^{1-\sigma_m}}. \tag{A.4}$$

The sectoral labor first-order condition for the producer implies:

$$w_j L_{j,m} = \eta_{j,m} Y_{j,m},$$

which gives us that:

$$\hat{Y}_{j,m} = \widehat{w_j L_{j,m}}.$$

Given $\hat{Y}_{j,m}$, we recover counterfactual revenue levels as $Y'_{j,m} = Y_{j,m}\hat{Y}_{j,m}$. From Cobb-Douglas cost shares, pre-tax materials expenditures satisfies:

$$X_{j,nm}^{I} = \omega_{j,nm}(1-\eta_{j,m})\frac{Y_{j,m}}{\psi_{j,nm}},$$

so we can express counterfactual levels as:

$$X_{j,nm}^{I\prime} = \omega_{j,nm}(1-\eta_{j,m})\frac{Y_{j,m}\hat{Y}_{j,m}}{\psi_{j,nm}\hat{\psi}_{j,nm}}. \tag{A.5}$$

Next, define total materials demand for destination sector m composite in country j as:

$$X_{j,m}^{I\prime} \equiv \sum_{u=1}^{M} X_{j,mu}^{I\prime}.$$

Then the gross expenditure identity in equation (11) implies

$$X_{j,m}^{\prime} = \alpha_{j,m}X_{j}^{F\prime} + X_{j,m}^{I\prime}. \tag{A.6}$$

Bilateral expenditures follow from the definition $X_{ij,m} = \lambda_{ij,m}X_{j,m}$:

$$X_{ij,m}^{\prime} = \lambda_{ij,m}\hat{\lambda}_{ij,m}X_{j,m}^{\prime}. \tag{A.7}$$

Finally, sales equal tariff-net expenditures from all destinations (equation (12)):

$$Y_{i,m}^{\prime} = \sum_{j=1}^{N}\frac{X_{ij,m}^{\prime}}{\varphi_{ij,m}^{\prime}}, \tag{A.8}$$

where $\varphi_{ij,m}^{\prime} = \hat{\varphi}_{ij,m}\varphi_{ij,m}$.

Next, define baseline labor income and its share in final expenditure:

$$w_jL_j \equiv \sum_m \eta_{j,m}Y_{j,m}, \qquad \pi_j^L \equiv \frac{w_jL_j}{X_j^F}.$$

Let $\bar{\tau}_{j,m}$ denote tariff revenue as a share of gross expenditure in destination (j,m) which can be expressed as:

$$\bar{\tau}_{j,m}^{\prime} \equiv \sum_{i=1}^{N}\lambda_{ij,m}^{\prime}\frac{t_{ij,m}^{\prime}}{\varphi_{ij,m}^{\prime}}.$$

Then total tariff revenue in levels is given by:

$$T_j^{\prime}L_j = \sum_m \bar{\tau}_{j,m}^{\prime}\left(\alpha_{j,m}X_j^{F\prime} + X_{j,m}^{I\prime}\right) = X_j^{F\prime}\sum_m \alpha_{j,m}\bar{\tau}_{j,m}^{\prime} + \sum_m \bar{\tau}_{j,m}^{\prime}X_{j,m}^{I\prime}.$$

Divide this by baseline final good expenditures X_j^F to obtain:

$$\frac{T_j^{\prime}L_j}{X_j^F} = \hat{X}_j^F f_j + h_j$$

where

$$f_j \equiv \sum_{m=1}^{M} \alpha_{j,m}\, \bar{\tau}'_{j,m}, \tag{A.9}$$

$$h_j \equiv \frac{1}{X_j^F} \sum_{m=1}^{M} \bar{\tau}'_{j,m}\, X_{j,m}^{I\prime}, . \tag{A.10}$$

Counterfactual carbon-tax revenue as a share of baseline expenditure is g_j where:

$$g_j \equiv \frac{1}{X_j^F} \sum_{m=1}^{M} \sum_{n \in \mathcal{E}} \left(\psi'_{j,nm} - 1\right) X_{j,nm}^{I\prime}. \tag{A.11}$$

Using the balanced budget identity:

$$X_j^{F\prime} = w_j L_j \hat{w}_j + T'_j L_j + \mathcal{T}'_j L_j,$$

dividing through by X_j^F yields:

$$\hat{X}_j^F = \pi_j^L \hat{w}_j + \hat{X}_j^F f_j + h_j + g_j.$$

We can then rearrange to get:

$$\hat{X}_j^F = \frac{\pi_j^L \hat{w}_j + h_j + g_j}{1 - f_j}. \tag{A.12}$$

A.2 Solution algorithm

Building on the hat equations in the previous section, we use the following algorithm to solve for the nested fixed point of the system of equations.

1. Guess an initial vector of sectoral revenue changes $\hat{Y}_{i,m}$.

2. Compute wages from the current guess of sectoral revenue changes $\hat{Y}_{i,m}$:

$$\hat{w}_i \;=\; \sum_{m=1}^{M} \Gamma_{i,m}\, \hat{Y}_{i,m}, \qquad \Gamma_{i,m} \equiv \frac{w_i L_{i,m}}{\sum_{k=1}^{M} w_i L_{i,k}}. \tag{A.13}$$

3. Given $\{\hat{Y}_{i,m}\}$, update sectoral revenues:

$$Y'_{i,m} = Y_{i,m} \hat{Y}_{i,m}. \tag{A.14}$$

4. **Inner loop:** Given a vector of wages $\{\hat{w}_j\}$ from the outer loop and a guess of $\{\hat{P}_{j,m}\}$, iterate on the following until convergence:

   (a) Solve for materials unit costs:

$$\hat{P}^M_{j,m} \;=\; \prod_{n=1}^{M} \left(\widehat{\widetilde{P}}_{j,nm}\right)^{\omega_{j,nm}} \qquad \widehat{\widetilde{P}}_{j,nm} = \begin{cases} \hat{\psi}_{j,nm}\hat{P}_{j,n}, & n \in \mathcal{E}, \\ \hat{P}_{j,n}, & n \notin \mathcal{E}, \end{cases} \tag{A.15}$$

   (b) Compute the factory-gate price:

$$\hat{p}_{j,m} \;=\; \hat{w}_j^{\eta_{j,m}} \left(\hat{P}^M_{j,m}\right)^{1-\eta_{j,m}}. \tag{A.16}$$

   (c) Update sectoral price indices:

$$\hat{P}^{\star}_{j,m} \;=\; \left[\sum_{i=1}^{N} \lambda_{ij,m} \left(\hat{p}_{i,m}\hat{\varphi}_{ij,m}\right)^{1-\sigma_m}\right]^{\frac{1}{1-\sigma_m}}, \qquad \hat{\varphi}_{ij,m} \equiv \varphi'_{ij,m}/\varphi_{ij,m}. \tag{A.17}$$

   Damp the inner-loop update with damping parameter $\kappa_P \in (0,1]$:

$$\hat{P}^{\text{new}}_{j,m} \;=\; (1-\kappa_P)\hat{P}^{\text{old}}_{j,m} + \kappa_P \hat{P}^{\star}_{j,m}. \tag{A.18}$$

5. Compute trade shares:

$$\hat{\lambda}_{ij,m} \;=\; \left(\frac{\hat{p}_{i,m}\hat{\varphi}_{ij,m}}{\hat{P}_{j,m}}\right)^{1-\sigma_m} \tag{A.19}$$

6. Compute materials expenditures on fossil fuel inputs: $(n \in \mathcal{E})$:

$$X^{I\prime}_{j,nm} \;=\; \left(\psi'_{j,nm}\right)^{-1} \omega_{j,nm} \left(1-\eta_{j,m}\right) Y'_{j,m}, \tag{A.20}$$

   and non-fossil fuel inputs $(n \notin \mathcal{E})$:

$$X^{I\prime}_{j,nm} \;=\; \omega_{j,nm} \left(1-\eta_{j,m}\right) Y'_{j,m}. \tag{A.21}$$

7. Solve for expenditures by first computing the following objects:

$$\bar{\tau}'_{j,m} = \sum_{i=1}^{N} t'_{ij,m} (\varphi'_{ij,m})^{-1} \lambda'_{ij,m} \tag{A.22}$$

$$f_j = \sum_{m=1}^{M} \alpha_{j,m} \bar{\tau}'_{j,m} \tag{A.23}$$

$$h_j = \frac{1}{X_j^F} \sum_{m=1}^{M} \bar{\tau}'_{j,m} \sum_{n=1}^{M} X_{j,mn}^{I\prime}, \tag{A.24}$$

$$\mathcal{T}'_j = \frac{1}{L_j} \sum_{m=1}^{M} \sum_{n \in \mathcal{E}} (\psi'_{j,nm} - 1) X_{j,nm}^{I\prime} \tag{A.25}$$

$$g_j \equiv \frac{\mathcal{T}'_j}{X_j^F / L_j}. \tag{A.26}$$

Then define the baseline expenditure share $\pi_j^L \equiv \frac{w_j L_j}{X_j^F}$ and compute:

$$\hat{X}_j^F \;=\; \frac{\pi_j^L \hat{w}_j + h_j + g_j}{1 - f_j}. \tag{A.27}$$

8. Compute total sectoral expenditures:

$$X'_{j,m} \;=\; \alpha_{j,m} \hat{X}_j^F X_j^F \;+\; \sum_{n=1}^{M} X_{j,mn}^{I\prime} \tag{A.28}$$

and bilateral trade flows:

$$X'_{ij,m} = \hat{\lambda}_{ij,m} \lambda_{ij,m} X'_{j,m}.$$

9. Update sectoral revenues:

$$Y'_{i,m} \;=\; \sum_{j=1}^{N} (\varphi'_{ij,m})^{-1} X'_{ij,m}, \qquad w'_i L'_{i,m} = \eta_{i,m} Y'_{i,m}. \tag{A.29}$$

$$\hat{Y}^*_{i,m} \;\equiv\; \frac{Y'_{i,m}}{Y_{i,m}}, \qquad \hat{Y}^*_{i,m} = 1 \text{ when } Y_{i,m} = 0. \tag{A.30}$$

Damp the update with damping parameter κ_L

$$\hat{Y}_{i,m}^{\text{new}} \;=\; (1 - \kappa_L) \hat{Y}_{i,m}^{\text{old}} + \kappa_L \hat{Y}^*_{i,m}, \qquad \kappa_L \in (0, 1]. \tag{A.31}$$

10. **Convergence.** Iterate Steps 2–9 until $\{\hat{Y}_{i,m}\}$ converges.

A.3 Outcome variables

This subsection details construction of key outcome variables from the solved hat variables.

Sectoral gross output quantity is $q_{j,m} = Y_{j,m}/p_{j,m}$, so:

$$\hat{q}_{j,m} = \frac{\hat{Y}_{j,m}}{\hat{p}_{j,m}}.$$

From equation (A.3), the change in the CES sector-level price index is:

$$\hat{P}_{j,m} = \left(\sum_{i=1}^{N} \lambda_{ij,m} \ (\hat{p}_{i,m} \hat{\varphi}_{ij,m})^{1-\sigma_m} \right)^{\frac{1}{1-\sigma_m}}. \tag{A.32}$$

From equation (2), the country consumption price index is:

$$\hat{P}_j = \prod_{m=1}^{M} \left(\hat{P}_{j,m} \right)^{\alpha_{j,m}}. \tag{A.33}$$

For emissions, we note that for fossil fuel inputs $n \in \mathcal{E}$ used by producers in (j,m), because we normalized $P_{j,n} = 1$, we have that $P'_{j,n} = \hat{P}_{j,n}$ which delivers:

$$M'_{j,nm} = \frac{X^{I\prime}_{j,nm}}{P'_{j,n}} = \frac{X^{I\prime}_{j,nm}}{\hat{P}_{j,n}}, \qquad E'_{j,nm} = \upsilon_{j,m} \upsilon_n \, M'_{j,nm} = \upsilon_{j,m} \upsilon_n \frac{X^{I\prime}_{j,nm}}{\hat{P}_{j,n}}.$$

Total global emissions are $E = \sum_{j,m} \sum_{n \in \mathcal{E}} E_{j,nm}$ and $E' = \sum_{j,m} \sum_{n \in \mathcal{E}} E'_{j,nm}$, with $\hat{E} = E'/E$.

GDP is the sum of income from labor, carbon tax revenue and tariffs. We recover tariff and tax revenue as follows:

$$T'_j = \frac{f_j \hat{X}^F_j X^F_j + h_j X^F_j}{L_j}, \tag{A.34}$$

$$\mathcal{T}'_j = \frac{g_j X^F_j}{L_j}. \tag{A.35}$$

Then, the change in real GDP is calculated as:

$$\widehat{\text{REAL GDP}}_j = \frac{w'_j L_j + T'_j L_j + \mathcal{T}'_j L_j}{w_j L_j + T_j L_j + \mathcal{T}_j L_j} \cdot \frac{1}{\hat{P}_j} = \frac{\hat{X}^F_j}{\hat{P}_j}. \tag{A.36}$$

For utility, note that $\hat{C}_j = \hat{X}_j^F / \hat{P}_j$ so:

$$\Delta U_j \equiv U_j^* - U_j = \ln\left(\frac{\hat{C}_j}{(\hat{E})^Z}\right). \tag{A.37}$$

To find the consumption equivalent variation (CEV), we need to find the change in initial consumption that yields the same welfare consequences as the observed changes in consumption and emissions following the policy experiment. So, we wish to solve:

$$\ln(CEV \cdot C) - Z\ln(E) = \ln(C') - Z\ln(E'), \tag{A.38}$$

which we can rearrange to find

$$\ln(CEV) = \ln\left(\frac{\hat{C}_j}{(\hat{E})^Z}\right) = \Delta U_j \tag{A.39}$$

and solve for CEV $= \frac{\hat{C}_j}{(\hat{E})^Z}$.

B Theory appendix: unbalanced model

Trade is unbalanced in the data used to quantify the model. This appendix extends the balanced model of Section 2 and Appendix A to allow for trade deficits (D_j). The balanced model we use in the main text is recovered when D_j is set to zero using hat algebra approaches.

B.1 Model extensions for a baseline equilibrium

This subsection introduces trade deficits to the model in Section 2 so that there is a baseline balanced trade equilibrium. Other Section 2 equations are unchanged.

Trade deficits A country-specific trade deficit closes the residual between gross imports and exports. Country j's trade deficit D_j is a constant share of world final expenditure $X_W^F \equiv \sum_{i=1}^N X_i^F$:

$$D_j = \Xi_j X_W^F, \qquad \sum_{j=1}^N \Xi_j = 0, \tag{B.1}$$

where $\pi_j^X \equiv X_j^F / X_W^F$ is country j's share of world final expenditure.

B.2 Exact hat algebra

We recover the balanced model in Section 2 by simulating our model with shocks that set the above trade deficit D_j equal to zero and then computing the counterfactual levels of variables needed for the balanced trade algorithm in Section A.2. Here we outline the changes relative to Section A.1.

As in Section A.1, define total materials demand for the destination sector m composite:

$$X_{j,m}^{I\prime} \equiv \sum_{u=1}^{M} X_{j,mu}^{I\prime}.$$

Then the gross expenditure identity is:

$$X_{j,m}^{\prime} = \alpha_{j,m} X_j^{F\prime} + X_{j,m}^{I\prime}. \tag{B.2}$$

Define the trade deficit share of final expenditure:

$$\pi_j^{D\prime} \equiv \frac{D_j^{\prime}}{X_j^F \hat{X}_W^F},$$

In the balancing exercise we will set it to zero. Total tariff revenue in levels is:

$$T_j^{\prime} L_j = \sum_m \bar{\tau}_{j,m}^{\prime} \left(\alpha_{j,m} X_j^{F\prime} + X_{j,m}^{I\prime} \right) = X_j^{F\prime} \sum_m \alpha_{j,m} \bar{\tau}_{j,m}^{\prime} + \sum_m \bar{\tau}_{j,m}^{\prime} X_{j,m}^{I\prime}.$$

Divide by baseline X_j^F and define

$$f_j \equiv \sum_{m=1}^{M} \alpha_{j,m} \, \bar{\tau}_{j,m}^{\prime}, \tag{B.3}$$

$$h_j \equiv \frac{1}{X_j^F} \sum_{m=1}^{M} \bar{\tau}_{j,m}^{\prime} \, X_{j,m}^{I\prime}, \tag{B.4}$$

to obtain

$$\frac{T_j^{\prime} L_j}{X_j^F} = \hat{X}_j^F \, f_j + h_j.$$

Counterfactual carbon-tax revenue per baseline expenditure is

$$g_j \equiv \frac{1}{X_j^F} \sum_{m=1}^{M} \sum_{n \in \mathcal{E}} \left(\psi_{j,nm}^{\prime} - 1 \right) X_{j,nm}^{I\prime}. \tag{B.5}$$

Using the unbalanced budget identity

$$X_j^{F\prime} = w_j L_j \hat{w}_j + T_j' L_j + \mathcal{T}_j' L_j + \pi_j^{D\prime} X_j^F \hat{X}_W^F,$$

divide through by X_j^F:

$$\hat{X}_j^F = \pi_j^L \hat{w}_j + \hat{X}_j^F f_j + h_j + g_j + \pi_j^{D\prime} \hat{X}_W^F.$$

Rearranging gives the country expenditure equation:

$$\hat{X}_j^F = \frac{\pi_j^L \hat{w}_j + h_j + g_j + \pi_j^{D\prime} \hat{X}_W^F}{1 - f_j}. \tag{B.6}$$

Note that $\hat{X}_j^F$ depends on $\hat{X}_W^F$, which itself depends on all countries' expenditures. Aggregating using weights π_j^X and solving for $\hat{X}_W^F$ gives the world expenditure equation:

$$\hat{X}_W^F = \frac{\sum_{j=1}^{N} \frac{\pi_j^X \left(\pi_j^L \hat{w}_j + h_j + g_j\right)}{1 - f_j}}{1 - \sum_{j=1}^{N} \frac{\pi_j^X \pi_j^{D\prime}}{1 - f_j}}. \tag{B.7}$$

B.3 Balancing solution algorithm

Building on the results in the previous section, we use the following algorithm to solve for a balanced trade equilibrium. We construct balanced baselines using the approach of Ossa (2014) where we solve a counterfactual with no change in carbon taxes or tariffs but exogenously set the deficit D to zero via $\pi_j^{D\prime} = 0$. The resulting equilibrium has $D_j' = 0$, recovering the balanced model in the main text. The balancing algorithm has the following steps:

1. Set $\pi_j^{D\prime} = 0$ or equivalently $D_j' = 0$.
2. Guess an initial vector of sectoral revenue changes $\hat{Y}_{i,m}$.
3. Compute wages from the current guess of sectoral revenue changes $\hat{Y}_{i,m}$:

$$\hat{w}_i = \sum_{m=1}^{M} \Gamma_{i,m} \hat{Y}_{i,m}, \qquad \Gamma_{i,m} \equiv \frac{w_i L_{i,m}}{\sum_{k=1}^{M} w_i L_{i,k}}. \tag{B.8}$$

4. Given $\{\hat{Y}_{i,m}\}$, update sectoral revenues:

$$Y'_{i,m} = Y_{i,m}\hat{Y}_{i,m}. \tag{B.9}$$

5. **Inner loop:** Given a vector of wages $\{\hat{w}_j\}$ from the outer loop and a guess of $\{\hat{P}_{j,m}\}$, iterate on the following until convergence:

   (a) Solve for materials unit costs:

$$\hat{P}^M_{j,m} \;=\; \prod_{n=1}^{M}\left(\hat{\tilde{P}}_{j,nm}\right)^{\omega_{j,nm}} \qquad \hat{\tilde{P}}_{j,nm} = \begin{cases} 1 \times \hat{P}_{j,n}, & n \in \mathcal{E}, \\ \hat{P}_{j,n}, & n \notin \mathcal{E}, \end{cases} \tag{B.10}$$

   (b) Compute the factory-gate price:

$$\hat{p}_{j,m} \;=\; \hat{w}_j^{\eta_{j,m}}\left(\hat{P}^M_{j,m}\right)^{1-\eta_{j,m}}. \tag{B.11}$$

   (c) Update sectoral price indices:

$$\hat{P}^{\star}_{j,m} \;=\; \left[\sum_{i=1}^{N}\lambda_{ij,m}\left(\hat{p}_{i,m}\hat{\varphi}_{ij,m}\right)^{1-\sigma_m}\right]^{\frac{1}{1-\sigma_m}}, \qquad \hat{\varphi}_{ij,m} \equiv \varphi'_{ij,m}/\varphi_{ij,m}. \tag{B.12}$$

   Damp the inner-loop update with damping parameter $\kappa_P \in (0,1]$:

$$\hat{P}^{\text{new}}_{j,m} \;=\; (1-\kappa_P)\hat{P}^{\text{old}}_{j,m} + \kappa_P\hat{P}^{\star}_{j,m}. \tag{B.13}$$

6. Compute trade shares:

$$\hat{\lambda}_{ij,m} \;=\; \left(\frac{\hat{p}_{i,m}\hat{\varphi}_{ij,m}}{\hat{P}_{j,m}}\right)^{1-\sigma_m} \tag{B.14}$$

7. Compute materials expenditures on fossil fuel inputs ($n \in \mathcal{E}$):

$$X^{I\prime}_{j,nm} \;=\; (\psi_{j,nm})^{-1}\,\omega_{j,nm}\,(1-\eta_{j,m})\,Y'_{j,m}, \tag{B.15}$$

   and non-fossil fuel inputs ($n \notin \mathcal{E}$):

$$X^{I\prime}_{j,nm} \;=\; \omega_{j,nm}\,(1-\eta_{j,m})\,Y'_{j,m}. \tag{B.16}$$

8. Solve for expenditures by first computing the following objects:

$$\bar{\tau}'_{j,m} = \sum_{i=1}^{N} t'_{ij,m} (\varphi'_{ij,m})^{-1} \lambda'_{ij,m} \tag{B.17}$$

$$f_j = \sum_{m=1}^{M} \alpha_{j,m} \bar{\tau}'_{j,m} \tag{B.18}$$

$$h_j = \frac{1}{X_j^F} \sum_{m=1}^{M} \bar{\tau}'_{j,m} \sum_{n=1}^{M} X_{j,mn}^{I\prime}, \tag{B.19}$$

$$\mathcal{T}'_j = \frac{1}{L_j} \sum_{m=1}^{M} \sum_{n \in \mathcal{E}} (\psi_{j,nm} - 1) X_{j,nm}^{I\prime} \tag{B.20}$$

$$g_j \equiv \frac{\mathcal{T}'_j}{X_j^F / L_j}. \tag{B.21}$$

Define the baseline expenditure shares $\pi_j^L \equiv \frac{w_j L_j}{X_j^F}$ and $\pi_j^X \equiv \frac{X_j^F}{X_W^F}$. For the balancing counterfactual, impose

$$\pi_j^{D\prime} \equiv \frac{D'_j}{X_j^F} = 0,$$

First compute world expenditure:

$$\hat{X}_W^F \;=\; \sum_{j=1}^{N} \frac{\pi_j^X \left(\pi_j^L \hat{w}_j + h_j + g_j \right)}{1 - f_j}. \tag{B.22}$$

Then compute country-level expenditure:

$$\hat{X}_j^F \;=\; \frac{\pi_j^L \hat{w}_j + h_j + g_j}{1 - f_j}. \tag{B.23}$$

9. Compute total sectoral expenditures:

$$X'_{j,m} \;=\; \alpha_{j,m} \hat{X}_j^F X_j^F \;+\; \sum_{n=1}^{M} X_{j,mn}^{I\prime} \tag{B.24}$$

and bilateral trade flows:

$$X'_{ij,m} = \hat{\lambda}_{ij,m} \lambda_{ij,m} X'_{j,m}.$$

10. Update sectoral revenues:

$$Y'_{i,m} \;=\; \sum_{j=1}^{N} (\varphi'_{ij,m})^{-1} X'_{ij,m}, \qquad w'_i L'_{i,m} = \eta_{i,m} Y'_{i,m}. \tag{B.25}$$

$$\hat{Y}^*_{i,m} \equiv \frac{Y'_{i,m}}{Y_{i,m}}, \qquad \hat{Y}^*_{i,m} = 1 \text{ when } Y_{i,m} = 0. \tag{B.26}$$

Damp the update with damping parameter κ_L

$$\hat{Y}^{\text{new}}_{i,m} = (1-\kappa_L)\hat{Y}^{\text{old}}_{i,m} + \kappa_L \hat{Y}^*_{i,m}, \qquad \kappa_L \in (0,1]. \tag{B.27}$$

11. **Convergence.** Iterate Steps 3–10 until $\{\hat{Y}_{i,m}\}$ converges.

C Calibration appendix

This section describes the calibration for the remaining model parameters and baseline data objects needed for the exact-hat algebra. The parameters are $\alpha_{j,m}$, $\eta_{j,m}$, $\omega_{j,nm}$, $\upsilon_{j,m}$, υ_n, and Z. The baseline data objects are $\lambda_{ij,m}$, $Y_{j,m}$, X^F_j, $\psi_{j,nm}$, and $\varphi_{ij,m}$. Table E.4 summarizes the dimension of each parameter and data object, how it is calibrated, and the data used. Model parameters such as $\eta_{j,m}, \omega_{j,nm}, \upsilon_{j,m}$ are calibrated before balancing the model.

C.1 Production technology

The Cobb-Douglas production function in equation (3) requires two sets of parameters: value added shares $\eta_{j,m}$ and materials input shares $\omega_{j,nm}$. Let $Z_{j,nm}$ denote the raw Exiobase materials-use value of the sector-n composite used by sector-m producers in country j, before applying the model's baseline carbon tax. $Z_{j,nm}$ is the raw data and $X^I_{j,nm}$ is the model-implied pre-tax materials expenditure. Define $Z^{\text{tot}}_{j,m} \equiv \sum_n Z_{j,nm}$.

We calibrate

$$\eta_{j,m} = \frac{\text{VA}_{j,m}}{Y_{j,m}},$$

where $\text{VA}_{j,m}$ is observed value added and $Y_{j,m}$ is producer revenue, constructed from tariff-net bilateral sales as described below in Section C.2.

Given the baseline carbon tax $\psi_{j,nm}$ defined in Section C.4, we set

$$\omega_{j,nm} = \frac{\psi_{j,nm} Z_{j,nm}}{\sum_{k=1}^{M} \psi_{j,km} Z_{j,km}}.$$

By construction, $\sum_n \omega_{j,nm} = 1$ whenever sector (j,m) uses materials inputs. Pre-tax materials expenditure is

$$X^I_{j,nm} = \frac{\omega_{j,nm}(1-\eta_{j,m}) Y_{j,m}}{\psi_{j,nm}}.$$

C.2 Trade shares and revenue

The trade share $\lambda_{ij,m}$ is given by:

$$\lambda_{ij,m} = \frac{X_{ij,m}}{\sum_{l=1}^{N} X_{lj,m}},$$

where $X_{ij,m}$ is the bilateral expenditure flow inclusive of tariffs, constructed from Exiobase bilateral trade flows and the WITS tariff wedge.

Sectoral revenue at producer prices is given by:

$$Y_{i,m} = \sum_{j=1}^{N} \frac{X_{ij,m}}{\varphi_{ij,m}}.$$

The tariff wedge is $\varphi_{ij,m} = 1 + t_{ij,m}$. Bilateral ad valorem tariff rates $t_{ij,m}$ are from the WITS database. We set $t_{jj,m} = 0$ for domestic flows.

C.3 Emissions factors

We calibrate υ_n, the emissions intensity for fossil fuel sectors $\mathcal{E}$, using combustion emission factors from IPCC (2006), converted to tCO_2/MMBtu, and matched to the corresponding Exiobase energy sectors. Table E.3 lists these fossil fuel materials and their values for υ_n.

For fossil-fuel materials $n \in \mathcal{E}$ used by producers in (j, m), recall that emissions are proportional to real material use:

$$E_{j,nm} \equiv \upsilon_{j,m}\upsilon_n M_{j,nm}, \qquad E_{j,nm} = 0 \text{ for } n \notin \mathcal{E}.$$

Here $M_{j,nm}$ is the real quantity of the sector-n composite used in production by sector m in country j. Quantities in the model are defined only up to units, whereas Exiobase data is available only in values. To accommodate this, we normalize units so that one unit of input n is defined to equal one baseline dollar of expenditure on that input:

$$M_{j,nm} = X^I_{j,nm}.$$

Under this convention, baseline materials quantities are value-scaled rather than in physical units.

The parameter υ_n is common to input n across all users and captures the carbon content of that fossil-fuel input. We calibrate υ_n from default combustion emission factors in IPCC (2006), converted to tCO_2/MMBtu, and matched to the corresponding Exiobase sectors.

Table E.3 lists the materials $n \in \mathcal{E}$ and their calibrated υ_n.

Because υ_n is measured in tCO_2/MMBtu, converting baseline-dollar purchases of fossil-fuel inputs into emissions requires a country-sector-specific conversion from baseline dollars into MMBtu. Parameter $\upsilon_{j,m}$ provides this conversion and has units of MMBtu per baseline dollar of materials expenditure.

We calibrate $\upsilon_{j,m}$ so that model-implied baseline emissions match observed direct Exiobase emissions, given the current $\eta_{j,m}$, $\omega_{j,nm}$, and $\psi_{j,nm}$. Note that model-implied pre-tax input use is

$$X^I_{j,nm} = \frac{(1-\eta_{j,m})Y_{j,m}Z_{j,nm}}{Z^{\text{tot}}_{j,m} + \delta_{j,m}\upsilon_{j,m}\sum_{k\in\mathcal{E}}\upsilon_k Z_{j,km}}.$$

Given the definition of emissions we then have that

$$E_{j,m} = \upsilon_{j,m}\sum_{n\in\mathcal{E}}\upsilon_n X^I_{j,nm} = \frac{\upsilon_{j,m}(1-\eta_{j,m})Y_{j,m}\sum_{n\in\mathcal{E}}\upsilon_n Z_{j,nm}}{Z^{\text{tot}}_{j,m} + \delta_{j,m}\upsilon_{j,m}\sum_{n\in\mathcal{E}}\upsilon_n Z_{j,nm}}.$$

Solving this equation gives us $\upsilon_{j,m}$

$$\upsilon_{j,m} = \frac{E_{j,m}Z^{\text{tot}}_{j,m}}{\left(\sum_{n\in\mathcal{E}}\upsilon_n Z_{j,nm}\right)\left((1-\eta_{j,m})Y_{j,m} - \delta_{j,m}E_{j,m}\right)}.$$

For country-sectors with no fossil fuel usage, model-implied emissions are zero and may not match positive observed emissions. This may be because there are process emissions, or there is measurement error in the emissions or materials use data. There are three such country-sectors: Indonesian Private Households, Japanese Private Households, and Taiwanese Secondary Raw materials. There are two country-sectors, Canadian Gas Electricity and Non-EU European Coal Electricity, for which the calibration is infeasible because the denominator is negative.[21] For these country sectors, we impute $\upsilon_{j,m}$ using the median value among countries in the same sector.

With $\upsilon_{j,m}$ and υ_n in hand, baseline direct emissions intensity of each country-sector is:

$$e_{j,m} = \frac{E_{j,m}}{Y_{j,m}} = \frac{\upsilon_{j,m}\sum_{n\in\mathcal{E}}\upsilon_n X^I_{j,nm}}{Y_{j,m}}.$$

This object is used in the main text to compare direct emissions intensity across sectors and countries, and to define carbon-intensive, trade-exposed (CITE) sectors.

The Exiobase intensities above measure direct emissions released at the last stage of production. As a robustness check, we apply carbon tariffs and taxes to the total GHG

[21] This occurs when the emissions tax payments, computed from Exiobase emissions and country-average carbon prices, exceed materials expenditures in Exiobase.

intensity of a good, which bundles direct emissions with the indirect emissions embodied in the materials inputs. These include upstream electricity, transportation, services and other inputs used to produce the good. We construct total intensity from the Exiobase IO tables. Let $X^I_{ij,nm}$ denote baseline dollar expenditure by sector m in country j on materials from sector n in country i, and define:

$$a_{ij,nm} = \frac{X^I_{ij,nm}}{Y_{j,m}},$$

(i, n) output used by (j, m) as a share of total (j, m) output. Stacking these $a_{ij,nm}$ across all country-sector pairs yields the global matrix A. Multiplying the vector of direct intensities $e_{i,n} = E_{i,n}/Y_{i,n}$ by the Leontief inverse $L = (I - A)^{-1}$ yields the total GHG intensity:[22]

$$e^{\text{total}}_{j,m} = \sum_{i,n} e_{i,n}\, L_{ij,nm},$$

in tons of CO_2e per dollar of output. In our robustness check for instruments applied to direct and indirect emissions, we replace the use of direct emissions $e_{j,m}$ in construction of our carbon tax and carbon import tariff with $e^{\text{total}}_{j,m}$.

C.4 Carbon prices

Baseline carbon prices $\delta_{j,m}$ (in USD per ton CO_2) are from the OECD Effective Carbon Rates database (OECD, 2023), which combines explicit carbon taxes and emissions trading system permit prices into a single effective rate. Baseline carbon prices are uniform across sectors within each country. Countries without an explicit carbon pricing mechanism have $\delta_{j,m} = 0$.

Given emissions factors, the baseline domestic ad valorem carbon tax on input n used by sector m in country j is:

$$\psi_{j,nm} = 1 + \delta_{j,m}\, \upsilon_{j,m}\, \upsilon_n, \qquad n \in \mathcal{E}, \qquad \psi_{j,nm} = 1, \qquad n \notin \mathcal{E}.$$

This wedge is the object used above to construct tax-inclusive materials input shares.

[22] We use baseline direct emissions intensity, implying that the tariffs do not respond to endogenous changes in indirect emissions intensity.

C.5 Expenditures and final demand

Given the calibrated values of $(\eta_{j,m}, \omega_{j,nm}, \psi_{j,nm})$ and observed sectoral revenue $Y_{j,m}$, the model-implied materials expenditure on sector n by producers in sector m is:

$$X^I_{j,nm} = \frac{\omega_{j,nm}(1-\eta_{j,m})Y_{j,m}}{\psi_{j,nm}}.$$

Total materials demand for the sector-m composite is:

$$X^I_{j,m} = \sum_{u=1}^{M} X^I_{j,mu}.$$

The residual between gross expenditure and materials demand identifies final demand:

$$X^F_{j,m} = \sum_{i=1}^{N} X_{ij,m} - X^I_{j,m}.$$

We define total final expenditure as:

$$X^F_j = \sum_m X^F_{j,m}$$

and compute the household consumption expenditure shares as:

$$\alpha_{j,m} = \frac{X^F_{j,m}}{X^F_j}.$$

Since $\eta_{j,m}$ and $\omega_{j,nm}$ are independently targeted from production data, $\alpha_{j,m}$ must absorb the remainder to ensure the model exactly replicates the observed baseline.

C.6 Household budget

In the unbalanced model, trade deficits close the gap between observed expenditure and domestic income plus tax revenue.

The trade deficit D_j of country j is computed from bilateral expenditure flows after removing tariffs, as the difference between total imports and total exports at producer prices. The household budget identity is:

$$X^F_j = w_j L_j + T_j L_j + \mathcal{T}_j L_j + D_j.$$

C.7 Calibrating climate damage

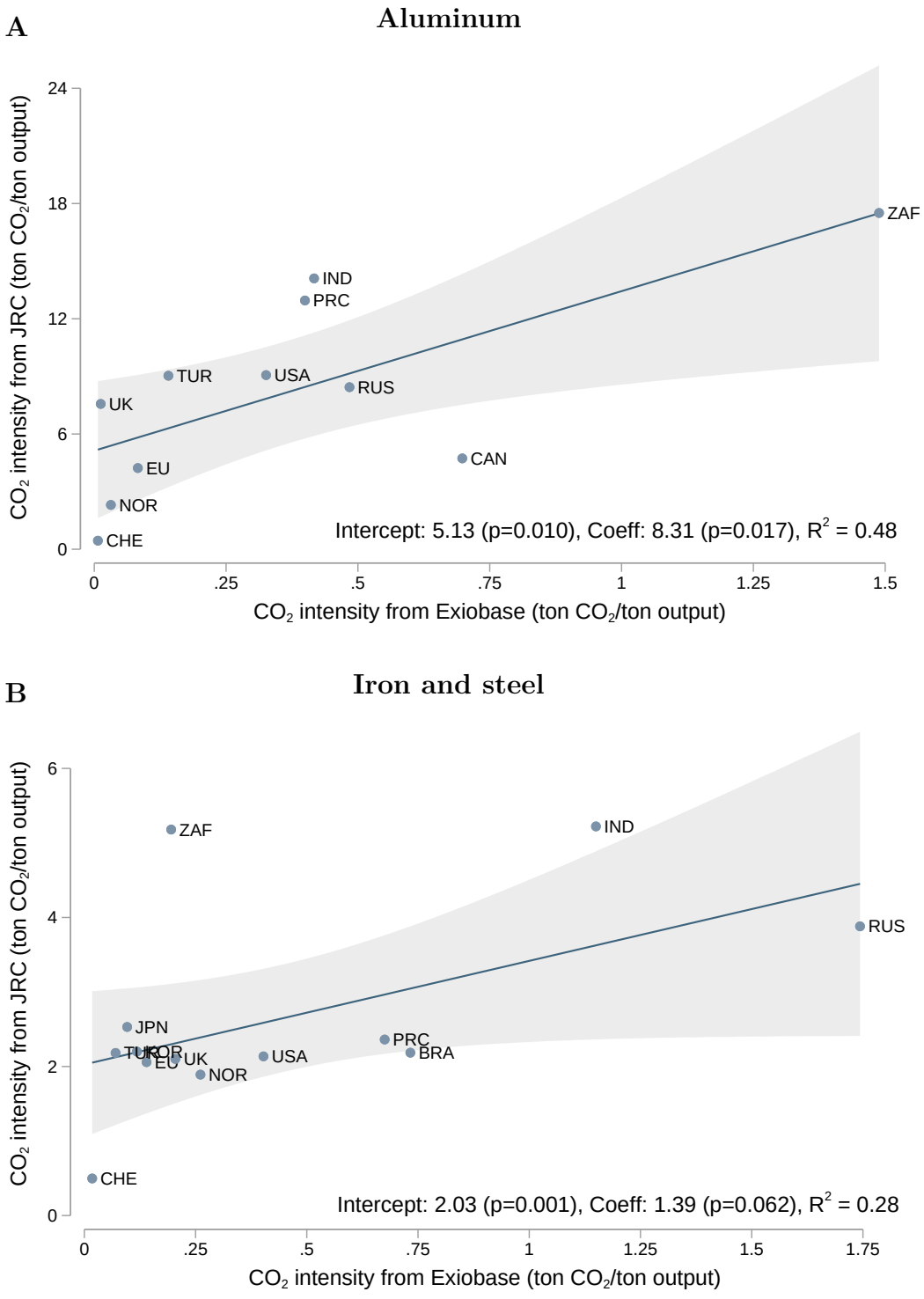
We calibrate Z to match the U.S. domestic social cost of carbon (SCC). We measure the SCC in terms of lost GDP. That is, the utility cost of a marginal change in emissions is equal to the domestic SCC multiplied by the utility cost of a marginal loss in real GDP:

$$\begin{aligned}
\frac{\partial U_j}{\partial E} &= -\text{SCC} \cdot \frac{\partial U_j}{\partial \text{GDP}_j} \\
-\frac{Z}{E} &= -\text{SCC} \cdot \frac{\partial U_j}{\partial C_j} \frac{\partial C_j}{\partial X_j^F} \frac{\partial X_j^F}{\partial \text{GDP}_j} \;\Rightarrow \\
\frac{Z}{E} &= \text{SCC} \cdot \frac{1}{C_j} \cdot \frac{1}{P_j} \cdot 1 = \text{SCC} \frac{1}{X_j^F} \;\Rightarrow \\
Z &= \frac{E \cdot \text{SCC}}{X_{\text{US}}^F},
\end{aligned}$$

where we assume that $\frac{\partial X_j^F}{\partial \text{GDP}_j} = 1$, because there is no saving. In our baseline balanced trade analysis, we then calibrate Z using data on global emissions, U.S. final expenditure X_{US}^F, and the SCC estimate from Kopits et al. (2025). $X_j^F = \text{GDP}_j$, so this is equivalent to using U.S. GDP. Intuitively, Z is analogous to an elasticity, and the calibration uses equilibrium expenditures and emissions, and an estimated SCC to compute Z.

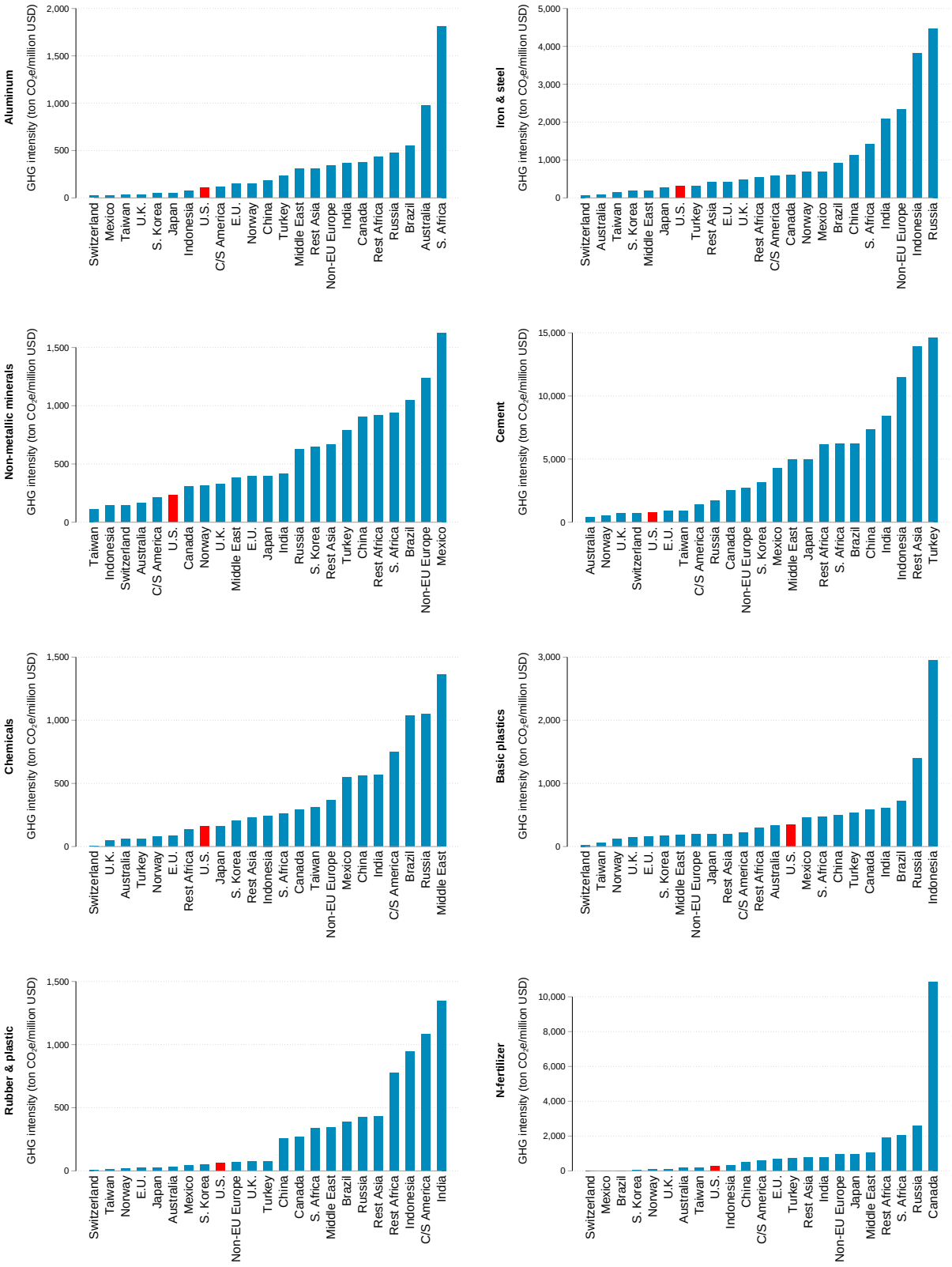
D Appendix Figures

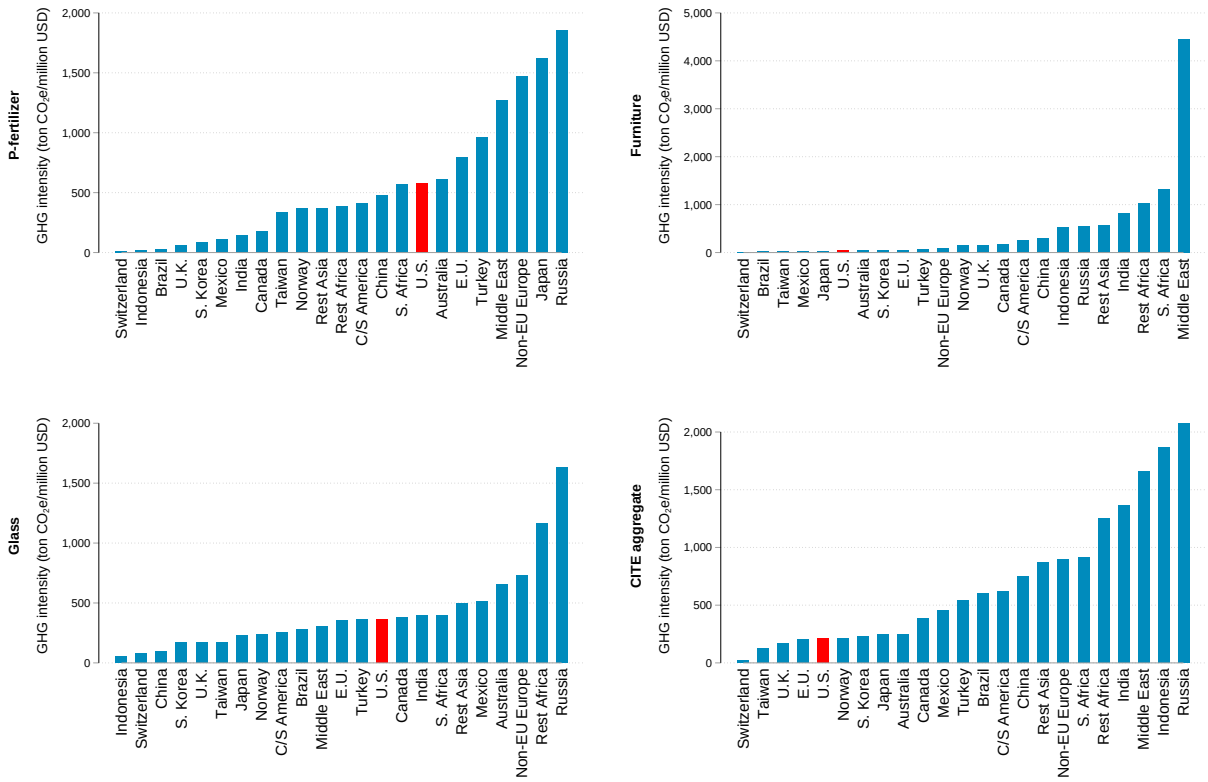
Figure D.1: Comparing Exiobase GHG intensities



Notes: Panels compare country-level Exiobase GHG intensities on horizontal axis against GHG intensities from E.U. JRC (Vidovic et al., 2023) for aluminum (Panel A) and iron and steel (Panel B). Each panel shows the linear fit and 95% confidence intervals as well as the estimated coefficients, p-values, and model R-squared.

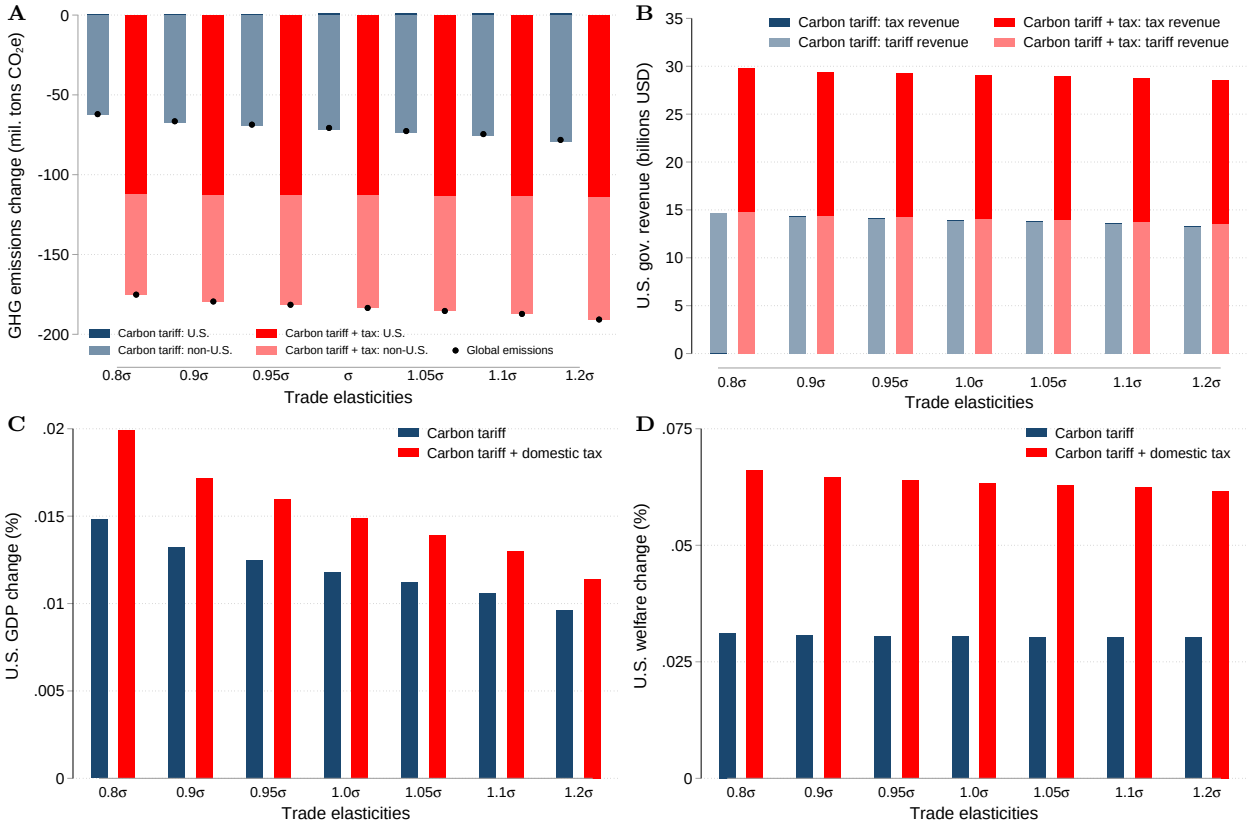
Figure D.2: GHG intensities by country





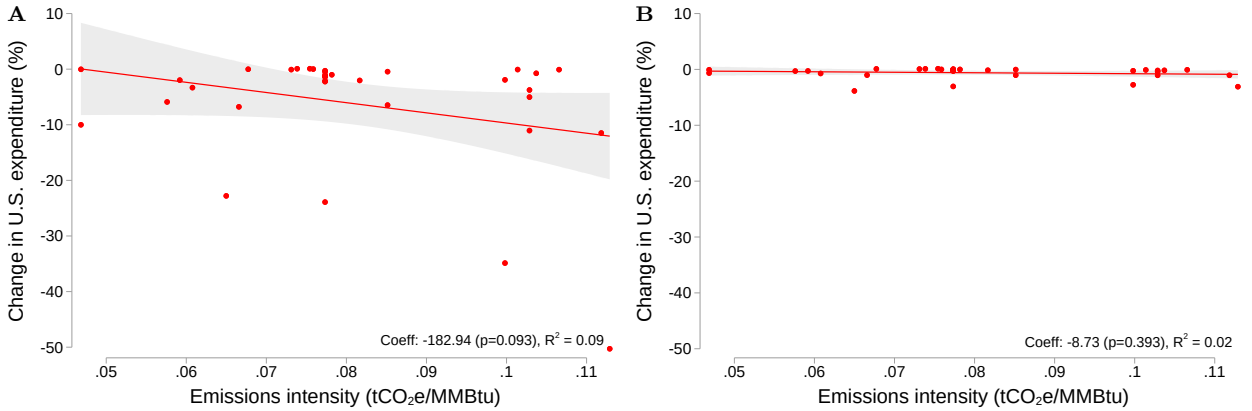
Notes: Each panel (except last) shows country direct GHG intensity (CO_2e per million USD) for a CITE sector. Last panel shows country aggregate CITE GHG intensity (CO_2e per million USD) as ratio of direct emissions summed across CITE sectors to output summed across CITE sectors. Red bar indicates the U.S.

Figure D.4: Robustness check: Aggregate impacts under higher trade elasticities



Notes: Modeled aggregate results for U.S. carbon tariff-only policy (in blue) and combined carbon tariff and domestic tax policy (in red) under benchmark trade elasticities and when all sectoral trade elasticities are multiplied by values of 0.8, 0.9, 0.95, 1.0 (benchmark), 1.05, 1.1, and 1.2. Policies valued at $60 per ton CO_2e (in 2025 USD). Panel A shows change in U.S. and non-U.S. GHG emissions (mil. tons CO_2e). Panel B shows change in U.S. government tariff and carbon tax revenues (bil. 2025 USD). Panel C shows U.S. real GDP change (%). Panel D shows U.S. welfare change (%).

Figure D.5: Fuel input responses to input versus output taxes



Notes: Panels show the relationship between the percentage change in U.S. material input expenditures under a policy against emissions intensity, υ_n, for each fossil fuel (see Table E.3). Both panels use modeled outputs from a combined U.S. carbon tariff and tax policy valued at $60 per ton CO_2e applied to benchmark CITE sectors. Panel (A) models the domestic carbon tax as an input tax (see results in Table 1(B)). Panel (B) models the domestic carbon tax as an output tax (see results in Table E.8(B)). Each panel shows the linear fit and 95% confidence intervals as well as the estimated coefficients, p-values, and model R-squared.

E Appendix Tables

Table E.1: Exiobase region definitions

Region	Countries
Modeled individually	Australia, Brazil, Canada, China, India, Indonesia, Japan, Mexico, Norway, Russia, South Africa, South Korea, Switzerland, Taiwan, Turkey, United Kingdom, United States
E.U.	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden
Rest of Asia and Pacific	Afghanistan, Armenia, Azerbaijan, Bangladesh, Bhutan, Brunei Darussalam, Cambodia, Cook Islands, Fed. Sts. Micronesia, Fiji, French Polynesia, Georgia, Hong Kong, Kazakhstan, Kiribati, Kyrgyz Republic, Laos, Macao, Malaysia, Maldives, Marshall Islands, Mongolia, Myanmar, Nauru, Nepal, New Caledonia, New Zealand, North Korea, Pakistan, Palau, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Sri Lanka, Tajikistan, Thailand, Timor-Leste, Tonga, Turkmenistan, Tuvalu, Uzbekistan, Vanuatu, Vietnam
Rest of America	Anguilla, Antigua and Barbuda, Argentina, Aruba, Bahamas, Barbados, Belize, Bermuda, Bolivia, British Virgin Islands, Cayman Islands, Chile, Colombia, Costa Rica, Cuba, Curacao, Dominica, Dominican Republic, Ecuador, El Salvador, Greenland, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Montserrat, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Sint Maarten, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Suriname, Trinidad and Tobago, Turks and Caicos Islands, Uruguay, Venezuela
Rest of Europe	Albania, Andorra, Belarus, Bosnia and Herzegovina, Iceland, Kosovo, Liechtenstein, Macedonia, Moldova, Monaco, Montenegro, San Marino, Serbia, Ukraine
Rest of Africa	Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Congo Republic, Cote d'Ivoire, DR Congo, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Sudan, Sudan, Swaziland, Tanzania, Togo, Tunisia, Uganda, Zambia, Zanzibar, Zimbabwe
Rest of Middle East	Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen

Notes: This shows how countries are grouped into regions in the Exiobase data.

Table E.2: Trade elasticities

Sector	σ	Sector	σ	Sector	σ
Additives/Blending Components	1.89	Food waste: landfill	3.63	Petroleum Coke	2.58
Air transport	3.63	Food waste: wastewater	3.63	Petroleum products nec	2.37
Aluminum	**2.47**	Forestry products	3.04	Pigs	3.31
Aluminum ores	3.43	Foundry services	3.63	Pipeline transport	3.63
Animal products	3.37	**Furniture**	**3.59**	Plant-based fibers	2.04
Anthracite	3.44	Gas Coke	1.92	Plastic waste: incineration	3.63
Apparel & furs	4.64	Gas Works Gas	3.63	Plastic waste: landfill	3.63
Ash	3.63	Gas distribution	3.63	Pork products	4.04
Aviation Gasoline	2.55	Gas/Diesel Oil	2.55	Post & telecom services	3.63
BKB/Peat Briquettes	4.45	**Glass**	**2.07**	Poultry	3.31
Basic plastics	**2.82**	Hazardous waste: landfill	6.51	Poultry products	4.04
Beef products	3.29	Health services	3.63	Precious metal ores	2.71
Beverages	3.13	Heavy Fuel Oil	2.55	Precious metals	7.12
Biodiesels	3.63	Hotels & restaurants	3.63	Precision & optical instruments	3.02
Biogas	3.63	Inland water transport	3.63	Printed matter & media	4.29
Biogasoline	3.63	Insurance services	3.63	Private households	3.63
Bitumen	2.45	**Iron & steel**	**2.57**	Processed rice	3.43
Blast Furnace Gas	3.63	Iron ores	1.99	Public administration	3.63
Bottle recycling	3.63	Jet fuel: gasoline	2.55	Pulp	2.45
Bricks, tiles & constr. products	1.90	Jet fuel: kerosene	2.55	Purified water	3.63
Business services	3.63	Kerosene	2.55	R&D services	3.63
Cattle	3.31	LPG	2.41	Radio, TV & comm. equipment	2.88
Cement	**2.05**	Land transport	3.63	Rail transport	3.63
Ceramic goods	2.59	Lead, zinc & tin ores & concentrates	2.83	Raw milk	3.63
Cereal grains	3.60	Lead, zinc & tin products	3.07	Real estate	3.63
Charcoal	2.35	Leather products	3.73	Rec., cultural & sporting services	3.63
Chem. & fert. minerals	4.33	Lignite/Brown Coal	4.45	Refinery Feedstocks	2.58
Chemicals: nec	**2.69**	Lubricants	2.58	Refinery Gas	3.63
Coal Tar	2.58	Machinery & equipment	3.07	Retail trade	3.63
Coke Oven Coke	1.92	Manure: biogas treatment	3.63	**Rubber & plastic products**	**3.18**
Coke oven gas	3.63	Manure: conventional treatment	3.63	Sand & clay	2.01
Coking Coal	3.44	Meat animals	3.31	Sea transport	3.63
Computer services	3.63	Meat products	3.76	Secondary aluminum	3.63
Construction	3.63	Membership org. services	3.63	Secondary construction material	3.63
Copper ores	8.52	Metal waste: incineration	3.63	Secondary copper	3.63
Copper products	4.95	Motor Gasoline	2.55	Secondary glass	1.91
Crops	3.15	Motor fuel retail	3.63	Secondary lead	3.63
Crude petroleum	3.96	Motor vehicle sales	3.63	Secondary non-ferrous metals	3.63
Dairy products	3.45	Motor vehicles & trailers	13.86	Secondary paper	3.63
Education	3.63	**N-fertilizer**	**2.25**	Secondary plastic	3.63
Electrical machinery	2.59	Naphtha	2.55	Secondary precious metals	3.63
Electricity distribution	3.63	Natural Gas Liquids	3.63	Secondary raw materials	3.63
Electricity nec	3.63	Natural gas	3.63	Secondary steel	3.63
Electricity transmission	3.63	Nickel ores	2.87	Sewage sludge: biogasification	3.63
Electricity: biomass	3.63	Non-ferrous metal ores	2.83	Steam & hot water	3.63
Electricity: coal	3.63	Non-ferrous metal products	2.45	Stone	2.01
Electricity: gas	3.63	**Non-metallic minerals**	**1.72**	Sub-Bituminous Coal	3.44
Electricity: geothermal	3.63	Nuclear fuel	4.45	Sugar	3.35
Electricity: hydro	3.63	Office machinery	6.36	Sugar cane, sugar beet	2.46
Electricity: nuclear	3.63	Oil seeds	3.13	Textile waste: incineration	3.63
Electricity: petroleum	3.63	Oil/hazardous waste: incineration	3.63	Textile waste: landfill	3.63
Electricity: solar PV	3.63	Other Bituminous Coal	3.44	Textiles	3.79
Electricity: solar thermal	3.63	Other Hydrocarbons	2.14	Tobacco	3.78
Electricity: tide	3.63	Other Liquid Biofuels	3.63	Transport aux. services	3.63
Electricity: wind	3.63	Other services	3.63	Transport equipment	6.37
Equipment rental	3.63	Other waste: wastewater	3.63	Uranium & thorium ores	3.63
Ethane	2.31	Oxygen Steel Furnace Gas	3.63	Vegetable oils & fats	4.00
Extra-territorial org.	3.63	**P-fertilizer**	**2.06**	Vegetables, fruit, nuts	3.14
Fabricated metals	2.78	Paddy rice	3.43	Wheat	4.00
Financial aux. services	3.63	Paper products	2.84	White Spirit & SBP	2.52
Financial services	3.63	Paper waste: biogasification	3.63	Wholesale trade	3.63
Fish & fishing products	3.62	Paper waste: incineration	3.63	Wood material: treatment	3.63
Fish products	3.76	Paper/wood waste: composting	3.63	Wood products	2.54
Food products	3.25	Paper: landfill	3.63	Wood waste: incineration	3.63
Food waste: biogasification	3.63	Paraffin Waxes	2.58	Wood waste: landfill	3.63
Food waste: composting	3.63	Patent Fuel	3.49	Wool, silk-worm cocoons	2.61
Food waste: incineration	3.63	Peat	4.45		

Notes: Table shows sector trade elasticities, σ_m, originally from Ossa (2015) matched to Exiobase sectors. CITE sectors in bold.

Table E.3: GHG intensities of fossil fuel materials

Sector	υ_n
Anthracite	0.10
Aviation Gasoline	0.07
BKB/Peat Briquettes	0.10
Biogas	0.06
Bitumen	0.09
Blast Furnace Gas	0.27
Coal Tar	0.09
Coke Oven Coke	0.11
Coke oven gas	0.05
Coking Coal	0.10
Crude petroleum	0.08
Ethane	0.06
Gas Coke	0.11
Gas Works Gas	0.05
Gas/Diesel Oil	0.08
Heavy Fuel Oil	0.08
Jet fuel: gasoline	0.07
Jet fuel: kerosene	0.08
Kerosene	0.08
LPG	0.07
Lignite/Brown Coal	0.11
Lubricants	0.08
Motor Gasoline	0.07
Naphtha	0.08
Natural Gas Liquids	0.07
Natural gas	0.06
Other Bituminous Coal	0.10
Other Hydrocarbons	0.08
Oxygen Steel Furnace Gas	0.19
Paraffin Waxes	0.08
Patent Fuel	0.10
Peat	0.11
Petroleum Coke	0.10
Petroleum products nec	0.08
Refinery Feedstocks	0.08
Refinery Gas	0.06
Sub-Bituminous Coal	0.10
White Spirit & SBP	0.08

Notes: Table shows GHG intensities, υ_n (in tCO_2e/MMBtu) from IPCC (2006) of fossil fuel materials, as defined in the KLEMS accounting framework in Timmer et al. (2007).

Table E.4: Calibration and data source for model parameters and data objects

Parameter/ Data Object	Dimension	Data Source	Calibration Method
σ_m	M	Ossa (2015)	Direct
$\eta_{j,m}$	$N \times M$	Exiobase IO tables	Full VA / producer revenue
$\omega_{j,nm}$	$N \times M \times M$	Exiobase IO tables	Tax-inclusive row-normalized flows
$\lambda_{ij,m}$	$N \times N \times M$	Exiobase trade	Expenditure shares
$Y_{i,m}$	$N \times M$	Exiobase trade	Tariff-net row sums
$t_{ij,m}$	$N \times N \times M$	World Bank (2022)	Direct
υ_n	$\lvert\mathcal{E}\rvert$	IPCC (2006)	Carbon content
$\upsilon_{j,m}$	$N \times M$	Exiobase emissions	Emissions inversion
$\delta_{j,m}$	$N \times M$	OECD (2023)	Direct
$\alpha_{j,m}$	$N \times M$	Residual	$X_{j,m} - X^I_{j,m}$
D_j	N	Exiobase trade	Imports − exports
Z	1	Kopits et al. (2025)	Domestic SCC calibration

Notes: Table summarizes for each model primitive and data object, its dimension, data source, and calibration method.

Table E.5: U.S. and global emissions and output shares under alternative CITE definitions

CITE definition	Num. of sectors	Share of global emissions	Share of global output	Share of U.S. emissions	Share of U.S. output	U.S. CITE emissions-wgt. export share
E.U. CBAM/U.S. FPFA	6	44.7	7.4	19.9	4.6	10.3
+ thresholds >2%	11	67.5	19.3	36.0	17.3	24.4
+ thresholds >1.5%	12	69.3	22.6	36.3	18.1	24.6
+ thresholds >1%	17	79.6	52.6	55.6	49.8	16.8
+ thresholds >0.5%	31	90.0	68.3	88.1	64.6	13.7

Notes: For each definition of CITE sectors, table shows the share of U.S. GHG emissions and output and global GHG emissions and output among globally traded, non-fossil fuel goods. The last column shows the U.S. emissions-weighted export share of output across CITE sectors as defined in footnote 19. First row shows sectors covered under the E.U. CBAM and U.S. FPFA (see Figure 1). Subsequent rows add sectors with global share of GHG emissions and global import penetration above 2%, 1.5%, 1% and 0.5%, not covered under E.U. CBAM and U.S. FPFA.

Table E.6: Impact of U.S. carbon tariffs with input-output linkages shut off

	Carbon import tariff, valued at $60 per tCO2e				
	U.S. economic impacts			GHG impacts	
Sector:	Imports	Output	U.S.	Other	Global
	% chg		% (mil. tons CO2e) chg		
Aluminum	−1.5	0.4	0.4 (0.0)	−0.2 (−0.2)	−0.2 (−0.2)
Iron and steel	−4.1	1.2	1.2 (0.5)	−0.1 (−3.6)	−0.1 (−3.0)
Non-metallic minerals	−1.8	0.7	0.7 (0.0)	−0.2 (−0.5)	−0.1 (−0.5)
Cement	−25.3	2.5	2.5 (1.5)	−1.3 (−30.0)	−1.2 (−28.5)
Chemicals	−1.5	0.2	0.2 (0.1)	−0.3 (−1.8)	−0.2 (−1.7)
Basic plastics	−2.2	0.0	0.0 (0.0)	−0.0 (−0.1)	−0.0 (−0.1)
Rubber and plastic	−1.9	0.7	0.7 (0.1)	−0.4 (−2.1)	−0.3 (−2.0)
N-fertilizer	−15.4	2.2	2.2 (0.0)	−1.6 (−0.5)	−1.5 (−0.5)
P-fertilizer	−2.4	0.3	0.3 (0.1)	−0.1 (−0.5)	−0.1 (−0.3)
Furniture	−4.5	2.6	2.6 (0.3)	−3.6 (−25.4)	−3.5 (−25.1)
Glass	−1.3	0.4	0.4 (0.1)	−0.1 (−0.2)	−0.1 (−0.1)
Aggregate:	Tariff rev.	Tax rev.	U.S.	Other	Global
	(bil. USD)		% (mil. tons CO2e) chg		
	14.0	0.0	0.0 (1.5)	−0.2 (−58.2)	−0.2 (−56.8)
				Real U.S. GDP (% chg):	0.007
				Climate impact-inclusive U.S. welfare (% chg):	0.015

Notes: Table shows modeled results for a U.S. carbon tariff-only policy valued at $60 per ton CO_2e (in 2025 USD) with input-output linkages shut off. For each CITE sector modeled, table shows sector-level change in U.S. import, output (%); U.S., non-U.S., and global GHG emissions (% and mil. tons CO_2e). Aggregate outcomes include carbon tariff and tax revenue (bil. 2025 USD); U.S., non-U.S., and global GHG emissions (% and mil. tons CO_2e); real GDP and climate impact-inclusive welfare (%).

Table E.7: Impact of U.S. carbon tariffs with & without U.S. carbon tax: direct + indirect emissions

A. Carbon import tariff, valued at $60 per tCO2e

Sector:	U.S. economic impacts: Imports (% chg)	U.S. economic impacts: Output (% chg)	GHG impacts: U.S. (% (mil. tons CO2e) chg)	GHG impacts: Other (% (mil. tons CO2e) chg)	GHG impacts: Global (% (mil. tons CO2e) chg)
Aluminum	−5.4	−0.5	0.8 (0.0)	−0.7 (−0.7)	−0.6 (−0.7)
Iron and steel	−8.9	0.6	1.3 (0.6)	−0.2 (−3.9)	−0.1 (−3.4)
Non-metallic minerals	−4.0	1.3	1.5 (0.1)	−0.3 (−1.1)	−0.3 (−1.0)
Cement	−28.0	2.7	3.0 (1.8)	−1.6 (−35.4)	−1.5 (−33.5)
Chemicals	−4.2	0.5	0.7 (0.4)	−0.8 (−5.2)	−0.7 (−4.8)
Basic plastics	−4.9	0.5	0.7 (0.3)	−0.4 (−1.7)	−0.3 (−1.3)
Rubber and plastic	−6.4	1.1	1.5 (0.3)	−0.8 (−4.6)	−0.8 (−4.4)
N-fertilizer	−18.4	2.3	2.6 (0.0)	−1.7 (−0.5)	−1.6 (−0.5)
P-fertilizer	−4.0	−0.5	0.7 (0.3)	−0.3 (−1.0)	−0.2 (−0.7)
Furniture	−8.9	5.1	5.2 (0.6)	−4.6 (−32.1)	−4.4 (−31.5)
Glass	−5.6	−0.9	−0.7 (−0.1)	−0.5 (−0.6)	−0.5 (−0.7)

Aggregate:	Tariff rev. (bil. USD)	Tax rev. (bil. USD)	U.S. (% (mil. tons CO2e) chg)	Other (% (mil. tons CO2e) chg)	Global (% (mil. tons CO2e) chg)
	30.0	0.0	0.0 (0.5)	−0.3 (−96.2)	−0.3 (−95.7)
				Real U.S. GDP (% chg):	0.024
				Climate impact-inclusive U.S. welfare (% chg):	0.049

B. Carbon tax + carbon import tariff, valued at $60 per tCO2e

Sector:	U.S. economic impacts: Imports (% chg)	U.S. economic impacts: Output (% chg)	GHG impacts: U.S. (% (mil. tons CO2e) chg)	GHG impacts: Other (% (mil. tons CO2e) chg)	GHG impacts: Global (% (mil. tons CO2e) chg)
Aluminum	−5.1	−1.7	−41.1 (−2.6)	−0.6 (−0.7)	−2.9 (−3.3)
Iron and steel	−7.7	−2.3	−47.5 (−20.1)	−0.1 (−3.0)	−0.9 (−23.1)
Non-metallic minerals	−3.6	−0.5	−30.7 (−1.7)	−0.3 (−1.0)	−0.8 (−2.7)
Cement	−25.6	−1.1	−53.1 (−32.3)	−1.5 (−34.5)	−2.9 (−66.8)
Chemicals	−3.5	−1.3	−6.2 (−3.7)	−0.6 (−4.0)	−1.1 (−7.7)
Basic plastics	−3.1	−2.9	−33.8 (−15.5)	−0.2 (−1.0)	−3.7 (−16.4)
Rubber and plastic	−5.7	−0.5	−4.6 (−0.8)	−0.7 (−4.1)	−0.9 (−4.9)
N-fertilizer	−16.8	−0.8	−13.4 (−0.1)	−1.6 (−0.5)	−1.8 (−0.6)
P-fertilizer	−0.8	−8.0	−47.7 (−19.8)	−0.2 (−0.6)	−5.0 (−20.4)
Furniture	−8.7	4.7	−13.0 (−1.5)	−4.5 (−31.9)	−4.7 (−33.4)
Glass	−4.6	−4.0	−27.6 (−4.2)	−0.4 (−0.5)	−3.6 (−4.7)

Aggregate:	Tariff rev. (bil. USD)	Tax rev. (bil. USD)	U.S. (% (mil. tons CO2e) chg)	Other (% (mil. tons CO2e) chg)	Global (% (mil. tons CO2e) chg)
	30.3	15.0	−2.8 (−114.0)	−0.3 (−95.2)	−0.6 (−209.2)
				Real U.S. GDP (% chg):	0.028
				Climate impact-inclusive U.S. welfare (% chg):	0.083

Notes: Table replicates Table 1 with carbon tariff applied to direct and indirect GHG emissions, not just direct GHG emissions as in benchmark model. Panel A (B) shows modeled results for a U.S. carbon tariff-only (carbon tariff and domestic carbon price) policy valued at $60 per ton CO_2e (in 2025 USD). Each panel shows for each CITE sector modeled, sector-level change in U.S. import, output (%); U.S., non-U.S., and global GHG emissions (% and mil. tons CO_2e). Aggregate outcomes include carbon tariff and tax revenue (bil. 2025 USD); U.S., non-U.S., and global GHG emissions (% and mil. tons CO_2e); real GDP and climate impact-inclusive welfare (%).

Table E.8: Impact of U.S. carbon tariffs with & without carbon tax: output tax

A. Carbon import tariff, valued at $60 per tCO2e

Sector:	U.S. economic impacts: Imports (% chg)	U.S. economic impacts: Output (% chg)	GHG impacts: U.S. (% (mil. tons CO2e) chg)	GHG impacts: Other (% (mil. tons CO2e) chg)	GHG impacts: Global (% (mil. tons CO2e) chg)
Aluminum	−1.5	−0.3	−0.0 (−0.0)	−0.2 (−0.3)	−0.2 (−0.3)
Iron and steel	−4.2	0.4	0.7 (0.3)	−0.1 (−3.1)	−0.1 (−2.8)
Non-metallic minerals	−1.8	0.6	0.7 (0.0)	−0.2 (−0.6)	−0.2 (−0.5)
Cement	−25.0	2.4	2.7 (1.6)	−1.5 (−32.5)	−1.3 (−30.9)
Chemicals	−1.6	0.1	0.2 (0.1)	−0.3 (−2.2)	−0.3 (−2.1)
Basic plastics	−1.9	0.2	0.3 (0.1)	−0.1 (−0.3)	−0.1 (−0.2)
Rubber and plastic	−2.2	0.2	0.4 (0.1)	−0.4 (−2.3)	−0.4 (−2.3)
N-fertilizer	−15.4	2.0	2.2 (0.0)	−1.6 (−0.5)	−1.5 (−0.5)
P-fertilizer	−1.9	−0.2	0.3 (0.1)	−0.1 (−0.4)	−0.1 (−0.3)
Furniture	−4.5	2.5	2.6 (0.3)	−3.7 (−25.9)	−3.6 (−25.6)
Glass	−2.2	−0.5	−0.4 (−0.1)	−0.2 (−0.3)	−0.2 (−0.3)
Aggregate:	Tariff rev. (bil. USD)	Tax rev. (bil. USD)	U.S. (% (mil. tons CO2e) chg)	Other (% (mil. tons CO2e) chg)	Global (% (mil. tons CO2e) chg)
	13.9	0.0	0.0 (0.8)	−0.2 (−71.5)	−0.2 (−70.7)
				Real U.S. GDP (% chg):	0.012
				Climate impact-inclusive U.S. welfare (% chg):	0.030

B. Carbon tax + carbon import tariff, valued at $60 per tCO2e

Sector:	U.S. economic impacts: Imports (% chg)	U.S. economic impacts: Output (% chg)	GHG impacts: U.S. (% (mil. tons CO2e) chg)	GHG impacts: Other (% (mil. tons CO2e) chg)	GHG impacts: Global (% (mil. tons CO2e) chg)
Aluminum	−1.5	−2.3	−1.6 (−0.1)	−0.2 (−0.2)	−0.3 (−0.3)
Iron and steel	−2.8	−4.0	−3.3 (−1.4)	−0.1 (−2.0)	−0.1 (−3.4)
Non-metallic minerals	−1.8	−1.9	−1.7 (−0.1)	−0.2 (−0.5)	−0.2 (−0.6)
Cement	−21.6	−3.5	−2.9 (−1.7)	−1.4 (−31.3)	−1.4 (−33.0)
Chemicals	−0.9	−1.7	−1.7 (−1.0)	−0.2 (−1.1)	−0.3 (−2.1)
Basic plastics	0.0	−4.1	−4.0 (−1.8)	0.1 (0.5)	−0.3 (−1.4)
Rubber and plastic	−1.5	−1.6	−0.9 (−0.2)	−0.3 (−1.8)	−0.3 (−1.9)
N-fertilizer	−14.3	−2.3	−1.4 (−0.0)	−1.5 (−0.5)	−1.5 (−0.5)
P-fertilizer	−1.5	−13.5	−9.7 (−4.0)	−0.0 (−0.1)	−1.0 (−4.2)
Furniture	−4.2	2.1	2.2 (0.2)	−3.7 (−25.7)	−3.6 (−25.5)
Glass	−1.1	−4.1	−3.9 (−0.6)	−0.1 (−0.1)	−0.5 (−0.7)
Aggregate:	Tariff rev. (bil. USD)	Tax rev. (bil. USD)	U.S. (% (mil. tons CO2e) chg)	Other (% (mil. tons CO2e) chg)	Global (% (mil. tons CO2e) chg)
	14.1	22.0	−0.4 (−15.9)	−0.2 (−66.4)	−0.2 (−82.2)
				Real U.S. GDP (% chg):	0.025
				Climate impact-inclusive U.S. welfare (% chg):	0.047

Notes: Table replicates Table 1 with domestic tax applied to output, not inputs as in benchmark model. Panel A (B) shows modeled results for a U.S. carbon tariff-only (carbon tariff and domestic carbon price) policy valued at $60 per ton CO_2e (in 2025 USD). Each panel shows for each CITE sector modeled, sector-level change in U.S. import, output (%); U.S., non-U.S., and global GHG emissions (% and mil. tons CO_2e). Aggregate outcomes include carbon tariff and tax revenue (bil. 2025 USD); U.S., non-U.S., and global GHG emissions (% and mil. tons CO_2e); real GDP and climate impact-inclusive welfare (%).