Trade Policy and Climate Mitigation: Carbon Tariffs and Climate Clubs

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Introduction

Climate change caused by increased levels of greenhouse gases (GHGs) in the atmosphere is already creating extreme heat in North America and South Asia, floods and droughts in Africa, and melting ice in the Arctic and Antarctica. The Intergovernmental Panel on Climate Change (IPCC 2022) warns that if global temperatures rise more than 1.5 degrees Celsius above pre-industrial levels, the effects on the planet could be catastrophic. Mitigating climate change by curbing GHG emissions, therefore, is a global public good. The most efficient instrument is a carbon tax adopted by all countries because it provides incentives for households and producers to substitute away from fossil fuels, the major source of GHG emissions (IMF 2019). However, each country has an incentive not to tax its own citizens and reap the benefits of other countries' actions—the classic free-rider problem.

Nevertheless, many countries, including the members of the European Union (EU), have introduced carbon taxes and other mitigation measures to limit GHG emissions. Non-taxing countries then have an unfair competitive advantage in trade since their producers have lower costs and can sell exports at lower prices. To level the playing field, the EU has proposed imposing tariffs on imports from non-taxing countries based on their carbon content, called a Carbon Border Adjustment Mechanism or CBAM.[2] The magnitude of the tariff will be country- and commodity-specific, starting with selected goods with high CO2 emissions in their production (cement, iron & steel, aluminum, fertilizers, and electricity).

In addition to the use of tariff policy to correct for unfair competition from non-taxers, there are proposals to use trade policy instruments more broadly to punish free-rider countries (or "holdouts") for not participating in the global effort to mitigate climate change. The goal is to induce these countries to decarbonize their economies in line with compliant countries. Nordhaus (2015) coined the term "Climate Club" to describe how 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 the tariffs on the carbon content of production in the non-club members.

The use of CBAM or Climate Clubs raises a critical question: How effective is trade policy in inducing countries to decarbonize? In this paper, we examine this question by empirically exploring the impacts of CBAM and punitive climate-club tariffs using a simulation model of the global trading system. The answer depends on the costs that trade restrictions impose on non-taxing countries and on the spillover effects of the trade policies on global trade flows.

We first explore how effective CBAM tariffs are in correcting for the unfair competitive advantage of non-taxers and in reducing global carbon emissions. Second, we consider the impact of a climate club in punishing one and/or two noncompliant countries that are major sources of GHG gases. We find, first, that CBAM tariffs are effective in offsetting the unfair competitive advantage of non-taxers in the markets of compliant countries. However, CBAM

[2] A general term for correcting for a domestic price distortion, used in the earlier literature, is "border tax adjustment mechanism."

tariffs do not affect non-taxers' trade much because the non-taxers can divert trade to other non-taxing countries. CBAM tariffs also have little impact on global CO2 emissions. Second, punitive climate-club tariffs are effective in inflicting significant damage to the economies of nonmembers. They suffer efficiency losses and lower export prices as their export markets are restricted. They cannot evade the impact by diverting trade because the club is global and accounts for all their markets. Furthermore, the revenue from the punitive tariffs accrues to the club members, reducing export earnings of the holdout country. The lost export earnings may motivate the holdout to join the club – an aspect of climate clubs not elsewhere recognized in the literature. Participants in the club collect significant government revenues from both the carbon tax and tariffs on non-members.

Selected Literature Survey

There is an extensive literature exploring the links between trade policy and climate mitigation. Modelling climate policy is complicated; we will summarize it with a carbon tax in this paper. The literature on trade policy and carbon taxes can be organized into two broad strands:

- The use of CBAM tariffs by a country, which already has a carbon tax, to "level the playing field" with countries that do not have a carbon tax. The non-tax countries are effectively subsidizing their exports, providing a competitive advantage against carbon tax countries.[3]
- The use of trade policy to induce countries to participate in a global carbon tax policy. The argument is that a "climate club" of carbon taxing countries can enforce the use of carbon taxes by imposing costs on nonmembers, encouraging them to become club members.

CBAM

Böhringer et al. (2012) survey recent studies that indicate CBAM has mixed results. It can effectively curb carbon leakage and offset competitiveness losses but is modest in reducing global carbon emissions, global cost savings, or the efficiency cost of meeting abatement targets.[4] McKibbin et al. (2018) and McKibbin and Wilcoxen (2009) find that carbon duties by the US and/or the EU are complicated to implement with negligible effects on trade and carbon emissions. Furthermore, Krugman (2021) notes that CBAM only concerns carbon embodied in trade and hence ignores the much larger amount of carbon embodied in domestic production for the domestic market.[5] In this paper, we simulate the effects of CBAM tariffs on domestic production and trade flows in a multisector, multi-country general equilibrium framework.

[3] These CBAM tariffs may be WTO consistent if the carbon tariff is considered legitimate. CBAM is effectively a countervailing duty.
[4] The paper is an overview of the articles in a special issue on the evaluation of CBAM in *Energy Economics*, December 2012.
[5] Krugman also notes a related problem that a country could argue that it uses only clean technology for exports and reserves dirty technology for goods sold on the domestic market. While potentially important for an argument about

Climate Clubs

Nordhaus (2015) notes that in terms of climate mitigation the world is in a noncooperative, low-abatement equilibrium (like the famous "prisoner's dilemma game"). This is the condition that doomed the Kyoto agreement and COP26. When only some countries implement carbon taxes, the problem is what do you do about the non-taxing "free riders" who gain from abatement polices but pay no price. Nordhaus argues that what is required is a mechanism ("persuasive coercion") to punish the free riders who currently gain from non-compliance. [6] He suggests that the carbon taxing countries form a "climate club" that will impose punitive tariffs against non-taxers in order to induce them to join the club.[7]

Unlike CBAM tariffs, the climate club members adopt a carbon tax and punish those outsides with a uniform import tariff to compel participation in using a carbon tax. Nordhaus shows that 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. However, if the target price is high, e.g., at $100 per ton, the required abatement cost for each country rises sharply, tilting towards nonparticipation even with higher tariffs.

This last point is consistent with Carrato (1993), who finds that although the conditions (profitability and stability) exist for no free riders in a coalition for an international agreement to protect the environment, cooperation among all countries is fragile, requiring suitable schemes of commitment and transfers.

Since it is a game-theoretic model of strategic interactions, Nordhaus's (2015) model is highly aggregated and stylized. For example, it does not consider the effects of trade diversion in response to tariff policies. Caron (2012) emphasizes that disaggregation matters, and aggregated calibrations will tend to underestimate the reduction in carbon leakages. Also, Duan et al. (2021) identify the determinants of international trade, such as productivity and trade costs, as the major factors that affect pollution emissions and abatement from environmental regulations. In other words, trade diversion matters.

Combining a game theory model of strategic participating with trade diversion in a disaggregated framework would be computationally challenging. For example, Böhringer et al. (2016) employ a general equilibrium framework to consider the strategic value of carbon tariffs but use a Nash equilibrium of simultaneous or predetermined moves from all parties (i.e., the strategic interactions are exogenous, unlike Nordhaus 2015). In their analysis, coalition countries reduce CO_2 emissions by 20% by using a uniform domestic carbon tax (across all sectors and countries) and then impose carbon tariffs against all other countries not in the coalition. For a large alliance

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the WTO legality of CBAM tariffs, the distinction is ignored in most empirical work. Examples of the legal debate about CBAM include McAusland and Najar (2013), Haubauer et al. (2009), and Howse and Eliason (2008).

[6] See, for example, Limão (2005) and Conconi and Perroni (2002) for two game-theoretic analyses of using trade sanctions to gain international cooperation on cross-border externalities.

[7] Clubs and club goods have an economic literature long associated with public goods and the theory of externalities. See, for example, Buchanan (1965) and Olson (1965) for early exposition about clubs, Sandler and Tschirhart (1980) for literature survey, or Cornes and Sandler (1986) for expanded textbook discussion.

of high-income and other countries, the findings indicate the threat to be credible in terms of welfare costs to the non-coalition countries, such as China and Russia.

The game theory analysis indicates that climate clubs are feasible and a potential tool to address the free-rider problem inherent in dealing with a global public good such as mitigating climate change. Climate club trade policies can have a significant impact on non-tax countries (persuasive coercion), facilitating cooperative behavior.

In this paper, we consider climate clubs in a global computable general equilibrium model that captures trade diversion in a disaggregated framework. We consider the impact of a uniform carbon tax as our base case and then consider various scenarios of club formation and dealing with potential holdout countries that are the largest emitters, China and the US.

Data

Greenhouse Gas Emissions

Greenhouse gas (GHG) emissions in the atmosphere depend on various sources. GHGs include carbon dioxide, nitrous oxide, methane, and water vapor (which all occur naturally), and fluorinated gases (which are synthetic). Our analysis focuses on CO2 emissions primarily from energy use in production and consumption. Figure 1 shows that energy use accounts for a substantial volume of total greenhouse gas emissions (73.2%), dwarfing that of agriculture, forestry & land use (18.4%), industry (5.2%), and waste (3.2%). Within energy use, the industry, building, and transport sectors can have varying levels of energy use and CO2 emissions. For example, road transport (about 12%), iron and steel (7.2%), and chemical production (3.6%) all use fossil fuels as intermediate inputs, accounting for their CO2 emitted (numbers in parenthesis). However, the production process for some industries like cement and chemicals also releases GHG emissions. (For example, limestone and clay require a high temperature to make cement, the limestone itself goes through a chemical reaction releasing gases in the process.[8]) We do not account for the additional GHGs from these industrial production processes (which make up the 5.2% cited above). The other two categories of GHG emissions - agriculture, forestry & land use, and waste - are likely due to non-CO2 sources of GHG emissions and are not part of this study.

[8] https://www.pbs.org/newshour/show/can-concrete-a-major-co2-emitter-be-made-greener

Figure 1:

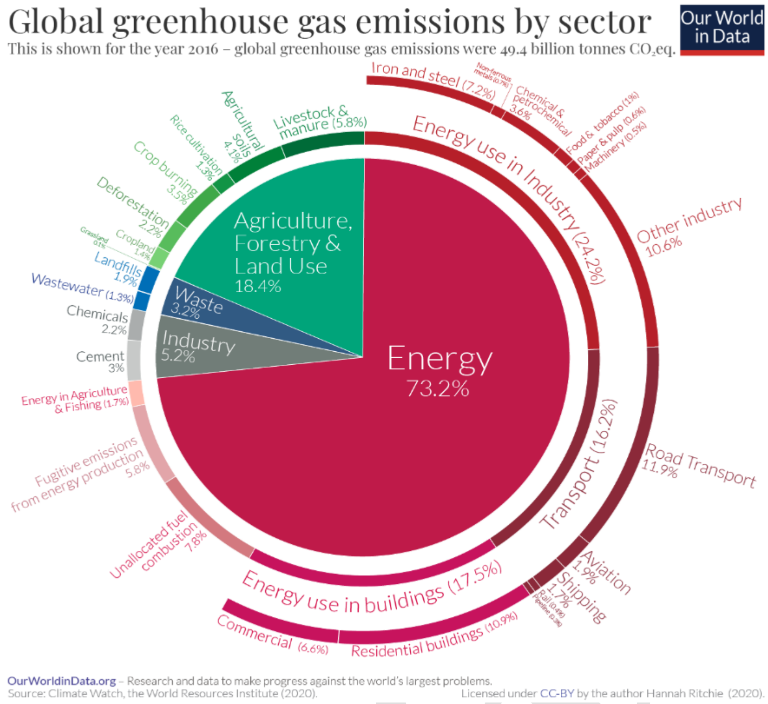
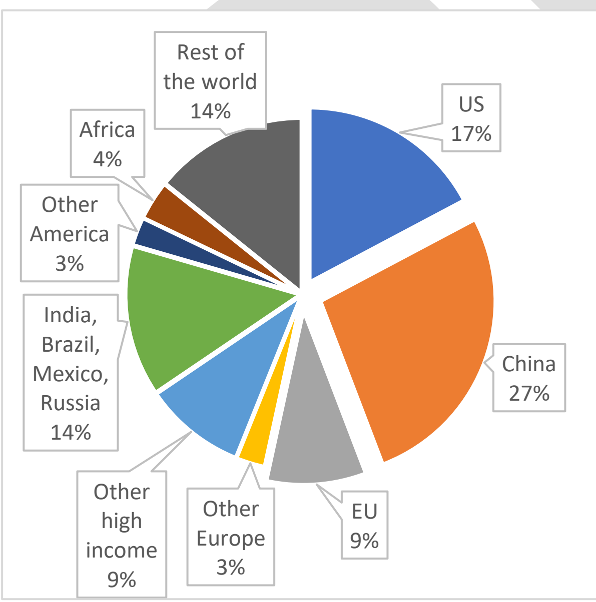
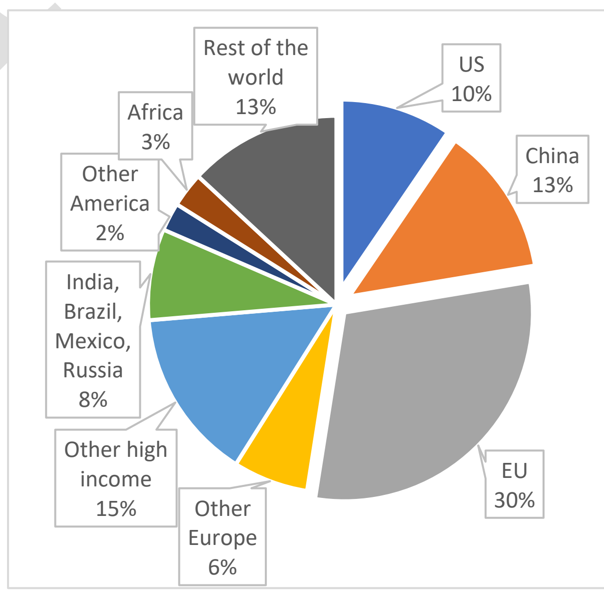


Figure 2: Distribution of Global CO2 Emissions and Trade in the Base Data (in percent share)

a. Global CO2 emissions by region	b. Global trade by region
	

Source: Model base-year data from GTAP v10, 2014. Authors' calculations.
Note: Global trade refers to exports in fob values.

GTAP Data

The data for our global simulation model are from the Global Trade Analysis Project (GTAP), version 10, with 2014 as the base year. Figure 2 provides data on carbon emissions by country/region and shares of global exports. Three countries (China, US, and the EU) account for 53% of global CO2 emissions. As a regional bloc, the EU (at 9%) is much lower than China and the US. Panel b presents the distribution of world trade. Here, China and the US still have the biggest weights, although their combined total at 23% is not as high as their carbon emissions. The EU's total weight is highest at 30%, which shows its potential for using trade policy instruments. If Other Europe and Other High-income Countries join the EU to form a climate club, the total trade weight will reach 51%. In the case of developing countries in Africa or Other America, their importance in global CO2 emissions and trade is comparatively small. Our focus is therefore on China, the US, and the EU.

The GTAP database consists of social accounting matrices (SAMs) with 65 sectors/products for 121 countries and 20 regions[9]. For our analysis, we aggregate the data into 19 regions with 22 sectors. The country groupings include the significant players in CO2 emissions and international trade. The sectors in the model include those likely to face a CBAM tariff: iron & steel, aluminum, cement, fertilizers, and electricity. See Annex 1 for details on the aggregation of the GTAP data.

The model also makes use of satellite account data produced by GTAP. Six (three-dimensional) matrices record the volumes of energy inputs used by activities and purchased by domestic institutions (i.e., households) in terms of 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. The GTAP v10 database also provides tax information on energy input use by purchasing agent, so the model includes the differences in energy policies by region. The database includes household consumption of energy commodities and their emission implications.[10] See Annex Figure A3a-3c for each region's average fossil fuel taxes by purchasing agent (activity average and household taxes). These tax rates do not change in the simulations.

Direct and Indirect CO2 emissions

The GTAP database includes for all regions input-output tables that trace 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, electricity generation using coal directly produces a lot of CO2. Any industry that uses electricity is indirectly contributing to CO2 emissions. Input-output analysis captures all the

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[9] The underlying database has become the standard for global general equilibrium modeling (Aguiar et al., 2016).

[10] 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 in the future would include the non-CO2 sources of GHG, found in Chepeliev (2020).

direct and indirect linkages and provides, by production activity, the shares of direct and indirect CO_2 per unit of sectoral output.

Simulation Model

We use a comparative static, multi-sector, multi-region global Computable General Equilibrium (CGE) simulation model.[11] The underlying approach to multi-region modelling is the construction of a series of single country CGE models that are linked through their trading relationships.[12] It is assumed that imports and domestic goods are imperfect substitutes in consumption, modeled using a Constant Elasticity of Substitution (CES) function; likewise, exports and domestic goods are imperfect substitutes, modeled using a Constant Elasticity of Transformation (CET) function. In each region, the current account balance is held constant and the nominal exchange rate adjusts. This specification means that there are no changes in international borrowing or lending as a result of the policy shock. All factors of production are fully mobile across sectors within regions but not across regions. It is assumed that there is full employment of all inputs in each region.

As is common in CGE models, the focus is upon movements in relative, rather than absolute, prices. Consequently, each region in the model has its own numéraire price, the consumer price index (CPI), while the model as a whole requires a global numéraire, which is an aggregate exchange rate index for a number of reference regions.

The model's production structure has a nested formulation that allows for substitution possibilities at each level (Annex 2, Figure 2-1). It includes incentives to substitute away from energy inputs as prices change. Each sector produces an output using a constant elasticity of substitution (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 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 non-electricity inputs. Finally, the non-electricity aggregate is a CES combination over all non-electricity inputs. The nesting structure allows one to vary the substitution elasticity at different levels of aggregation. It also provides substitution among energy inputs and other primary inputs (land, labor, and capital). When choosing inputs for production, producers take into account the relative prices of the inputs and can substitute away from more expensive inputs.

The *carbon tax* in the model is specified as follows:

[11] See Thierfelder (2021), McDonald and Thierfelder (2016), and McDonald et al. (2007). for a description of the GLOBE model. Aguiar et al. (2016) describe the GTAP dataset that underpins most global CGE models.

[12] 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).

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

$TCARB_{c,a,r}$ is the specific tax on the intermediate energy input commodities, *c*, that emit CO2: coal, oil extraction, gas extraction, petroleum, and gas distribution & manufacturing (for all other commodities, $TCARB_{c,a,r}$ equals zero). It is calculated as the tax per ton of carbon emitted by region, TC_r, times the tons of CO2 emitted $CO2EMIT_{c,a,r}$, per unit of the intermediate input commodity *c* used in activity *a* in the base data, $QINTD0_{c,a,r}$. 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. The specific tax on inputs enters the first-order condition for the demand for energy inputs (included in value-added, so producers will substitute away from the energy inputs in response to a tax on them, see Figure A-1 for the production structure). Since all prices are set to 1.0 in the base year, the specific carbon tax is equivalent to an ad valorem tax.

The tax revenue collected, $CARBTAX_r$, depends on the amount of intermediate good used, $QINTD_{c,a,r}$, and the specific tax, $TCARB_{c,a,r}$, as follows:

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

The carbon tariff, *CBAM*, is also calculated as a specific tax:

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

where $TMCARB_{w,c,r}$ is a specific tax on imports of commodity *c* from trade partner *w* by region *r*. It is the tax per ton of CO2 on commodity c produced in region w and imported into region r, TMC_w, times the CO2 emitted in region w when producing good a, $CO2EMIT_{a,w}$, expressed as a share of the output of good *a*, $QX0_{a,w}$. Note that the matrix $ioqxcqx_{a,c,w}$ converts production activity *a* to commodity *c*. In the GTAP data, there is a one-to-one mapping between activities and commodities.

The specific tax on imports, based on the carbon content of production, enters the domestic price of imports of commodity *c* from trade partner *w* by region *r* ($PMR_{w,c,r}$) as follows:

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

It is the *cif* price of imports of commodity *c* from trade partner *w* by region *r* valued at world prices, ($PWM_{w,c,r}$) times one plus the ad valorem tariff rate on imports of commodity *c* from trade partner *w* by region *r* ($tm_{w,c,r}$) plus the specific import tax based on the carbon content of imports of commodity *c* from trade partner *w* by region *r* ($TMCARB_{w,c,r}$) times the exchange rate in region r, ER_r.

The carbon tariff revenue, $MCARBTAX_r$, 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*

($TMCARB_{w,c,r}$) times the import quantity of commodity *c* from trade partner *w* by region *r* ($QMR_{w,c,r}$) times the exchange rate in region *r* (ER_r):

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

The *macro model closure* defines macroeconomic behavior. When the external current account balance is fixed as selected in the simulations, 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 impact all components of total absorption (aggregate domestic final demand). In this formulation, households, government, and investment spending adjusts 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 – in addition to reducing carbon emissions, the tax revenue generated can reduce taxes elsewhere in the economy. Adjusting income taxes can be a non-distorting 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.

Some caveats are in order. This global CGE model with neoclassical specifications is not a dynamic framework accounting for additional output growth from factor accumulation. However, the model does reallocate existing capital stocks and labor across sectors for each region. It also does not incorporate potential gains of better technology and productivity in producing less carbon content in outputs. The analysis does not allow for unemployment or dislocations from shocks. Because external account balances are fixed, there are no additional resource flows from the rest of the world to change the outcomes in each country or region. The analysis in this sense is therefore conservative.

Scenarios

CGE models are simulation laboratories within which "what-if" economic experiments explore the relationships between policy options and economic consequences. In this paper we do comparative static simulations that describe the state of the economy before and after a shock when a new equilibrium is reached. We do not consider the time period between "before" and "after" nor do we consider the dynamic adjustment process. The scenarios are not forecasts but conditional projections of the implications of controlled experiments, changing only selected policy instruments.

In this study we focus on changes in the structure of production, global trade, and carbon emissions that would occur in response to a combination of carbon taxes and tariffs against imports from non-compliant regions. The base simulation replicates the base year data and constitutes business as usual. No carbon taxes exist in the base data of the model. Counterfactual scenarios compare the impact of the introduction of carbon taxes with different tariff scenarios, against the base case.

We consider the following counterfactual simulations:

1. **\$75 carbon tax per ton of CO2 in all countries:** This scenario is the "first-best" reference case against which all alternative scenarios are compared. Each region taxes carbon at \$75 per ton of carbon emitted. As reflected in the base data, each region has existing production technologies that differ from other regions. The EU, for example, having made more progress toward reducing CO2 emissions, has less CO2 emissions per unit of output than other regions such as China or SACU. We choose the \$75 per ton tax rate as it is the price proposed by the International Monetary Fund (IMF) and others in various ways (Parry et al., 2021).
2. **Basic CBAM:** Only high-income regions (US, Canada, EU-27, Other Europe, Japan and High-inome Asia) have a \$75 carbon tax, and they impose CBAM tariffs on imports of only dirty goods from all other regions without a carbon tax. In effect, the carbon taxing countries are operating as a club but the motivation is individual (eliminate unfair trade practices affecting each country) rather than collective.
3. **Comprehensive CBAM or carbon tariffs:** High-income regions have a \$75 carbon tax and extend CBAM beyond the dirty goods by imposing carbon tariffs on all imports based on the carbon content of production of exporting countries for each traded good.
4. **Climate club action against China as a lone holdout:** We consider the case in which there is only one region outside the club and this holdout region does not adopt a carbon tax (of \$75) and faces a 30 percentage point increase in tariffs by all club members against its exports.
5. **Climate club action against the US as a lone holdout:** This scenario replaces China with the US as the lone holdout.
6. **Climate club action against China and the US as two holdouts:** China and the US are two holdouts and every other country is in the club. No change in tariffs between China and the US.

Simulation Results

We divide and report the results in two sets, separating the CBAM and carbon tariffs results of scenarios 1 to 3 from the climate club simulations 4 to 6.

CBAM and carbon tariffs

Table 1 summarizes the main results of simulations 1 to 3. Detailed results are available in the appendices. First, the simulations have striking effects on carbon emissions. If all countries impose a \$75 carbon tax (simulation 1), global carbon emissions will fall by about 25% from the baseline. However, if only high-income countries impose the carbon tax and CBAM tariffs only on dirty goods (simulation 2), the abatement is only about 7%, less than a third of the previous scenario. Expanding the CBAM to more general carbon tariffs from high-income countries (simulation 3) does not yield more carbon emissions abatement. Raising tariffs based only on the direct carbon contents of commodities produces only small changes. The sensitivity test (last column of Table 1) confirms that the carbon tax in high-income countries in simulations 2 and 3 is the main factor in the 7% abatement; the CBAM does little to reduce carbon emissions. The reason for the modest decline in CO2 emissions (7%) compared to simulation 1 (25%) is that China, the major polluter, does not pay a carbon tax.

The most significant impact of the simulations on real exchange rates and imports falls on fossil fuel exporters, such as the Middle East, Russian Federation, and Indonesia. Their exchange rates depreciate and imports decrease. A global carbon tax (simulation 1) has the most significant impact, followed broadly by the other simulations. The real exchange rates of two large countries China and India (and, to an insignificant extent, the EU and the US) will appreciate when the carbon tax by all countries dampens energy prices. Except for the energy-exporting regions, the effects of CBAM and carbon tariffs are generally minor for all other regions or countries in simulations 2 and 3, confirming the results of other studies. The intuition is that the non-compliant countries, even though they face tariffs on their exports to compliant countries, can still trade with other non-compliant countries (trade diversion), so that the net effect on their exports is minimal.

Real absorption (total final demand) is a measure of welfare in the simulations. The balanced macro closure of the model implies that components of real absorption (private consumption, public consumption, and investment) will move in tandem with the aggregate. The results generally follow the outcomes on trade (imports). Outside of the major energy exporters, the effects are minor.

Table 1 Selected effects of CBAM and carbon tariffs

Simulation 1 to 3, percent deviation from base

	Simulation 1	**Simulation 2**	**Simulation 3**	**Sensitivity test**
	All countries impose a $75 carbon tax	High-income countries impose a $75 carbon tax and CBAM tariffs on dirty goods	High income countries impose a $75 carbon tax and carbon tariffs on all imports	High income countries impose a $75 carbon tax but no CBAM or carbon tariffs
1. Global carbon emissions	-24.8	-7.2	-7.2	-7.2
2. Real absorption				
EU	0.0	0.1	0.2	0.1
US	-0.3	-0.2	-0.2	-0.2
Other High-income countries	-0.1	0.1	0.1	0.1
China	-1.0	-0.1	-0.2	-0.1
India	-0.4	0.1	0.1	0.1
Indonesia	-0.7	-0.4	-0.4	-0.4
Middle East	-4.7	-2.4	-2.8	-2.3
Russian Federation	-2.3	-1.5	-1.6	-1.5
LAC	-0.4	-0.2	-0.3	-0.2
All other countries	-0.5	-0.3	-0.4	-0.3
3. Real exchange rates				
EU	-0.1	-0.1	-0.1	0.0
US	0.0	-0.2	-0.2	-0.2
Other High-income countries	0.3	0.2	0.2	0.2
China	-1.4	1.1	1.7	1.0
India	-3.1	1.4	2.0	1.1
Indonesia	6.8	3.8	4.5	3.5
Middle East	15.3	7.7	9.0	7.2
Russian Federation	9.6	7.9	8.8	7.4
LAC	1.4	2.2	2.9	2.0
All other countries	1.9	2.5	3.5	2.3
4. Imports				
EU	-0.7	-0.6	-0.6	-0.6
US	-1.2	-0.5	-0.4	-0.5
Other High-income countries	-1.2	-0.8	-0.9	-0.8
China	-1.2	-0.4	-0.5	-0.3
India	-1.1	0.3	0.3	0.4
Indonesia	-4.7	-1.5	-1.7	-1.5
Middle East	-8.7	-4.3	-4.9	-4.1
Russian Federation	-6.7	-4.9	-5.2	-4.7
LAC	-2.0	-0.8	-1.0	-0.7
All other countries	-2.3	-0.6	-0.9	-0.6

Source: Authors' calculations using a global simulation model.

Climate club actions against holdout(s)

Nordhaus finds that a uniform 2% tariff against holdouts is sufficient to induce countries to join the club in his simplified, aggregated model. We tried a 2% tariff scenario and found the signs of the costs are correct, but the increased costs are small because our disaggregated model allows more substitution possibilities. We therefore decided to specify a scenario in which tariffs increase 30 percentage points, which is consistent with magnitudes observed in past punitive tariffs (e.g., Smoot-Hawley tariffs, Trump trade wars).[13]

Table 2 summarizes the global carbon changes due to climate clubs, simulations 4 - 6. Table 3 reports the impact of the punitive tariffs on various macro indicators for the holdout countries. All club members adopt a $75 carbon tax and a punitive 30 percentage point increase in tariffs on all import from the holdout(s). The effects on global carbon emissions (Table 2) show remarkable differences between the holdouts. Looking down the first column (no punitive tariffs), the club without China reduces carbon emissions by 12.9% relative to the base with no carbon tax, compared to a 24.8% reduction in global carbon emissions when everyone is in the club. When the US is the non-club member, global carbon emissions decline 20.0%.

Table 2 Global CO2 emissions (percent change from base)

	Club only	**Club and punitive tariffs**
	Members adopt $75 carbon tax	30 percentage point increase on all commodities against holdouts
Club types		
No holdouts	-24.8	N/A
China holdout	-12.9	-13.7
US holdout	-20.0	-20.7
China & US holdout	-8.1	-9.5

Source: Authors' calculations using a global simulation model.

In short, it is much more important that China be a member of the club than the US in order to reach global CO2 reductions goals. China is by far the largest CO2 emitter and most of China's emissions are from production (93% compared to 80% for the US,) which means that the carbon tax is much more effective in China – hitting a larger share of a larger base.

The second column of Table 2 indicates the marginal impact of the punitive tariffs imposed by club members on global CO2 emissions. They are small, 0.7 to 1.4 percent additional reduction. The trade policy as a "club" to hit non-club members works only if it induces the holdouts to join the club. The crucial issue is therefore the magnitude of the costs that club members impose on nonmembers. Table 3 indicates those costs.

By all indicators, punitive tariffs damage China more than the US when each is a holdout (see Table 3). The shocks to China when it is the lone holdout are large – imports fall by 16.3%, the exchange rate depreciates 31%, and real absorption declines 4.5%. The volume of real exports actually increases slightly (0.7%) indicating that even with a dramatic fall in its export prices, China has to maintain exports to pay for crucial imports (which is indicated by the dramatic depreciation). The impact of the shock to its international terms of trade, maintaining exports to pay for far fewer imports, results in a fall in aggregate absorption.

[13] See Devarajan et al. (2021), Robinson and Thierfelder (2021), and Bown (2022).

Table 3 Damage from climate clubs and punitive tariffs

	Holdout region			
	China	US	China & US	
			China	US
percent change in:				
Real exchange rate	31.5	18.5	24.0	18.1
Real absorption	-4.5	-1.7	-3.7	-1.3
Real imports	-16.3	-12.7	-13.7	-9.9
Real exports	0.7	-3.5	0.5	-3.3
Terms of trade (base = 1)	0.9	0.8	0.9	0.9
Tariff revenue collected as a share of export revenue	28.7	29.7	26.4	22.5

Source: Authors' calculations using a global simulation model.

When the US is the lone holdout, the story is similar but less extreme than for China. Real exports fall 3.5% along with real imports (12.7%) The depreciation is also smaller (18.5%). The US has smaller trade shares than China, which limits the damage from punitive tariffs.

The next several sub-scenarios about CBAM and carbon tariffs indicate the futility of using trade policies to reduce global CO2 emissions. Even when a punitive CBAM or carbon tariff is imposed, the decrease in global carbon emissions is marginal (compared to the first sub-scenario case and one another.) This robust result is due to two factors. First, the tariff rates for dirty goods are already low (thanks to the past efforts of GATT and WTO), so adjusting them based on the carbon tax does not impose a significant cost. Second, fossil fuels are essential inputs with low substitution possibilities in this model with no technological change. Incorporating technological change would produce bigger results but that would be by assumption. Nevertheless, it suggests the importance of technology in the long term.

The case of a punitive import tariff uniformly applied on all commodities of the holdout countries will produce significant adverse effects on the economy of China, the US, or both. Their real exchange rate will depreciate markedly, and absorption (indicative of welfare) and imports will fall significantly. Although the policy will not change carbon emissions much further, it is likely a persuasive tool to convince participation by the holdout(s). In contrast, CBAM will be unpersuasive and only somewhat so in the punitive case.

Table 3 also reports the tariff revenue collected by club members relative to the holdout's export sales. Had the holdout imposed a carbon tax, it would have earned tax revenues instead of the club members. The share of export revenue the holdout region is giving up to foreign governments is substantial, approximately 30% when either the US or China is the lone holdout.

Finally, it is interesting to note the effect of punitive tariffs on trade for the club members (see Table 4). Canada and Mexico are closely linked to the US. When the US is the holdout region and the club members impose punitive damages, Mexico's exports to the US decline 14.7% and its total exports decline by 11.2%, more than any other club member. Canada experiences a similar pattern, Canada's exports to the US decline 12.5% when club members impose punitive tariffs against the US as a holdout region and Canada's total exports decline 8.7 percent. Since Mexico and Canada are so dependent on the US for trade, they may not have incentives to impose punitive tariffs against the US who is also their major trading partner. A similar pattern holds for countries in East and Southeast Asia when China is the holdout.

Table 4 Bilateral exports (percent change) when club imposes punitive tariffs

	US holdout		China holdout		US & China holdout		
	Exports to US	Total Exports	Exports to China	Total Exports	Exports to US	Exports to China	Total Exports
USA	7.4	-3.7	-19.3	-4.0	5.8	0.1	-3.4
Canada	-12.5	-8.8	-18.6	-2.4	-13.7	-18.0	-10.7
Mexico	-14.7	-11.2	-20.0	-4.6	-18.1	-19.4	-14.6
EU 27	-13.2	-1.9	-18.9	-1.9	-13.9	-17.7	-2.8
Other Europe	-12.3	-1.8	-18.1	-2.1	-12.6	-16.8	-3.0
China	-13.2	-3.8	2.4	0.2	6.6	2.3	0.0
Japan	-12.2	-2.8	-17.4	-5.0	-12.5	-15.9	-6.4
Other High-income Asia	-13.2	-3.7	-16.4	-5.1	-12.5	-16.0	-6.7
Indonesia	-9.4	-4.2	-18.5	-5.5	-11.1	-16.4	-6.1
Other Southeast Asia	-13.4	-3.5	-20.2	-6.8	-15.6	-18.8	-7.8
India	-13.6	-4.1	-20.7	-4.9	-14.3	-18.3	-5.4
Othr_S_Asia	-14.7	-3.9	-23.6	-6.6	-18.2	-20.8	-7.3
Russian Federation	-7.8	-1.1	-11.6	-1.4	-8.5	-10.7	-2.3
West Asia	-11.4	-2.0	-14.1	-2.8	-12.0	-12.5	-3.4
Middle East	-6.6	-0.3	-6.8	0.1	-5.8	-6.0	-1.1
SACU	-12.8	-4.8	-18.1	-6.4	-13.4	-16.5	-7.0
Other Africa	-11.6	-3.1	-14.0	-4.3	-12.2	-12.8	-4.8
Brazil	-12.4	-3.0	-17.2	-3.7	-12.3	-16.3	-5.0
Other America	-12.3	-4.2	-17.7	-3.7	-12.9	-17.1	-6.2

Note: Exports from row to column region.
Source: Authors' calculations using global simulation model.

All told, the most effective tool for reducing CO2 emissions is the carbon tax by all countries (simulation 1). Although trade policies are ineffective in reducing pollution, a punitive import tariff by a climate club is still persuasive in its economic effects against big polluters like China, the US, or both as holdouts. It is more important to persuade China to join the club because it is the major polluter.

Conclusion

This study explores the potential role trade policy can play in the global effort to reduce CO2 emissions. From the perspective of economic theory, the first-best policy is for every country to institute a tax on CO2 emissions. We start from that scenario as the base case. We do not consider other policy mixes such as quantitative controls, cap and trade, or subsidy schemes that could, if implemented properly, approximate the results of a universal carbon tax. We then explore two sets of scenarios: (1) countries that implement a carbon tax also charge tariffs on imports from non-tax countries based on their carbon content to correct for their unfair competitive advantage ("carbon based border adjustment" or CBAM); and (2) countries that implement a carbon tax form a "club" that seeks to induce non-member (non-tax) countries to join the club by having all members charge punitive tariffs on all imports from the non-tax countries. The Climate Club differs from CBAM in two ways: (1) more countries participate, restricting the possibilities of trade diversion, and (2) tariff rates are punitive and apply to all goods rather than selected dirty sectors. With a climate club, it is more difficult for the holdout to divert trade and the holdout is "clubbed" with higher tariffs against all goods. The results from the CBAM scenarios indicate that tariffs imposed by carbon-tax countries based on the carbon content of imports from non-tax countries do correct for the unfair advantage of exports from non-tax countries. Imports of carbon-intensive goods from non-tax countries fall and domestic production of those goods increases. There is essentially no impact of CBAM policies on global emissions. If only a few carbon-tax countries impose CBAM tariffs, the result is that non-tax countries can divert trade to non-CBAM countries, with minimal effect on their total exports of those commodities.

The formation of a club of carbon-tax countries that uses coordinated tariff policy to punish non-tax countries ("free riders") and induce them to join the club is potentially a powerful mechanism for achieving global cooperation in carbon reduction. We consider scenarios where the two countries with the largest initial levels of CO_2 emissions, China and the US, decide not to institute carbon taxes while all other countries are in the club. We find that punitive club tariffs impose serious costs to the non-tax countries, including reduction in aggregate final demand (absorption) and the need for major adjustment in the structure of production and trade. Since the tariff revenue goes to the club members, the result is also an effective transfer of potential export revenue to club members. In addition, non-tax countries lose the potential government revenue from a carbon tax.

The impact on club members of unified punitive tariffs on non-taxers varies widely and depends on the magnitude and structure of their trade with non-tax countries. If those trade relations are "deep" (e.g., Mexico and Canada with the US, China with countries in East and Southeast Asia), the gains from increased tariffs may be offset by losses due to the disruption to extensive supply chains and other trade between the club members and targeted non-tax counties.

In the carbon-tax club scenarios, the direct impact of the punitive tariffs on CO_2 emissions is very small. The real contribution of trade policy, therefore, is that it provides a credible mechanism to enforce participation by countries in global efforts to reduce CO_2 emissions. It may well be that the costs imposed on non-participating countries through club tariffs, while significant, will not be large enough to encourage countries to join the club. In that case, the club may have to consider financial as well as trade instruments, hitting asset markets as well as commodity markets.

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Annex 1: Aggregation of GTAP data to GLOBE model

Table A1-1: Region aggregation

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 A1-1: Region aggregation (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 A1-1: Region aggregation (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 A1-1: Region aggregation (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 A1-2: Sector aggregation

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 A1-2: Sector aggregation (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 A1-3: Factor Aggregation

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

Annex 2: Production Structure to include substitution among energy inputs

Figure 2-1: Production Structure in GLOBE

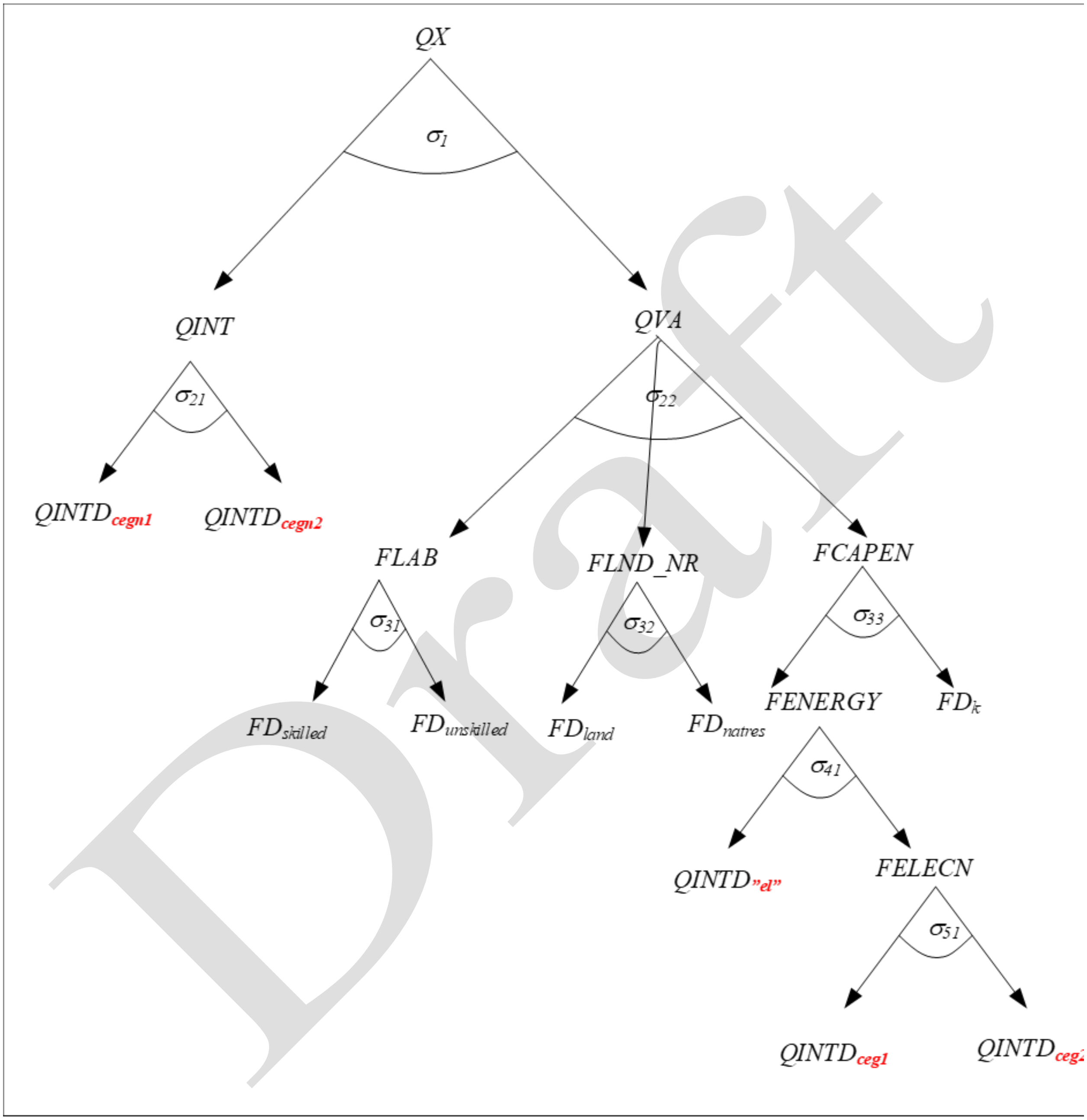

Table A2-1: Elasticity of substitution for energy in value added

Name in Figure 2-1	Long Name	Elements in the Nest	Elasticity of substitution
FLAB	Labor	Skilled labor Unskilled labor	0.8
FLND_NR	Land & Natural Resources	Land Natural resources	0.5
FCAPEN	Capital & Energy Aggregate	Capital Energy Aggregate	0.5
FENERGY	Energy Aggregate	Electricity Non-electricity Energy Aggregate	0.5
FELECN	Non-electricity Energy Aggregate	Coal Oil extraction Gas extraction Gas distribution & manufacturing Petroleum	0.5

Annex 3: Background tables on CO2 Emissions

Table A3-1 Region comparisons (ranked by CO2 emissions)

	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
SACU	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

Source: GTAP v10 data.

Table A3-2 Direct CO2 intensity, selected sectors, millions of tons of CO2 per billion dollars of output

	Production of:				
	Fertilizer	Iron & Steel	Aluminum	Cement	Electricity
USA	0.1	0.2	0.1	0.7	4.7
Canada	0.1	0.3	0.0	0.8	1.8
Mexico	0.3	0.4	0.0	1.3	3.3
EU 27	0.1	0.1	0.0	0.5	1.9
Other Europe	0.1	0.4	0.0	0.6	1.9
China	0.3	0.4	0.1	2.2	8.2
Japan	0.2	0.1	0.0	0.8	2.3
Other High-income Asia	0.1	0.1	0.1	0.9	3.6
Indonesia	0.2	0.4	0.4	1.3	10.2
Other Southeast Asia	0.2	0.4	0.1	2.6	4.9
India	0.3	1.9	0.2	3.8	4.7
Othr_S_Asia	0.5	0.5	0.1	2.1	3.2
Russian Federation	0.4	0.5	0.0	1.8	4.6
West Asia	0.4	0.6	0.2	1.7	4.8
Middle East	0.7	0.3	0.2	0.9	5.0
SACU	0.2	0.7	0.2	2.9	15.2
Other Africa	0.2	0.4	0.0	1.0	3.5
Brazil	0.1	0.3	0.5	0.8	1.1
Other America	0.3	0.6	0.1	0.8	2.9

Source: GTAP v10 data.

Table A3-3 Millions of tons of CO2 emissions per billion dollar of intermediate input use, selected sectors and regions

		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

Table A3-4 Ratio of direct and indirect CO2 per unit of output to direct CO2 per unit of output

	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 As	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
Othr_S_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
SACU	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

Table A3-5 CO2 emissions by user and region

	Household	Producers	All
USA	20.1	79.9	100.0
Canada	17.6	82.4	100.0
Mexico	19.3	80.7	100.0
EU 27	17.8	82.2	100.0
Other Europe	21.4	78.6	100.0
China	6.9	93.1	100.0
Japan	12.4	87.6	100.0
Other High-income Asia	9.3	90.7	100.0
Indonesia	15.4	84.6	100.0
Other Southeast Asia	9.8	90.2	100.0
India	7.8	92.2	100.0
Othr_S_Asia	18.9	81.1	100.0
Russian Federation	13.7	86.3	100.0
West Asia	19.5	80.5	100.0
Middle East	10.6	89.4	100.0
SACU	7.6	92.4	100.0
Other Africa	21.4	78.6	100.0
Brazil	17.9	82.1	100.0
Other America	16.9	83.1	100.0

Source: GTAP v10 data.

Table A3-6 Bilateral trade with US and China, percent, base data

	Exports *fob* to:		**Imports *cif* from:**	
	China	US	China	US
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: GTAP v10 data.

Figure A3-1: CO2 emission ranking

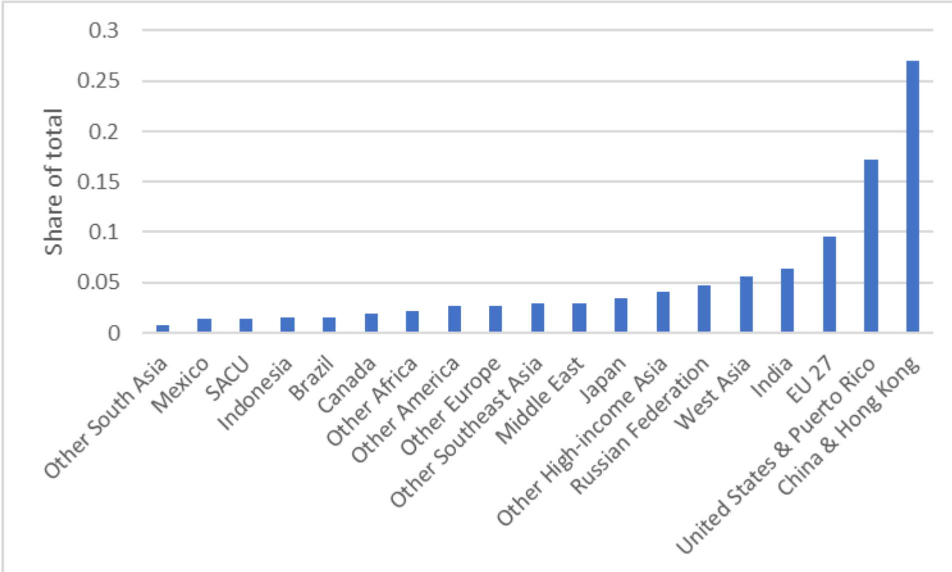

Figure A3-2: CO2 shares

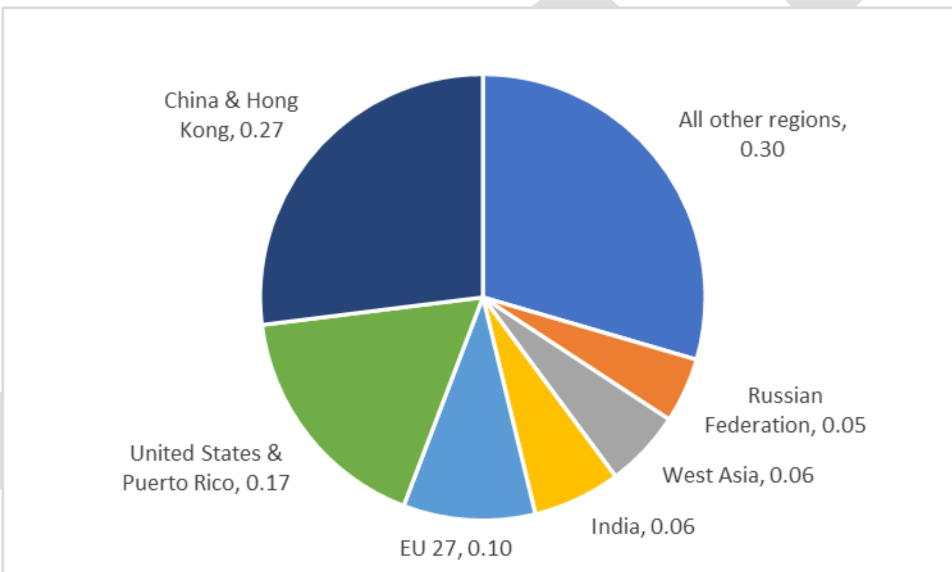

Figure A3-3: Ratio of region CO2 emissions per G.D.P. relative to .U.E.U. 27

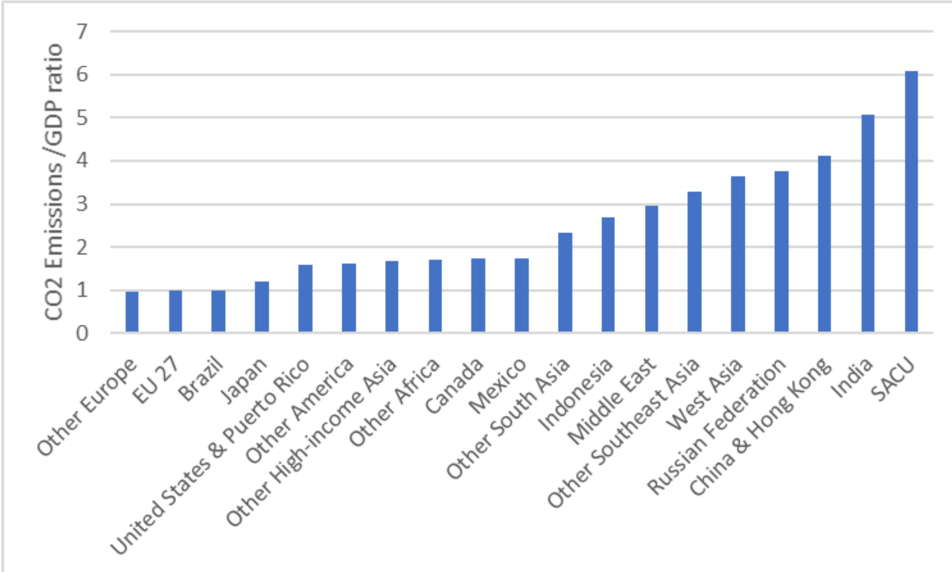

Figure A3-4: CO2 emission relative to population

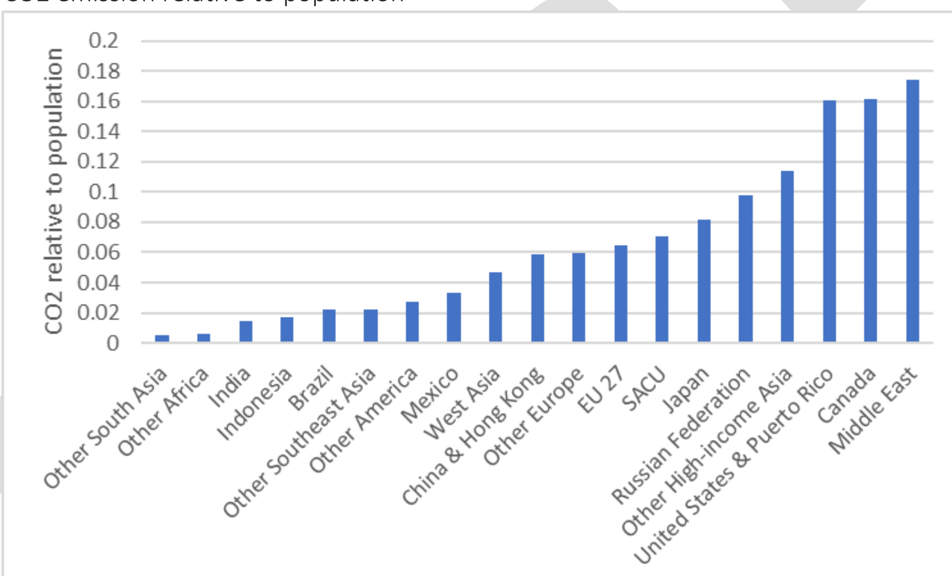

Figure A3-5a Average fossil fuel taxes (ad valorem) by region

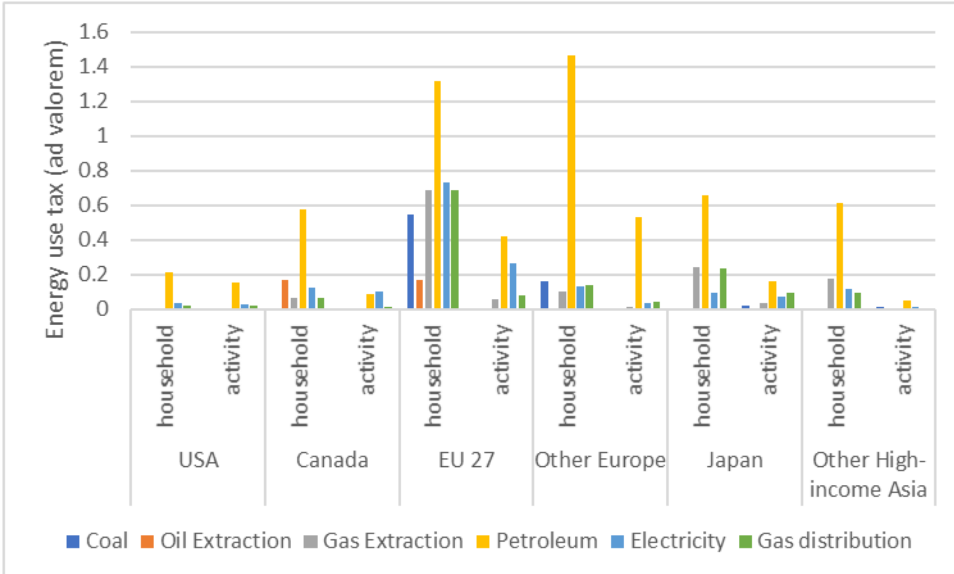

Figure A3-5b Average fossil fuel taxes (ad valorem) by region

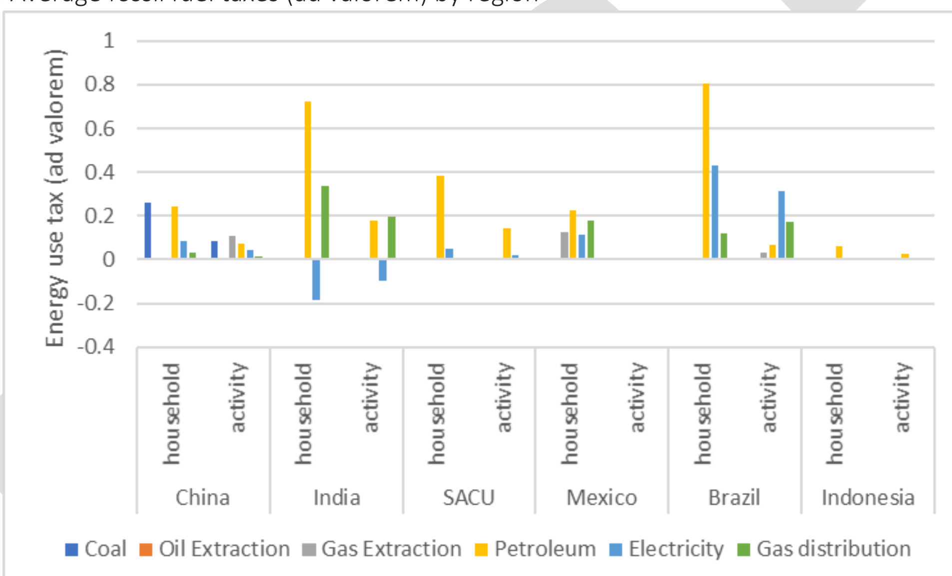

Figure A3-5c Average fossil fuel taxes (ad valorem) by region