Trade Policy as Climate Policy:

Payoffs and Tradeoffs

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Abstract

Reducing carbon emissions is a global public good: every country has an incentive not to reduce its own emissions and still benefit from the actions of compliant countries. We explore how import tariffs can solve this free-rider problem. We use a multi-region, multi-sector simulation model in which some countries adopt a carbon tax and compete with non-compliant countries in global markets. First, we consider the European Union (EU)'s carbon border adjustment mechanism (CBAM) in which non-compliant countries face import tariffs in selected sectors based on the carbon emitted in production. While it helps EU producers, CBAM will not reduce global emissions because exporting countries can diversify their trade to non-EU countries. Next, we consider a climate club in which members adopt a carbon tax and impose punitive tariffs against all products from non-members. In this case, tariffs can reduce global emissions by inducing non-taxing countries to join the club. However, climate clubs are fragile. When club members are strongly linked to non-club regions through integrated production relationships, in which imports complement domestic goods, they suffer trade losses, adding to the cost of club membership. Furthermore, high punitive tariffs are needed to induce all regions to join the club.

Keywords: carbon border adjustment mechanism (CBAM); climate clubs; tariffs; computable general equilibrium (CGE) models; climate mitigation policies; carbon tax

JEL Codes: C68, D61, F18, H23, Q43, Q54

[1] The views in this paper are those of the authors and not their respective institutions.

I. Introduction

Climate change caused by increased levels of greenhouse gases (GHGs) is heating the globe, creating extreme weather events (droughts, floods, and fires) and melting ice in the Arctic, Antarctica, and glaciers. The Intergovernmental Panel on Climate Change (IPCC 2022) warns that if global temperatures rise more than two degrees Celsius above preindustrial levels, the effects on the planet could be catastrophic.

Mitigating climate change by curbing GHG emissions is a global public good. In theory, a universally adopted carbon tax is the most efficient instrument for reducing emissions, inducing households and producers to substitute away from fossil fuels, the primary source of GHG emissions (see, for example, Pigou 1920, Summers 1991, and IMF 2019). Other, less efficient nontax policies can achieve the same reduction in carbon emissions, and so comply with the goals of the Paris Agreement. However, every country has an incentive not to comply and still reap the benefits of the actions of compliant countries—a classic free-rider problem.

Some countries, including the members of the European Union (EU), have introduced carbon taxes and other measures to limit their GHG emissions. These measures give non-taxing countries an unfair competitive advantage in trade because their producers have lower costs and can sell exports at lower prices. To level the playing field, in March 2022, the European Union agreed in principle to impose tariffs on imports from non-compliant countries based on their carbon content through its carbon border adjustment mechanism (CBAM). The magnitude of the tariff will be country- and commodity-specific, starting with goods in five sectors (cement, iron and steel, aluminum, fertilizers, and electricity) with high carbon dioxide (CO2) emissions in their production.

Trade policy instruments can also be used more broadly to punish free-rider countries (or "holdouts") for not participating in the global effort to mitigate climate change. As described in Kemfert (2004) and Nordhaus (2015), a "climate club" or a coalition of compliant countries can collectively punish non-compliant countries by raising tariffs on all imports from non-members. Unlike CBAM tariffs, the climate club approach does not base tariffs on the carbon content of production of non-club members. The goal is to inflict enough damage to the export markets for non-compliant countries that they are better off joining the climate club.

We use a multi-sector, multi-region computable general equilibrium (CGE) model to examine the effectiveness of these climate-linked trade policies. We find that CBAM tariffs imposed by the EU work as expected—they level the playing field in EU markets—but they have little effect on aggregate trade because exporters can divert trade to other countries. As a result, there is little impact on global CO2 emissions.

Next, we examine a climate club and evaluate the impact of using punitive tariffs to punish non-member countries. In this context, tariffs can reduce global emissions if the loss of export markets causes more economic damage than adopting carbon taxes and induces non-taxing countries to join the club. Tariffs are more effective when there are more members in the climate club because there are fewer opportunities for non-members to divert trade and avoid punitive tariffs.

We start with a stylized club to illustrate the game theoretic model from Nordhaus, in which the two players are the EU and all other regions. In effect we extend CBAM to a climate club with the carbon tax rate and punitive tariff rates from Nordhaus. Our analysis uses a model with product differentiation, many sectors, and three integrated trading regions based on trade data: NAFTA, Europe, and East and Southeast Asia. With this more detailed market structure and imperfect substitution between imported and domestic goods, we find that higher punitive tariffs than Nordhaus recommends are needed to achieve a stable climate club as a Nash equilibrium

Finally, a large country with high CO2 emissions, like the US or China, may be reluctant to join the climate club due to the cost of climate mitigation. Hence, we also consider climate club scenarios with only one holdout country. In this case, tariffs are most effective because there are no opportunities for the holdout region to diversify trade. Our results indicate that punitive climate club tariffs are an effective tool and inflict significant damage on the economy of the non-member, who faces lower export prices and cannot diversify trade because the climate club is large.

Our results also suggest that the success of a climate club depends on the level of trade integration between members and non-members. Club members who trade extensively with the non-member suffer when punitive tariffs are imposed on the non-member. For example, if Mexico and Canada are club members and the United States is not, punitive club tariffs against the United States will hurt Mexico and Canada, both members of NAFTA (now called the USMCA) with extensive trade relations with the US. Their exports to the US decline and they have limited options to diversify. Such trade dependencies complicate any game-theoretic analysis because the punitive tariffs will damage linked club members, possibly destabilizing the coalition.

In this non-cooperative game between climate club members and nonmembers, the CO2 benefits are enjoyed by both parties, so the benefits do not enter into each player's calculation. Each country minimizes the reduction in total demand (real absorption) in their decisions about joining the club. However, the CO2 benefits do affect social welfare. We find that the Nash equilibrium is unlikely to be socially optimal in many of the selected scenarios.

II. Recent Literature

As evident in the ongoing negotiations to reduce global CO2 emissions, global commitments are difficult to enforce. A tax on carbon, or other measures to reduce CO2 emissions, increases production costs, creating a competitive disadvantage against producers in non-taxing countries.[2] Furthermore, an uneven use of carbon taxes across countries can offset the gains due to carbon leakage: dirty sectors can relocate to countries without a carbon tax. In addition, a carbon tax reduces demand for fossil fuels, lowering their price. Producers in non-taxing regions can benefit – increasing their use of fossil fuels and CO2 emissions. Tariffs (also called border tax adjustments, BTAs, "green tariffs," and, more recently, carbon border adjustment mechanisms, CBAM) are one potential solution to the problem of uneven application of carbon taxes across countries.

Numerous studies demonstrate that tariffs can "level the playing field" and offset the cost disadvantage to producers in taxing countries. For example, Babiker and Rutherford (2005) use a CGE model and consider a menu of border adjustment mechanisms to protect industries in regions with a carbon tax. They find that countervailing carbon duties can reduce the welfare loss

[2] See Timilsina (2022) for a survey of the issues related to using carbon taxes.

in regions with a carbon tax. Elliot et al. (2010) and Elliot et al. (2013) use a CGE model to analyze the effects of border tax adjustments on carbon leakage. They find that border tax adjustments reduce carbon leakage but are complex to administer because the importing country must determine emissions from a good produced abroad. Böhringer et al. (2012a) and Böhringer et al. (2018) find that border carbon taxes can effectively curb carbon leakage and offset competitiveness losses but have modest effects on reducing global carbon emissions or increasing the efficiency of meeting abatement targets. McKibbin et al. (2018) and McKibbin and Wilcoxen (2009) find that carbon duties by the United States and the European Union have negligible effects on trade and carbon emissions. Dissou and Eyland (2011) evaluate the role of unilateral border tax adjustments based on the carbon content in production, using a multi-sector static computable general equilibrium model for Canada. Like Böhringer et al. (2012a), they find that border tax adjustments restore the competitiveness of domestic industries that pay a tax on carbon. However, Dissou and Eyland also note that imported intermediates become more expensive, reducing overall welfare.

Another question about border tax adjustments is how to measure them. Elliot et al. (2013) note that a country needs information about production in the importing country to calculate a tariff that offsets differences in production costs due to different climate policies. Böhringer et al. (2012c) consider different methods to compute the carbon-content in production in the exporting region, different eligible commodities, and whether to differentiate by exporting region and export commodity or just by export commodity. They find that carbon tariffs based on direct CO_2 emissions plus indirect CO_2 emissions from electricity use as an intermediate input are the most efficient tariff instruments taking into account the complexity of calculating a carbon tariff and the legal and practical difficulties of using them. Mattoo et al. (2009) compare alternative calculations of border adjustment taxes based on either the carbon content of imports or the carbon content in domestic production. They find that carbon tariffs calculated on the carbon content of imports would cause more damage to developing countries than carbon tariffs calculated based on carbon in domestic production in developed countries.

Böhringer et al. (2022) suggest that border carbon adjustment taxes will be difficult to implement. Although they may comply with international law, implementing them faces practical challenges, such as the cost of administering the tax and enforcing firms' compliance.[3] They note that border carbon adjustment taxes (a) create incentives for exporters to send goods produced with dirty technology to regions without a border carbon adjustment; (b) may have little effect on non-compliant regions if it is easy to divert trade; (c) may not induce non-compliant regions to adopt a carbon tax, because trade represents a small share of total production; (d) may lead to trade wars; and (e) may reduce global cooperation efforts on climate change. Likewise, Sakai and Barrett (2016) argue that border carbon adjustment taxes will be complex to implement and may not be effective policy instruments. Krugman (2021) notes that the CBAM concerns only carbon embodied in trade, ignoring the much larger volume of carbon embodied in production for the domestic market.[4]

To support its efforts to reduce global carbon emissions, the European Union proposed the CBAM (EC 2021 and EC 2022) and is in the process of implementing it. Under this mechanism, the European Union will tax imports to ensure that domestic and imported goods face the same tax on the carbon embodied in production. For regions without a domestic carbon tax, tariffs will be based on the CO2 emitted in production in the exporting region.[5] Currently, CBAM tariffs will apply to five dirty sectors: fertilizer, iron and steel, aluminum, cement, and electricity. Numerous studies have explored the effects of CBAM on domestic competitiveness and global carbon emissions. The consensus is that CBAM tariffs level the playing field for domestic

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3 Whether the CBAM is compliant with World Trade Organization (WTO) rules has not been adjudicated. CBAM tariffs could be viewed as countervailing duties to offset a cost advantage in countries without a tax on carbon (see Hufbauer 2021a, 2021b and Hufbauer et al. 2021). For an earlier discussion of climate policies and WTO compliance, see Hufbauer et al. (2009). Horn and Mavroidis (2011) argue that border tax adjustments can be designed to be compatible with WTO rules.

4 Krugman (2021) also notes a related problem: the fact that a country could argue that it uses only clean technology for exports and reserves dirty technology for goods sold on the domestic market. Although potentially important for an argument about the WTO legality of CBAM tariffs, the distinction is ignored in most empirical work. McAusland and Najar (2013); Hufbauer et al. (2009); and Howse and Eliason (2008) discuss the legality of the CBAM.

5 See Mörsdorf (2022) for a discussion and empirical assessment of the CBAM using the Global Trade Analysis Project (GTAP)-E model.

producers in the EU but have little effect on global CO2 emissions (see, for example, Zhongi and Pei 2022 and Xiaobel et al. 2022).

However, CBAM tariffs are applied by one region, the EU, against a limited number of commodities. In this context, exporting regions have ample opportunity to divert trade around the EU. As more countries introduce a carbon tax, expand the sectors against which to apply border adjustment tariffs and increase the level of such tariffs, trade policy may induce countries to comply. The cost of a tax on carbon may be less than the cost of punitive tariffs against a country's exports when there are few markets in which to divert trade. Nordhaus (2015) explores this role of trade to support climate policy. Using a stylized model of the economy with one sector, Nordhaus explores the relationship between the level of a carbon tax and the level of a punitive tariff needed to induce all regions to join the climate club and therefore eliminate the free-rider problem.[6]

Nordhaus argues that a mechanism ("persuasive coercion") is needed to punish the free riders who currently gain from noncompliance.[7] He suggests that carbon-taxing countries form a "climate club" that imposes punitive tariffs against non-taxers to induce them to join the club.[8] According to Nordhaus, if the target carbon price is low (say, $25 per ton), a relatively low uniform import tariff of about 2 percent will induce full participation in the cooperative equilibrium. If the target price is high (say, $100 per ton), the required abatement cost for each country rises sharply, tilting toward nonparticipation even with higher tariffs.

This last point is consistent with the results of Carraro and Siniscalco (1993), who find that the game-theoretic conditions (profitability and stability) exist for there to be no free riders in a

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6 In an earlier study, Kemfert (2004) also assess the incentives for countries to join a climate coalition – she considers both technology transfers and punitive tariffs as the mechanism to induce countries to join the coalition. Using a game theoretic approach, she finds that technology transfers can induce all regions to join the climate coalition. In contrast, punitive tariffs on non-coalition members may not be an effective instrument to induce them to join. Tarr et al. (2023) also explore the effectiveness of a climate club with punitive tariffs and technology transfers to induce countries to join the club.

7 See, also Limão (2005), Conconi and Perroni (2002) and Khourdajie and Finus (2020) for game-theoretic analyses of the use of trade sanctions to gain international cooperation on cross-border externalities.

8 See Buchanan (1965) and Olson (1965) for early expositions, Sandler and Tschirhart (1980) for a literature survey, and Cornes and Sandler (1986) for an expanded textbook discussion of clubs.

coalition for an international agreement to protect the environment. However, cooperation among all countries is fragile, requiring suitable schemes of commitment and transfers. Hagen and Schneider (2021) examine the strength of coalitions when non-members retaliate and raise tariffs against their imports from club members. They find that stable coalitions must be larger when non-members can retaliate.

As a game theory model of strategic interactions, Nordhaus's (2015) model is highly aggregated and stylized. Caron (2012) emphasizes that sector disaggregation matters and that aggregated calibrations will tend to underestimate the reduction in carbon leakages. But combining a game theory model of strategic participation with trade diversion in a disaggregated framework is computationally challenging. Böhringer et al. (2016) use a general equilibrium framework to consider the strategic value of carbon tariffs with a Nash equilibrium of simultaneous or predetermined moves from all parties (unlike in Nordhaus 2015, the strategic interactions are exogenous). In their analysis, coalition countries reduce CO2 emissions by 20 percent by using a uniform domestic carbon tax (across all sectors and countries) and imposing carbon tariffs on all countries not in the coalition. Their results indicate that the threat of carbon tariffs can induce non-members to join the coalition.

We use a multi-sector, multi-region CGE model to analyze the effectiveness of tariffs when linked to climate policies. First, we simulate the effects of CBAM tariffs on domestic production, trade flows, and global CO2 emissions.[9] Then, we simulate a specific climate club

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[9] There is a long tradition of using CGE models to analyze the links between unilateral climate policy and competitiveness. See Carbone and Rivers (2017) for a survey. Böhringer et al. (2021) review the links between carbon tariffs and carbon leakages in a global CGE model using data from different observation years between 200 and 2014. Even so, Stern, Stiglitz, and Taylor (2022) argued that climate change presents deep uncertainty, immense risks, and other issues of radical change that are challenging to model. They discussed the shortcomings of Integrated Assessment Models (IAMs) for assessing climate change and suggest research options to address them. In particular, each model should not try to capture everything but focus on a key issue or issues following Rodrik's dictum (2015): "unrealistic assumptions are ok; unrealistic critical assumptions are not ok." In this paper, we focus on the effectiveness of tariffs in inducing compliance in CBAM and climate clubs by introducing factors such as imperfect substitution of domestic and foreign goods and integrated production and supply chain issues that may modify Nordhaus (2015) results. In this context, CGE models are ideally suited to explore these critical assumptions.

that excludes the biggest CO2 emitters, China and the United States.[10] We consider two variants of the climate club – one in which China is the lone holdout and one in which the US is the lone holdout. Trade policy (punitive tariffs by club members against the nonmember) is most effective in the extreme case of a single holdout because it provides no possibility for trade diversion. Leaving major polluters out of the club limits the global CO2 reduction when club members impose a carbon tax.

Both China and the United States are likely to hold out. Neither has a carbon tax, and both seem reluctant to adopt domestic strategies to mitigate CO2 emissions.[11] At the same time, both countries have strong trade ties with other regions through global value chains. Mexico and Canada depend heavily on trade with the United States; East and Southeast Asia depend heavily on trade with China. Club members may be hurt when punitive tariffs are applied to a holdout region that is an important trade partner. The simulations presented illustrate the power of this effect, which can subvert the results from aggregate, game-theoretic models.

Our analysis addresses two issues not emphasized in the literature. The first is substantial trade and production integration among certain groups, which could make the coalition fragile. Trade-dependent club members may hesitate to use punitive tariffs against their major trade partners outside the club. Second, the analysis considers the magnitude of forgone export earnings for the holdout region as club members collect tariff revenue against exports from the holdout. The effective transfer of export earnings to club members may induce the holdouts to join the club.[12]

[10] China introduced an emissions trading scheme in 2020 (see IEA 2020 for a description). As a result, it is farther along than the United States with respect to establishing a domestic price of carbon. Both regions have low taxes on energy input use, see Figure C-1.

[11] The recently signed Inflation Reduction Act in the US establishes a collection of subsidy policies to reduce emissions and represents a modest step towards meeting the US's carbon reduction goals. See de Bolle (2019) for a discussion of a potential carbon tax in the United States and Hufbauer (2021a, 2021b) for a discussion of trade implications

[12] Similarly, in Babiker and Rutherford (2005), a voluntary export restraint has the highest welfare gain for non-coalition countries.

III. Data

The data for the global simulation model come from the Global Trade Analysis Project (GTAP), version 10, which uses 2014 as the base year. The database includes information on CO2 emissions by user – each production activity and the household. Figures 1a and 1b provide data on carbon emissions and shares of global exports by country/region (for more details, see appendix Table C.1).[13] Three economies (China, the United States, and the European Union) account for 54 percent of global CO2 emissions. At 10 percent, the EU27 accounts for a much smaller share of global emissions than China (27 percent) or the United States (17 percent).[14]

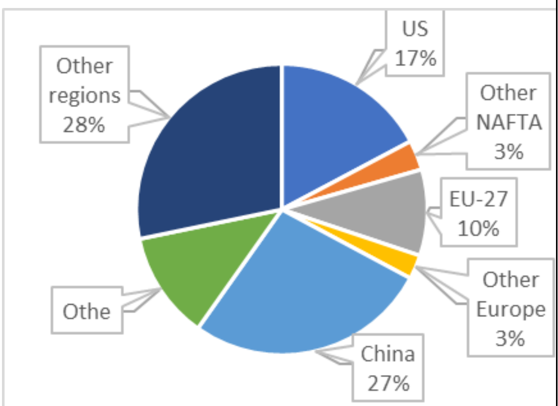

Figure 1a Global share of CO2 emissions

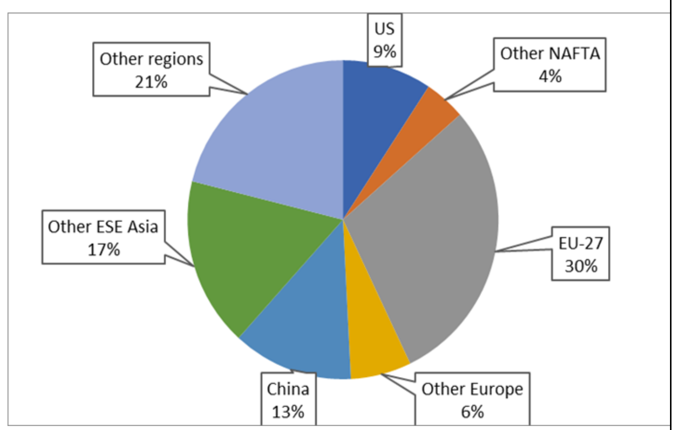

Figure 1b Global share of trade

Source: Authors' calculations using GTAP v10 data, 2014.
Notes: Other Europe excludes EU-27; Other NAFTA excludes US; ESE Asia=East and Southeast Asia; Other ESE excludes China.

Together, China and the United States account for 22 percent of global trade—a much lower share than their share of carbon emissions (44 percent). The EU-27 has the largest share of global trade (30 percent), indicating its strong potential for using trade policy instruments. If

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13 According to the United States Environmental Protection Agency (EPA), CO2 accounted for 65% of greenhouse gas emissions in 2010. (See epa.gov/ghgemissions/global-greenhouse-gas-emissions-data). We focus on CO2 emissions in this study.

14 China and the US continue to be large emitters of CO2. According to data on emissions from the 2018 World Development Indicators (the last pre- COVID year for which data are available), China accounted for 30 percent of global CO2 emissions and the United States for 15 percent.

other high-income countries (excluding the United States) joined the European Union to form a climate club, the total trade weight would reach 51 percent (see Table 1). China is more trade-dependent, measured as total trade as a share of GDP, than the US. (see Table 1).

The GTAP database consists of social accounting matrices (SAMs) with 65 sectors or products and 141 countries and regions.[15] The model treats regions and countries as unified economies. This study examined 19 economies (countries or regions) and 22 sectors. The sectors include the five sectors likely to face CBAM tariffs: iron and steel, aluminum, cement, fertilizers, and electricity. (See Appendix A for details on the aggregation of the GTAP data.)

Table 1: Emissions, trade, GDP, and population comparisons

	Percent of global				
	CO2 Emissions	Trade	GDP	Population	Trade Dependency
USA	17.2	9.5	22.3	4.4	13.3
Canada	1.9	2.4	2.3	0.5	30.3
Mexico	1.4	1.9	1.7	1.7	32.7
EU 27	9.6	30.1	19.9	6.1	40.1
Other Europe	2.7	6.5	5.7	1.9	31.5
China	27.0	12.9	13.6	18.9	23.3
Japan	3.4	4.2	5.9	1.8	19.8
Other High-income Asia	4.1	8.1	5.0	1.5	41.3
Indonesia	1.5	1.0	1.1	3.5	23.0
Other Southeast Asia	3.0	4.4	1.9	5.6	62.6
India	6.4	2.0	2.6	17.9	23.1
Other South Asia	0.8	0.4	0.7	5.9	20.5
Russian Federation	4.7	2.6	2.6	2.0	23.5
West Asia	5.6	3.3	3.2	5.0	29.6
Middle East	3.0	4.0	2.1	0.7	42.9
SACU	1.5	0.6	0.5	0.9	34.0
Other Africa	2.2	2.3	2.7	14.9	25.7
Brazil	1.5	1.2	3.1	2.8	11.9
Other America	2.6	2.4	3.3	4.0	20.4
Total/ Average	100.0	100.0	100.0	100.0	28.9

Source: Authors' calculations using GTAP v10 data, 2014.

15 The underlying database has become the standard for global general equilibrium modeling (Aguiar et al. 2019).

The model also uses satellite account data produced by the GTAP. Six (three-dimensional energy by user by region) matrices record the volumes of energy inputs used by activities and purchased by households, in million tons of oil equivalent (MTOE). Another six (three-dimensional) matrices produce the CO2 emissions associated with each energy commodity and user agent. This database supports analysis of the quantities of energy inputs used, inherent differences between energy commodities, and variations in the technologies used by producers and consumers in different regions. It also provides tax information on energy inputs used by purchasing agents, allowing the model to incorporate differences in energy policies by region (for 2014). The database includes household consumption of energy commodities and their emission implications.[16] (Appendix Figure C.1 shows each region's average fossil fuel taxes by purchasing agent. These taxes are on energy use and do not account for the CO2 emitted in the use of energy by purchasing agents. These tax rates do not change in the simulations.)

For all regions, the GTAP database includes input-output tables that trace the supply chains of intermediate inputs used in production. A standard analysis uses the input-output tables to compute the direct and indirect sources of CO2 emissions from production processes. For example, generating electricity by burning coal directly produces huge volumes of CO2. Any industry that uses electricity indirectly produces CO2 emissions. The input-output analysis captures all direct and indirect linkages. For all production activities, it provides the shares of direct and indirect CO2 per unit of sectoral output (see appendix table C.4 for a comparison of the direct and indirect CO2 emissions to the direct CO2 emissions for selected sectors).

The paper identifies a potential threat to climate clubs due to strong trade dependence between some club members and holdout countries (the United States and China). The US, Mexico, and Canada represent an inter-connected regional economy (ICRE), with production characterized by extensive supply chains across the borders. East and Southeast Asia, from

16 Golub and McDougall (2007) describe the fossil fuel emissions data provided as a satellite dataset for the GTAP database. A potential extension of this study would include the non-CO2 sources of GHG found in Chepeliev (2020).

China and Japan to Australia and New Zealand, also form an ICRE. The US and China are anchor countries in their respective ICREs.

These strong trade relationships are evident in data on trade shares, see Table 2.[17] For example, over 50 percent of imports into Mexico and Canada are from the US, and over two-thirds of their exports are to the US. Similarly, China is a major destination and source for trade with other countries in its ICRE. The implication is that the imposition of punitive tariffs by ICRE club members against their anchor country will damage the ICRE club members.

Table 2: Bilateral trade with the US and China

	Exports *fob* to:		Imports *cif* from:	
	China	USA	China	USA
USA	10.0	0.5	19.2	0.4
Canada	5.7	**65.5**	12.2	**50.3**
Mexico	2.9	**69.9**	18.8	**51.4**
EU 27	5.2	7.4	7.4	6.7
Other Europe	7.7	9.3	7.9	8.6
China	3.3	18.1	4.0	9.2
Japan	**26.7**	15.4	**22.8**	10.0
Other High-income Asia	**29.5**	9.4	**18.5**	11.5
Indonesia	**12.9**	10.3	**20.7**	5.3
Other Southeast Asia	**19.5**	12.1	**26.2**	6.0
India	7.3	13.5	14.4	5.4
Othr_S_Asia	6.0	17.4	25.4	4.0
Russian Federation	7.2	4.5	17.2	7.6
West Asia	12.5	9.3	15.4	7.4
Middle East	13.8	9.1	12.9	11.3
SACU	14.1	7.4	15.0	6.0
Other Africa	13.0	7.2	17.3	8.2
Brazil	19.1	12.8	15.4	16.1
Other America	11.1	21.5	15.9	24.8

Source: Authors' calculations using GTAP v10 data, 2014.
Note: See Appendix A for the aggregation scheme and definition of regions.

[17] The importance of ICREs to the global economy are explored in Robinson and Thierfelder (2019a and 2019b). The European Union and the other countries in Western Europe represent the third major ICRE. For this paper, that is not relevant to the analysis because all the ICRE countries are club members

Among the three ICREs, Europe is the most interconnected, with 21.1 percent of global trade accounted for by trade in that region; East and Southeast Asia is another strong region, with 13.5 percent of global trade accounted for by trade in the region. In contrast, NAFTA is a smaller region, accounting for only 5.4 percent of global trade (see Table 3).

Table 3: Bilateral trade as a percent of global trade, by interconnected regional economies (ICREs)

	NAFTA	Europe	ESE Asia	Other	Total
NAFTA	5.4	2.9	2.9	2.4	13.6
Europe	3.4	21.1	4.5	6.6	35.6
ESE Asia	5.4	4.9	13.5	5.9	29.7
Other	2.7	6.2	6.2	6.1	21.1
Total	16.9	35.1	27.0	21.0	

Source: Authors' calculations using GTAP v10 data, 2014.
Note: See Appendix A for the aggregation scheme and definition of regions.

Table 4: Exports from row region to column region, percent of total

	NAFTA	Europe	ESE Asia	Other	Total
NAFTA	40.0	21.1	21.2	17.7	100.0
Europe	9.5	59.3	12.6	18.6	100.0
ESEAsia	18.2	16.6	45.3	20.0	100.0
Other	12.6	29.3	29.3	28.8	100.0

Source: Authors' calculations using GTAP v10 data, 2014.
Note: See Appendix A for the aggregation scheme and definition of regions.

Bilateral trade flows also indicate trade integration within the regions, as export shares are the highest by region. For example, 40 percent of NAFTA's exports are to NAFTA countries, 59 percent of Europe's exports are to Europe, and 45 percent of East and Southeast Asia's are to East and Southeast Asia (see Table 4).

IV. Simulation Model

The underlying approach to multi-region modeling is the construction of a series of single-country CGE models that are linked through their trading relationships.[18] This modeling assumes that aggregate imports and domestic goods are imperfect substitutes in consumption, modeled using a constant elasticity of substitution (CES) function; it assumes that exports and domestic goods are imperfect substitutes, modeled using a constant elasticity of transformation (CET) function. To better represent trade dependencies among regions, we extend the trade nest: aggregate imports are a CES function over aggregate regions: NAFTA, Europe, East and Southeast Asia, and the Rest of the World. Imports by aggregate regions are modeled as a CES function over imports from the region's members. For example, the aggregate region NAFTA is comprised of the US, Canada, and Mexico. Within the three inter-connected regional economies, there is low trade substitution among members for intermediate goods – this reflects the integrated nature of trade in each region – production is highly specialized, and intermediate goods are shipped multiple times across borders in the region – imports of intermediate goods by different countries in the region are poor substitutes.

As is common in CGE models, the focus is on relative, rather than absolute, price changes. Consequently, each region in the model has its own numeraire price, the consumer price index (CPI); the model requires a global numeraire, which is an aggregate exchange rate index, a trade-weighted average of the nominal exchange rates for high-income countries.

The model's production structure has a nested formulation that allows for substitution possibilities at each level (see appendix figure B.1). It includes incentives to substitute away from energy inputs as prices change. Each sector produces an output using a CES function over aggregated intermediate inputs and value-added. Value added also has nested CES functions, allowing substitution between aggregate labor, land and natural resources, and aggregate capital energy. The aggregate labor input is another CES function over skilled and unskilled labor; the

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18 See Thierfelder (2021) and McDonald et al. (2007) for descriptions of the GLOBE model. The model is a member of a family of CGE models that model trade relationships using principles described in the 1-2-3 model (de Melo and Robinson 1989; Devarajan et al. 1990; and standard multi-sectoral versions for developing countries [Dervis et al. 1982]). Aguiar et al. (2019) describe the GTAP dataset that underpins most global CGE models.

aggregate of land and natural resources is a CES function over those two inputs. The composite of capital and energy constitutes a CES aggregation of capital and energy, an aggregate of electricity and nonelectricity inputs. The nonelectricity aggregate is a CES combination of all nonelectricity inputs. The nesting structure allows the substitution elasticity to vary at different aggregation levels. It also allows substitution among energy and other primary inputs (land, labor, and capital). When choosing inputs for production, producers consider the relative prices of inputs and can substitute away from more expensive inputs.

The nonenergy intermediate inputs used in production are assumed to be demanded with fixed proportions, the input-output matrix. This matrix describes supply chains due to inter-industry linkages in the economy. In a modern economy, sectors are linked both directly and indirectly through this input-output structure. For example, electricity is an important input to production for most sectors. Any shocks to the electricity sector will reverberate throughout the economy. Electricity production is energy-intensive, particularly using coal in many countries. A carbon tax, which makes coal expensive, will make electricity expensive and reverberate across the economy.

Using the input-output table, one can measure the direct and indirect effects arising from a shock to a particular sector. The direct effect will be on the shocked sector. The one-round indirect effect takes into account the impact on sectors that directly use the output of the shocked sector as an input. The shock to electricity affects sectors using electricity. The total direct and indirect effects account for all indirect linkages between the shocked sector and the rest of the economy. For example, users of steel are affected by a shock on electricity since it affects the cost of producing steel. Formally, one can solve the input-output system to capture the complete mix of direct and indirect links.[19]

The tax on the use of fossil fuels as an input to production considers the tax per unit of carbon and the emission per unit of fossil fuel used in production. The tax rate, TCARBc, a,r is indexed over commodity, c; production activity, a; and region, r (where region is either a country or regional aggregate), specified as

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[19] Any introduction to input-output models will explain the mathematics of this relationship. See, for example, Miller and Blair (2009).

$$TCARB_{c,a,r} = TC_r * \frac{CO2EMIT_{c,a,r}}{QINTD0_{c,a,r}}$$

where TCr is the tax per ton of carbon emitted in region r times the tons of CO2 emitted, CO2EMITc,a,r, per unit of the intermediate input commodity c used in activity a in region r, QINTD0c,a,r (where 0 denotes the value in the base data). The tax takes into account the carbon intensity of production in the base data; countries have different starting points because they have different taxes on energy inputs in production in the base data.[20] The specific tax on inputs, TCARBc,a,r, enters the first-order condition for the demand for energy inputs that are substitutable with capital, so producers substitute away from energy inputs in response to a tax on them (see Figure B.1 for the production structure).[21] The tax revenue collected, CARBTAXr, depends on the amount of intermediate goods used, QINTDc,a,r, and the specific tax, TCARBc,a,r, as follows:[22]

$$CARBTAX_r = \sum_{c,a} TCARB_{c,a,r} * QINTD_{c,a,r}$$

The carbon tariff is also calculated based on the carbon content of production in the trade partner region:[23]

$$TMCARB_{w,c,r} = TMC_w * \sum_a ioqxcqx_{a,c,w} * \frac{\sum_c CO2EMIT_{c,a,w}}{QX0_{a,w}},$$

TMCARBw,c,r is a specific tax on imports of commodity c in region r from trade partner w[24]. This carbon tariff is based on the tax per ton of carbon applied to the trade partner (TMCw)

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20 See appendix figure C.1 for the energy use taxes in production by region for an indication of the different starting positions. The EU-27 and "other Europe" impose much higher taxes on energy inputs in the base data than other regions.

21 As all prices are set to 1.0 in the base year, the specific carbon tax is equivalent to an ad valorem tax

22 QINTDc,a,r is the amount of intermediate input of commodity c used in production activity a in region r. It changes with the policy shock. QINTD0c,a,r is the base value. It is used to calibrate the carbon intensity of input use.

23 This specification measures the direct CO2 emitted in production. The analysis considers two alternative direct and indirect CO2 specifications discussed below.

24 The indices refer to the trade partners and commodities for each region. For example, $TMCARB_{Canada,mfg,USA}$ is the carbon tariff the United States (region r) imposes on manufacturing (commodity c) imports from Canada (trade partner w).

and the carbon intensity of production in the exporting region (i.e., the total emissions when activity a uses commodity c in production [ΣcC02EMITc,a,w] divided by the base level of output [QX0a,w]). The matrix ioqxcqxa,c,w converts production activity a to commodity c. In the GTAP data, there is a one-to-one mapping between activities and commodities.

TMCARBw,c,r is included in the domestic price of imports of commodity c from trade partner w by region r (PMRw,c,r) as follows:

$$PMR_{w,c,r} = \left[PWM_{w,c,r} * \left(1 + tm_{w,c,r}\right) + TMCARB_{w,c,r}\right] * ER_r$$

where PWMw,c,r is the cif price of imports of commodity c in region r from trade partner w valued at world prices; tmw,c,r is the ad valorem tariff rate on imports of commodity c from trade partner w by country/region r; and ERr is the nominal exchange rate in region r.

The carbon tariff revenue, MCARBTAXr, is the sum over trade partners w and commodities c of the carbon tariff per unit of import of commodity c from trade partner w by region r (TMCARBw,c,r) times the import quantity of commodity c from trade partner w by region r (QMRw,c,r) times the exchange rate in region r (ERr):

$$MCARBTAX_r = \sum_{c,w} QMR_{w,c,r} * TMCARB_{w,c,r} * ER_r.$$

The macro model closure defines macroeconomic behavior. The external current account balance is assumed to be fixed. Changes in economic activity will not lead to a change in foreign borrowing. Instead, the exchange rate will adjust in each region. A fixed current account closure also ensures that income changes in the economy will uniformly affect all components of total absorption (aggregate domestic final demand, a measure of welfare). In this formulation, households, the government, and investment spending adjust with constant expenditure shares.

The internal balance is held constant, and any change in tax revenue collected is redistributed to households as a lump-sum change in income taxes. A fixed internal balance also has a "double dividend" effect of environmental tax policy: The tax reduces carbon emissions, and the tax revenue generated can reduce taxes elsewhere in the economy. Adjusting income taxes can be a nondistorting change, as income taxes in this model are lump-sum taxes; other tax replacement options, such as a reduction in sales taxes, work through the price system and affect decisions at the margin. Labor and capital are fully employed and fully mobile across all activities in all regions. In each region, the current account balance is valued using the global numeraire exchange rate (a weighted average of exchange rates of high-income countries).

The results from this study are conservative due to model assumptions. The model assumes full employment and reallocates existing capital stocks and labor across sectors within each region to achieve equilibrium in product and factor markets. The model does not incorporate potential productivity gains as the economy shifts to lower-carbon technologies. Because external account balances are fixed, there are no international investment flows that would change regional capital stocks. Finally, the model is comparative static, not dynamic, so it does not account for growth from factor accumulation.

V. Scenarios

To explore the role of tariffs in supporting climate policies, we consider a variety of scenarios and compare the results to the base case in which tariffs are at the levels observed in the 2014 GTAP v10 database and carbon taxes are zero.[25] First, we consider CBAM by the EU-27 as described by the European Commission (EC 2021). A carbon tax is used to represent a carbon pricing system rather than a more complicated system, such as the European Union Emissions Trading System (ETS). Carbon tariffs are applied to imports of fertilizer, iron and steel, aluminum, cement, and electricity from all other regions.[26] We consider different calculations of carbon tariffs based on the exporter's (i) direct CO2 emissions; (ii) direct and indirect CO2 emissions; and (3) direct plus one round of indirect CO2 emissions in production.

Next, we expand CBAM into a climate club described by Nordhaus – EU-27 countries constitute the only region in the club; the region imposes a low carbon tax ($25 per ton of carbon) and has a 2% punitive tariff against all other regions. This club is a natural extension of

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25 CGE models are simulation laboratories within which "what if" economic experiments explore the relationships between policy options and economic consequences. The comparative static simulations presented in this paper describe the state of the economy before and after a shock when a new equilibrium is reached. The analysis does not consider the period between "before" and "after" or the dynamic adjustment process. The scenarios are not forecasts but conditional projections of the implications of controlled experiments, changing only selected policy instruments.

26 The analysis does not consider an export subsidy which would make producers in a carbon tax country competitive in markets where there is no carbon tax. However, such a subsidy is inconsistent with the goal of discouraging dirty production in a country. See Martin (2022) for a discussion of a carbon tariff and a subsidy to exports.

CBAM, and we use it to compare Nordhaus' results from a stylized, one-sector model to our multi-sector, multi-country framework.

Finally, we consider two likely and realistic holdouts, China and the US, which have the highest CO2 emissions and would face significant costs to climate mitigation. We set carbon taxes at $75 per ton, as recommended by Parry and Roaf (2021). Table 5 summarizes the various scenarios. The analysis focuses on changes in the production structure, global trade, and carbon emissions that would occur in response to a combination of carbon taxes and tariffs against imports from non-compliant regions.

Table 5: Scenarios

CBAM scenarios

EU-27 imposes a $75 tax on carbon and imposes tariffs on imports of high-pollution goods ((fertilizer, iron and steel, aluminum, cement, and electricity) from all regions; tariffs are calculated as follows:

a. No tariff
b. Tariff of $75 per ton of direct CO_2 emitted per unit of output in the exporting region (the actual tariff charged depends on the exporting region's emission of carbon in production)
c. Tariff of $75 per ton of direct plus one round of indirect CO_2 emitted per unit of output in the exporting region
d. Tariff of $75 per ton of total direct and indirect CO_2 emitted per unit of output in the exporting region

Climate club scenarios

club members put a tax on carbon and a punitive tariff on all imports from non-club members; we consider three different clubs; each club has one holdout region and all other regions are in the club. For reference, we consider the "first best" case in which all regions are in the club.

Holdout	**Carbon tariff for club members**	**Punitive tariffs against non-club members**
EU-27	$25 per ton of carbon emitted	2%
No holdout, all regions in the club	$75 per ton of carbon emitted, the price proposed	N/A

	by the International Monetary Fund (IMF) and others (Parry, Black, and Roaf 2021)	
China	$75 per ton of carbon emitted	30%
US	$75 per ton of carbon emitted	30%

VI. Simulation Results

CBAM Scenarios

When the EU-27 imposes a tax on carbon, its cost of production increases; there is a decrease in demand for energy inputs. Output of "dirty" sectors with high carbon emissions in production decline. For example, the output of electricity declines 14 percent, see Figure 2. Tariffs to offset unfair competition to domestic producers in the EU-27 dampen the output decline as imports decline (see Figure 3). Consistent with other studies we find that border tariffs help to level the playing field for domestic producers but have little effect on global CO2 emissions because countries facing tariffs by the EU-27 divert trade.

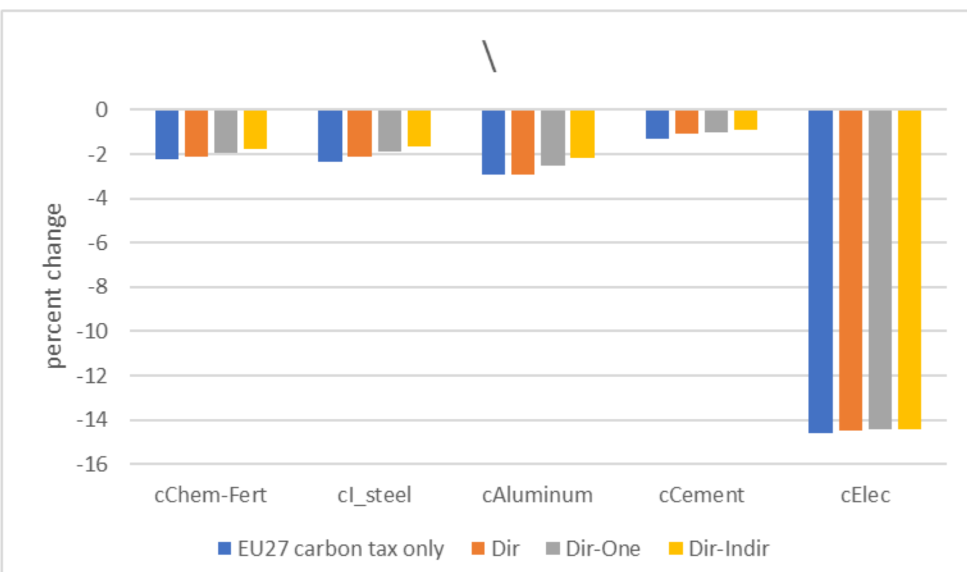

Figure 2: Production of CBAM commodities in the EU-27, percent change

Source: Simulation results from Globe model.

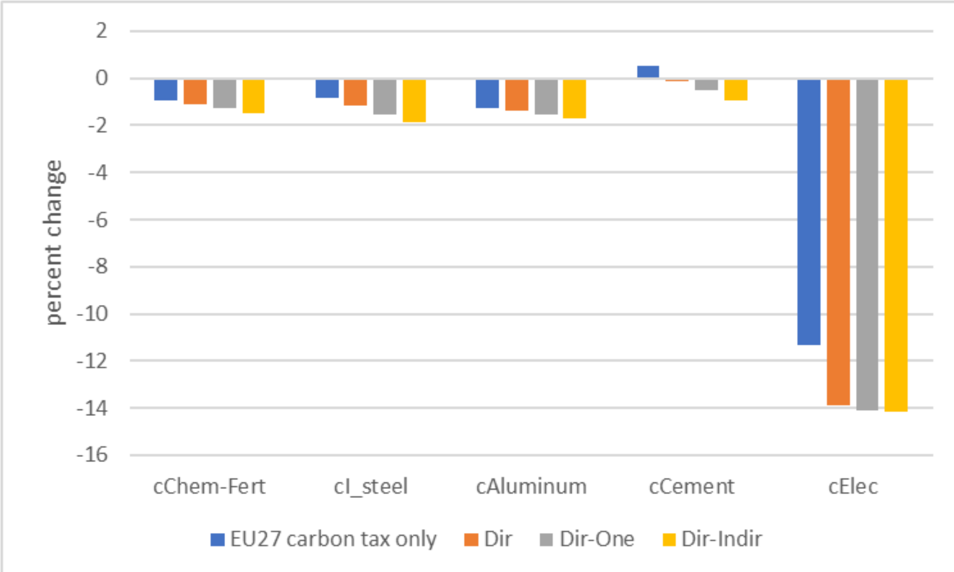

Figure 3: EU-27 imports of CBAM commodities, percent change

Source: Simulation results from Globe model.

Countries dependent on trade with the EU-27 in the five dirty commodities do see a decline in exports to the EU-27. For example, India's exports to the EU-27 decline by 11 percent, and SACU's exports to the EU-27 decline by 10 percent (see Table 6). However, those countries are able to divert trade to other regions, so total exports of the dirty commodities decline by much less – around 1 percent.

Consistent with the trade diversion effect, and regardless of how the CBAM tariffs are calculated (direct, one-round indirect, or direct and indirect), there is no decline in global CO2 emissions.

Table 6: Exports of dirty commodities to the EU-27 and total, percent change

	Percent change in exports to	
	EU-27	Total
USA	-1.85	-0.47
Canada	-2.69	-0.06
Mexico	-3.07	-0.08
EU 27	-1.68	-2.40
Other Europe	-0.72	-0.73
China	-6.37	-0.52
Japan	-3.36	-0.04
Other High-income Asia	-3.93	-0.10
Indonesia	-4.54	-0.25
Other Southeast Asia	-5.81	-0.27
India	-11.33	-1.37
Other South Asia	-5.19	-0.71
Russian Federation	0.51	5.22
West Asia	-7.59	-0.80
Middle East	-2.04	1.27
SACU	-10.49	-1.15
Other Africa	-0.51	1.56
Brazil	-0.94	-0.16
Other America	-2.39	0.40

Source: Simulation results from Globe model. CBAM tariffs are calculated based on direct and indirect CO2 emissions in the exporting region.

Climate club scenarios

Since CBAM is likely to be ineffective in curbing carbon emissions and incentivizing other countries to adopt carbon taxes, we turn to climate clubs.[27] We focus on a climate club in which one region (the "holdout") does not join to focus on the role of trade policy in inducing nonmembers to join the club. When there is one holdout region, punitive tariffs are most effective – the region not in the club cannot diversify its exports because all regions impose punitive tariffs against its goods. The question becomes, will the damage from punitive tariffs be

[27] An extensive body of literature examines the game-theoretic problem of how to form a club (see Nordhaus 2015; Böhringer, et al., 2016; and Hagen and Schneider 2021). We do not evaluate club formation or optimal club membership.

enough to induce the holdout to join the club and adopt the carbon tax that other countries impose? If that is the case, then tariffs will contribute to a reduction in global warming.

Stylized Club: EU-27 and all other regions

We start with a stylized case – suppose the EU-27 uses punitive tariffs rather than CBAM tariffs. Following Nordhaus, we consider carbon tax of $25 per ton of CO2 emission and a punitive tariff of 2%.[28] We present our results in a payoff matrix, reporting the percent change in real absorption and global or total CO2 emission for the two players in the game, the EU-27 and all other regions (see Figure 5). Each player has two options: join the club and impose a carbon tax, or don't join the club (by imposing no carbon tax) but face punitive tariffs against its exports to all club members.

In the analysis, we assume countries only consider the percent change in real absorption, the known effects on their total demand that measures the private interest they face when deciding whether or not to join the climate club. The reduction of total CO2 emissions, however, connotes the social welfare in the presence of the global public good that is climate change, but the effort is subject to the problem of free riders. Moreover, we assume that countries do not know how to assess the future damage of climate change on real absorption (which has deep uncertainty and risks - Stern, Stiglitz, and Taylor 2022) and, therefore, do not factor it into their immediate decisions.

We find that the dominant strategy is for the EU-27 to join the club. When it is the only club member, it gains due to terms of trade effects as the only region introducing tariffs. When the other regions join the club and the EU-27 does not, it loses because punitive tariffs reduce its exports. However, the EU-27 gains when it also joins the club because it keeps its access to other countries' markets. Hence, the EU-27's dominant strategy is to join the club.

The other region's dominant strategy is to holdout and not join the climate club. If the EU-27 holds out and all other regions hold out, the cost of imposing a carbon tax dominates the effect of imposing punitive tariffs on the EU-27 and the gain from terms of trade (0 > -0.16). If the EU-27 joins the club, all other regions will do better by holding out (-0.1 > -0.25). They lose

[28] This combination of carbon tax and punitive tariff induces all countries to join the climate club in Nordhaus (2015).

more when joining the club because the cost of a carbon tax is higher than the cost of EU-27 punitive tariffs against the exports; the other regions can diversify trade among themselves.

Hence, the Nash equilibrium in this particular non-cooperative game is one where the EU-27 join the club and the other regions holdout. This equilibrium does not yield the largest reduction in carbon emissions, which is the one where both regions join the club.

		EU-27	
		Holdout	Join Club
AO All other countries	**Holdout:** No tax on carbon and no additional tariffs	EU-27: 0 **(0.0)** AO: 0	EU-27: 0.3 **(-0.8%)** AO: -0.1
	Join Club: Tax on carbon = $25 and punitive tariffs (of +.02, 2 percentage points) on non-club members	EU-27: -0.26 **(-18.4%)** AO: -0.16	EU-27: 0.07 **(-19%)** AO: -0.25

Figure 5: Climate Club Payoff matrix for EU vs. All other regions, (percent change in real absorption by player vs. percent change in global CO2 emission)
Source: Simulation results from Globe model
Note: AO = all regions – holdout region; percent change in real absorption represented by numbers in black; percent change in global CO2 emissions represented in numbers in red and in parenthesis.

Our result qualifies Nordhaus' conclusion that for a relatively low carbon tax, such as $25 per ton of carbon, a 2% tariff will induce all regions to join the club. We find that a higher tariff is needed to induce all countries to join the club because we include many sectors and product differentiation in the model. When imports and the domestic variety are imperfect substitutes in consumption, a higher tariff is needed (compared to the case perfect substitution or homogenous goods of pure trade theory) to reduce exports in the non-club regions.[29]

China Holdout

Next, we consider a more realistic scenario in which the holdout region is either the US or China. Both are big CO2 emitters, so it is essential that they be included in the club to reduce global CO2 emissions. At the same time, each country is tightly linked through trade and global supply chains to other countries in its region. China is important in East and Southeast Asia, the US is important in the NAFTA region (see Tables 2,3,4, which describe trade dependencies).

When it is the lone holdout, China faces considerable damage: Its real imports fall 17.3 percent, its exchange rate depreciates 32.8 percent, and its real absorption (aggregate final demand) declines 4.7 percent (see Table 7). The volume of exports will increase slightly (by 0.02 percent), indicating that even with a dramatic decline in its export prices (because of punitive tariffs, which reduce demand for China's exports), China has to maintain exports to pay for crucial imports (indicated by the dramatic depreciation). The shock to China's international terms of trade results in a decline in aggregate final demand.

Table 7: Damage imposed on holdouts and linked regions

	US holdout			China holdout				
	US	Canada	Mexico	China	Japan	Other high-income Asia	Indonesia	Other Southeast Asia
Percent change in								
Real exchange rate	19.13	-0.88	-6.33	32.77	-4.52	2.96	13.26	-5.98
Real absorption	-1.82	1.29	1.55	-4.67	1.29	0.71	-0.60	3.79
Real imports	-13.63	-3.63	-3.73	-17.32	0.38	-4.30	-5.86	-5.86
Real exports	-4.12	-10.24	-12.72	0.02	-7.12	-6.36	-5.86	-7.56
Terms of trade	0.83	1.06	1.09	0.88	1.07	1.03	0.99	1.08
Tariff revenuc collected as a share of export revenue	0.30			0.29				

Source: Simulation results from Globe model

29 We consider sensitivity analysis to the size of the punitive tariff and find a punitive tariff of 20 percentage points will induce all regions to join the club. The damage to real absorption in all other regions when only the EU-27 is in the club is enough to induce all other regions to join the club. See Appendix D, Figure D-1 for the payoff matrix.

Table 7 also reports the tariff revenue collected by club members relative to the holdout's export sales. Had the holdout, rather than club members, imposed a carbon tax, it would have earned these tax revenues. The share of export revenue the holdout region is giving up to foreign governments is substantial, at about 30 percent, when either the United States or China is the lone holdout.

Countries closely linked to China suffer trade losses when China is the lone holdout to the climate club—for example, exports from the regions in East and Southeast Asia decline between 5.8 and 7.7 percent. When China depreciates its exchange rate, its imports become more expensive, reducing sales from linked regions.

Figure 6 shows the game payoffs when the players are China and all other regions. The two options are (1) to join the climate club and impose a $75 carbon tax and an illustrative tariff of 30 percentage points on imports from all non-club members or (2) not join the club and impose no carbon taxes.

All other countries are somewhat ambivalent about starting a club; their real absorption does not change much (left column) although it is slightly better with club formation. If they do not form a club, then China's preferred option is to do nothing (upper left quadrant). There is a disincentive for it to start one, given the impact on its aggregate demand – the trivial inaction will continue (upper right quadrant). However, when all other countries start a climate club, the incentive is for China to join to minimize the impact on its real absorption, and total CO2 emissions will fall significantly. Thus, in this case, the Nash equilibrium is likely the social optimum (the lower right quadrant).

The significance of China in reducing global CO2 emissions is illuminated as follows: when China alone forms a climate club, global emissions decline by 16%; when the club forms without China, global emissions decline by 24%; and if China joins, global emissions decline by 38%. China is by far the largest CO2 emitter, and most of its emissions are from production (93 percent compared with 80 percent for the United States [see appendix Table C.4]). The carbon tax is, therefore, much more effective in China, where it hits a larger share of a larger base. When China imposes a carbon tax, its CO2 emissions decline almost 60 percent (see Table 9).

Although a cooperative outcome seems apparent in the presence of a global public good, it is by no means inevitable. A punishing tariff of 30% (the level is illustrative) is required for

China to join the climate club initiated by all other countries when product differentiation is prevalent. Although immediate real absorption will decline for all players, this price should be weighed against a likely more severe but unknown global damage of climate change in the future.

East and Southeast Asia = Japan, Other high-income Asia, China, Indonesia, Other East and Southeast Asia Results are given for an aggregate of club members and the individual club members who are in the region of East and Southeast Asia.		China	
		Holdout	Join Club
AO All other countries	**Holdout:** No tax on carbon and no additional tariffs	China: 0 **(0 %)** All: 0 Japan: 0 Other H-Asia: 0 Indonesia: 0 Other ESE Asia: 0	China: 2.13 **(-16 %)** All: -0.77 Japan: -0.98 Other H-Asia: -2.03 Indonesia: -2.13 Other ESE Asia: -3.61
	Join Club: Tax on carbon = $75 and punitive tariffs (of +.3) on non-club members	China: -4.67 **(-24 %)** All: 0.02 Japan: 1.29 Other H-Asia: 0.71 Indonesia: -0.60 Other ESE Asia: 3.79	China: -0.71 **(-38 %)** All: -0.72 Japan: 0.57 Other H-Asia: -0.03 Indonesia: -2.22 Other ESE Asia:-0.40

Figure 6: Payoff matrix for the effective club, China versus all other regions (AO) (percent change in real absorption vs. percent change in global CO2 emission)

Source: Simulation results from Globe model

Note: AO = all regions – holdout region; percent change in real absorption represented by numbers in black; percent change in global CO2 emissions represented in numbers in red and in parenthesis.

Table 8: Percent change in bilateral exports, holdout scenarios

	US holdout		China holdout	
	Exports to US	Total Exports	Exports to China	Total Exports
USA	7.4	-3.7	-19.3	-4.0
Canada	-12.5	-8.8	-18.6	-2.4
Mexico	-14.7	-11.2	-20.0	-4.6
EU 27	-13.2	-1.9	-18.9	-1.9
Other Europe	-12.3	-1.8	-18.1	-2.1
China	-13.2	-3.8	2.4	0.2
Japan	-12.2	-2.8	-17.4	-5.0
Other High-income Asia	-13.2	-3.7	-16.4	-5.1
Indonesia	-9.4	-4.2	-18.5	-5.5
Other Southeast Asia	-13.4	-3.5	-20.2	-6.8
India	-13.6	-4.1	-20.7	-4.9
Other South Asia	-14.7	-3.9	-23.6	-6.6
Russian Federation	-7.8	-1.1	-11.6	-1.4
West Asia	-11.4	-2.0	-14.1	-2.8
Middle East	-6.6	-0.3	-6.8	0.1
Southern African Customs Union	-12.8	-4.8	-18.1	-6.4
Other Africa	-11.6	-3.1	-14.0	-4.3
Brazil	-12.4	-3.0	-17.2	-3.7
Other America	-12.3	-4.2	-17.7	-3.7

Source: Simulation results from Globe model

Table 9: CO2 emissions by region under alternative "effective club" membership

	Club Membership				
	All	US Only	China Only	All except US	All except China
USA	-37.6	-38.6	0.6	-6.5	-37.7
Canada	-27.7	-10.0	-0.2	-26.0	-27.7
Mexico	-26.5	-12.1	0.2	-26.7	-25.3
EU 27	-19.4	-0.9	2.7	-19.3	-20.3
Other Europe	-20.7	-0.6	1.6	-20.7	-21.4
China	-58.3	0.3	-60.0	-58.6	-7.5
Japan	-13.8	1.2	0.9	-14.1	-14.6
Other High-income Asia	-29.5	0.5	-0.5	-29.4	-31.0
Indonesia	-33.8	0.5	-2.2	-34.2	-33.0
Other Southeast Asia	-35.9	0.5	-4.4	-36.3	-34.4
India	-41.8	0.2	1.6	-42.1	-41.7
Other South Asia	-23.3	1.6	1.5	-24.3	-21.7
Russian Federation	-29.8	-0.1	-0.5	-29.8	-29.6
West Asia	-30.9	-1.5	-0.5	-30.5	-30.6
Middle East	-30.1	-0.3	-0.2	-29.8	-29.9
SACU	-60.0	0.9	0.6	-60.3	-60.1
Other Africa	-24.6	-0.8	0.0	-24.7	-24.2
Brazil	-18.6	-1.5	0.1	-18.5	-18.7
Other America	-24.0	-2.8	-0.2	-24.6	-23.9
Total	-38.0	-7.1	-15.9	-32.7	-24.3

Source: Simulation results from Globe model. An "effective club" has a $75 tax per ton of CO2 and punitive tariffs of 30 percentage points.

US Holdout

When the United States is the lone holdout, the story is similar but less extreme than it is when China is the lone holdout. US Real exports will fall by 4.1 percent, and real imports decline by 13.6 percent (see Table 7). The depreciation is also smaller (19.1 percent). These more moderate effects reflect the fact that the United States is less dependent on trade than China (see Table 1).

Club members closely linked to the US suffer trade losses (see Table 8). When the United States is the holdout region and club members impose punitive damages. Mexico's exports to the United States decline14.7 percent, and its total exports decline 11.2 percent, more than any other club member. Canada experiences a similar pattern, with its exports to the United States decreasing 12.5 percent when club members impose punitive tariffs against the United States and its total exports falling 8.8 percent. Because Mexico and Canada are so dependent on the United

States for trade, they may not have the incentive to impose punitive tariffs against their major trading partner.

NAFTA = US, Canada, Mexico Results are given for an aggregate of all club members and individual NAFTA countries in the club		US	
		Holdout	Join Club
AO All other countries	**Holdout:** No tax on carbon and no additional tariffs	US: 0 (0.0) AO: 0 Mexico: 0 Canada: 0	US: 0.73 (-7 %) AO: -0.47 Mexico: -3.23 Canada: -3.24
	Join Club: Tax on carbon = $75 and punitive tariffs (of +.3) on non-club members	US -1.82 (-33%) AO -0.35 Mexico: 1.55 Canada: 1.29	US: -.44 (-38 %) AO: -0.81 Mexico: -1.01 Canada: -1.50

Figure 7: Payoff matrix for the effective club, US versus all other regions (AO) (percent change in real absorption by player vs. percent change in global CO2 emission)
Source: Simulation results from Globe model.
Note: AO = all regions – holdout region; percent change in real absorption represented by numbers in black; percent change in global CO2 emissions represented in numbers in red and in parenthesis.

The payoff matrix in this game shows some fascinating results. The best strategy for all other countries is not to start a climate club and protect their aggregate demand. Unlike the trivial case for China in Figure 6, the preferred strategy for the US (Figure 7) is to initiate a climate club and impose punishing tariffs on others because the trade-related effects will raise its aggregate demand. The outcome looks a lot like the classic trade war –the terms of trade gains dominate and offset the cost of imposing a carbon tax so the US has a real absorption gain.[30] Yet, in this situation, the best course of action for all other countries is to refrain from joining since their real absorption will fall less. The Nash equilibrium is for the US to form a club and all other

[30] Note, our analysis assumes no retaliation, following Nordhaus' climate club specifications. However, this is unrealistic. See Devarajan et al (2020) which shows the US loses from a trade war when there is retaliation.

countries to stay out. The stability is fragile, however, because the real absorption of NAFTA members like Canada and Mexico will decline the most among all possible actions.

The largest reduction of CO2 emissions is when all countries join (lower right quadrant). Emissions decline by 38% as opposed to 7%. What is stopping the join-join the Nash equilibrium? The oil exporters are hurt when they join a climate club and their real absorption declines. We also are not accounting for the future and unknown damage of climate change from less reduction of carbon emissions; the strategies are based on real absorption changes only.

VII. Conclusion

This study examines the potential role of trade policy in global efforts to reduce CO2 emissions in the absence of a universal carbon tax or other policies achieving the same results. It explores two sets of scenarios. In the first, countries that implement a carbon tax also charge tariffs on selected imports from nontax countries, based on their carbon content, to correct for their unfair competitive advantage—a carbon border adjustment mechanism or CBAM. In the second, countries that implement a carbon tax form a club that seeks to induce nonmember countries to join by having all members charge punitive tariffs on all imports from the nontax countries.

The results of the CBAM scenarios indicate that tariffs imposed by carbon-tax countries based on the carbon content of imports from nontax countries do correct for the unfair advantage of exports from the latter countries: Imports of carbon-intensive goods from nontax countries fall, and domestic production of those goods increases. CBAM tariffs generate political support from domestic producers who face increased costs of production with a carbon tax and unfair competition from imports from noncarbon tax regions. In theory, they can support global efforts to reduce CO2 emissions by inducing nontax countries to impose a carbon tax and avoid the CBAM tariff. However, our simulation results suggest that CBAM tariffs have no direct impact on global emissions because of the possibility of trade diversion among the affected countries.

A climate club differs from CBAM in two ways. First, more countries participate, restricting the possibilities for trade diversion. Second, tariff rates are punitive and apply to all goods rather than only goods from selected dirty sectors. A climate club makes it more difficult for the holdout to divert trade, and the holdout is "clubbed" with higher tariffs against all goods.

The formation of a club of carbon-tax countries that use coordinated tariff policy to punish nontax countries and induces them to join the club is a potentially powerful mechanism for achieving global cooperation in carbon reduction.

The analysis considers scenarios in which the two countries with the highest initial levels of CO2 emissions—China and the United States—decide not to institute carbon taxes (or equivalent nontax policies) while all other countries join the club. In this case, punitive club tariffs impose heavy costs on the nontax countries, reducing aggregate final demand and inducing major adjustments in the structure of production and trade. As the tariff revenue goes to the club members, the club also transfers potential export revenue to club members, as nontax countries forgo such revenues. Such a climate club could induce the holdout country to join, greatly reducing global CO2 emissions.

In the case of a climate club when China is the holdout country, the benefits to China of joining the club outweigh the costs of the punitive tariffs, so the Nash equilibrium is one where everybody joins the club and carbon emissions decline by 38%. In the case of the US being the holdout, the Nash equilibrium is one where the US forms a climate club and all other countries stay out. This is mainly driven by the facts that the terms of trade gains to the US from imposing a punitive tariff offset the costs of a carbon tax (as suggested by the literature on trade wars) and that countries such as Mexico and Canada are so closely linked to the US in production chains that they risk being hurt by imposing a punitive tariff on the US.

More generally, the impact on club members of unified punitive tariffs on nontaxers varies widely and depends on the magnitude and structure of their trade with nontax countries. If those trade relations are deep (e.g., Mexico and Canada with the United States, China with countries in East and Southeast Asia), the gains from increased tariffs may be offset by losses caused by the disruption to extensive supply chains and other trade between club members and the targeted nontax counties. Such links could potentially make the coalition of the club fragile.

In sum, the direct impact of selective or punitive, across-the-board tariffs on global CO2 emissions is very small. The real contribution of trade policy is that, in some cases, it provides a credible mechanism to encourage countries to participate in global efforts to reduce CO2 emissions.

Appendix A: Aggregation of GTAP Data to the GLOBE Model

The GTAP database has become the standard for global general equilibrium modeling. It consists of social accounting matrices (SAMs) and trade data for 141 countries/regions. There are 65 sectors/products and 8 factors. The analysis in this study uses an aggregation of the GTAP v10 database in the GLOBE model.

The GTAP data are aggregated into 19 economies (countries or regions), 22 sectors, and .5 factors. The sectors include the five sectors likely to face CBAM tariffs: iron and steel, aluminum, cement, fertilizers, and electricity. The aggregations are described in the tables below.

Table A.1 Regional aggregation from GTAPv10 to GLOBE model

GTAP	Long Name	GLOBE	Long Name
usa	United States of America	USA2	United States and Puerto Rico
pri	Puerto Rico		
can	Canada	Can2	Canada
aut	Austria	EU_27	EU 27
bel	Belgium		
bgr	Bulgaria		
hrv	Croatia		
cyp	Cyprus		
cze	Czech Republic		
dnk	Denmark		
est	Estonia		
fin	Finland		
fra	France		
deu	Germany		
grc	Greece		
hun	Hungary		
irl	Ireland		
ita	Italy		
lva	Latvia		
ltu	Lithuania		
lux	Luxembourg		
mlt	Malta		
nld	Netherlands		
pol	Poland		
prt	Portugal		
rou	Romania		
svk	Slovakia		
svn	Slovenia		
esp	Spain		
swe	Sweden		
gbr	United Kingdom	Othr_Europe	Other Europe
che	Switzerland		
nor	Norway		
xef	Rest of EFTA		
alb	Albania		
blr	Belarus		
ukr	Ukraine		
xtw	Rest of the World		

Table A.1 Regional aggregation from GTAPv10 to GLOBE model (continued)

GTAP	Long Name	GLOBE	Long Name
jpn	Japan	Japn	Japan
aus	Australia	Othr_H_Asia	Other high-income Asia
nzl	New Zealand		
xoc	Rest of Oceania		
kor	Korea		
twn	Taiwan		
chn	China	China_HK	China and Hong Kong
hkg	Hong Kong		
ind	India	India	India
bwa	Botswana	SACU	South African Customs Union
nam	Namibia		
zaf	South Africa		
xsc	Rest of South African Customs		
mex	Mexico	Mex2	Mexico
bra	Brazil	Brazil	Brazil
idn	Indonesia	Indo	Indonesia
rus	Russian Federation	Russ	Russian federation
egy	Egypt	Othr_Afr	Other Africa
mar	Morocco		
tun	Tunisia		
xnf	Rest of North Africa		
ben	Benin		
bfa	Burkina Faso		
cmr	Cameroon		
civ	Cote d'Ivoire		
gha	Ghana		
gin	Guinea		
nga	Nigeria		
sen	Senegal		
tgo	Togo		
xwf	Rest of Western Africa		
xcf	Central Africa		
xac	South Central Africa		
eth	Ethiopia		
ken	Kenya		
mdg	Madagascar		
mwi	Malawi		
mus	Mauritius		
moz	Mozambique		
rwa	Rwanda		
tza	Tanzania		
uga	Uganda		
zmb	Zambia		
zwe	Zimbabwe		
xec	Rest of Eastern Africa		

Table A.1 Regional aggregation from GTAPv10 to GLOBE model (continued)

GTAP	Long Name	GLOBE	Long Name
bhr	Bahrain	M_east	Middle east oil exporters
kwt	Kuwait		
omn	Oman		
qat	Qatar		
sau	Saudi Arabia		
are	United Arab Emirates		
xna	Rest of North America	Othr_Amer	Lat Amer_Cent Amer_Caribbean
arg	Argentina		
bol	Bolivia		
chl	Chile		
col	Colombia		
ecu	Ecuador		
pry	Paraguay		
per	Peru		
ury	Uruguay		
ven	Venezuela		
xsm	Rest of South America		
cri	Costa Rica		
gtm	Guatemala		
hnd	Honduras		
nic	Nicaragua		
pan	Panama		
slv	El Salvador		
xca	Rest of Central America		
dom	Dominican Republic		
jam	Jamaica		
tto	Trinidad and Tobago		
xcb	Caribbean		
bgd	Bangladesh	Othr_S_Asia	Other South Asia
npl	Nepal		
pak	Pakistan		
lka	Sri Lanka		
xsa	Rest of South Asia		
lao	Lao People's Democratic Republ	Othr_SE_Asia	Other Southeast Asia
mys	Malaysia		
phl	Philippines		
sgp	Singapore		
tha	Thailand		
vnm	Viet Nam		
mng	Mongolia		
xea	Rest of East Asia		
brn	Brunei Darussalam		
khm	Cambodia		
xse	Rest of Southeast Asia		

Table A.1 Regional aggregation from GTAPv10 to GLOBE model (continued)

GTAP	Long Name	GLOBE	Long Name
xee	Rest of Eastern Europe	W_Asia	West Asia
xer	Rest of Europe		
kaz	Kazakhstan		
kgz	Kyrgyzstan		
tjk	Tajikistan		
xsu	Rest of Former Soviet Union		
arm	Armenia		
aze	Azerbaijan		
geo	Georgia		
irn	Iran Islamic Republic of		
isr	Israel		
jor	Jordan		
tur	Turkey		
xws	Rest of Western Asia		

Table A.2 Sectoral aggregation from GTAP v10 to the GLOBE model

GTAP	Long Name	GLOBE	Long Name
pdr	Paddy rice	Crops	Crops
wht	Wheat		
gro	Cereal grains nec		
v_f	Vegetables fruit nuts		
osd	Oil seeds		
c_b	Sugar cane sugar beet		
pfb	Plant based fibers		
ocr	Crops nec		
ctl	Bovine cattle sheep and goats	Othr_Agr	Other agriculture
oap	Animal products nec		
rmk	Raw milk		
wol	Wool silk worm cocoons		
frs	Forestry		
fsh	Fishing		
coa	Coal	Coal	Coal
oil	Oil	Oil_ext	Extraction of crude petroleum
gas	Gas	Gas_ext	Extraction of natural gas
oxt	Minerals nec	Mines	Other mining extraction
cmt	Bovine meat products	Food	Processed food bev and tobacco
omt	Meat products nec		
vol	Vegetable oils and fats		
mil	Dairy products		
pcr	Processed rice		
sgr	Sugar		
ofd	Food products nec		
b_t	Beverages and tobacco products		
tex	Textiles	L_mfg	Light maufacturing
wap	Wearing apparel		
lea	Leather products		
lum	Wood products		
ppp	Paper products publishing		

Table A.2 Sectoral aggregation from GTAP v10 to the GLOBE model (continued)

GTAP	Long Name	GLOBE	Long Name
p_c	Petroleum coal products	Petro	Petroleum
chm	Chemical products	Chem-Fert	Chemical products inc fertlizer
bph	Basic pharmaceutical products	Int_mfg	Intermediate manufacturing
rpp	Rubber and plastic products		
fmp	Metal products		
nmm	Mineral products nec	Cement	Cement
i_s	Ferrous metals	I_steel	Iron and steel
nfm	Metals nec	Aluminum	Non-ferrous metals incl aluminum
ele	Computer electronic and optic	Othr_mfg	Other manufacturing
eeq	Electrical equipment		
ome	Machinery and equipment nec		
mvh	Motor vehicles and parts		
otn	Transport equipment nec		
omf	Manufactures nec		
ely	Electricity	Elec	Electricity
gdt	Gas manufacture distribution	Gas_dist	Gas manufacture and distribution
cns	Construction	Const	Construction
wtr	Water	Othr_svc	Other services
trd	Trade		
afs	Accommodation Food and servic		
whs	Warehousing and support activi		
otp	Transport nec	O_tp	Other transport Land and pipelines
wtp	Water transport	W_tp	Water transport
atp	Air transport	A_tp	Air transport

Table A.3 Factor aggregation from GTAP v10 to the GLOBE model

GTAP	Long Name	GLOBE	Long Name
nld	Land	Land	Land
ltech	Technicians and Skilled	SkLab	Skilled labor
loff	Office Managerial and Professional		
lclerk	Clerks	UnskLab	Unskilled labor
lserv	Service and shop		
lagr	Agriculture and Other workers		
kap	Capital	Cap	Capital
nres	Natural Resources	Nres	Natural resources

Appendix B: Production Structure to Include Substitution among Energy Inputs

This appendix provides a schematic explaining the GLBOE model's production relationships.

There are many substitution possibilities among inputs, and these relationships can be described in a diagram with a "nest" structure and nodes representing aggregate inputs. For example, in Figure B.1, "FLAB" is an aggregate of skilled labor ($FD_{skilled}$) and unskilled labor ($FD_{unskilled}$). At each node, there is an elasticity of substitution, σ (with subscripts to indicate the level of the production nest). When σ is not zero, the producer may substitute between the entries in the nest based on the cost of each input. Constant elasticity of substitution (CES) functions represent production technology in the model. There is a CES function for each aggregate in the diagram. For example, there is a CES function in which FLAB is an aggregate of skilled and unskilled labor.

An important feature of production in the GLOBE model is the inclusion of energy commodities as substitutes with capital in production. See the aggregate "FKAPEN" in Figure B.1, which is comprised of aggregate energy, "FENERGY," and capital, "FD_k "(the subscript *k* indicates capital). When energy gets more expensive due to a carbon tax, for example, producers can substitute away from energy as an input in production. In the aggregation used in this study, there are six energy inputs (coal, extraction of oil, extraction of natural gas, petroleum, electricity, gas distribution, and manufacturing). The aggregate "FENERGY" comprises electricity and an aggregate of non-electricity energy inputs.

When the elasticity of substitution is zero, inputs are specified as used in fixed proportions to output (known as "Leontief technology"). This relationship applies to all nonenergy intermediate inputs, represented by "$QINTD_{cegn1}$" where the subscript refers to nonenergy intermediate goods. These are referred to as input-output coefficients.

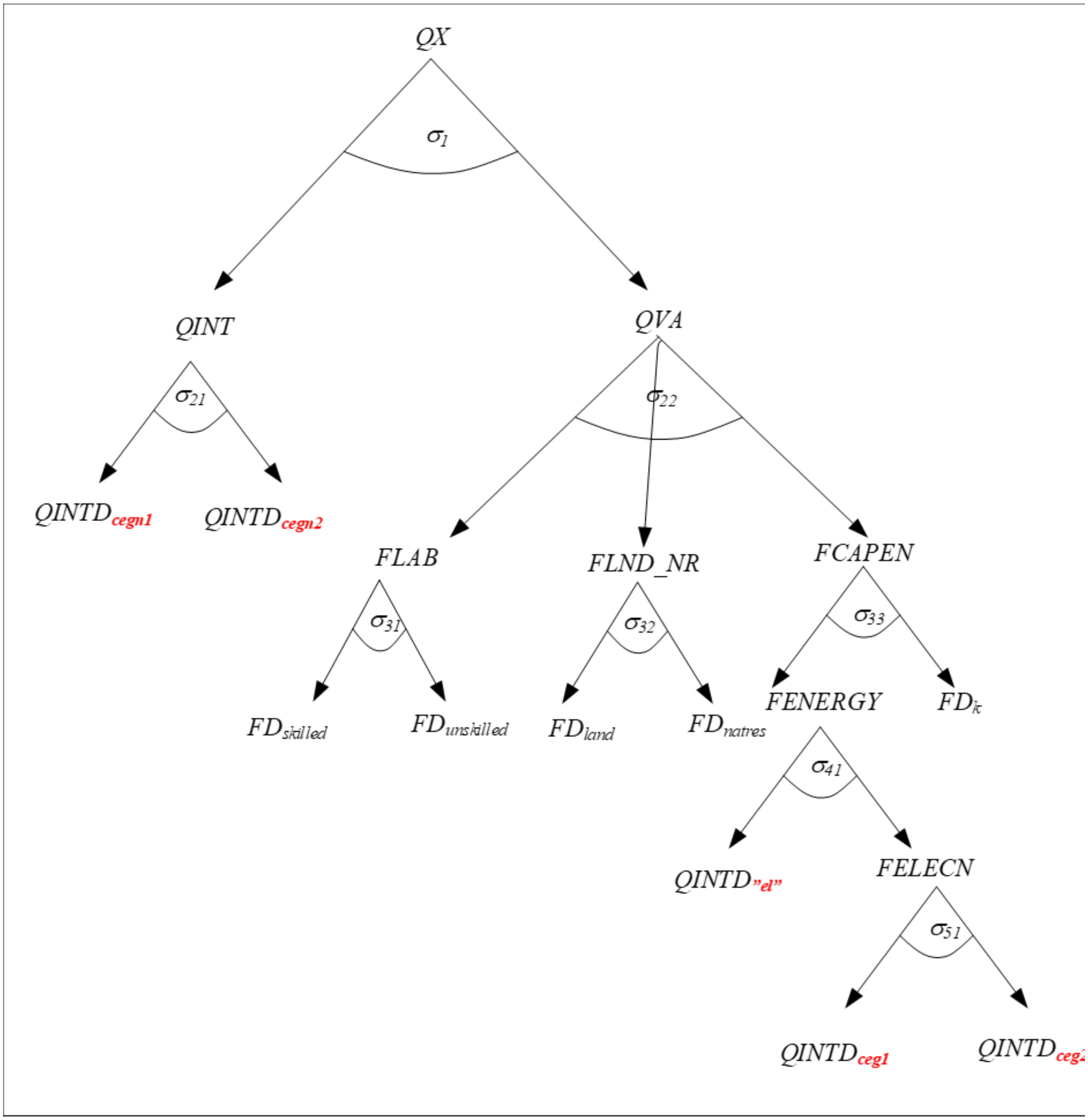

Figure B.1 Production structure for a representative production activity in GLOBE

Note: For definitions of variables and elasticities of substitution, see table B.1.

Table B.1 Elasticity of substitution in production

Variable name in Figure B.1	*Long name*	*Elements in the nest*	*Elasticity of substitution*
QX	Output	Aggregate intermediate inputs, aggregate value added	$\sigma_1 = 0.5$
QINT	Aggregate intermediate inputs	$QINTD_{cegn}$, all nonenergy intermediate inputs	$\sigma_{21} = 0.0$; fixed coefficients
QVA	Aggregate value added	Labor aggregate, land and natural resources, capital and energy aggregate	σ_{22} ; varies by production activity, derived from GTAP data
FLAB	Labor aggregate	Skilled labor, unskilled labor	$\sigma_{31} = 0.8$
FLND_NR	Land and natural resources	Land, natural resources	$\sigma_{32} = 0.5$
FCAPEN	Capital and energy aggregate	Capital energy aggregate	$\sigma_{33} = 0.5$
FENERGY	Energy aggregate	Electricity and non-electricity energy aggregate	$\sigma_{41} = 0.5$
FELECN	Non-electricity energy aggregate	Coal, oil extraction, gas extraction, gas distribution and manufacturing, petroleum	$\sigma_{51} = 0.5$

Note, in order of appearance in the Figure above.

Appendix C: CO_2 Emissions in Selected Countries and Regions

The GTAP v10 database includes data on energy use and CO_2 emissions for the regions and sectors in the database. Six (three-dimensional: energy by user by region) matrices record the volumes of energy inputs used by production activities and purchased by households, in million tons of oil equivalent (MTOE). Another six (three-dimensional) matrices report the CO_2 emissions associated with each energy commodity and user (producer or household).

The tables in this appendix provide information about CO_2 emission for the aggregation of the GTAP v10 database used in the GLOBE model.

Table C.1 GDP, population, CO_2 emissions, and exports as percent of global total in selected countries and regions, 2014

	Percent of global:			
	GDP	Population	CO2 Emission	Exports
China	13.6	18.9	27.0	12.9
USA	22.3	4.4	17.2	9.5
EU 27	19.9	6.1	9.6	30.1
India	2.6	17.9	6.4	2.0
West Asia	3.2	5.0	5.6	3.3
Russian Federation	2.6	2.0	4.7	2.6
Other High-income Asia	5.0	1.5	4.1	8.1
Japan	5.9	1.8	3.4	4.2
Middle East	2.1	0.7	3.0	4.0
Other Southeast Asia	1.9	5.6	3.0	4.4
Other Europe	5.7	1.9	2.7	6.5
Other America	3.3	4.0	2.6	2.4
Other Africa	2.7	14.9	2.2	2.3
Canada	2.3	0.5	1.9	2.4
Brazil	3.1	2.8	1.5	1.2
Indonesia	1.1	3.5	1.5	1.0
Southern African Customs Union	0.5	0.9	1.5	0.6
Mexico	1.7	1.7	1.4	1.9
Other South Asia	0.7	5.9	0.8	0.4
Total	100.0	100.0	100.0	100.0

Source: Authors' calculations using GTAP v10 data.

Table C.2 CO_2 intensity of five sectors in selected countries and regions (millions of tons of CO_2 per billion dollars of output), 2014

	Production of:				
	Fertilizer	Iron & Steel	Aluminum	Cement	Electricity
USA	0.1	0.2	0.1	0.3	4.7
Canada	0.1	0.3	0.0	0.3	1.8
Mexico	0.3	0.4	0.0	0.6	3.3
EU 27	0.1	0.1	0.0	0.2	1.9
Other Europe	0.1	0.4	0.0	0.3	1.9
China	0.3	0.4	0.1	0.8	8.2
Japan	0.2	0.1	0.0	0.4	2.3
Other High-income Asia	0.1	0.1	0.1	0.3	3.6
Indonesia	0.2	0.4	0.4	0.8	10.2
Other Southeast Asia	0.2	0.4	0.1	1.5	4.9
India	0.3	1.9	0.2	2.4	4.7
Other South Asia	0.5	0.5	0.1	1.7	3.2
Russian Federation	0.4	0.5	0.0	0.8	4.6
West Asia	0.4	0.6	0.2	0.7	4.8
Middle East	0.7	0.3	0.2	0.7	5.0
Southern African Customs Union	0.2	0.7	0.2	1.2	15.2
Other Africa	0.2	0.4	0.0	0.5	3.5
Brazil	0.1	0.3	0.5	0.5	1.1
Other America	0.3	0.6	0.1	0.4	2.9

Source: Authors' calculations using GTAP v10 data.

Table C.3 CO_2 intensity of energy use in five sectors in selected countries and regions, by energy source (millions of tons of CO_2 emissions per billion dollar of intermediate input use), 2014

		Production of:				
		Fertilizer	Iron & Steel	Aluminum	Cement	Electricity
US	Coal	26.6	27.1	31.5	26.6	26.6
	Oil	1.8	0.0	0.0	0.0	4.6
	Gas	3.6	11.6	5.8	11.8	9.4
	Petroleum	0.2	2.6	0.6	2.5	1.4
	Gas distribution	8.9	13.4	13.2	13.5	12.8
EU-27	Coal	19.6	18.3	25.6	19.1	21.3
	Oil	2.3	0.0	0.0	5.4	5.3
	Gas	2.5	4.6	4.7	4.5	4.5
	Petroleum	0.4	2.8	2.0	2.7	2.4
	Gas distribution	1.8	5.4	5.3	5.8	5.0
China	Coal	31.8	31.6	32.1	32.5	32.4
	Oil	0.2	0.0	0.0	343.9	5.1
	Gas	8.7	18.3	16.1	17.3	12.7
	Petroleum	1.4	3.5	3.4	2.9	2.3
	Gas distribution	17.6	33.0	27.8	31.6	24.5

Source: Authors' calculations using GTAP v10 data.

Table C.4 Ratio of direct and indirect CO_2 emissions per unit of output to direct CO_2 emissions per unit of output in five sectors in selected countries and regions, 2014

	Production of:				
	Fertilizer	Iron & Steel	Aluminum	Cement	Electricity
USA	5.0	3.7	11.6	2.3	1.1
Canada	5.1	2.9	13.2	2.3	1.2
Mexico	4.0	3.5	17.5	2.2	1.4
EU 27	4.1	3.8	8.0	2.1	1.1
Other Europe	6.3	2.3	21.2	2.1	1.1
China	6.7	4.4	16.6	2.6	1.2
Japan	3.0	5.9	12.3	1.9	1.1
Other High-income Asia	6.1	6.7	6.8	2.5	1.1
Indonesia	4.7	3.6	2.5	1.5	1.1
Other Southeast Asia	5.0	4.7	10.4	1.7	1.2
India	5.3	2.1	10.9	1.6	1.2
Other South Asia	2.0	3.0	11.8	1.3	1.1
Russian Federation	3.3	3.7	476.6	2.3	1.1
West Asia	3.5	3.8	6.0	2.3	1.2
Middle East	1.6	2.3	3.5	1.3	1.1
Southern African Customs Union	9.8	3.2	8.6	2.5	1.1
Other Africa	3.7	3.8	15.8	2.1	1.1
Brazil	4.0	2.2	2.1	1.7	1.2
Other America	2.8	2.5	8.4	1.9	1.2

Source: Authors' calculations using GTAP v10 data.

Table C.5 Percentage shares of CO_2 emissions by households and producers in selected countries and regions, 2014

	Household	Producers
USA	20.1	79.9
Canada	17.6	82.4
Mexico	19.3	80.7
EU 27	17.8	82.2
Other Europe	21.4	78.6
China	6.9	93.1
Japan	12.4	87.6
Other High-income Asia	9.3	90.7
Indonesia	15.4	84.6
Other Southeast Asia	9.8	90.2
India	7.8	92.2
Other South Asia	18.9	81.1
Russian Federation	13.7	86.3
West Asia	19.5	80.5
Middle East	10.6	89.4
Southern African Customs Union	7.6	92.4
Other Africa	21.4	78.6
Brazil	17.9	82.1
Other America	16.9	83.1

Source: Authors' calculations using GTAP v10 data.
Note: rows sum to 100.

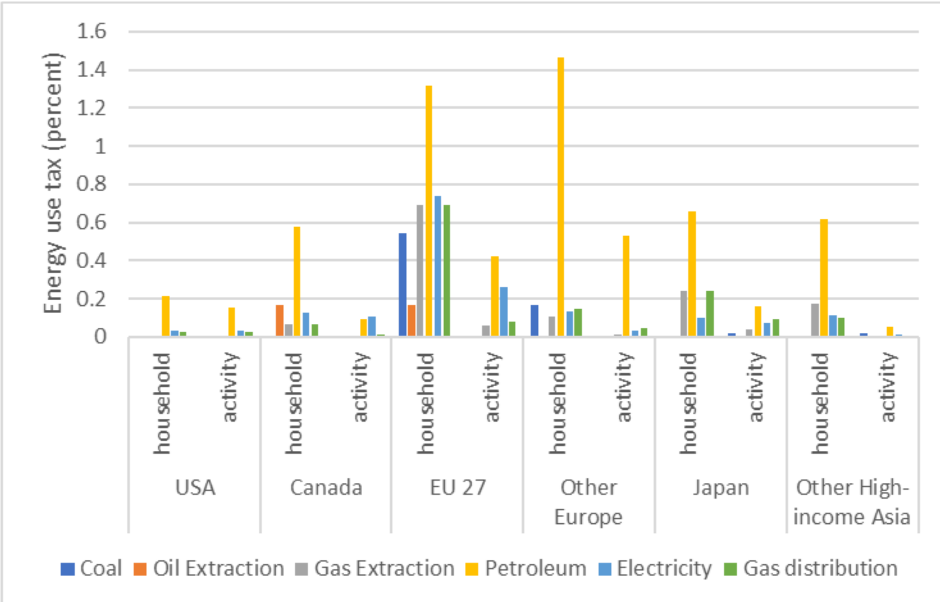

Figure C.1 Average energy input taxes (ad valorem) in selected countries and regions, 2014

Source: Authors' calculations using GTAP v10 data.

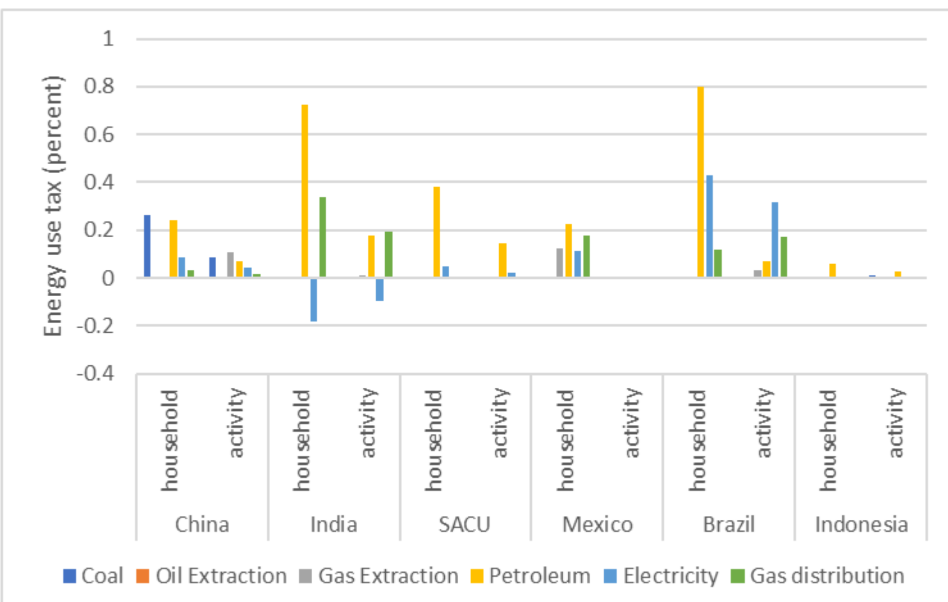

Figure C.2 Average energy input taxes (ad valorem) in selected countries and regions, 2014

Source: Authors' calculations using GTAP v10 data.

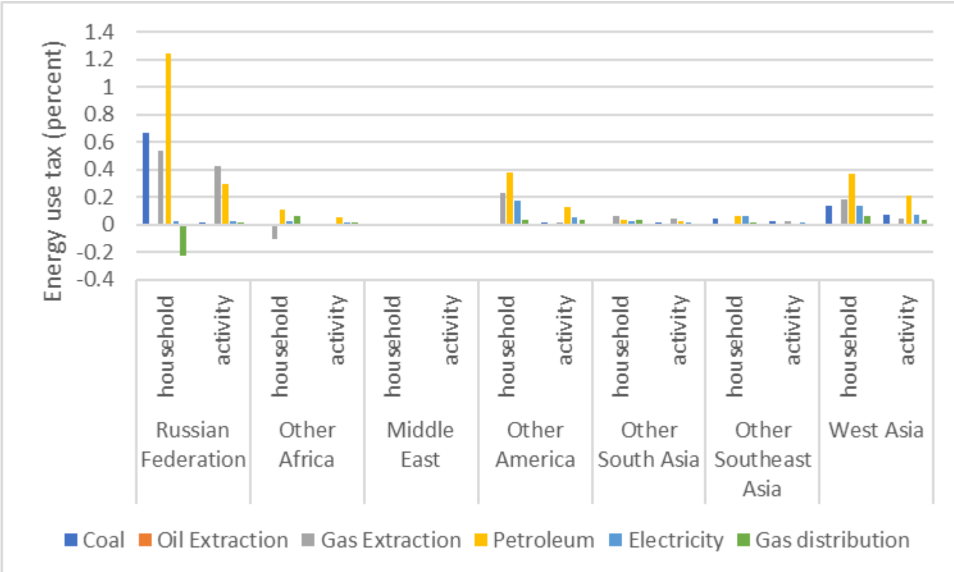

Figure C.3 Average energy input taxes (ad valorem) in selected countries and regions, 2014

Source: Authors' calculations using GTAP v10 data.

Appendix D: Sensitivity Analysis

In this section we report the payoff matrix for the stylized club with the EU-27 and all other regions. When the punitive tariff is high, 20 percentage points above base tariffs, all regions have incentive to join the climate club. The decline in real absorption when a region does not join the club is worse than the decline in real absorption when joining the club. Here, the Nash Equilibrium is for each region to join the club.

		EU-27	
		Holdout	Join Club
AO All other countries	**Holdout:** No tax on carbon and no additional tariffs	EU-27: 0 **(0.0)** AO: 0	EU-27: 1.74 **(-0.91)** AO: -0.54
	Join Club: Tax on carbon = $25 and punitive tariffs (of +.02, 2 percentage points) on non-club members	EU-27: -2.1 **(-19.2)** AO: 0.14	EU-27: 0.07 **(-19.03)** AO: -0.25

Figure D-1: Payoff matrix for the Nordhaus Club, same elasticities, higher punitive tariff (0.2), EU vs. All other regions, percent change in real absorption by player and % change in global CO2 emission

Source: Simulation results from Globe model.

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