PROTECTIONISM IN A GREEN SUIT? MARKET POWER IN CARBON-BASED TRADE POLICY

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Carbon tariffs have received widespread support as a second-best policy tool to regulate foreign emissions indirectly. In this paper, I document novel evidence suggesting that carbon-intensive sectors have higher market power and thus charge higher markups. Thus, carbon tariffs lead to sizable profit-shifting across countries. I build a multi-industry structural model of international trade with input-output linkages to analyze the welfare implications of a carbon-based trade policy reform. I study the nature of profit shifting in response to the carbon-embodied tariffs and quantify the aggregate and distributional effects on welfare and emissions. The findings suggest that accounting for market power increases the effectiveness of trade policy in reducing global emissions. However, it generates heterogeneous effects across countries where countries may lose as high as four percentage points or gain more after accounting for profits with the counterfactual trade policy reform. India, for example, experiences a welfare gain of 0.34 percentage points.

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Non-Technical Summary

Climate change is one of the most urgent global policy challenges. It is a universal problem that requires worldwide consensus among various nation-states. However, there is a lack of globally coordinated efforts to combat the climate crisis. The Paris Agreement does not prescribe legally binding emission caps for individual countries. Many countries are committed to reducing their greenhouse gas (GHG) emissions through nationally determined contributions (NDCs). The contributions depend on the national government's commitment and public support toward climate change and the trade-off it faces with its economic growth. There is no legal penalty if a government fails to reach its targets. As a result, different countries have pledged to different emission reduction targets. Moreover, countries with stringent environmental policies face the risk of production leakage of emission-intensive and trade-exposed industries. Given the lack of stringent and uniform emission pricing, international trade policies, through import carbon tariffs, have garnered policy attention to increase the effectiveness of unilateral emissions pricing and indirectly regulate foreign emissions. It is crucial to understand the effectiveness of trade policy in reducing global emissions and its economic impact on various countries.

Carbon-based tariff adjustments make it expensive to trade carbon-intensive goods from other countries. This results in production reallocation to domestic countries or countries with comparative advantage. Interestingly, this paper documents a novel finding suggesting that carbon-intensive industries have higher market power than cleaner industries. Thus, they charge higher markups and earn higher profits. As a result, carbon-based trade policy leads to sizable profit-shifting across countries. This paper aims to quantify the role of market power in understanding the impact of carbon-based trade policy adjustments on global emissions and economic welfare.

The emission intensity (tons of CO_2 per \$ of output) of net importers of carbon-intensive goods drives the impact on global emissions. As tariffs are raised on carbon-intensive products, production reallocates to countries otherwise importing these goods. If these importers have lower emission intensity, it will lead to a reduction in global emissions. On average, advanced economies are net importers with lower emission intensity. As production reallocates to countries with lower emission intensity, the policy change reduces global emissions. Notably, the production reallocates high-markup and high-profit industries in home countries. Thus, market power exacerbates the reallocation of carbon-intensive industries in countries with lower emission intensity. As a result, introducing markups increases the effectiveness of reducing global emissions through trade policy.

Unpacking the impact of market power on economic welfare is more challenging. The effect depends on whether a country is a net importer of carbon-intensive goods and which of the two channels, price or profits, is stronger. Carbon-based tariffs may be costlier for countries that net import upstream carbon-intensive goods, particularly when countries do not have the comparative advantage in producing these goods. Higher importing costs, through input-output linkages, spill over to higher prices, reducing welfare. Contrastingly, the profit channel may be stronger for countries if the production of high-markup, high-profit industries reallocate to home, increasing welfare. On the other hand, net exporters of carbon-intensive goods lose market share in high-markup and high-profit markets, reducing welfare.

To study these channels and the impact of market power, I run a counterfactual experiment where tariffs are effectively raised in carbon-intensive industries and lowered in cleaner industries. I then compare the results with a setup with no market power. First, I find that incorporating market power increases the effectiveness of trade policy in reducing global emissions. Secondly, I find that countries experience a heterogenous impact on economic welfare. Net exporters of carbon-intensive goods lose more when market power is accounted. The effect on net importers depends on which of the two channels is stronger. Overall, the paper studies a novel channel of market power and reassesses the environmental and distributional consequences of a carbon-based trade policy.

1 Introduction

The lack of global consensus on a uniform carbon tax has led to the increased acceptance of carbon tariffs by advanced economies to regulate foreign emissions indirectly. (Böhringer et al. (2012); Branger and Quirion (2014); Carbone and Rivers (2017)). However, carbon tariffs are controversial as they may be a protectionism tool under the guise of climate security.[2]Advanced economies may levy carbon tariffs to shelter domestic industries, undermining the pro-competitive effects of global trade. Carbon tariffs may come at the expense of developing countries which are net exporters of carbon-intensive goods, exacerbating the burden-shifting effect as profits shift from developing to advanced economies. Most research assumes perfect competition to analyze carbon-based tariffs masking the potential reshuffling of profits across countries. In this paper, I break the assumption of perfectly competitive markets. I explore the role of market power, quantifying the international profit-shifting in response to carbon-based tariff adjustments using a structural trade model.

The profit-shifting channel is crucial in studying carbon-based tariffs because I find that incorporating market power increases the effectiveness of trade policy in reducing global emissions. However, it generates heterogeneous effects across countries. I document novel, suggestive evidence exploring the relationship between an industry's market power and carbon intensity. I find that carbon-intensive goods are, on average, high markup goods, showing that market power is more widespread in energy-intensive sectors. As a result, carbon-based tariff adjustments relocate high markup industries to the domestic country or the countries with comparative advantage. The production reallocation results in significant profit-shifting and revision of aggregate welfare across countries. Net exporters of carbon-intensive goods are most likely to lose, while net importers are most likely to gain, relative to a case of perfectly competitive markets. I then build a quantitative structural model of international trade to estimate the effect of this relationship on welfare and global emissions, accounting for the revision of aggregate profits. The model evaluates the distributional outcome across countries to examine the burden-shifting effects and assess if carbon-based tariffs contradict the principles of Common But Differentiated Responsibility[3] in which industrialized countries commit to avoiding negative

[2]see National Post Opinion: Carbon tariffs as protectionism tool

[3]The UNFCCC describes CBDR in Article 3.1: "The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof."

economic spillover of their environmental policy to developing countries.

I use two data estimation techniques to explore the relationship between an industry's carbon intensity and market power. First, to measure carbon intensity, I use environmentally-extended multi-region input-output tables to measure the direct carbon emissions (through the combustion of fossil fuels) and the indirect carbon emissions (through the use of carbon-intensive intermediates). Second, to measure the market power, I estimate the import demand elasticity of an industry using the limited information maximum likelihood (LIML) technique detailed in Soderbery (2015).

I present a stylized fact that reveals a positive correlation between the two variables. Thus, the evidence suggests that carbon-intensive goods are high markup goods. Carbon-based tariff adjustments aim to increase the cost of importing a carbon-intensive good from a given source country. A higher import cost might be welfare-reducing for net importers of carbon-intensive goods as higher import cost spillovers to a higher cost of living. However, if carbon-intensive goods are high markup goods, carbon tariffs might relocate the production of the high-markup industries to the domestic country, reaping profits and enhancing welfare. In contrast, a tariff increase is potentially costlier for exporters of high-markup goods, as it shifts the profits away from the exporter to the destination country or other competing countries with comparative advantage.

I build a multi-country, multi-industry structural model of international trade with global input-output linkages to account for this profit-shifting channel and estimate the aggregate effects on welfare and global emissions. The model departs from the assumption of perfect competition and tractably accounts for the profit-shifting across countries in response to carbon-based tariff adjustments. Heterogeneity in the demand elasticity drives the responsiveness of the import demand to the higher import cost. It thus affects the relative market shares of the source country and its aggregate markups. Given the dispersion in the demand elasticity across industries, carbon-based tariff adjustments can generate sizable gains or losses for the countries.

I study a counterfactual trade policy reform where each country implements a single tariff per trading partner (equal to the mean baseline bilateral tariff). As documented in Shapiro (2021), the baseline tariffs are lower for carbon-intensive imports. This fact is referred to as the environmental bias of trade policy and is widespread across all countries. Thus, the counterfactual policy reform effectively increases import tariffs for carbon-intensive industries and lowers them for cleaner industries. The counterfactual is similar to the central quantitative assessment in Shapiro (2021), allowing a straightforward comparison with the literature. More generally, low protection in carbon-intensive upstream industries stems from a strong industry lobby for lower import costs for these upstream goods. WTO has sought to decrease the protection of downstream industries relative to upstream industries since such policy reform would let developing countries sell more advanced goods to rich countries. This counterfactual is similar to WTO's policy objective and imposes uniform bilateral tariffs across all goods while pricing the carbon emissions embodied in its imports. Governments have a sub-optimal baseline trade policy where tariffs are lower for carbon-intensive sectors. As a result, the policy reform effectively raises tariffs on carbon-intensive sectors and lowers them for cleaner sectors.

Accounting for profit shifting increases the effectiveness of trade policy to reduce global emissions. The counterfactual policy reform reduce global emissions by 5.7% in the case of imperfect competition and by 3.7% in the case of perfect competition. The extent of domestic reallocation explains the difference between these two cases. When we account for profit-shifting, there is a higher domestic reallocation of carbon-intensive sectors in countries that are net importers, as these sectors are high markup sectors. For example, domestic production reallocation is considerably higher under imperfect competition for many advanced economies, including the United States. Since advanced economies, on average, have lower emission intensity and are net importers of carbon-intensive goods, the strength of domestic production reallocation exacerbates the reduction in total global emissions under imperfect competition. The results highlight the potency of trade policy as a second-best policy tool to reduce global emissions.

Quantifying the markup channel has important implications for a country's aggregate welfare in response to carbon-based trade policy reform. Under perfect competition, all countries gain real income. While increasing tariffs on carbon-intensive sectors, carbon-based tariffs also reduce tariffs on cleaner sectors. The clean industries are downstream industries and thus have a higher share of the final consumption of the consumers (Shapiro (2021), Antràs et al. (2012)). As a result, the policy reform lowers the price and encourages international trade of cleaner industries. It leads to heterogeneous positive distributional effects across countries depending on each country's consumption basket and international input-output linkages. The aggregate welfare effect varies widely from 10% in Norway and 3.65% in Sweden to less than 1% in India, Indonesia, and Australia. These results are similar to Shapiro (2021), which reports a positive effect on real income across different regions under perfect competition.

The quantitative assessment in this paper importantly accounts for profit-shifting across countries as the production of high-markup carbon-intensive industries reallocates in response to carbon-based tariff adjustments. The results highlight that unaccounted profits overestimate the welfare effects of countries like China as high as 4.48 percentage points (pp) and Russia (2.69 pp). Unlike perfect competition, a few countries lose real income: China loses by 1.40%, Indonesia by 0.23%, Mexico by 0.17%, and the Netherlands by 1.18%. Russia only gains by 0.82% relative to 3.51% in case of perfect competition. The heterogeneous effects across countries are explained by their trade portfolio and their role in the global input-output linkages. Countries that are net exporters of carbon-intensive goods lose the most from this adjustment. The trade reform is strikingly costly for net exporters of carbon-intensive goods as their export profits erode. In contrast, the net importers of carbon-intensive goods gain real income as the profits and production of high markup industries likely reallocate to their own country.

Literature

Climate change is one of the most urgent global policy challenges. Due to industrialization, deforestation, and large-scale agriculture, human-generated carbon emissions and other greenhouse gases have increased global temperatures and thus are an undisputed driver of climate change. A changing climate can disastrously impact our ecological, physical, and health systems, including extreme weather events, rising sea levels, hampered agricultural growth, and polluted water systems (IPCC (2014)). It is a universal problem that requires worldwide consensus among various nation-states. However, there need to be more globally coordinated efforts to combat the climate crisis. The Paris Agreement of 2015 does not prescribe legally binding emission caps for individual countries. Many countries are committed to reducing their greenhouse gas (GHG) emissions through nationally determined contributions (NDCs). The contributions depend on the national government's commitment and public support toward climate change and the trade-off it faces with its economic growth. As a result, different countries have pledged to different emission reduction targets.[4] If a government fails to reach its targets, there is no legal penalty. Given the lack of stringent and uniform emission pricing, international trade policies, through import carbon tariffs, can play a crucial role in increasing the effectiveness of unilateral emissions pricing.

The differences in the stringency of environmental regulations across countries contribute to the leakage risk whereby rich countries offshore the production of trade-exposed and carbon-intensive goods to countries where the environmental regulation is relatively relaxed. (Hoel (1991); Felder and Rutherford (1993); Markusen (1975); Fischer and Fox

[4]To view updated NDCs for different countries, visit here

(2012); Fowlie and Reguant (2022)). Leakage reduces the cost-effectiveness of unilateral climate policy and comes at the cost of competition loss for emission-intensive and trade-exposed (EITE) industries in stringent countries. Furthermore, emission regulation in stringent countries lowers the demand for fossil fuels and thus reduces their international price. Lower prices incentivize non-stringent countries to increase the use of fossil fuels. The empirical evidence on the leakage risk is relatively modest. Most papers find leakage rates of less than a third using numerical methods and partial equilibrium quantitative models (Babiker (2005); Droege and Panezi (2022)). Some papers find potential leakage ranging from 20 to 73% in emission-intensive industries. (Demailly and Quirion (2006); Ponssard and Walker (2008); Fowlie et al. (2018)). This leakage risk jeopardizes any gains in environmental quality by trading off emission reduction in stringent countries for emission increases in non-stringent countries, defeating the goal of domestic regulation.

These issues have highlighted the significance of using carbon tariffs or carbon border adjustments to price the behavior of foreign firms. For instance, European Union passed a proposal for Carbon Border Adjustment Mechanism whose transitional phase is set to begin in October 2023.[5] Nordhaus (2015) shows how an international climate treaty that combines target carbon pricing and trade sanctions can induce substantial abatement. The modeling results in Nordhaus (2015) indicate that modest trade penalties on relaxed countries by a "climate club" of stringent countries can induce a coalition that approaches the optimal level of abatement.

Trade policy is important because carbon emissions create a pollution externality that is inconsequential for location. Unlike flow pollutants, CO_2 is a stock pollutant. With flow pollutants, environmental regulations can result in production leaving the country and hurting people in other countries.[6] However, with carbon emissions, if a country regulates emissions and the production moves to another country, the regulating country will still suffer from carbon emissions since the concern is with the stock of CO_2, regardless of its origin. Thus, the "optimal" policy would impose a uniform Pigovian tax (or a quantity mechanism like cap-and-trade) in all countries and industries.

Most studies estimate the tax to be around 40-80$ per ton of CO_2, depending on the dis-

[5]Under the adjustment, EU importers will buy carbon certificates corresponding to the carbon price that would have been paid had the goods been produced under the EU's carbon pricing rules. The mechanism creates a level playing field between home and foreign producers to avoid the risk of leakage, effectively increasing tariffs on carbon-intensive imports.

[6]For example, when California banned spray finishes, production moved to Mexico. The negative externality from the pollutant in spray finishes (like the health effects when spraying on the furniture - a flow) also moved to Mexico.

count rate.[7] However, due to the lack of globally coordinated efforts to impose a uniform tax on carbon, trade policy has been proposed as a 'second-best' policy tool to regulate foreign emissions indirectly. Redesigning tariff policy in conjunction with their carbon content raises the global prices of carbon-intensive goods, reducing their market shares; and lowering the costs of cleaner goods, encouraging international exchange. Empirical analysis on carbon tariffs has found the potency of carbon tariffs in reducing emission leakage and lowering output losses for EITE industries in stringent countries (Böhringer et al. (2012); Branger and Quirion (2014); Carbone and Rivers (2017)). However, the literature has not explored the quantitative importance of reshuffling of aggregate profits across countries in response to carbon-based tariff adjustments.

In addition to the leakage risk, the current international trade structure and tariff policy contribute to global emissions. Specific facts established in the literature highlight the consequences of our international trade policy on global carbon emissions. Internationally traded goods account for about 22 to 35 percent of global pollution emissions (Copeland et al. (2021)). Pollution-intensive industries are more exposed to trade and relish lower tariff and non-tariff barriers (Shapiro (2021)). This pattern exists globally and within almost all countries. The difference in trade barriers between carbon-intensive (or dirty) and clean industries creates an implicit subsidy for carbon emissions in internationally traded goods. Shapiro (2021) estimates that this global implicit subsidy is between 85$ to 120$ per ton of CO_2, which is higher than the estimated optimal tax on CO_2 at $40 per ton. He explains the existence of environmental bias in our trade policy. Trade barriers are generally lower on upstream goods because industries lobby for lower tariffs on intermediate goods.[8] He finds that upstream goods are also carbon-intensive. The downstream goods are cleaner but face higher tariffs as final consumers are poorly organized. Given this unintentional design, international trade encourages the exchange of dirtier carbon-intensive goods, contributing to global emissions and climate change. This paper contributes to this strand of literature by exploring a novel relationship between carbon intensity and market power. In particular, carbon-intensive sectors are not only subjected to lower tariffs but also, as this research suggests, enjoy a higher market power and thus charge higher markups.

Shapiro (2021) builds a quantitative world economy model to understand the effectiveness of redesigning tariffs. The paper studies a single tariff per trading partner (equal to mean baseline tariffs), raising tariffs in carbon-intensive sectors and lowering them in

[7] Social cost of carbon under different discount rates

[8] Examples of industries with low upstreamness is automobiles, household furniture, etc. while industries with high upstreamness include petrochemicals, copper smelting/refining, etc.

cleaner sectors. Shapiro (2021) finds that such a policy change will lead to global emission reduction by 3.6% and a modest increase in real income in all countries. This striking result fills a critical knowledge gap in the literature. The quantitative assessment shows that we can correct the unintentional environmental bias of our trade policy without hampering the global real income by redesigning our tariff structure.

This paper builds on Shapiro (2021) but targets quantifying the role of profit-shifting under the same trade policy reform. It breaks the assumption that the markets are perfectly competitive and focuses on an increasingly relevant trend in economic literature: markups and market power (De Loecker and Eeckhout (2018); De Loecker et al. (2021)). To capture market power, the model allows for demand elasticity to vary not only across sectors but also across destination countries.[9] Heterogeneity in the destination-specific demand elasticity generates differences in import and export markups, which augments the fact that some countries are net exporters of high-markup goods. At the same time, some are net importers of high-markup goods (Firooz and Heins (2020)). Consequently, a tariff increase is potentially costlier for exporters of high-markup goods, as it shifts the profits away from the exporter to the destination country or other competing countries with comparative advantage. Specifically, carbon-based tariff adjustments aim to increase the cost of importing a carbon-intensive good from a given source country. Heterogeneity in the destination elasticity drives the responsiveness of the import demand to the higher import cost. It thus affects the relative market shares of the source country and its aggregate markups. Given the motivating evidence that carbon-intensive sectors are high markup sectors, tariff adjustments can generate sizable gains or losses for the countries. The paper aims to quantify profit-shifting and its role in evaluating aggregate welfare and emission changes in response to carbon-based tariff adjustments.

In addition to quantifying profits, the paper runs the analysis for a more granular sectoral detail and with the recent data for 2016. This is relevant because Shapiro runs the quantitative assessment for the year 2007. However, as documented in Böhringer et al. (2021), the global economy has undergone a substantial structural change regarding production, consumption, and trade since the financial crisis. Trade in carbon embodied in goods increased until 2007-2008 but modestly decreased afterward. They find that the effectiveness of carbon tariffs is higher when there is a higher trade in carbon. This paper analyzes 2016 to understand the quantitative importance of the profit channel for more recent data. Another reason more current data is useful is that carbon intensity changes due to decarbonization over time (by a change in the mix of fuels, output, or efficiency).

[9]Evidence of heterogeneous demand elasticity has been expressed in various papers, e.g., Handbury (2021), Faber and Fally (2017), Adao et al. (2017), or Heins (2019)

Furthermore, the paper analyzes a sample of 24 countries and a Rest of the World (ROW) aggregate rather than combining them with specific regions (OECD, Non-OECD, Eurozone, Asia). Understanding if the carbon-based tariff adjustments spur global inequalities by shifting export-based profits from developing countries to rich countries is imperative. This paper identifies specific countries in these groups that may gain or lose due to these adjustments.

The remainder of the paper is structured as follows. In Section 2, I detail the data and estimation technique to measure an industry's carbon intensity and market power (through the estimated import demand elasticity). In Section 3, I provide suggestive evidence about the positive relationship between carbon intensity and market power. In Section 4, I describe a quantitative structural model that enables us to account for profit-shifting tractably and estimates the aggregate effects on welfare and emissions. In Section 5, I present the results of a counterfactual exercise and evaluate the aggregate and distributional effect of a trade policy reform. Section 6 concludes.

2 Data and Estimation

The paper uses three main variables to present a stylized fact and to run the quantitative analysis: carbon emissions, market power, and trade policy. To measure carbon emissions, I use the Exiobase Version 3.8 Database (Stadler et al. (2021)). I measure the market power of an industry by estimating the import demand elasticity (σ) using the limited information maximum likelihood hybrid estimator (Soderbery (2015)). To measure the baseline trade policy, I use the WITS database[10] that reports the sector-specific bilateral ad-valorem tariffs. I use the TRAINS database[11] to measure the ad valorem equivalent of non-tariff measures.

2.1 Carbon Emissions

I use the environmentally extended multi-regional input-output tables (EE MRIO) from Exiobase Version 3.8. EE-MRIO by Exiobase, supported by the European Union, has emerged as a pivotal database to analyze the environmental impact of production, trade, and global supply chains. Exiobase reports the world input-output details for 200 prod-

[10]WITS database can be accessed here
[11]Non-Tariff Measures can be accessed here

ucts for 44 countries and five country aggregates, which collectively account for 90% of the world GDP. The database is consistent with the recommended accounting systems of the United National System of Environmental-Economic Accounting (UN-SEEA), which makes it the best available resource for international comparisons across countries and regions (Stadler et al. (2018)). Exiobase is built from several primary data sources (Wood et al. (2014)). It measures trade using BACI, based on the UN's Comtrade database and the UN's services trade databases. Much of the global supply chain literature has used either the World Input-Output Database (WIOD) or the Global Trade Analysis Project (GTAP - MRIO). However, Exiobase EE MRIO provides a richer and more consistent level of sector detail, enabling us to assess the carbon sources of the global value chains adequately.

There are two types of carbon emissions: direct and indirect emissions. Carbon emitted by the combustion of fossil fuels (coal, petroleum, and natural gas) accounts for the direct emissions of industry. Indirect emissions are the carbon emitted in the intermediate goods produced as inputs to make that final good. An input-output table reports the dollars of output from a row industry used to produce one dollar of the output of the column industry. If there are S industries, an input-output table is an $[S \times S]$ matrix detailing the dollar value of each input used to produce each good in the economy. This permits the calculation of the dollar amount of fossil fuels used to produce each good. The database combines the emission factor for each fossil fuel (obtained from the TEAM model, Pulles et al. (2007)) with the national price per physical unit to arrive at the tons of CO_2 emitted to infer the carbon emissions for each dollar of fossil fuels used directly in the production. An industry's "direct" emission rate is inferred by multiplying the total expenditures on each fossil fuel with their respective CO_2 emission per dollar of the fossil fuels used. Exiobase reports the direct impact of each industry in terms of CO_2 emissions in 1000 tons[12] per one million dollars of output from fossil fuel combustion. Table 1 summarizes the cleanest and dirtiest five industries by the median value of direct carbon emissions. In most countries, the highest emissions stem from electricity production, which is not traded internationally as much but is used as a primary input in the production process. Therefore, it is crucial to account for the use of electricity (and hence fossil fuels) as intermediates in producing final tradable goods.

The "default" method of CO_2 described above measures the direct emissions from producing a good but ignores the life-cycle measurement of CO_2 emissions in its value chain

[12]Here, tons refers to metric tons. Exiobase reports the carbon emissions from the combustion of fossil fuels in Gigagrams (Gg) per 1 million euros of output. 1Gg = 1000 metric tons. I use the mean annual exchange rate from the IMF's International Financial Statistics to convert Euros to dollars.

Table 1: Cleanest and Dirtiest Industries by Direct Carbon Emissions

Industry	Direct CO_2 emissions
Panel A: Cleanest Industries	
Post and Telecommunication Services	0.08
Education/Financial Services	0.11
Public Administration and Defense Services	0.13
Electricity by Nuclear/Hydro	0.14
Real Estate Services	0.15
Panel B: Dirtiest Industries	
Electricity by Coal	86.23
Wool, Silk-Worm Cocoons	56.12
Natural Gas Extraction	19.63
Electricity by Petroleum/Oil Derivatives	17.75
Coke Oven Coke	15.92

CO_2 combustion measures the 1000 metric tons of CO_2 per million USD from combustion of fossil fuels

(such as the use of electricity as an intermediate good). To measure the total carbon intensity of an industry, we need to account for the CO_2 emitted in the production of the inputs used, the inputs used in that input, and so on. For example, direct CO_2 emissions from Automobile manufacturing account for the fossil fuels used to manufacture the automobile. However, it neglects the emissions from inputs like steel, which in turn has burned fossil fuels for its production. To permit the calculation of indirect emissions, I calculate the Leontief inverse or a matrix of total requirements. Leontief inverse details the dollars of each input (including those required to produce intermediate inputs, inputs to inputs, and so on) needed to make an additional dollar of the final demand of that industry.

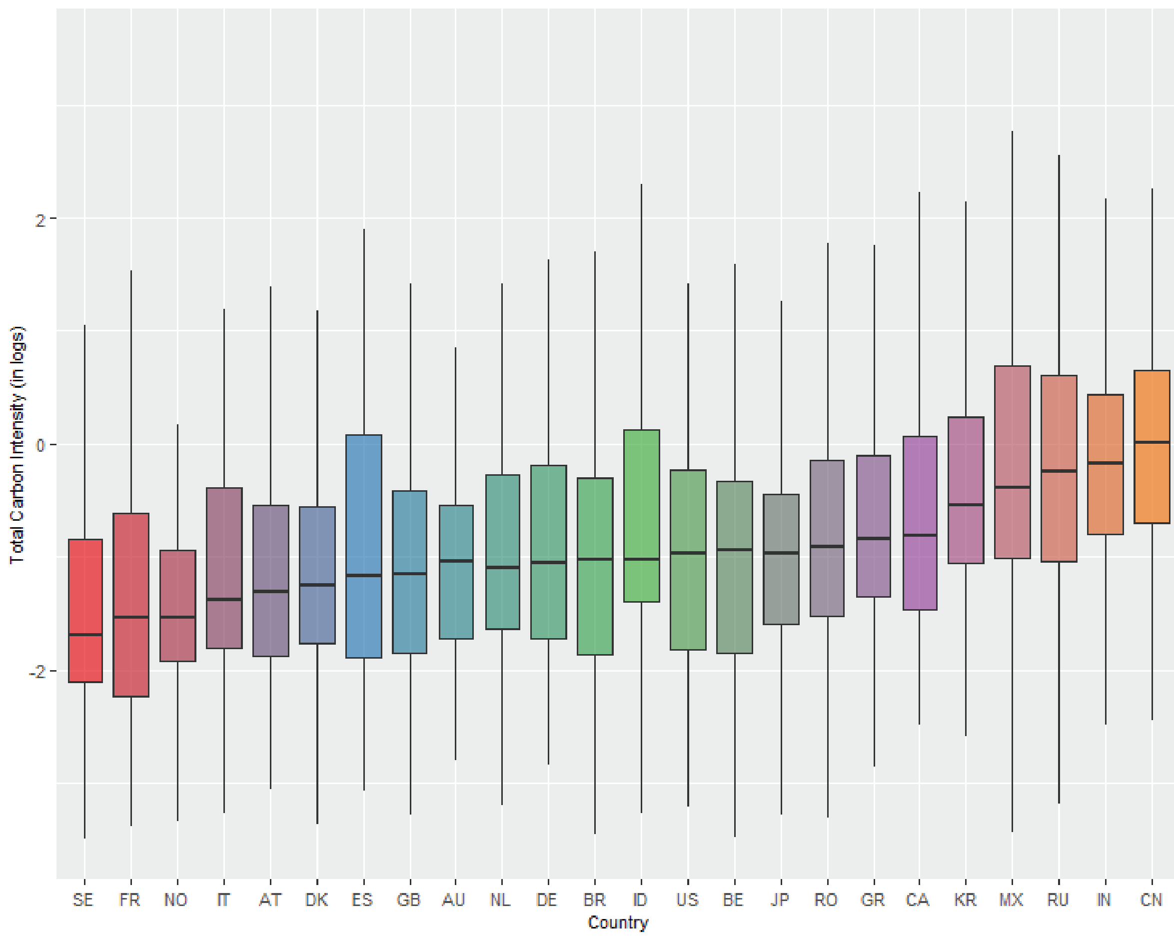
To explain in the context of multiple open countries, a multi-region input-output table (MRIO) extends the national I-O tables to many countries and accounts for the dollar value from one country-industry used in the production of 1$ of output in any other country-industry. If there are N countries and S industries in each country, then A is a MRIO matrix, $[NS \times NS]$, describing this "global" supply chain. Let X be a $[NS \times 1]$ vector of gross output and D be a $[NS \times 1]$ vector of final demand. Then the accounting equation, $X = AX + D$ states that an industry's gross output is equal to its output value used as intermediate goods and as final demand. Here, $X = (I - A)^{-1}D$. This enables us to calculate the Leontief inverse, $L \equiv (I - A)^{-1}$. Let L_{ijst} denote the entry of the multi-region Leontief inverse, that is, the dollar of output from industry s in country i required to produce \$1 of output in industry t in country j.

If E^d_{is} is the direct emissions from combustion of fossil fuels in industry s in country i, then the total carbon intensity of a sector-country, E_{it} is measured by incorporating the

Leontief inverse:

$$E_{jt} = \sum_{i,s} L_{ijst} E^d_{is} \tag{1}$$

Figure 1: Summary Statistics: Total Carbon Intensity



The variation in the total carbon intensity of producing a $ of output across countries and products. Each box shows the median and the interquartile range in the carbon intensity across products in each country. Carbon Intensity measure the metric tons of CO_2 emitted per $ of output directly (through the combustion of fossil fuels) as well as indirectly (through the use of intermediates)

Figure 1 summarizes the CO_2 intensity of production in each country. The figure shows the variation within and across countries in total carbon emissions of tradable goods for selected countries, arranged in ascending order.[13] For each country, the boxplot shows the

[13]Countries from left to right: Sweden, France, Norway, Italy, Austria, Denmark, Spain, United Kingdom, Australia, Netherlands, Germany, Brazil, Indonesia, United States, Belgium, Japan, Romania,Greece, Canada, South Korea, Mexico, Russia, India, China.

median and interquartile range (25th-75th percentile) across tradable industries. One of the key takeaways from Figure 1 is that countries with relatively relaxed environmental regulations, like Russia, Mexico, India, and China, are at the right extreme of the graph. Most European countries occupy the left extreme, with the median in China being eight times that of Sweden. This figure complements the finding that differences in the emission intensities vary hugely across countries[14].

2.2 Market Power and Demand Elasticity

To quantify the sources of market power, I estimate the import demand elasticity of various country-sector pairs, using the hybrid estimator method (LIML) proposed in Soderbery (2015). The estimation procedure is based on the approach developed by Feenstra (1994), but addresses potential small sample biases and grid search inefficiencies in previous applications. Elasticity estimates based on the Feenstra method have been frequently used and referred to in various papers in the literature (Broda et al. (2008), Hsieh and Klenow (2009), Khandelwal (2010), and Ossa (2014)). Soderbery (2015) approach is also consistent with the theoretical framework as the demand side in both settings is derived from CES preferences. This section details the estimation methodology used by Soderbery (2015) to estimate demand elasticity.

Specifically, the methodology introduces a time subscript t and time-variety-specific taste shocks $b_{jst}(\omega)$ into the CES aggregator. Here, q_{jst} is the quantity of good s demanded in country j at time period t, which is a CES aggregate over varieties ω.

$$q_{jst} = \left[\int b_{jst}^{j(k)}(\omega)^{\frac{1}{\sigma_{js}}} q_{jst}(\omega)^{\frac{\sigma_{js}-1}{\sigma_{js}}} d\omega \right]^{\frac{\sigma_{js}}{\sigma_{js}-1}} \tag{2}$$

I treat each HS6-country[15] pair that we observe in data as one variety ω who is the winner of the competition in a subset of HS2 products. I follow Soderbery (2015) and Broda and Weinstein (2006) and allow for a potentially upward-sloping export supply curve, in

[14]Stylized Fact 5 in Copeland et al. (2021)

[15]HS6 here refers to the Harmonized Commodity Description and Coding System, generally referred to as "Harmonized System". It comprises more than 5,000 commodity groups; each identified by a six-digit code, arranged in a legal and logical structure, and supported by well-defined rules to achieve uniform classification.

which case this structure implies demand and supply curves of the form

$$\Delta^m ln(s_{jst}(\omega)) = -(\sigma_{js} - 1)\Delta^m ln(p_{jst}(\omega)) - \xi_{jst}(\omega) \quad (3)$$

$$\Delta^m ln(p_{jst}(\omega)) = \left[\frac{\kappa_{js}}{1+\kappa_{js}}\right]\Delta^m ln(s_{jst}(\omega)) + \delta_{jst}(\omega) \quad (4)$$

where Δ^m denotes double differencing with respect to time and a reference variety m, κ_{js} denotes the inverse export supply elasticity for good s, s_{jst} its expenditure share, and $\xi_{jst}(\omega)$ and $\delta_{jst}(\omega)$ reflect unobservable demand and supply shocks.

Following Feenstra (1994)'s identifying assumption that these demand and supply shocks are orthogonal, i.e., $E[\xi_{jst}(\omega)\delta_{jst}(\omega)] = 0$, one can then multiply the two shocks to convert the structural equations of demand and supply into one estimation equation

$$\Big(\Delta^m ln(p_{jst}(\omega))\Big)^2 = \lambda_{1,s}\Big(\Delta^m ln(s_{jst}(\omega))\Big)^2 + \lambda_{2,s}\Big(\Delta^m ln(p_{jst}(\omega))\Big)\Big(\Delta^m ln(s_{jst}(\omega))\Big) + u_{jst} \quad (5)$$

where $\lambda_{1,s} = \kappa_{js}/[(\kappa_{js}+1)\cdot(\sigma_{js}-1)]$ and $\lambda_{2,s} = [1-\kappa_{js}(\sigma_{js}-2)]/[(\kappa_{js}+1)\cdot(\sigma_{js}-1)]$, which can be consistently estimated using 2SLS estimation with variety indicators as instruments.[16]

I employ bilateral trade data on the HS6 level for the years between 1995 and 2015 and estimate σ_{js} separately for each HS2 sector and country to allow for the possibility that traded varieties of each good as well as the demand for them may differ across countries. Table 2 provides summary statistics and shows the distribution of the estimated import demand elasticities across countries. I estimate σ to be particularly low for Australia, the U.K., Italy, and Japan. On the other end, I estimate comparably large elasticities of substitution for India, Canada, Belgium, and China.

The parameter estimate σ plays an important role as it quantifies model-implied profits ($\frac{1}{\sigma}$) and markups ($\frac{\sigma}{\sigma-1}$) as is detailed in the quantitative model in Section 4. Essentially, lower demand elasticity in an industry (σ) implies that firms enjoy higher market power, reap higher implied profits and charge higher markups.

[16]Following Soderberry(2015), I weight varieties by their respective estimated residuals to limit the impact of outliers.

Table 2: Distribution of parameter estimates for σ

σ	Median	1st Quartile	3rd Quartile
Australia	1.93	1.47	3.11
Austria	2.76	1.70	6.31
Belgium	3.15	1.94	6.73
Brazil	2.58	1.74	4.28
Canada	4.41	2.09	11.13
China	3.05	1.85	6.52
Denmark	2.40	1.67	4.71
France	2.49	1.64	4.98
Germany	2.65	1.70	5.23
Greece	2.27	1.68	3.59
India	3.48	2.08	7.68
Indonesia	2.37	1.70	3.87
Italy	2.10	1.53	3.71
Japan	2.19	1.61	3.65
Rep. of Korea	2.63	1.70	4.65
Mexico	2.64	1.77	4.89
Netherlands	2.45	1.65	4.71
New Zealand	2.70	1.78	4.77
Norway	2.30	1.72	3.38
Romania	2.48	1.70	4.19
Russia	2.53	1.73	4.38
Spain	2.56	1.76	4.11
Sweden	3.04	1.79	6.73
United Kingdom	1.96	1.50	3.34
USA	2.49	1.61	5.99
ROW	2.72	1.58	7.02

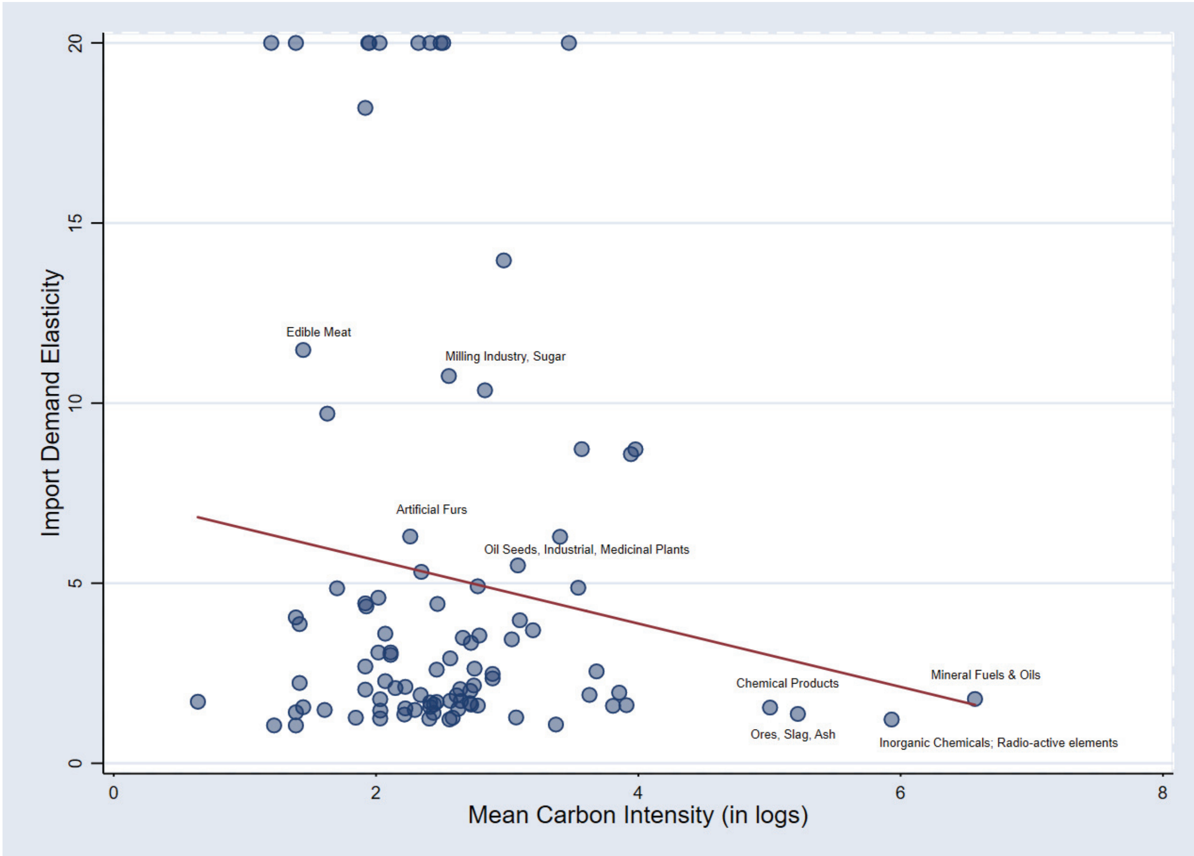
Notes: This table provides summary statistics for the parameter estimates of σ. The median and quartiles are taken over product categories.

3 Relationship between Carbon Intensity and Market Power

In this section, I provide suggestive evidence about the correlation between the carbon intensity of sectors with market power. Figure 2 plots the two variables to motivate the relationship. The figure indicates that carbon-intensive sectors have relatively lower demand elasticity, suggesting that the carbon-intensive sectors have higher market power. To further support the correlation, I run a regression of the per-unit model implied profits ($\frac{1}{\sigma_{js}}$) on the total carbon intensity (E_{js}) of the country-sector pair. As implied by the measured demand elasticity, the results support a positive correlation between the two variables, indicating that the carbon-intensive sectors are, *on average*, high markup sectors.

Exiobase reports the direct emissions from the combustion of fossil fuels for country-

Figure 2: Relationship between Carbon Intensity and Demand Elasticity



Relationship between carbon intensity and demand elasticity. The x axis plot the mean carbon intensity across countries, weighted by the expenditures. The y axis plots the estimated demand elasticity

sector pairs. I use the global input-output tables to infer indirect and total emissions for a particular good using the Leontief matrix. The database uses product codes closely based on the International Standard Industrial Classification. The elasticity estimates are based on the Comtrade database, which uses Harmonized System (HS 2012) classification. I use published concordances to crosswalk each of the Exiobase product codes to an HS2 category using import share as weights[17]. I run the regression with a sample of 24 major economies and the rest of the world aggregate for 96 HS-2 digit industries. I run two sets of regressions to establish the association between carbon intensity and market power. The first uses the US industry-specific elasticity to infer the market power of an industry. The second allows the elasticity to vary across countries.

Table 3 reports the results when US elasticity is used to infer the industry's market power. I use the implied profits in the model, $1/\sigma$, as the dependent variable and regress it on an

[17]Concordances between various industrial classifications can be accessed here

industry's mean total carbon intensity by weighing each country by its import size. The estimates reported in Columns (1) and (2) indicate that carbon-intensive sectors are, on average, associated with higher per-unit implied profits. Measuring total CO_2 emissions from the input-output table may invite measurement errors as it requires harmonization of industrial data across many countries. To address the potential measurement error, I use direct emissions as an instrumental variable for the total emissions. I use the two stages SLS to investigate if the relationship still holds. Columns (4) and (5) report the results of the two-stage IV regression. The results confirm the suggestion that carbon-intensive sectors are correlated with higher profits.

Table 3: Regression of US Elasticity on Mean Carbon Intensity, by Industry

	(1)	(2)	(3)	(4)	(5)
Dependant Variable	$1/\sigma$	$\log(1/\sigma)$	σ	$1/\sigma$	$\log(1/\sigma)$
Mean Carbon Intensity (log)	0.020**	0.066***	-0.379***	0.022**	0.070**
	(0.009)	(0.023)	(0.141)	(0.009)	(0.027)
Constant	0.357***	-1.365***	6.231***	0.353***	-1.376***
	(0.040)	(0.132)	(0.886)	(0.041)	(0.137)
Observations	96	96	96	96	96
IV Regression	No	No	No	Yes	Yes

Standard errors in parentheses
Independant Variable: Mean Carbon Intensity by industry, weighted by the import of each country
Data source: Exiobase and ComTrade
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

In the second case, I use the estimated country-specific elasticity to allow for the variation in the market power across industries and countries. To measure the difference in the implied profits between clean and dirty industries, I estimate the following equation:

$$\tilde{\pi}_{js} = \alpha_0 + \alpha E_{js} + \mu_j + \epsilon_{js} \quad (6)$$

Here, E_{js} reflects the total carbon intensity of sector s in country j. This means that it incorporates not only the direct emissions by the combustion of fossil fuels, but also the indirect emissions incorporated in the inputs used in the production of the sector s. The parameter α represents the difference in the implied profits $(1/\sigma)$ of carbon-intensive (dirty) industries with respect to cleaner industries; μ_j reflects country fixed effects.

Column (1) in Table 4 reports the value of α. The results indicate that the association of carbon-intensive sectors with higher implied profits still holds. In Column (2), I weigh each country sector by the size of their import share and still find a positive association. The results for the IV regression are reported in Column (4), indicating a more positive and statistically significant relationship between the implied profits and the carbon intensity.

Table 4: Regression of Inverse Elasticity on Carbon Intensity

	(1)	(2)	(3)	(4)
Total carbon intensity (Log)	0.018*	0.013*	0.025**	0.019**
	(0.009)	(0.007)	(0.011)	(0.009)
Constant	-1.802***	-1.819***	-1.851***	-1.856***
	(0.114)	(0.119)	(0.124)	(0.124)
Observations	2399	2398	2399	2398
Country FE	Yes	Yes	Yes	Yes
Weights	No	Yes	No	Yes
IV Regression	No	No	Yes	Yes

Standard errors in parentheses
Dependant variable: Inverse of Demand Elasticity (Sigma)
Data source: Exiobase and ComTrade
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

In light of this suggestive evidence, carbon-based tariffs could have sizable welfare implications in reshuffling bilateral profits. Notably, a tariff could be hurtful for countries that export carbon-intensive goods to destinations with high implied profits. This is because their export profits dwindle in response to production potentially shifting to the destination country or other countries with comparative advantages. Consequently, for an importing country with a positive association between carbon intensity and implied profits, a carbon-based tariff might be beneficial as it shifts the production of the high markup sector domestically, reaping additional aggregate profits. A country that exports goods to destinations where carbon-intensive sectors are high markup goods are the ones to lose the most from carbon-based tariffs. On the contrary, a country that imports high-markup carbon-intensive goods is most likely to gain from carbon-based tariffs. The extent to which carbon-based tariffs result in aggregate welfare gains for a country is mired in its complex relationship of carbon intensity with market power, market shares, and its global input-output linkages. In the next section, I build a quantitative structural model of trade which tractably accounts for the profit-shifting channel to quantify the welfare implications of carbon-based tariff changes.

4 Quantitative Model

This section details the paper's theoretical contribution, which enables us to account for markups and profit shifting in the counterfactual analysis of carbon-based tariff changes. Trade between countries creates transboundary pollution, which negatively affects the utility. Countries have pre-existing and sub-optimal trade policy where tariffs are lower on carbon-intensive sectors. In the counterfactual scenario, the tariffs adjust to accommodate the carbon content in its offshore production. Such a policy internalizes the cost of carbon and indirectly regulates the emissions among the trading partners. The heterogeneity in the import demand elasticity across countries and sectors drives the responsiveness of the import demand to these carbon-based tariff adjustments. Production relocates to countries with relative comparative advantage in response to the adjusted import costs. The industries are linked through global input-output linkages. As a result, the tariff adjustments generate general equilibrium effects, which account for the changes in the industry expenditures and, thus, the aggregate revision of the market shares and the bilateral profits. The objective is to measure the effects on social welfare while accounting for profits in response to tariff shocks, considering the global linkages.

4.1 Model

Preferences: The representative agent in country j maximizes national utility which is Cobb-Douglas over various sectors s

$$U_j = \Pi_s Q_{js}^{\beta_{js}} f(Z) \tag{7}$$

Q_{js} is the quantity of output consumed in sector s. β_{js} is the weight given to each sector by the consumer for final consumption. $f(Z)$ is the climate damage function which accounts for the disutility from increase in global emissions Z[18].

[18]Specifically, functional form of climate damage is $f(Z) = [1 + \delta(Z - Z_0)]^{-1}$. δ is the damage parameter, Z_0 refers to the baseline global emissions and Z refers to the counterfactual global emissions. δ is estimated such that one unit increase in global emissions ($Z - Z_0$) leads to a utility decline equivalent to the calculated social cost of carbon (approx. $40 per ton).

Sector s is a CES aggregate over various varieties, depending on the source country (Armington (1969)). The elasticity of substitution is allowed to differ at country-sector level.

$$Q_{js} = \left(\sum_i q_{ijs}^{\frac{\sigma_{js}-1}{\sigma_{js}}} \right)^{\frac{\sigma_{js}}{\sigma_{js}-1}} \tag{8}$$

The representative consumer chooses q_{ijs} to maximize Q_{js} such that the total expenditure on good s in country j is $X_{js} = \sum_i p_{ijs} q_{ijs}$. Solving the maximization problem gives us

$$q_{ijs} = \frac{p_{ijs}^{-\sigma_{js}}}{\sum_i p_{ijs}^{1-\sigma_{js}}} X_{js} \tag{9}$$

Total expenditure on good s from country i in country j is

$$X_{ijs} = p_{ijs} q_{ijs} = \frac{p_{ijs}^{1-\sigma_{js}}}{\sum_i p_{ijs}^{1-\sigma_{js}}} X_{js} \tag{10}$$

Thus the market share of country i in country j is $\lambda_{ijs} = \frac{p_{ijs}^{1-\sigma_{js}}}{\sum_i p_{ijs}^{1-\sigma_{js}}}$

Technology: Production of good s in country i requires labor and intermediate inputs. Thus the unit cost is given by

$$c_{is} = w_i^{1-\alpha_{is}} \Pi_k P_{ik}^{\alpha_{iks}} \tag{11}$$

where α is the cost share to produce the goods.

To serve market j, the representative firm in country i incurs an additional cost in terms of tariff and non-tariff barriers given by $\phi_{ijs} = (1+t_{ijs})(1+\eta_{ijs})$. Here t_{ijs} are the ad-valorem tariffs imposed by country j on good s from country i. η_{ijs} are the non-tariff barriers. Thus the marginal cost of exporting good from country i to country j is $c_{ijs} = \phi_{ijs} c_{is}$. Intranational trade costs equal one:$\phi_{jjs} = 1$

Pollution: The pollution emitted to sell goods in a particular destination is

$$Z_{ijs} = \gamma_{is} \frac{X_{ijs}}{p_{ijs}} \tag{12}$$

The coefficient γ_{is} refers to the pollution intensity of producing good s in country i, which is the metric tons of CO_2 emitted per dollar of output in the fossil fuel extraction. A country's total pollution emission is the sum of emission incurred for domestic production and its exports. Thus $Z_i = \sum_{s,j} Z_{ijs}$. The global pollution is $Z = \sum_i Z_i$

Market Structure: We assume that firms in industry s and in country j engage in monopolistic competition and choose prices to maximize profits, given the preference equations. The price charged is a markup over the marginal cost of production

$$\pi_{ijs} = p_{ijs}q_{ijs} - c_{ijs}q_{ijs}$$

Maximizing profits given (8) gives us

$$p_{ijs} = \frac{\sigma_{js}}{\sigma_{js} - 1} c_{ijs} \tag{13}$$

The aggregate price in country j for sector s is

$$P_{js} = \left[\sum_i p_{ijs}^{1-\sigma_{js}}\right]^{\frac{1}{1-\sigma_{js}}} = \frac{\sigma_{js}}{\sigma_{js} - 1}\left[\sum_i c_{ijs}^{1-\sigma_{js}}\right]^{\frac{1}{1-\sigma_{js}}} = \frac{\sigma_{js}}{\sigma_{js} - 1}\left[\sum_i [w_i^{1-\alpha_{is}} \Pi_k P_{ik}^{\alpha_{iks}} \phi_{ijs}]^{1-\sigma_{js}}\right]^{\frac{1}{1-\sigma_{js}}} \tag{14}$$

Aggregation: Total expenditure incurred on goods from country j in sector s is the expenditure incurred by the representative consumer as final consumption expenditure on that good (which is the share of total income) and the expenditure incurred by other industries k using s as intermediate inputs. The total income, $I_j = w_j L_j + \pi_j + T_j + D_j$

$$X_{js} = \beta_{js} I_j + \sum_k \alpha_{jsk} R_{jk} = \beta_{js}(w_j L_j + \pi_j + T_j + D_j) + \sum_k \alpha_{jsk} \sum_i \frac{\lambda_{jik} X_{ik}}{(1 + t_{ijk})} \tag{15}$$

The total profits π_j can be written as

$$\pi_j = \sum_s \sum_i \frac{1}{\sigma_{is}} \frac{\lambda_{jis} X_{is}}{1 + t_{jis}} \tag{16}$$

The total tariff revenues:

$$T_j = \sum_s \sum_i \frac{t_{ijs}}{1 + t_{ijs}} \lambda_{ijs} X_{js} \tag{17}$$

The expenditures are then given as:

$$X_{js} = \beta_{js}(w_j L_j + \sum_s \sum_i \frac{1}{\sigma_{is}} \frac{\lambda_{jis} X_{is}}{1 + t_{jis}} + \sum_s \sum_i \frac{t_{ijs}}{1 + t_{ijs}} \lambda_{ijs} X_{js} + D_j) + \sum_k \alpha_{jsk} \sum_i \frac{\lambda_{jik} X_{ik}}{(1 + t_{ijk})} \tag{18}$$

The deficits,D_j are given by:

$$\sum_s \sum_i \frac{\lambda_{jis} X_{is}}{1 + t_{jis}} = \sum_s \sum_i \frac{\lambda_{ijs} X_{js}}{1 + t_{ijs}} - D_j \tag{19}$$

Value Added and Labor Market Clearing: The value added of a sector-country is the difference between the revenues and the total expenditures on intermediate goods. This means,

$$Y_{js} = \sum_i \frac{\lambda_{jis} X_{is}}{1 + t_{jis}} - \sum_k \alpha_{jks} \sum_i \lambda_{ijk} X_{jk} = R_{js} - \alpha_{js} R_{js} = (1 - \alpha_{js}) R_{js}$$

The value added is the revenues after paying for intermediate inputs. This revenue is then allocated between labor in form of wages ($w_j L_j$) and profits.

$$w_j L_j = \sum_s Y_{js} - \sum_s \sum_i \frac{1}{\sigma_{is}} \frac{\lambda_{jis} X_{is}}{1 + t_{jis}}$$

$$w_j L_j = \sum_s \Big[\sum_i \frac{\lambda_{jis} X_{is}}{1 + t_{jis}} - \sum_k \alpha_{jks} \sum_i \lambda_{ijk} X_{jk} \Big] - \sum_s \sum_i \frac{1}{\sigma_{is}} \frac{\lambda_{jis} X_{is}}{1 + t_{jis}}$$

This gives us

$$w_j L_j = \sum_s \sum_i \frac{\sigma_{is} - 1}{\sigma_{is}} \frac{\lambda_{jis} X_{is}}{1 + t_{jis}} - \sum_s \sum_k \alpha_{jks} \sum_i \lambda_{ijk} X_{jk} \tag{20}$$

In baseline and counterfactual equilibrium, consumers maximize their utility, firms maximize profits, deficits remain the same and markets clear.

4.2 Counterfactual Analysis

For a counterfactual change in trade costs given by $\hat{\phi}_{ijs}$, I use hat algebra to solve for equilibrium in changes (Dekle et al. (2008); Caliendo and Parro (2015)). If x' denotes a variable in the counterfactual scenario and x denotes the variable in the baseline, then $\hat{x} = \frac{x'}{x}$

$$\hat{P}_{js} = \left[\sum_i \lambda_{ijs} (\hat{c}_{is} \hat{\phi}_{ijs})^{1-\sigma_{js}} \right]^{\frac{1}{1-\sigma_{js}}} \tag{21}$$

$$\hat{\lambda}_{ijs} = \left(\frac{\hat{c}_{is} \hat{\phi}_{ijs}}{\hat{P}_{js}} \right)^{1-\sigma_{js}} \tag{22}$$

$$\hat{c}_{is} = \hat{w}_i^{1-\alpha_{is}} \Pi_k \hat{P}_{ik}^{\alpha_{iks}} \tag{23}$$

Counterfactual changes in trade costs ϕ_{ijs} affect the marginal cost of importing goods from country i to the country j. This change alters the aggregate price of good s in the country j (Equation 21). The price changes affect the marginal cost of producing goods through input-output linkages (Equation 23). This in turn alters the market share of country i in country j (Equation 22). I solve the above system of non-linear equations to get $\hat{\lambda}_{ijs}$ and $\hat{P}_{js}$.

To close the model, I then solve for the counterfactual sector-country expenditures. This is motivated by the fact that in the counterfactual equilibrium, expenditures equal revenues.

$$\hat{X}_{js} X_{js} = \beta_{js} \Big[\hat{w}_j (w_j L_j) + \sum_s \sum_i \frac{1}{\sigma_{is}} \frac{\hat{\lambda}_{jis} \lambda_{jis} \hat{X}_{is} X_{is}}{1 + t'_{jis}} + \sum_s \sum_i \frac{t'_{ijs}}{1 + t'_{ijs}} \hat{\lambda}_{ijs} \lambda_{ijs} \hat{X}_{js} X_{js} + D_j \Big] + \sum_k \alpha_{jsk} \sum_i \frac{\hat{\lambda}_{jik} \lambda_{jik} \hat{X}_{ik} X_{ik}}{(1 + t'_{ijk})} \tag{24}$$

Equation 24 is a system of equations where the expenditures X_{js} is not only dependant on expenditures in other countries X_{is} but also expenditures on different sectors in different countries X_{ik} through input-output linkages.

After solving the above system of equation, I solve for labor market clearing which implies that the country deficits remain the same in the counterfactual.

$$\hat{w}_j w_j L_j = \sum_s \sum_i \frac{\sigma_{is} - 1}{\sigma_{is}} \frac{\hat{\lambda}_{jis} \lambda_{jis} \hat{X}_{is} X_{is}}{1 + t'_{jis}} - \sum_s \sum_k \alpha_{jks} \sum_i \hat{\lambda}_{ijk} \lambda_{ijk} X_{jk} \hat{X}_{jk} \tag{25}$$

To find the changes in the real income (welfare) $\hat{V}_j$, I use the changes in wages, profits, tariff revenues and prices to infer

$$\hat{V}_j = \frac{\hat{w}_j w_j L_j + \hat{\pi}_j + \hat{T}_j + D_j}{\hat{P}_j} \tag{26}$$

where

$$\hat{P}_j = \Pi_s \hat{P}_{js}^{\beta_{js}} \tag{27}$$

The effect on aggregate profits in country j is:

$$\hat{\pi}_j = \frac{\pi_j^{'}}{\pi_j} = \frac{\sum_{s,i} \frac{1}{\sigma_{is}} \frac{\hat{\lambda}_{jis}\lambda_{jis}\hat{X}_{is}X_{is}}{1+t_{jis}^{'}}}{\sum_{s,i} \frac{1}{\sigma_{is}} \frac{\lambda_{jis}X_{is}}{1+t_{jis}}}$$

Total change in pollution in a given country for a change in tariffs are given as

$$\hat{Z}_i = \frac{\sum_s \gamma_{is}\lambda_{ijs}\hat{\lambda}_{ijs}X_{js}\hat{X}_{js}/P_{ijs}'}{\sum_s \gamma_{is}\lambda_{ijs}X_{js}/P_{ijs}} \tag{28}$$

4.3 Estimation Procedure

1. Start with a guess of a vector of ones for the changes in the marginal costs and wage changes: $(\hat{c}_{is}, \hat{w}_{is})$. This is $[N \times S + N]$ vector
2. Use Equations 21-23 to calculate $\hat{P}_{js}$ and $\hat{\lambda}_{ijs}$
3. Calculate the "ERROR 1" by using Equation 23: the unit cost equation. This is $[N \times S]$
4. Use Equation 24 to solve for counterfactual expenditures given $\hat{P}_{js}$ and $\hat{\lambda}_{ijs}$
5. Calculate "ERROR 2" using Equation 25. This is $[N \times 1]$
6. Use an optimizer to find $(\hat{c}_{is}, \hat{w}_i)$ such that the errors $[N \times S + N]$ are minimized.
7. Use Equations 26 and 28 to infer the changes in real income and carbon emissions.

I elaborate on these steps in detail in Appendix Section B.

5 Results

In this section, I report the results of a counterfactual trade policy reform where a country's import tariffs are adjusted to accommodate the carbon embodied in its imports. Particularly, each country's bilateral import tariffs are set equal to the country's weighted mean baseline bilateral tariffs, with weights equal to the baseline bilateral trade value.

$$t'_{ijs} = \frac{\sum_s \frac{t_{ijs} X_{ijs}}{1+t_{ijs}}}{\sum_s \frac{X_{ijs}}{1+t_{ijs}}}$$

As documented in Shapiro (2021), the baseline tariffs are lower for carbon-intensive imports. This fact is referred to as the environmental bias of trade policy and is widespread across all countries. Thus, this counterfactual effectively increases import tariffs for carbon-intensive industries and lowers them for cleaner industries. This trade policy reform is similar to the quantitative assessment in Shapiro (2021). More generally, low protection in carbon-intensive *upstream* industries stems from a strong industry lobby for lower import costs for these upstream goods. Downstream goods, which are relatively less carbon-intensive, have higher tariffs as consumers are poorly organized to lobby for lower tariffs. From the policy perspective, WTO has sought to decrease the protection of downstream industries relative to upstream industries since such reform would let developing countries sell more advanced goods to rich countries. This counterfactual is similar to WTO's policy objective of imposing uniform bilateral tariffs across all goods while pricing the carbon emissions embodied in its imports.

If we eliminate the environmentally-biased price signal in our trade policy, will such a reform lead to a reduction in global emissions? What will be the welfare impact across countries? In particular, since carbon-intensive goods have higher market power, the paper aims to quantify the importance of market power in estimating the effect of the trade policy reform on global emissions and real income across countries.

I run two models to quantitatively assess the significance of the market power channel: one with perfect competition and the other with monopolistic competition. Table 5 reports the results in a perfect competition model. Table 6 reports the results of imperfect competition. In both the tables, I report the changes in the *real* variables, except for emission changes ($\frac{Z'_j}{Z_j}$). For example, Column 1 in Table 5 reports the changes in real income ($\frac{I'_j/P'_j}{I_j/P_j}$). For example, if the table reports the real income change is 1.02, the real income increases by 2% in the counterfactual policy relative to the baseline policy. Global changes in real income, real wages, real tariff revenues, and aggregate prices are calculated by weighing each country by its GDP share in the baseline. In both cases, global emissions decrease with the trade policy reform. In perfect competition, the global emissions reduce by 3.7%, while in imperfect competition, the global emissions reduce by 5.7%. In other words, the results highlight the potency of redesigning trade barriers as an effective second-best policy tool to curtail global emissions.

Perfect Competition: As reflected in Table 5, the policy reform leads to heterogeneous effects across countries in perfect competition. Notably, all countries gain real income. This is augmented by a decline in aggregate prices in many countries, as given in equation (27). Aggregate prices reduce because the counterfactual reform also lowers the baseline tariffs in cleaner industries. Cleaner industries are downstream goods with a higher share in final consumption β_{js}, predicting an overall decline in aggregate prices. The policy reform causes the global emissions to reduce by 3.76% and increase global real income by 1.98%.[19] Eliminating or harmonizing trade policy across goods can increase real income because baseline trade policy encourages consumption and production of dirty goods. Eliminating this price signal decreases the consumption and production of those dirty goods and encourages the consumption and production of downstream cleaner goods.

Market Power and Imperfect Competition: The stylized fact presented in Section 3 highlights that carbon-intensive sector are correlated with higher market power. As a result, carbon-based policy reform leads to a sizable shifting of aggregate profits and markups across countries. How does the markup channel affect the impact of policy change on global emissions? Do all countries benefit from this reform (as is the case with perfect competition)? In Table 6, I present the results of imperfect markets that account for profit shifting across countries.

The most striking result is that accounting for market power increases the effectiveness of trade policy to reduce global emissions. The emissions reduce by 5.7%, relative to 3.7% in the case of perfect competition. When import tariffs increase on carbon-intensive goods, countries find it expensive to trade them and reallocate production to the domestic country. The fact that these sectors reap high profits expedites the extent of the domestic reallocation of these industries. Two facts in the data further support the higher decline in global emissions in imperfect competition. Advanced economies are, on average, net

[19] Shapiro (2021) finds global emissions reduce by 3.6% while a moderate increase in real income by 0.6% for the same policy experiment.

Table 5: Counterfactual Results: Perfect Competition

	Welfare	Emissions	Wages	Tariff Rev.	Prices
Global	1.0198	0.9624	1.0198	1.0317	0.9809
Australia	1.0002	0.9916	1.0004	0.9812	1.0126
Austria	1.0233	0.9877	1.0259	0.9897	0.9853
Belgium	1.0227	0.9669	1.0269	0.9825	0.9742
Brazil	1.0201	1.0016	1.0196	1.0489	0.9708
Canada	1.0256	0.9901	1.0259	1.0074	0.9873
China	1.0298	0.9791	1.0249	1.1077	1.0106
Denmark	1.0147	0.9863	1.0192	0.9536	0.9828
France	1.0129	1.0105	1.0162	0.9746	0.9946
Germany	1.0256	1.0097	1.0277	0.9986	0.9797
Greece	1.0273	0.9116	1.0308	0.9996	0.9602
India	1.0077	1.0223	1.0046	1.1245	0.9785
Indonesia	1.0037	0.9928	1.0039	0.9847	0.9951
Italy	1.0260	0.9620	1.0301	0.9892	0.9741
Japan	1.0185	1.0058	1.0181	1.0612	1.0067
Mexico	1.0070	0.9863	1.0053	1.0960	0.9996
Netherlands	1.0029	0.9365	1.0059	0.9525	1.0061
Norway	1.1085	0.9933	1.1124	1.0666	0.9091
Romania	1.0476	0.9285	1.0547	1.0015	0.9335
Russia	1.0351	0.9262	1.0339	1.1368	1.0263
Spain	1.0164	0.9766	1.0199	0.9774	0.9867
Sweden	1.0365	0.9708	1.0428	0.9731	0.9776
United Kingdom	1.0111	0.9974	1.0128	0.9782	0.9976
United States	1.0031	0.9959	1.0031	1.0033	1.0040
ROW	1.0169	0.8842	1.0211	0.9745	0.9546

Notes: This table reports the $\hat{x} = x^{'}/x$ for the counterfactual changes in tariffs in a perfectly competitive markets. The aggregate real income is decomposed using Equation 26 in terms of real wages and real tariff revenues. Profits are not accounted here. The global values for economic variables are calculated by weighing each country by its relative GDP. The change in emissions, $Z = \sum_i \hat{Z}_i^{\prime} / \sum_i Z_i$

importers of carbon-intensive goods.[20]Second, the emission intensity is relatively lower in advanced economies.[21] As domestic reallocation speeds up, the production of carbon-intensive goods reallocates to advanced economies with lower emission intensity. Figure 3 plots the change in domestic profits of carbon-intensive sectors and the emission intensity against the net imports of most carbon-intensive sectors. There are three takeaways from the figure. One, net importers of carbon-intensive goods gain a higher increase in domestic profits (blue). Second, The net importers have a lower emission intensity (or-

[20]see Figure 14 and Figure 15
[21]see Figure 1

Table 6: Counterfactual Results: Imperfect Competition, US Elasticity

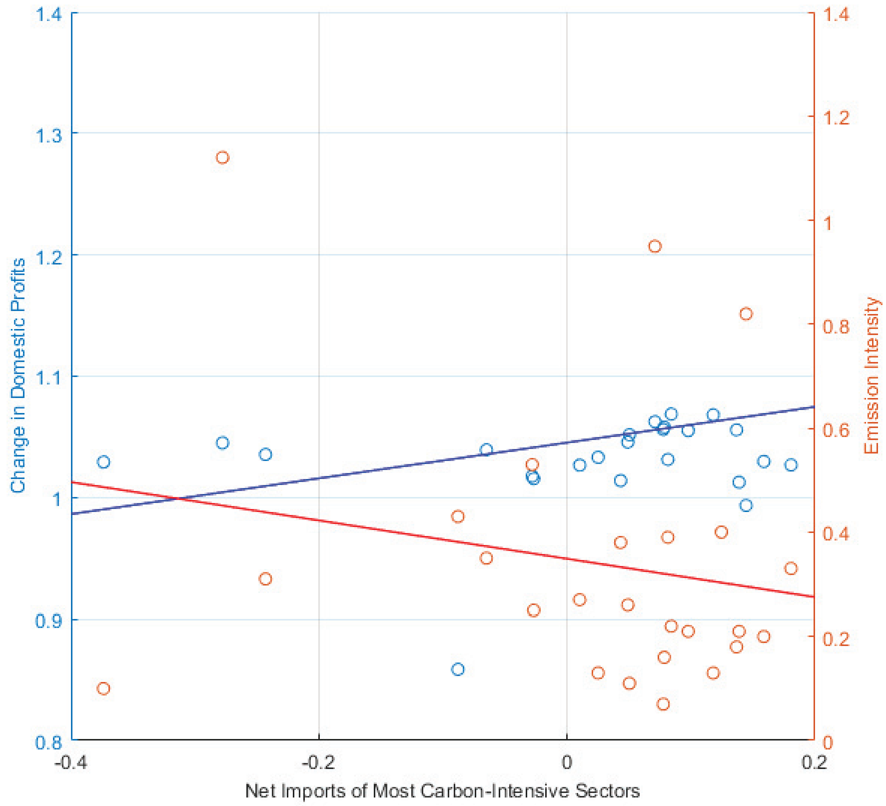
	Welfare	Emissions	Wages	Profits	Tariff Rev.	Prices
Global	1.0076	0.9430	1.0196	0.9969	1.0139	0.9931
Australia	1.0011	0.9962	0.9989	1.0042	0.9784	1.0218
Austria	1.0154	0.9819	1.0211	1.0160	0.9720	0.9984
Belgium	1.0080	0.9552	1.0238	1.0007	0.9625	0.9878
Brazil	1.0148	0.9936	1.0192	1.0063	1.0385	0.9813
Canada	1.0290	0.9940	1.0243	1.0401	1.0058	0.9963
China	0.9860	0.9418	1.0293	0.9636	1.0903	1.0261
Denmark	1.0205	0.9932	1.0116	1.0444	0.9443	0.9943
France	1.0118	1.0122	1.0099	1.0236	0.9599	1.0072
Germany	1.0236	1.0120	1.0207	1.0326	0.9841	0.9921
Greece	1.0036	0.8902	1.0298	0.9807	0.9762	0.9758
India	1.0111	1.0198	1.0026	1.0157	1.1176	0.9880
Indonesia	0.9977	0.9854	1.0031	0.9917	0.9701	1.0058
Italy	1.0125	0.9501	1.0268	1.0074	0.9694	0.9883
Japan	1.0156	1.0054	1.0166	1.0132	1.0527	1.0163
Mexico	0.9983	0.9797	1.0066	0.9873	1.0883	1.0101
Netherlands	0.9882	0.9230	1.0033	0.9746	0.9330	1.0201
Norway	1.0862	0.9756	1.1151	1.0663	1.0443	0.9214
Romania	1.0120	0.9015	1.0554	0.9733	0.9701	0.9492
Russia	1.0082	0.9052	1.0349	0.9675	1.1087	1.0420
Spain	1.0102	0.9717	1.0150	1.0139	0.9609	1.0000
Sweden	1.0277	0.9649	1.0376	1.0318	0.9556	0.9906
United Kingdom	0.9975	0.9889	1.0110	0.9885	0.9587	1.0098
United States	1.0054	0.9976	1.0016	1.0105	0.9945	1.0132
ROW	0.9829	0.8607	1.0255	0.9417	0.9367	0.9694

Notes: This table reports the $\hat{x} = x'/x$ for the counterfactual changes in tariffs in a monopolistically competitive markets. Welfare, wages and tariffs are in real terms. The global values for economic variables are calculated by weighing each country by its relative GDP. The change in emissions, $Z = \sum_i \hat{Z}'_i / \sum_i Z_i$

ange). Third, these two facts together explain the decline in global emissions. Essentially, eliminating the price signal between dirty and clean industries leads to a modest increase in domestic reallocation in countries with lower emission intensity. These mechanisms contribute to the decline in global emissions.

Impact on Real Income: Accounting for market power generates a heterogeneous impact on real income across countries. It creates sizable losses as high as 4.38 percentage points for China and sizable gains for countries like Australia (0.79 pp), India (0.34 pp), and the United States (0.23 pp). Overall, in the case of imperfect competition, I find that China, Mexico, Indonesia, the United Kingdom, etc., lose real income from the trade pol-

Figure 3

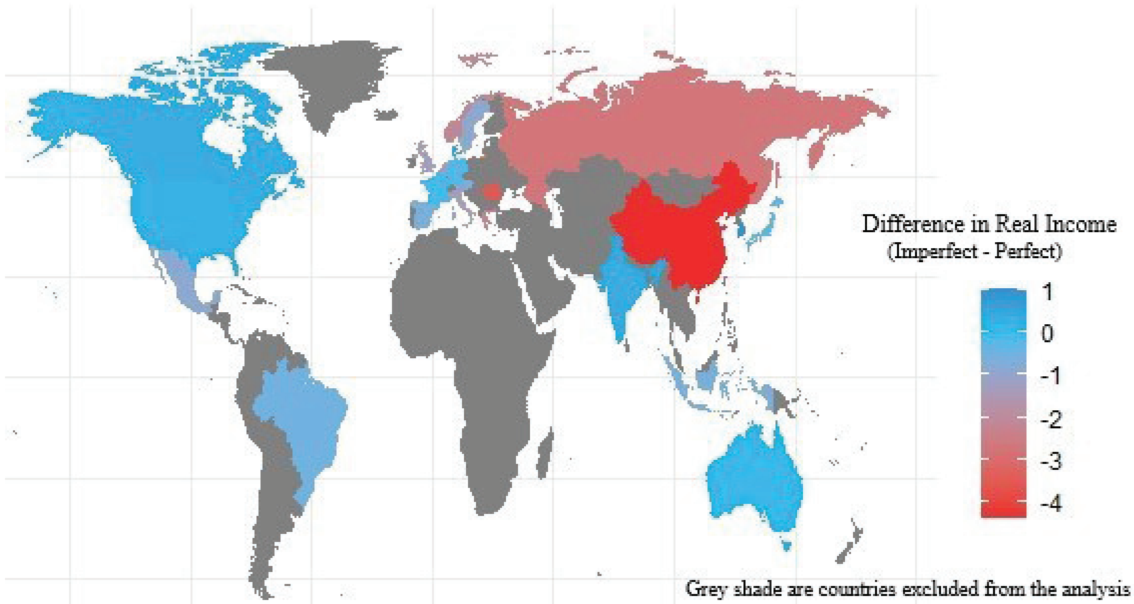


Notes: The left y axis plots the change in domestic profit for carbon-intensive goods, as predicted by the model. The right y axis plots the emission intensity of producing a 1$ worth of output. The x axis plots the net imports of most carbon-intensive goods (mineral fuels, mineral oils, waxes, lime and cement, ores, slag and ash, inorganic chemicals, compound of precious metals, radio-active elements and isotopes) relative to a country's GDP

icy reform. To visualize the difference in the real income in both models, Figure 4 plots the difference in a world map. Countries in red, like China, Russia, Romania, Mexico, Greece, Italy, etc., lose more when we account for market power, while countries like the United States, Canada, India, Australia, etc., gain the most in real income after accounting for the reshuffling of profits. As is evident from the figure, the welfare impact is markedly different in imperfect competition relative to perfect competition.

How important is the quantification of market power in estimating the welfare effects across countries? Figure 5 plots the change in real profits against the change in real income. Countries that lose in real income also experience a decline in their real profits, indicating that market power is an essential channel that explains the decline in real income in these countries under imperfect competition.

Figure 4: Differences in Real Income

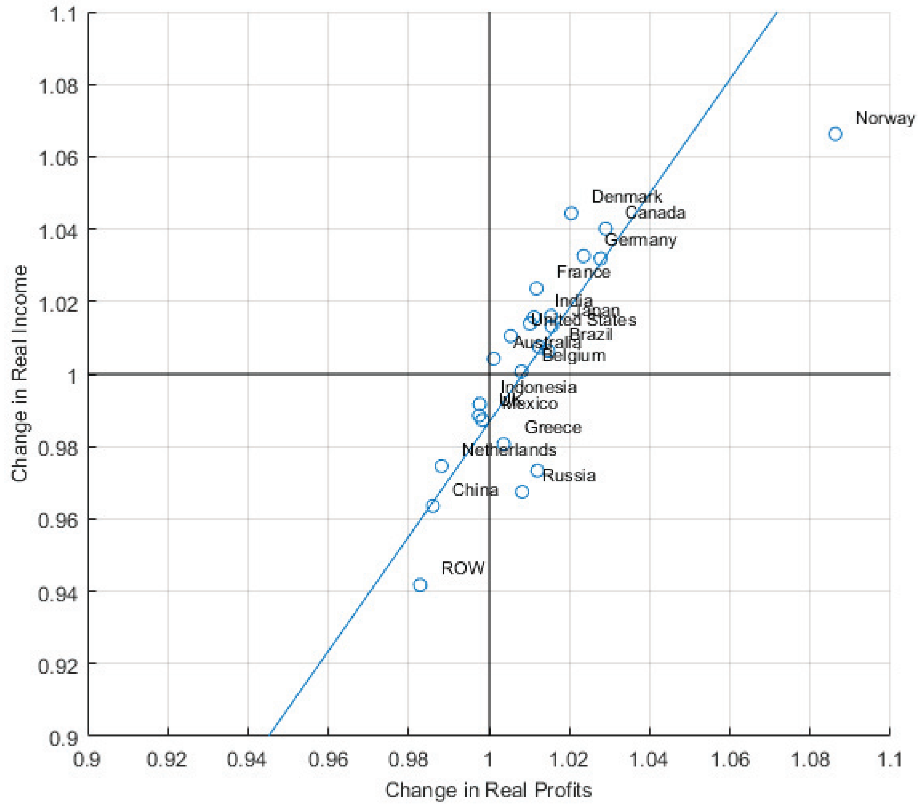


The figure shows the heterogeneity in the welfare estimates across countries. It plots the difference in the real income change between imperfect and perfect competition. Countries in the red lose the most, and countries in the blue gain the most when profits are accounted for. The figure plots the difference in percentage points: *(Change in Real Income in Imperfect Competition - Change in Real Income in Perfect Competition)*100* for each country. The

What explains the heterogeneous effects across countries? The aggregate welfare effects depend on whether a country is a net exporter of the most carbon-intensive goods. As tariffs increase on carbon-intensive sectors, the production reallocation shifts profits to the domestic country. As a result, we expect net importers of the most carbon-intensive goods to gain real profits (if the increase in nominal profits is more significant than the increase in aggregate prices). Figure 6 plots the net imports of the most carbon-intensive goods against the change in real profits predicted by the model. I find that, on average, countries that are net importers of carbon-intensive goods gain real profits from the counterfactual trade policy reform.

Production Reallocation in Developing Countries, including India: Given that the richer countries, on average, have a higher environmental bias and are net importer of carbon-intensive goods, we expect advanced countries to gain the most from the counterfactual trade policy reform. In contrast, as net exporters of high-markup carbon-intensive goods, developing countries would likely lose from the trade policy reform. However, among the developing economies, India gains from the trade policy reform while China, Russia, Mexico, Indonesia, etc, lose from the carbon-based tariff adjustments.

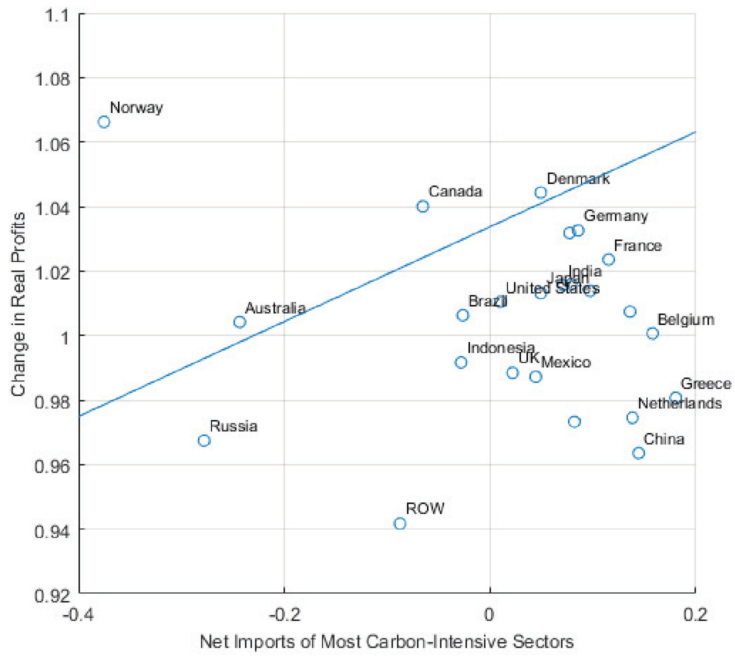
Figure 5: Real Profits vs Real Income



As tariffs increase on high-markup carbon-intensive sectors, the production potentially reallocates to the domestic country, reaping aggregate profits. The extent to which production reallocates to the domestic country explain the magnitude of welfare-enhancing effects. In Figure 7, I compare the size of production reallocation for a select set of developing countries. In the counterfactual, we observe that China, Russia, and Indonesia lose from the counterfactual trade policy reform while India gains. For each country, I plot the change in mean import tariffs for each industry against the change in domestic profits, as predicted by the model. I find that the extent of production reallocation is greatest for India, which potentially explains India's sizable gain from counterfactual trade policy reform relative to other countries.

Further, as documented in Figure 10, the average inverse demand elasticity $1/\sigma_s$ for a country's imports relative to its exports in the carbon-intensive sectors, i.e., the average profit per dollar that countries pay (via imports) minus the average profit per dollar that countries earn (via exports) in carbon-intensive sectors, has a large predictive power for

Figure 6: Net Imports of Carbon-Intensive Goods

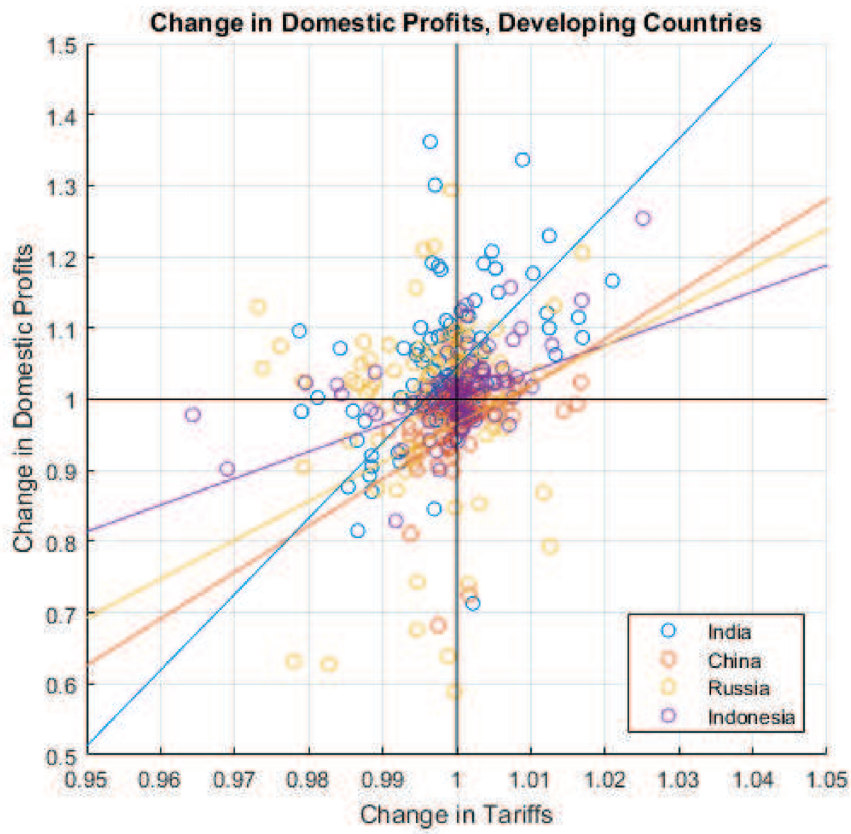


The figure plots the net imports (imports-exports) of the most carbon-intensive sectors (mineral fuels, mineral oils, waxes, lime and cement, ores, slag and ash, inorganic chemicals, compound of precious metals, radio-active elements and isotopes) relative to its GDP against the change in real profits, predicted by the model.

the welfare results. This means that countries that pay more for the imports of carbon-intensive goods relative to earnings in their exports gain real income. This channel is ignored when we are in a perfectly competitive environment.

Country Quadrants: The countries can be classified into four different quadrants after the accounting of market power. The classification depends on whether the country is a net importer of carbon-intensive goods and the relative strength of the markup and price channel. As explained above, a country loses real income if it net exports carbon-intensive goods. This is because its export profits dwindle in response to higher tariffs. These exporting countries include Russia, Brazil, Indonesia, Mexico, etc. Countries that are net importers gain as the domestic reallocation of carbon-intensive sectors, and the resultant gains in profits enhance welfare. These importing countries include the United States, India, and Denmark. A carbon-intensive importer may lose from the policy reform because the increase in import costs spillovers to the aggregate prices for these countries

Figure 7: Production Reallocation in Select countries

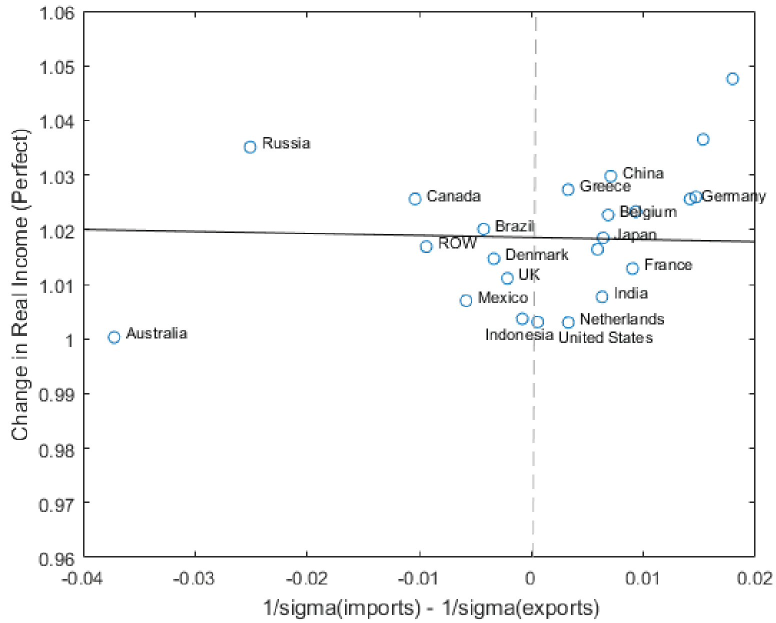


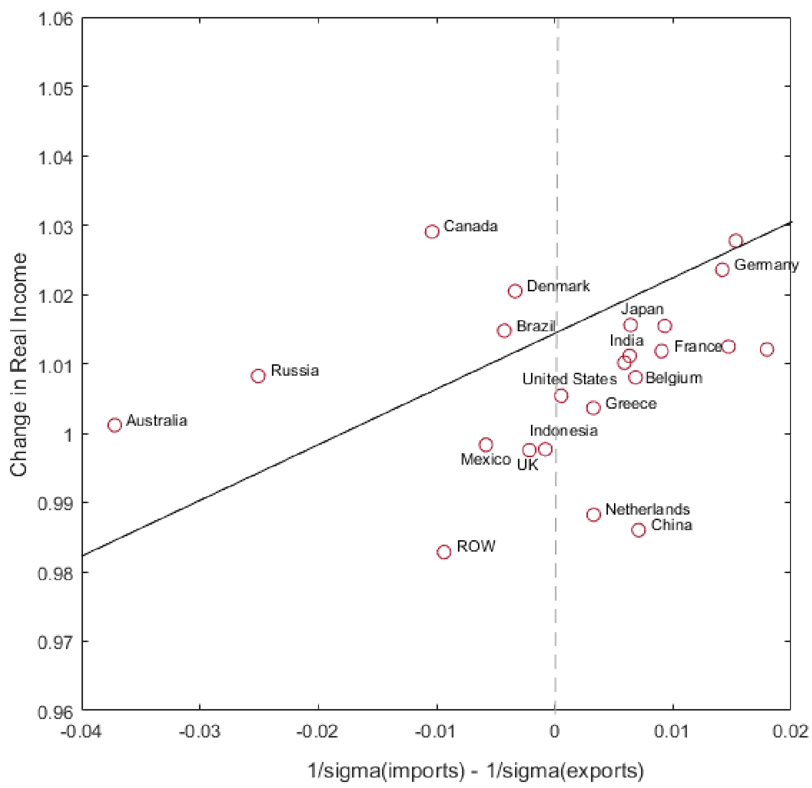
The figure plots the change in mean import tariffs in the counterfactual against the change in the domestic profits, as predicted by the model. For example, If the change in tariffs is greater than 1.01, that means that counterfactual reform increase the mean import tariffs on that industry by 1 percent. If change in domestic profits is 1.1, this means that model predicts a 10% increase in domestic profits.

hampering real income. Conversely, some exporters may gain real income depending on their comparative advantage in cleaner industries (Australia, Canada, etc.)

How does this outcome influence our understanding of carbon-based policy reform? One of the core findings is that not accounting for market power, on average, leads to overestimating the welfare gains of net exporters of carbon-intensive goods. While the counterfactual trade policy reforms lead to heterogeneous effects across countries, the results point that, on average, countries that are a net exporters of carbon-intensive goods lose more. Figure 12 plots the change in the real income against the net imports of most carbon-intensive products (mineral fuels) relative to the GDP for both perfect and imperfect competition. Figure 12 highlights that the welfare changes are relatively lower for net importers of carbon-intensive goods. When we account for markups, we see that the welfare impact is higher. Thus, not accounting for markups underestimates the welfare effect of importers of carbon-intensive goods and overestimates the welfare effect of exporters of carbon-intensive goods.

Figure 10: Change in Real Income against average profits





The horizontal axis measures the average inverse demand elasticity for imports minus that for each country's exports in the carbon-intensive sector. The vertical axis describes the percentage changes in welfare for the counterfactual policy reform under perfect and imperfect competition

Figure 11: Country Quadrants

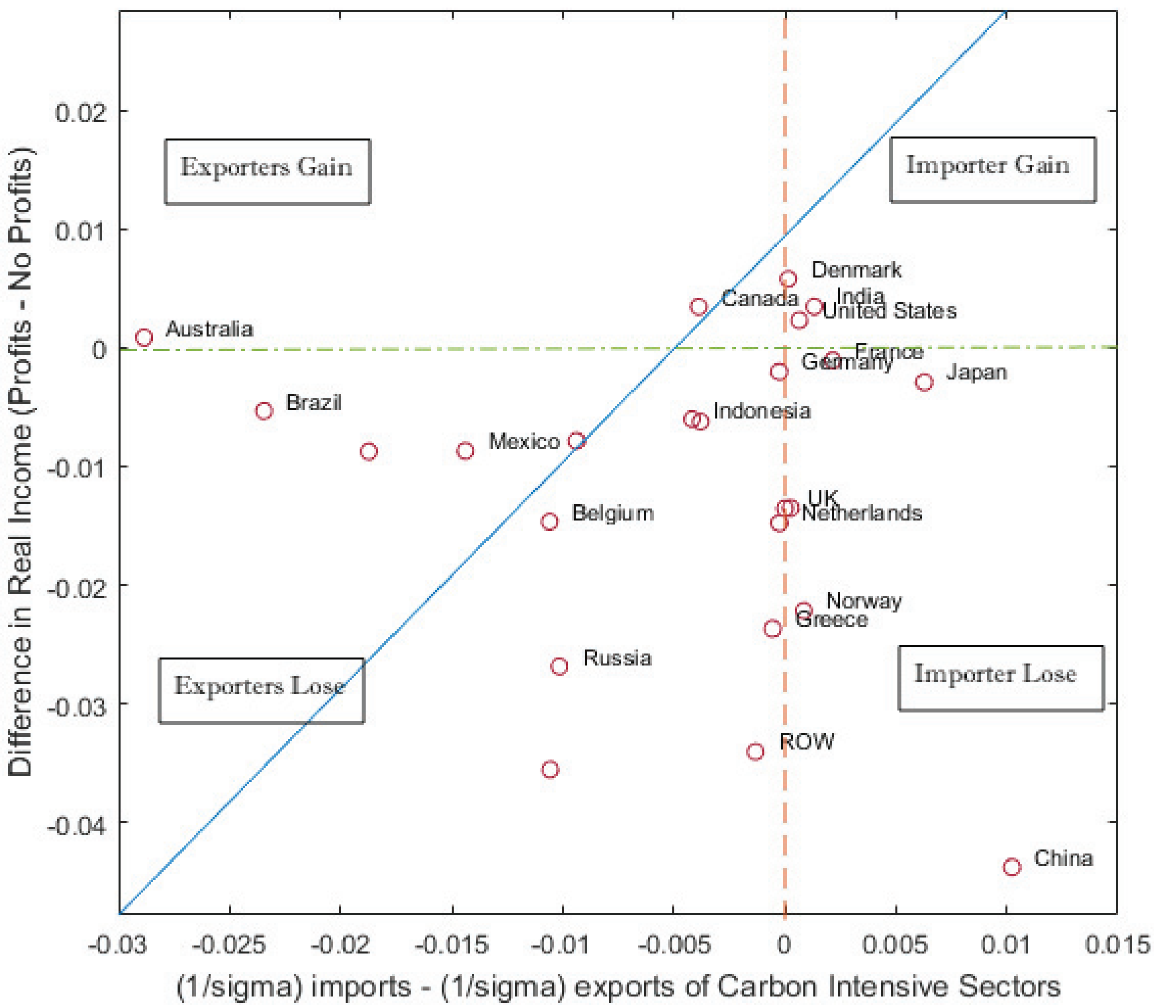
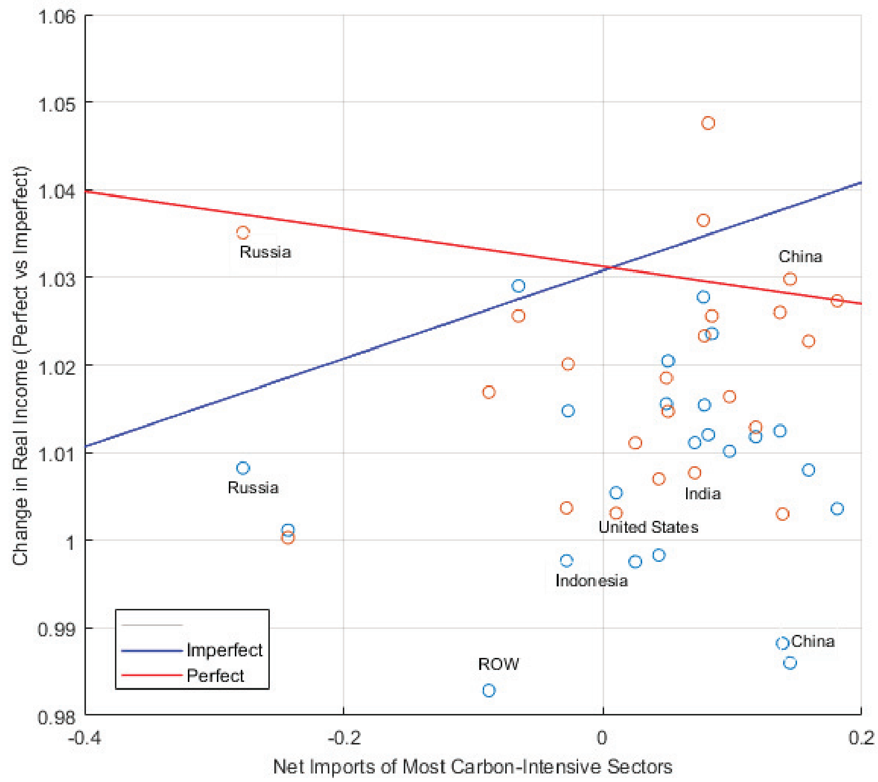


Figure 12: Differences in Real Income: Perfect vs Imperfect



The figure highlights that the welfare changes are relatively lower for net importers of carbon-intensive goods. When we account for markups, we see that the welfare impact is higher. The figure highlights that not accounting for markups underestimates the welfare effect of importers of carbon-intensive goods and overestimates the welfare effect of exporters of carbon-intensive goods.

6 Conclusion

This paper documents novel evidence that suggests a positive correlation between carbon-intensive sectors and market power. In light of this evidence, carbon-based tariffs result in sizable profit-shifting across countries. The paper develops a multi-industry, multi-country structural model of international trade with global input-output linkages. The model accounts for the profit-shifting across countries as tariffs are adjusted to accommodate its carbon content. There are three main takeaways from the paper. First, the findings suggest that accounting for profits increases the effectiveness of trade policy to reduce global emissions. Second, it may result in welfare losses for countries like China, Russia, Indonesia, etc., and may lead to higher welfare gains for many advanced economies, including the United States and Canada, and emerging economies like India. Third, not accounting for market power overestimates the welfare gains for net exporters and underestimates the welfare gains for net importers. The paper discusses the potential forces behind the heterogeneous effects across countries: production reallocation effect and carbon content in its net imports.

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APPENDIX

A Derivation of Equilibrium Conditions

A.1 Demand

A representative consumer in country j derives utility from consumption of s products, and derives disutility from total global pollution Z

$$U_j = \Pi_s Q_{js}^{\beta_{js}} f(Z) \tag{29}$$

where Q_{js} is the consumption aggregate given by CES aggregate $Q_{js} \equiv (\sum_i q_{ijs}^{\frac{\sigma_{js}-1}{\sigma_{js}}})^{\frac{\sigma_{js}}{\sigma_{js}-1}}$ where elasticity of substitution is allowed to vary by country-sector. β_{js} is the weight given to each sectors by the share of final consumption in country j.

Representative consumer chooses q_{ijs} to maximize Q_{js} subject to the budget constraint

$$\mathcal{L} = (\sum_i q_{ijs}^{\frac{\sigma_{js}-1}{\sigma_{js}}})^{\frac{\sigma_{js}}{\sigma_{js}-1}} + \lambda \Big[X_{js} - \sum_i p_{ijs} q_{ijs} \Big]$$

The solution to the above problem gives us

$$q_{ijs} = \frac{p_{ijs}^{-\sigma_{js}}}{\sum_i p_{ijs}^{1-\sigma_{js}}} X_{js}$$

Thus, the expenditure on goods from country i in country j is

$$X_{ijs} = p_{ijs} q_{ijs} = \underbrace{\frac{p_{ijs}^{1-\sigma_{js}}}{\sum_i p_{ijs}^{1-\sigma_{js}}}}_{L_{ijs}} X_{js}$$

Here, L_{ijs} is the market share of country i in country j. The aggregate price index of good s in country j is $P_{js} = \Big(\sum_i p_{ijs}^{1-\sigma_{js}} \Big)^{\frac{1}{1-\sigma_{js}}}$.

A.2 Firms

Given the demand equation, representative firm in an industry engages in monopolistic competition to choose quantity to maximize profits

$$\max_{q_{ijs}} \pi_{ijs} = p_{ijs}q_{ijs} - c_{ijs}q_{ijs}$$

Maximizing the above problem gives us

$$\frac{\partial \pi_{ijs}}{\partial q_{ijs}} = p_{ijs} + q_{ijs}\frac{\partial p_{ijs}}{\partial q_{ijs}} - c_{ijs} = 0$$

$$\implies p_{ijs}\Big[1 + \underbrace{\frac{q_{ijs}}{p_{ijs}}\frac{\partial p_{ijs}}{\partial q_{ijs}}}_{-1/\sigma_{js}}\Big] = c_{ijs}$$

From the demand equation,

$$\frac{q_{ijs}}{p_{ijs}}\frac{\partial p_{ijs}}{\partial q_{ijs}} = -1/\sigma_{js}$$

This gives us

$$p_{ijs} = \underbrace{\frac{\sigma_{js}}{\sigma_{js}-1}}_{\mu_{ijs}} c_{ijs}$$

Here, c_{ijs} is the marginal cost which includes the local cost of production $c_{is} = w_i^{1-\alpha_{is}}\Pi_k P_{ik}^{\alpha_{iks}}$ and the trade cost ϕ_{ijs} that includes tariff and non-tariff barriers.

Thus the firm in country i charges a Dixit-Stiglitz markup $\frac{\sigma_{js}}{\sigma_{js}-1}$ over their marginal cost of serving market j. Thus, the profits that the firm in country i earns by serving market j is

$$\pi_{ijs} = \frac{\sigma_{js}}{\sigma_{js}-1}c_{ijs}q_{ijs} - c_{ijs}q_{ijs} \implies \pi_{ijs} = \frac{1}{\sigma_{js}}X_{ijs} \equiv \frac{1}{\sigma_{js}}L_{ijs}X_{js}$$

B Estimation Procedure

I present step by step description on how to solve the model. We consider a change in policy from t to new policy t', which incorporates carbon-based tariff adjustments, which changes the marginal cost of serving from country i to country j, given by $\hat{\phi}_{ijs}$.

- Step 1: Start with a guess for the changes in the marginal costs for each country-sector $\hat{c}_{is} \equiv (\hat{c}_{11}, \hat{c}_{12}, ...\hat{c}_{1S}, \hat{c}_{21}, \hat{c}_{22}, ..., \hat{c}_{NS})$ and changes in wages $\hat{w}_i \equiv (\hat{w}_1, \hat{w}_2, ...\hat{w}_N)$

- Step 2: For the given trade policy shock (carbon-based tariffs), $p\hat{h}i_{ijs}$ and our guess for $\hat{c}_{is}$ and $\hat{w}_i$, and the market shares in the data λ_{ijs} we use the following equilibrium conditions to calculate $\hat{P}_{js}$ and $\hat{c}_{is}$

$$\hat{P}_{js} = \left[\sum_i \lambda_{ijs} (\hat{c}_{is} \hat{\phi}_{ijs})^{1-\sigma_{js}} \right]^{\frac{1}{1-\sigma_{js}}} \tag{30}$$

$$\hat{c}_{is} = \hat{w}_i^{1-\alpha_{is}} \Pi_k \hat{P}_{ik}^{\alpha_{iks}} \tag{31}$$

$$\hat{\lambda}_{ijs} = \left(\frac{\hat{c}_{is} \hat{\phi}_{ijs}}{\hat{P}_{js}} \right)^{1-\sigma_{js}} \tag{32}$$

- Step 3: Given the changes in market shares $\hat{\lambda}_{ijs}$, sigma elasticicities σ_{is} and share of intermediates α_{jsk}, we solve for counterfactual changes in the expenditure $X'_{js} = \hat{X}_{js} X_{js}$

$$\hat{X}_{js} X_{js} = \beta_{js} \Big[\hat{w}_j (w_j L_j) + \sum_s \sum_i \frac{1}{\sigma_{is}} \frac{\hat{\lambda}_{jis} \lambda_{jis} \hat{X}_{is} X_{is}}{1 + t'_{jis}} + \sum_s \sum_i \frac{t'_{ijs}}{1 + t'_{ijs}} \hat{\lambda}_{ijs} \lambda_{ijs} \hat{X}_{js} X_{js} + D'_j \Big] + \sum_k \alpha_{jsk} \sum_i \frac{\hat{\lambda}_{jik} \lambda_{jik} \hat{X}_{ik} X_{ik}}{(1 + t'_{ijk})} \tag{33}$$

The above equation is a system of $N \times S$ non-linear equations in $N \times S$ unknown counterfactual expenditures. If $\phi_{ijs} = \phi'_{ijs}$ then $D'_j = D_j$ and $\hat{w} = 1$ and $X'_{js} = X_{js}$. Re-writing the system of equations in matrix form:

$$\underset{NS \times NS}{\boldsymbol{\Omega}(\hat{\boldsymbol{w}}, \hat{\boldsymbol{c}})} \underset{NS \times 1}{X} = \underset{NS \times 1}{C(\hat{\boldsymbol{w}}, \hat{\boldsymbol{c}})}$$

Here $\mathbf{X}$ is a vector of expenditures for each sector and country and C is a vector of containing the share of labor income and aggregate trade deficits

$$\mathbf{X} = \begin{bmatrix} X'_{11} \\ \vdots \\ X'_{1S} \\ \vdots \\ \vdots \\ X'_{N1} \\ \vdots \\ X'_{NS} \end{bmatrix} \qquad C(\hat{\boldsymbol{w}}, \hat{\boldsymbol{c}}) = \begin{bmatrix} \beta_{11}(\hat{w}_1 w_1 L_1 + D_1) \\ \vdots \\ \beta_{1S}(\hat{w}_1 w_1 L_1 + D_1) \\ \vdots \\ \beta_{N1}(\hat{w}_N w_N L_N + D_N) \\ \vdots \\ \beta_{NS}(\hat{w}_N w_N L_N + D_N) \end{bmatrix}$$

The matrix $\boldsymbol{\Omega}(\hat{\boldsymbol{w}}, \hat{\boldsymbol{c}})$ captures the general equilibrium effects of how carbon-based tariff adjustments in one sector and country can impact the expenditures in all other countries and sectors. $\boldsymbol{\Omega}(\hat{\boldsymbol{w}}, \hat{\boldsymbol{c}})$ is constructed using five matrices: $\boldsymbol{\beta}$, $\boldsymbol{\Pi}$, $\boldsymbol{\zeta}$, $\boldsymbol{\Gamma}$ and $\boldsymbol{\kappa}$

The matrix $\boldsymbol{\beta}$ captures the share of final expenditure of each sector in a country and the matrix.

$$\boldsymbol{\beta} = \begin{bmatrix} \beta_{11} \\ \vdots \\ \beta_{1S} \\ \vdots \\ \vdots \\ \beta_{N1} \\ \vdots \\ \beta_{NS} \end{bmatrix}$$

$\boldsymbol{\Pi}$ captures the equilibrium effects of profits that a source sectors earns in a destination country, which is dependant on the expenditures in the destination country.

Here $\Lambda'_{ijs} = \frac{\lambda'_{ijs}}{t'_{ijs}}$

$$\underset{NS\times NS}{\mathbf{\Pi}} = \begin{bmatrix}
\frac{1}{\sigma_{11}}\Lambda'_{111} & \frac{1}{\sigma_{12}}\Lambda'_{112}\cdots\frac{1}{\sigma_{1S}}\Lambda'_{11S} & \frac{1}{\sigma_{21}}\Lambda'_{121}\cdots\frac{1}{\sigma_{2S}}\Lambda'_{12S}\cdots\cdots\frac{1}{\sigma_{N1}}\Lambda'_{1N1}\cdots\frac{1}{\sigma_{NS}}\Lambda'_{1NS} \\
\frac{1}{\sigma_{11}}\Lambda'_{111} & \frac{1}{\sigma_{12}}\Lambda'_{112}\cdots\frac{1}{\sigma_{1S}}\Lambda'_{11S} & \frac{1}{\sigma_{21}}\Lambda'_{121}\cdots\frac{1}{\sigma_{2S}}\Lambda'_{12S}\cdots\cdots\frac{1}{\sigma_{N1}}\Lambda'_{1N1}\cdots\frac{1}{\sigma_{NS}}\Lambda'_{1NS} \\
\vdots & \ddots & \vdots \\
\frac{1}{\sigma_{11}}\Lambda'_{111} & \frac{1}{\sigma_{12}}\Lambda'_{112}\cdots\frac{1}{\sigma_{1S}}\Lambda'_{11S} & \frac{1}{\sigma_{21}}\Lambda'_{121}\cdots\frac{1}{\sigma_{2S}}\Lambda'_{12S}\cdots\cdots\frac{1}{\sigma_{N1}}\Lambda'_{1N1}\cdots\frac{1}{\sigma_{NS}}\Lambda'_{1NS} \\
\frac{1}{\sigma_{11}}\Lambda'_{211} & \frac{1}{\sigma_{12}}\Lambda'_{212}\cdots\frac{1}{\sigma_{1S}}\Lambda'_{21S} & \frac{1}{\sigma_{21}}\Lambda'_{221}\cdots\frac{1}{\sigma_{2S}}\Lambda'_{22S}\cdots\cdots\frac{1}{\sigma_{N1}}\Lambda'_{2N1}\cdots\frac{1}{\sigma_{NS}}\Lambda'_{2NS} \\
\frac{1}{\sigma_{11}}\Lambda'_{211} & \frac{1}{\sigma_{12}}\Lambda'_{212}\cdots\frac{1}{\sigma_{1S}}\Lambda'_{21S} & \frac{1}{\sigma_{21}}\Lambda'_{221}\cdots\frac{1}{\sigma_{2S}}\Lambda'_{22S}\cdots\cdots\frac{1}{\sigma_{N1}}\Lambda'_{2N1}\cdots\frac{1}{\sigma_{NS}}\Lambda'_{2NS} \\
\vdots & \ddots & \vdots \\
\frac{1}{\sigma_{11}}\Lambda'_{211} & \frac{1}{\sigma_{12}}\Lambda'_{212}\cdots\frac{1}{\sigma_{1S}}\Lambda'_{21S} & \frac{1}{\sigma_{21}}\Lambda'_{221}\cdots\frac{1}{\sigma_{2S}}\Lambda'_{22S}\cdots\cdots\frac{1}{\sigma_{N1}}\Lambda'_{2N1}\cdots\frac{1}{\sigma_{NS}}\Lambda'_{2NS} \\
\vdots & \ddots & \vdots \\
\vdots & \ddots & \vdots \\
\vdots & \ddots & \vdots \\
\frac{1}{\sigma_{11}}\Lambda'_{N11} & \frac{1}{\sigma_{12}}\Lambda'_{N12}\cdots\frac{1}{\sigma_{1S}}\Lambda'_{N1S} & \frac{1}{\sigma_{21}}\Lambda'_{N21}\cdots\frac{1}{\sigma_{2S}}\Lambda'_{N2S}\cdots\cdots\frac{1}{\sigma_{N1}}\Lambda'_{NN1}\cdots\frac{1}{\sigma_{NS}}\Lambda'_{NNS} \\
\frac{1}{\sigma_{11}}\Lambda'_{N11} & \frac{1}{\sigma_{12}}\Lambda'_{N12}\cdots\frac{1}{\sigma_{1S}}\Lambda'_{N1S} & \frac{1}{\sigma_{21}}\Lambda'_{N21}\cdots\frac{1}{\sigma_{2S}}\Lambda'_{N2S}\cdots\cdots\frac{1}{\sigma_{N1}}\Lambda'_{NN1}\cdots\frac{1}{\sigma_{NS}}\Lambda'_{NNS} \\
\vdots & \ddots & \vdots \\
\frac{1}{\sigma_{11}}\Lambda'_{N11} & \frac{1}{\sigma_{12}}\Lambda'_{N12}\cdots\frac{1}{\sigma_{1S}}\Lambda'_{N1S} & \frac{1}{\sigma_{21}}\Lambda'_{N21}\cdots\frac{1}{\sigma_{2S}}\Lambda'_{N2S}\cdots\cdots\frac{1}{\sigma_{N1}}\Lambda'_{NN1}\cdots\frac{1}{\sigma_{NS}}\Lambda'_{NNS}
\end{bmatrix}$$

The matrix ζ captures the aggregate tariff revenues. Here $\Psi_{js} = \sum_i \frac{t_{ijs}}{1+t_{ijs}}\lambda_{ijs}$

$$
\underset{NS\times NS}{\boldsymbol{\zeta}} = \begin{bmatrix}
\begin{bmatrix} \Psi_{11} & \Psi_{12}\ldots\Psi_{1S} \\ \vdots & \vdots \\ \Psi_{11} & \Psi_{12}\ldots\Psi_{1S} \end{bmatrix} & \mathbf{0} & \mathbf{0} & \ldots & \mathbf{0} \\
\mathbf{0} & \begin{bmatrix} \Psi_{21} & \Psi_{22}\ldots\Psi_{2S} \\ \vdots & \vdots \\ \Psi_{21} & \Psi_{22}\ldots\Psi_{2S} \end{bmatrix} & \mathbf{0} & \ldots & \mathbf{0} \\
\mathbf{0} & \mathbf{0} & \begin{bmatrix} \ddots \end{bmatrix} & \ldots & \mathbf{0} \\
\vdots & \vdots & \ddots & \ddots & \vdots \\
\vdots & \vdots & \ddots & \ddots & \vdots \\
\mathbf{0} & \mathbf{0} & \mathbf{0} & \ldots & \begin{bmatrix} \Psi_{N1} & \Psi_{N2}\ldots\Psi_{NS} \\ \vdots & \vdots \\ \Psi_{N1} & \Psi_{N2}\ldots\Psi_{NS} \end{bmatrix}
\end{bmatrix}
$$

The matrix $\mathbf{\Gamma}$ captures the share of intermediates α_{jsk}, i.e, the share of good s used in the production of good k in country j.

$$
\underset{NS\times NS}{\mathbf{\Gamma}} = \begin{bmatrix}
\alpha_{111} & \alpha_{112} & \ldots & \alpha_{11S} & \alpha_{111} & \alpha_{112} & \ldots & \alpha_{11S} & \ldots & \ldots & \alpha_{111} & \alpha_{112} & \ldots & \alpha_{11S} \\
\alpha_{121} & \alpha_{122} & \ldots & \alpha_{12S} & \alpha_{121} & \alpha_{122} & \ldots & \alpha_{12S} & \ldots & \ldots & \alpha_{121} & \alpha_{122} & \ldots & \alpha_{12S} \\
\vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots & \\
\alpha_{1S1} & \alpha_{1S2} & \ldots & \alpha_{1SS} & \alpha_{1S1} & \alpha_{1S2} & \ldots & \alpha_{1SS} & \ldots & \ldots & \alpha_{1S1} & \alpha_{1S2} & \ldots & \alpha_{1SS} \\
\alpha_{211} & \alpha_{212} & \ldots & \alpha_{21S} & \alpha_{211} & \alpha_{212} & \ldots & \alpha_{21S} & \ldots & \ldots & \alpha_{211} & \alpha_{212} & \ldots & \alpha_{21S} \\
\alpha_{221} & \alpha_{222} & \ldots & \alpha_{22S} & \alpha_{221} & \alpha_{222} & \ldots & \alpha_{22S} & \ldots & \ldots & \alpha_{221} & \alpha_{222} & \ldots & \alpha_{22S} \\
\vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots & \\
\alpha_{2S1} & \alpha_{2S2} & \ldots & \alpha_{2SS} & \alpha_{2S1} & \alpha_{2S2} & \ldots & \alpha_{2SS} & \ldots & \ldots & \alpha_{2S1} & \alpha_{2S2} & \ldots & \alpha_{2SS} \\
\vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots & \\
\vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots & \\
\alpha_{N11} & \alpha_{N12} & \ldots & \alpha_{N1S} & \alpha_{N11} & \alpha_{N12} & \ldots & \alpha_{N1S} & \ldots & \ldots & \alpha_{N11} & \alpha_{N12} & \ldots & \alpha_{N1S} \\
\alpha_{N21} & \alpha_{N22} & \ldots & \alpha_{N2S} & \alpha_{N21} & \alpha_{N22} & \ldots & \alpha_{N2S} & \ldots & \ldots & \alpha_{N21} & \alpha_{N22} & \ldots & \alpha_{N2S} \\
\vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots & \\
\alpha_{NS1} & \alpha_{NS2} & \ldots & \alpha_{NSS} & \alpha_{NS1} & \alpha_{NS2} & \ldots & \alpha_{NSS} & \ldots & \ldots & \alpha_{NS1} & \alpha_{NS2} & \ldots & \alpha_{NSS}
\end{bmatrix}
$$

$\boldsymbol{\kappa}$ captures the market share of country i in country j in a sector s

$$\underset{NS\times NS}{\boldsymbol{\kappa}} = \begin{bmatrix} \lambda^{'}_{111} & \lambda^{'}_{112}\dots\lambda^{'}_{11S} & \lambda^{'}_{121}\dots\lambda^{'}_{12S}\dots\dots\lambda^{'}_{1N1}\dots\lambda^{'}_{1NS} \\ \lambda^{'}_{111} & \lambda^{'}_{112}\dots\lambda^{'}_{11S} & \lambda^{'}_{121}\dots\lambda^{'}_{12S}\dots\dots\lambda^{'}_{1N1}\dots\lambda^{'}_{1NS} \\ \vdots & \ddots & \vdots \\ \lambda^{'}_{111} & \lambda^{'}_{112}\dots\lambda^{'}_{11S} & \lambda^{'}_{121}\dots\lambda^{'}_{12S}\dots\dots\lambda^{'}_{1N1}\dots\lambda^{'}_{1NS} \\ \lambda^{'}_{211} & \lambda^{'}_{212}\dots\lambda^{'}_{21S} & \lambda^{'}_{221}\dots\lambda^{'}_{22S}\dots\dots\lambda^{'}_{2N1}\dots\lambda^{'}_{2NS} \\ \lambda^{'}_{211} & \lambda^{'}_{212}\dots\lambda^{'}_{21S} & \lambda^{'}_{221}\dots\lambda^{'}_{22S}\dots\dots\lambda^{'}_{2N1}\dots\lambda^{'}_{2NS} \\ \vdots & \ddots & \vdots \\ \lambda^{'}_{211} & \lambda^{'}_{212}\dots\lambda^{'}_{21S} & \lambda^{'}_{221}\dots\lambda^{'}_{22S}\dots\dots\lambda^{'}_{2N1}\dots\lambda^{'}_{2NS} \\ \vdots & \ddots & \vdots \\ \vdots & \ddots & \vdots \\ \vdots & \ddots & \vdots \\ \lambda^{'}_{N11} & \lambda^{'}_{N12}\dots\lambda^{'}_{N1S} & \lambda^{'}_{N21}\dots\lambda^{'}_{N2S}\dots\dots\lambda^{'}_{NN1}\dots\lambda^{'}_{NNS} \\ \lambda^{'}_{N11} & \lambda^{'}_{N12}\dots\lambda^{'}_{N1S} & \lambda^{'}_{N21}\dots\lambda^{'}_{N2S}\dots\dots\lambda^{'}_{NN1}\dots\lambda^{'}_{NNS} \\ \vdots & \ddots & \vdots \\ \lambda^{'}_{N11} & \lambda^{'}_{N12}\dots\lambda^{'}_{N1S} & \lambda^{'}_{N21}\dots\lambda^{'}_{N2S}\dots\dots\lambda^{'}_{NN1}\dots\lambda^{'}_{NNS} \end{bmatrix}$$

The solutions for counterfactual expenditures is given by

$$\underset{NS\times NS}{\boldsymbol{X}} = \underbrace{\Big[\underset{NS\times NS}{\boldsymbol{I}} - \Big(\boldsymbol{\beta}\cdot(\boldsymbol{\Pi}+\boldsymbol{\zeta}) + \boldsymbol{\Gamma}\cdot\boldsymbol{\kappa}\Big)\Big]^{-1}}_{\Omega(\hat{\boldsymbol{w}})} \cdot \boldsymbol{C}(\hat{\boldsymbol{w}})$$

- Step 4: After solving for the counterfactual expenditures $\boldsymbol{X}(\hat{\boldsymbol{w}}$, substitute the solution with $\hat{\boldsymbol{\lambda}}_{\boldsymbol{ijs}}$ such that the labor market clears in the aggregate and the deficits remain the same in the counterfactual

$$\hat{w}_j w_j L_j = \sum_s \sum_i \frac{\sigma_{is}-1}{\sigma_{is}} \frac{\hat{\lambda}_{jis}\lambda_{jis}\hat{X}_{is}X_{is}}{1+t^{'}_{jis}} - \sum_s \sum_k \alpha_{jks} \sum_i \hat{\lambda}_{ijk}\lambda_{ijk}X_{jk}\hat{X}_{jk} \tag{34}$$

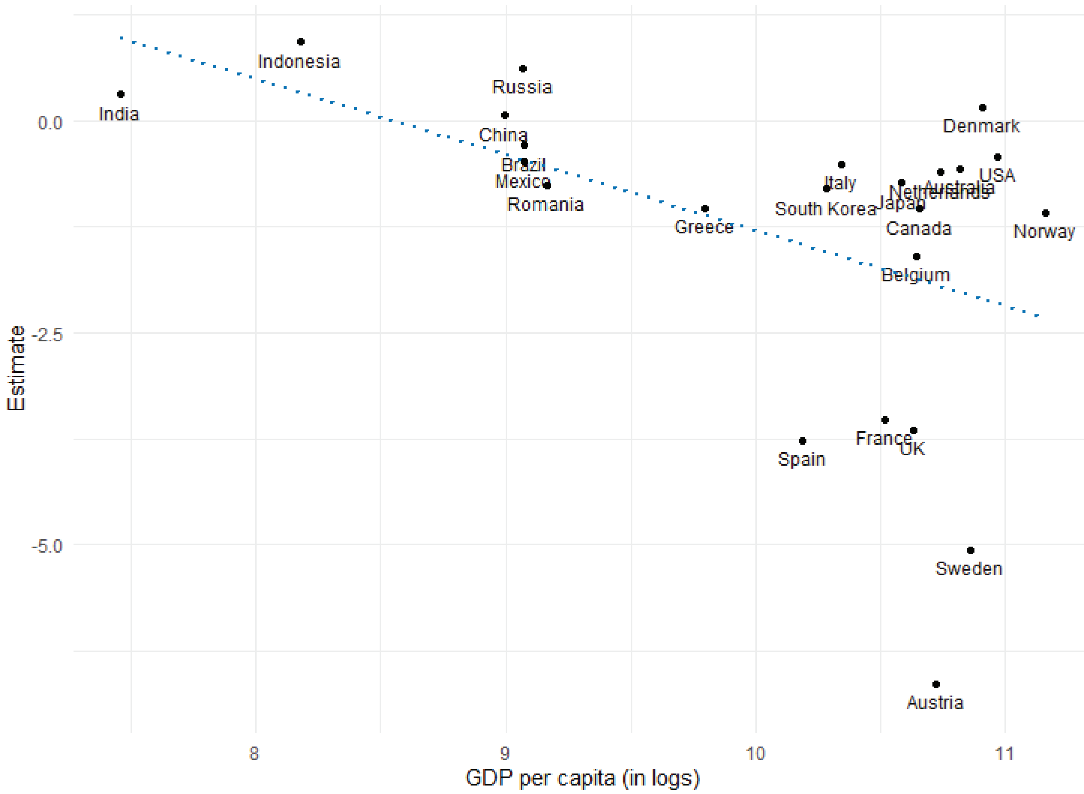
- Step 5: If the above equation does not hold true, we update our guess of $\hat{\boldsymbol{w}}$ until the equilibrium conditions are satisfied.

C Discussion

The exact mechanism that explains these results is not straightforward, as it is hard to assess the extent to which specific endogenous changes in the model influence the aggregate results. I aim to illustrate some essential country characteristics that justify the distributional impact across countries.

Environmental bias of trade policy: Tariff barriers are lower in carbon-intensive sectors for most countries, which is referred to as the environmental bias of trade policy (Shapiro (2021)). However, the extent of this bias differs across countries. The counterfactual tariff adjustments are highest for the countries with the most bias. The country with the lowest trade barrier on carbon-intensive goods experiences the highest increase in import tariffs. This may be welfare-reducing as importing upstream goods become expensive, spilling over to aggregate prices. If there is a significant reallocation of the high-markup carbon-intensive industries, a higher environmental bias might enhance welfare. Contrastingly, trade policy reform lowers tariffs on cleaner industries benefiting the countries with comparative advantage in cleaner sectors. Figure 13 reports the coefficient when a country's weighted mean import tariff is regressed against the carbon embodied in its imports, weighted by the import value. A negative coefficient implies that, on average, sectors with high carbon-embodied in imports have a lower import tariff. Richer countries, on average, have a higher environmental bias. This corroborates that richer economies import upstream carbon-intensive goods from middle-income developing countries, hence imposing a lower import tariff.

Figure 13: Coefficient of environmental bias



The figure reports the coefficient when the weighted mean import tariff of a country is regressed against the weighted carbon-embodied in its imports, weighted by the import value. A negative coefficient implies that on average, sectors with high carbon-embodied in imports have a lower import tariff

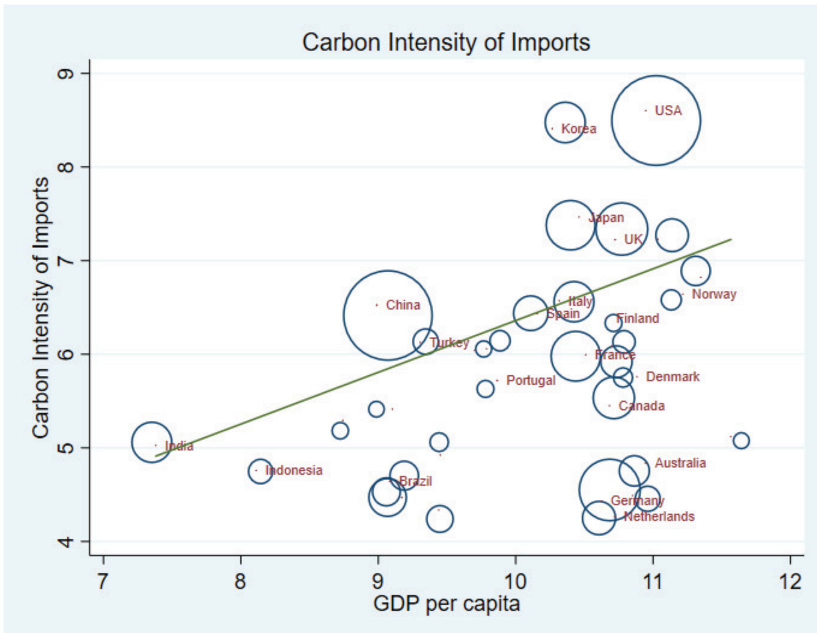
Carbon-Intensity of Trade: The magnitude of the welfare effects of a country in response to the carbon-based tariff adjustments depends on the carbon intensity of its imports vis-a-vis its exports. I define the carbon intensity of imports, ζ_j^{imp} as the total carbon embodied in the imports of a particular country, j

$$\zeta_j^{imp} = \sum_s \theta_{js}^{imp} \sum_{i \neq j} \lambda_{ijs} E_{is} \tag{35}$$

Here, E_{is} is the carbon intensity of producing sector s in country i. The emission intensity is weighted by the market share of country i in country j, given by λ_{ijs}. Each sector s is weighted by their import share in country j, θ_{js}.

Figure 14 plots the carbon intensity of imports of each country with respect to its GDP per capita. Each country is weighted by the size of its total imports relative to global imports. The plot reflects that, on average, the developed countries have a much higher carbon content in their imports than developing countries. This relationship is particularly striking for rich countries like USA, Norway, and Japan and for developing and emerging market economies like Indonesia, China, and Brazil.

Figure 14: Carbon Intensity of Imports



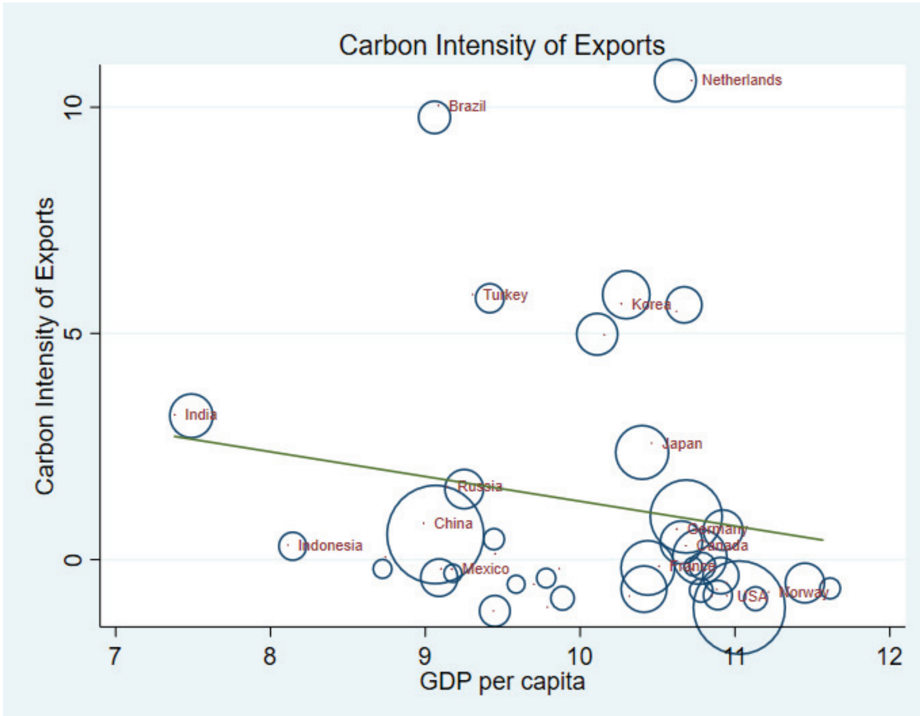
The figure plots the carbon-intensity of imports (in logs) with respect to its GDP per capita (in logs). The circle size represents the share of country's imports in global imports. The fitted line reflects the positive association between the carbon-intensity of imports and GDP per capita, weighted by the country's total imports in global imports

An opposite relationship is observed when we measure the carbon-intensity of exports against the country's GDP per capita. I define the carbon-intensity of exports ζ_j^{exp} as the total carbon-embodied in the exports of a particular country, j

$$\zeta_j^{exp} = \sum_s \kappa_{js} E_{js} \tag{36}$$

Here, κ_{js} is the share of sector s exports in country j's total exports. Figure 15 plots the carbon-intensity of exports of each country relative to its GDP per capita. Each country is weighted by the relative size of its total exports in global exports. We find that, on average, the developing countries export carbon-intensive goods, relative to the developed country.

Figure 15: Carbon Intensity of Exports



Carbon Intensity of Exports. The figure plots the carbon-intensity of exports (in logs) with respect to its GDP per capita (in logs). The circle size represents the share of country's exports in global imports. The fitted line reflects the negative association between the carbon-intensity of exports and GDP per capita, weighted by the country's total exports in global export value.

D Additional Counterfactuals

To ascertain the quantitative importance of the heterogeneity in market power across industries, Table 7 and Table 8 report a counterfactual where σ is the mean value across industries (equal for all industries, $\sigma = 4.75$). The counterfactual eliminates the difference in market power across industries. In the case of perfect competition, global emissions reduce by less than 1%, while all countries still gain real income due to tariff changes. In the case of imperfect competition, emissions increase by almost 6%. We observe that the exporters of carbon-intensive goods do not experience as high loss in real income. Carbon-intensive sectors have higher market power, exacerbating the production reallocation to countries and industries with lower emission intensity. Eliminating the market power shows that carbon-based tariff adjustments are counter-productive and create almost no effect or an increase in global emissions (under different market assumptions). The results highlight the importance of heterogeneity in market power for the policy reform to be effective in reducing emissions.

Table 7: Results: Perfect Competition, sigma = 4.75

	Welfare	Emissions	Wages	Tariff Rev.	Prices
Global Total	1.0240	0.9910	1.0228	1.0624	0.9782
Australia	1.0056	1.0073	1.0055	1.0121	1.0151
Austria	1.0258	1.1113	1.0283	0.9938	0.9750
Belgium	1.0209	1.0900	1.0241	0.9902	0.9585
Brazil	1.0049	1.0564	1.0045	1.0271	0.9809
Canada	1.0374	1.0242	1.0373	1.0437	0.9742
China	1.0316	1.0428	1.0232	1.1649	1.0024
Denmark	1.0188	1.1015	1.0233	0.9585	0.9693
France	1.0177	1.1588	1.0209	0.9809	0.9843
Germany	1.0291	1.1545	1.0317	0.9968	0.9696
Greece	1.0254	1.0351	1.0281	1.0042	0.9446
India	1.0273	1.1164	1.0179	1.3783	1.0095
Indonesia	1.0064	1.0190	1.0061	1.0292	1.0038
Italy	1.0250	1.1213	1.0282	0.9967	0.9604
Japan	1.0178	1.0412	1.0171	1.0936	1.0002
Mexico	1.0080	0.9924	1.0071	1.0550	1.0050
Netherlands	1.0007	0.9733	1.0021	0.9766	0.9945
Norway	1.1640	1.0388	1.1652	1.1511	0.8783
Romania	1.0407	1.1177	1.0427	1.0278	0.9242
Russia	1.0437	0.8751	1.0420	1.1901	1.0264
Spain	1.0185	1.0958	1.0220	0.9780	0.9747
Sweden	1.0443	1.0644	1.0492	0.9944	0.9635
United Kingdom	1.0228	1.0972	1.0217	1.0433	0.9813
United States	1.0038	1.0200	1.0038	1.0123	1.0028
ROW	1.0230	0.8168	1.0284	0.9677	0.9538

Notes: This table reports the $\hat{x} = x^{'}/x$ for the counterfactual changes in tariffs in a perfectly competitive markets. The aggregate real income is decomposed using Equation 26 in terms of real wages and real tariff revenues. Profits are not accounted here. The global values for economic variables are calculated by weighing each country by its relative GDP. The change in emissions, $\hat{Z} = \sum_i Z_i'/\sum_i Z_i$

Table 8: Results: Imperfect Competition, sigma = 4.75

	Welfare	Emissions	Wages	Profits	Tariff Rev.	Prices
Global Total	1.0715	1.0604	1.0248	1.0747	1.0912	0.9415
Australia	0.9938	1.0126	1.0125	0.9642	1.0139	0.9835
Austria	1.0216	1.1218	1.0277	1.0179	0.9958	0.9432
Belgium	1.0260	1.1071	1.0234	1.0341	0.9985	0.9265
Brazil	1.0042	1.0582	1.0050	1.0017	1.0321	0.9428
Canada	1.0288	1.0135	1.0429	1.0050	1.0418	0.9380
China	1.0891	1.1050	1.0275	1.0741	1.3326	0.9577
Denmark	1.0177	1.1116	1.0229	1.0207	0.9605	0.9375
France	1.0118	1.1600	1.0237	0.9985	0.9888	0.9532
Germany	1.0276	1.1677	1.0311	1.0285	0.9981	0.9380
Greece	1.0111	1.0220	1.0325	0.9816	1.0110	0.9171
India	1.0788	1.1673	1.0173	1.1456	1.4195	0.9698
Indonesia	0.9931	1.0263	1.0068	0.9690	1.0065	0.9704
Italy	1.0276	1.1343	1.0285	1.0322	1.0053	0.9298
Japan	1.0301	1.0745	1.0171	1.0400	1.1116	0.9614
Mexico	1.0185	1.0168	1.0127	1.0199	1.1279	0.9658
Netherlands	0.9870	0.9689	1.0062	0.9608	0.9760	0.9626
Norway	1.1558	1.0402	1.1705	1.1400	1.1314	0.8470
Romania	1.0277	1.1105	1.0432	1.0093	1.0234	0.8960
Russia	1.0388	0.8895	1.0443	1.0222	1.1708	0.9914
Spain	1.0142	1.1008	1.0240	1.0071	0.9845	0.9438
Sweden	1.0447	1.0775	1.0480	1.0510	0.9980	0.9313
United Kingdom	1.0245	1.1239	1.0238	1.0226	1.0500	0.9470
United States	1.0112	1.0351	1.0045	1.0198	1.0181	0.9653
ROW	1.0063	0.8212	1.0370	0.9734	0.9350	0.9210

Notes: This table reports the $\hat{x} = x'/x$ for the counterfactual changes in tariffs in a monopolistically competitive markets. Welfare, wages and tariffs are in real terms. The global values for economic variables are calculated by weighing each country by its relative GDP. The change in emissions, $Z = \sum_i \hat{Z}'_i / \sum_i Z_i$