Online Technical Modeling Appendix

Putting Climate Coalitions into Practice:
A Common Framework for Balancing Competitiveness and Equity
Report of the Global Climate Policy Project (GCPP) Working Group on Climate Coalitions
(the "Report")

Introduction

This online appendix describes the framework, data, and assumptions used to generate the simulation results presented in the Report. The analysis applies the Model without Trade Frictions developed in the 2025 GCPP flagship report, updated to reflect the countries that endorsed the declaration on the Open Coalition in Belém as an illustrative example of the coalition approach, recent developments in carbon pricing policy, and updated plant-level production, capacity, cost, and emissions data. The model simulates carbon pricing in four emissions-intensive industries: steel, aluminum, cement, and fertilizers.

The analysis considers two coalition scenarios—the *Uniform Price* and *Graduated Price* scenarios—and compares their outcomes with an updated *Current Policy Baseline*. Carbon pricing policy is modeled at the country level in the coalition scenarios, where a single price floor applies across all four industries. For ease of modeling, we assume that there are no free allowances in the coalition scenarios, so that the domestic revenue accrued from an emissions trading system or carbon tax would be equivalent, given that the resulting allowance trading price is equal to the level of the carbon tax. We assume that auction reserve prices can keep the carbon price generated by an emissions trading system at or above the level of the price floors for each scenario. We further assume that carbon prices are equal to the price floor for each scenario, rather than above it. Finally, we assume that carbon prices cover both Scope 1 emissions (from fuel combustion and chemical processes) and Scope 2 emissions (from electricity used in production).

Table OA1, reproduced from Table 2 of the Report, summarizes the principal assumptions for the two coalition scenarios and the *Current Policy Baseline*.

Table OA1: Overview of coalition scenarios

	Current Policy Baseline	Uniform Price	Graduated Price
Country membership	European Union, United Kingdom, Iceland, Liechtenstein, Norway, Switzerland	European Union, Andorra, Canada, Chile, Iceland, Liechtenstein, Monaco, New Zealand, Norway, Singapore, Switzerland, United Kingdom, Armenia, Brazil, China, Mexico, Guinea, Rwanda, Zambia	
Carbon price floor	\$75/t	\$50/t	HIC: \$75/t UMIC: \$50/t LMIC/LIC: \$25/t
Border adjustment	\$75/t	\$50/t	\$75/t
Free allowances	Yes	No	No

Notes: In the *Graduated Price* scenario, all countries set the border adjustment to the same value, 75 USD per ton, while varying the level of their domestic carbon prices. The graduated carbon price floor levels and income groups follow Parry, Black, and Roaf (2021) and the World Bank Group FY26 income classifications (World Bank, 2025), respectively.

Importantly, we carry the broad assumption that producers not subject to a carbon price in a given scenario face a carbon price of 0 USD — all countries outside the coalition in the coalition scenarios, and, in the *Current Policy Baseline*, all countries outside the European Union, United Kingdom, Iceland, Liechtenstein, Norway, and Switzerland. We also calculate a "2025 regulation baseline" in which each producer faces the effective carbon cost implied by the system it is actually subject to. In this baseline, effective carbon costs are specified at the country-industry level, reflecting the industry-specific coverage and carbon cost relief provisions of each jurisdiction. By modeling firm decisions as a function of the effective carbon cost rather than the headline price, we assume that firms respond to the average rather than the marginal carbon cost. This is a reasonable approximation for non-marginal decisions, such as whether to open or close a plant, since these decisions can themselves affect the free allocation a plant receives.

Countries may implement different carbon pricing instruments, including carbon taxes, emissions trading systems, tradable performance standards, and hybrid approaches, but the model abstracts from differences in instrument type and represents each policy through the carbon cost faced by producers. We use this as a standardized reference baseline and as the basis for estimating the impacts of the *Current Policy Baseline*. Although many jurisdictions have relatively high headline carbon prices, the effective carbon costs faced by regulated producers can be substantially lower because of free allowances and other forms of carbon cost relief. Table OA2 summarizes the distribution of effective carbon costs across the industries in the coalition countries included in our analysis.

Table OA2 Distribution of effective carbon costs by industry in coalition countries

Industry	Jurisdictions	Mean Headline Price	Mean ECC	Median ECC	Minimum ECC	Maximum ECC
Steel	11	\$48.23	\$14.40	\$8.03	\$0.06	\$44.21
Aluminum	8	\$62.86	\$15.95	\$20.62	\$0.00	\$31.32
Ammonia	8	\$55.50	\$15.37	\$3.01	\$0.00	\$42.12
Cement	10	\$51.14	\$5.97	\$4.97	\$0.00	\$14.98

Notes: Effective carbon costs (ECCs) and headline carbon prices are reported in 2025 USD per ton CO_2e. ECCs account for policy coverage, free allocation, output-based benchmarks, and other forms of carbon cost relief. Statistics are unweighted across coalition-member jurisdictions with existing carbon pricing mechanisms and production in each industry; jurisdictions with no relevant production are excluded. Zero values indicate that producers face no effective carbon cost under the applicable carbon pricing system.

The model is static: it represents each policy scenario as a new equilibrium with the policy fully in place and all changes already realized. The model is designed to capture differences between counterfactual scenarios in static equilibrium states; it does not address the timeline for implementation nor how long it would take for the changes between states to take place. For each scenario and the 2025 regulation baseline, we calculate prices, emissions, production, producer revenue (price multiplied by production), domestic carbon pricing revenue, and border carbon adjustment fee revenue. In the 2025 regulation baseline, existing effective carbon costs generate approximately 9.2 billion USD in domestic carbon pricing revenue, while border carbon adjustment fee revenue is 0 USD. For the coalition scenarios (*Uniform Price* and *Graduated Price*), we report output and price changes as percentage changes from the *Current Policy Baseline*. We calculate domestic carbon pricing revenue at the country level as the sum of carbon price payments made by all domestic producers in that country. Domestic carbon pricing revenue is reported as the change in revenue relative to the 2025 regulation baseline rather than as the total revenue generated under each scenario. Emissions changes are also calculated from the 2025 regulation baseline, and we assume that emissions in the 2025 regulation baseline align with actual 2025 emissions. Therefore, the reported emissions changes reflect the modeled abatement impacts of each policy scenario relative to existing carbon pricing policies.

Literature

The model builds on a growing body of work that studies the environmental effects of trade policy, specifically border carbon adjustment mechanisms (BCAs), including but not restricted to Ismer & Neuhoff (2007); Elliott et al. (2010); Böhringer et al. (2012); Fischer & Fox (2012); Schinko et al. (2014); Fowlie et al. (2016); Kortum & Weisbach (2017); Mehling et al. (2019); Böhringer et al. (2021); Böhringer et al. (2022); Fowlie & Reguant (2022); Grubb et al. (2022); Perdana & Vielle (2022); Zhong & Pei (2022); Clausing and Wolfram (2023); Bellora & Fontagné (2023); Lin & Zhao (2023); Rorke et al. (2023); Coster et al. (2024); Perdana et al. (2024); Takeda & Arimura (2024); Magacho et al. (2024); Clausing et al. (2025); Tanaka & Nagashima (2025); and Walczak et al. (2025). The *Model Without Trade Frictions* builds on the model in Clausing et al. (2025) and lies in the realm of quantitative microeconomic trade models tied to the field of empirical industrial organization that leverage firm-level data on individual industries (Bernard et al., 2003; Demailly & Quirion, 2006; De Loecker, 2011; Eaton et al., 2011; Ryan, 2012; Collard-Wexler & De Loecker, 2015; Roberts et al., 2018; Shapiro & Walker, 2018). Overall, in line with general trends in the economic trade literature, the model puts more emphasis on transparency and less emphasis on capturing all features of the relevant markets. It is designed to be powerful enough to capture first-order features of the data, like the role of country size and emissions intensity, but simple enough that we can credibly identify the crucial parameters and see how changing them shifts the policy predictions.

The following sections outline the data and methodology behind the model.

Data

Production

We use detailed, plant-level data on production, capacity, costs, and emissions for four industries: steel, aluminum, cement, and fertilizers. We use the ammonia industry as a proxy for fertilizers due to data limitations and as ammonia production accounts for the majority of carbon dioxide emissions associated with manufacturing nitrogenous fertilizers. The exclusion of potassium and phosphorous fertilizers is due to data limitations but also follows the EU CBAM's focus on nitrogenous fertilizers, which are relatively more emissions intensive than other types of fertilizers, as they primarily use natural gas or coal as a feedstock rather than a mined natural mineral (like phosphate or potash). Data for primary aluminum and ammonia, and for the majority of iron and steel plants, are from CRU Group's Multicommodity Costs and Emissions Data, a proprietary 2025 plant-level dataset prepared for the Massachusetts Institute of Technology; a further

96 steel plants are drawn from the Climate TRACE Emissions Inventory. Data for secondary aluminum are from the World Bureau of Metal Statistics from the London Stock Exchange Group. Data for cement are from the Climate TRACE Emissions Inventory dataset. The data are from 2025 and include 1,056 steel plants, 190 aluminum plants, 2,158 cement plants, and 268 fertilizer plants. Comparison with the World Steel Association and U.S. Geological Survey indicates that the underlying steel data capture approximately 67% of China's 2025 crude steel production. To account for this incomplete coverage, Chinese production and capacity are scaled proportionally to match the reported national production total; the resulting estimate of global steel production is within 0.7% of the World Steel Association's reported 2025 total. Steel production includes primary steel (produced in a basic oxygen furnace) and secondary steel (produced in an electric arc furnace). Aluminum production includes primary aluminum (from mined bauxite ore which is refined to alumina and then reduced via the Hall-Héroult process to yield aluminum) and secondary aluminum (produced from recycled aluminum scrap). We treat primary and secondary materials as perfect substitutes.

Consumption

We estimate consumption as production plus net imports, using 2025 country-level trade data from UN Comtrade (except for Russia where we use 2021 data due to availability). The HS codes for steel are those targeted by the EU CBAM: HS codes 7201, 720211, 720219, 720241, 720249, 720260, 7203, and 7205 through 7229. The HS code for aluminum is 7601, "Aluminum; unwrought." The HS code for cement is 2523, and for ammonia is 281410. Trade values are reported more consistently than trade quantities, and so we focus on the trade value data. We compute quantities by dividing these values by the average global prices in 2025.

Prices

World price data for all industries come from UN Comtrade. We calculate a global price as the weighted average of export prices for each product, using reported trade values and quantities. The average aluminum price was 2,657 USD per ton, the average steel price was 971 USD per ton, the average ammonia price was 467 USD per ton, and the average cement price was 73 USD per ton.

We construct global data on carbon pricing. We collect prevailing carbon prices and policy parameters for existing carbon pricing systems from primary legislative and regulatory sources (see Report Appendix E). The 2025 regulation baseline incorporates effective carbon costs for countries with carbon pricing systems recognized by the CBAM. Rather than applying reported tax rates or allowance trading prices directly, we adjust headline carbon prices to account for industry- and product-specific policy coverage, free allocation, output-based benchmarks, performance standards, exemptions, and other forms of carbon cost relief. Where possible, we use facility-level production and emissions data to calculate these costs and aggregate them to the country-industry level. These effective carbon costs reflect the average carbon compliance costs borne by regulated facilities and can therefore be substantially lower than reported tax rates or allowance trading prices.

Model

Structure

We combine our microdata with a quantitative equilibrium model of global trade. In each scenario we model carbon pricing and a border carbon adjustment (BCA) in a world commodity market. The model considers two markets. In the coalition scenarios, the first consists of coalition member countries, all of which impose carbon prices on domestic production and border carbon fees on imports from non-member trading partners; the second comprises the rest of the world, where carbon emissions are not priced. In the *Current Policy Baseline* the first market is narrower, comprising only the European Union, United Kingdom, Iceland, Liechtenstein, Norway, and Switzerland; the remaining coalition members are treated as part of the second market. For each market, we use our country-level consumption data and specify log-linear demand with a constant price elasticity of demand of -0.8, which is consistent with empirical estimates for these sorts of primary commodities (Clausing et al., 2025). We aggregate across countries to measure consumption by market. We obtain empirical demand curves that identify how demand in each market responds to prices. Global demand is the sum of demand across each market. Goods from each industry are assumed to be homogenous and are treated as perfect substitutes across countries (e.g., a consumer values a ton of aluminum from the United States the same as a ton of aluminum from China, regardless of where the consumer is located, all else equal).

We use our plant-level data to construct supply. Each producer has a fixed capacity and a constant marginal cost that are observed in the data; we assume that changes in capacity and cost require significant investment that is challenging in the short run. Assuming constant marginal costs allows us to read costs from our plant-level data akin to Asker et al. (2014). We use observed production and capacity to compute capacity utilization, and we observe that capacity utilization is highest for low-cost producers and lowest for high-cost producers. We allow production and prices to respond endogenously to regulation. We assume that each producer has a collection of production lines that can be "on" or "off" and we model the utility of operating a production line. We use a profit coefficient that captures how producers value profits in utility terms and governs how changes in prices or costs translate to changes in production, estimated in Clausing et al. (2025) by logit regression of capacity utilization on the price-cost margin with plant fixed effects, and applied here across all four industries. For a given producer, production lines have common observed costs, common unobserved costs, and idiosyncratic unobserved costs, which we assume are logit distributed. We model producer choices at the production line level; a producer will operate a line when its profit plus the idiosyncratic unobserved cost is positive. We interpret the fraction of lines that will operate as capacity utilization. Capacity utilization increases when a producer's per-unit profits (the market price minus the per-unit production cost including any carbon prices) increase and falls when per-unit profits decrease. Thus, there is a smooth, extensive-margin supply response: small price or cost changes shift utilization continuously up to a plant's capacity. Output at the producer level is capacity multiplied by capacity utilization. World supply is the sum of output across all producers.

Carbon policy enters through the producer's per-unit profits. If a market levies a domestic carbon tax, per-unit profits are reduced in proportion to the producer's emissions intensity. Producers abate in response. The model allows producers emissions per ton to fall when the carbon cost is higher, using a fixed elasticity of 0.3‰ per dollar of carbon price, consistent with empirical studies of the abatement response to carbon pricing. Sen and Vollebergh (2018) use data on energy tax rates of 20 OECD countries to study the responsiveness of fossil fuel emissions to changes in a carbon tax, estimating an elasticity of -0.32. Choi et al. (2010) set a fixed elasticity of -0.3 across 30 sectors to capture the emissions effects of a US carbon price in an input-output model. This abatement channel partially offsets the reduction in profits from the carbon price itself.

A BCA is modeled as a price wedge equal to the regulated market's carbon price floor. The price wedge is an adjustment such that all consumption in the regulated market is subject to a price floor. Goods produced in the regulated market face a price floor during production, while goods imported from the unregulated market face the price floor at the border. Prices no longer equalize across markets, and so we distinguish between prices in the regulated market and prices in the unregulated market. Producers decide which market to serve, and so regulation affects trade. Producers in the regulated market can choose among the two prices, but they are always subject to the domestic carbon price floor; they do not receive a tax refund when exporting to the unregulated market. We define net prices less the carbon price floor for regulated producers who sell into the regulated market and who sell into the unregulated market. We also define net prices for producers in the unregulated market which experience a carbon price only when exporting to the regulated market. Producers choose their highest net price—they sell into the regulated market when net prices in the regulated market dominate, otherwise they serve the unregulated market. Producers do not face increased costs for adjusting exports across markets and can immediately redirect their production to more profitable destinations in response to policy changes. Under these assumptions, even small changes in relative prices or trade costs because of carbon pricing policy can lead to adjustments in trade flows between markets.

In the 2025 regulation baseline, equilibrium prices clear global markets, so we see a single global price per industry (which we observe in the data). Under a climate coalition with a BCA, there is a price wedge. In equilibrium, the price in the unregulated market and the price in the regulated market clear each market separately so we see two prices per industry—one for each market. The marginal producer will be indifferent between selling to the regulated market or the unregulated market.

When the regulated market imports from the unregulated market, then the regulated market's price ends up higher than the unregulated because selling into the regulated market requires paying the higher carbon price. Clean plants (with a low emissions intensity in our data) can profitably access the higher price in the regulated market and redirect shipments there, moderating the regulated market's price increase with increased supply while dirtier exporters are pushed toward the unregulated market, which expands supply and puts downward pressure on the unregulated market's price.

Estimation

Using our country-level consumption data and plant-level production data described above, we construct empirical supply and demand curves for both markets (unregulated and regulated) for each of the four industries. We solve each industry separately and thus the model does not capture any spillover effects between industries. We vary the levels of carbon taxation and market membership according to the three scenarios (*Uniform Price*, *Graduated Price*, and *Current Policy Baseline*) as well as a 2025 regulation baseline. For the *Graduated Price* scenario, we evaluate impacts on the regulated market divided into high-income countries (HIC), upper-middle-income countries (UMIC) and lower-middle-income and low-income countries (LMIC/LIC). We vary the level of domestic carbon pricing for these submarkets but not the BCA fee. We report equilibrium prices, emissions, production, producer revenue (price multiplied by production), domestic carbon tax revenue, and border carbon adjustment fee revenue.

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