Trade, Taxation, and the Environment: Evaluating the Economic Impact on Households

Matthew Murillo

Abstract

This paper shows that the environmental bias in trade policy not only extends to domestic tax policy but also imposes a greater burden on consumers. In estimating the revenues collected per ton of CO_2 emissions, taxes on final good consumption overwhelmingly exceed tariffs, taxes on production, and taxes on intermediate good consumption. In light of these findings, I derive a welfare decomposition from existing general equilibrium trade models to assess the impact from changes to domestic tax policy. Specifically, I evaluate the implications of addressing the disparities between producer and consumer taxes. My findings reveal that the current tax structure in the United States is suboptimal, and households would gain by increasing production taxes while simultaneously reducing consumption taxes on specific dirty sectors like petroleum. Moreover, the analysis of each counterfactual reveals a consistent pattern: increases in real income are accompanied by reductions in global emissions. Notably, when U.S. policy is constrained not to make the rest of the world worse off, it successfully prevents carbon leakage. These findings open the door for further research on the interplay between domestic and international carbon tax policy.[1]

1 Introduction

Recent evidence has revealed an environmental bias in trade policy (Shapiro [2020]). The tariff rates on goods with higher emissions intensities tend to be lower relative to cleaner goods. This tariff rate difference implies an implicit global subsidy on the import of carbon emissions. In this paper, I evaluate the extent of environmental bias in domestic tax policy. Using a sample of 141 countries and 65 sectors, I analyze the relationship between the carbon intensity and the tax rates associated with imported goods, intermediate goods consumption, production, and final goods consumption across different industries and regions.

My goal for the econometric section is twofold: (1) determine whether environmental bias in trade policy is present using tariffs from WITS and input-output data from GTAP 10, and (2) extend this analysis to domestic policy using local tax data from GTAP 10. The degree of regressivity or progressivity of domestic and international trade policies is sensitive to the industry, region, and tax channel analyzed. I consider four industry groups: manufacturing, agriculture, services, and a general category encompassing all industries. For each industry group, I consider three regions: OECD, non-OECD, and global. For each instrument, I run OLS regressions of the associated tax rate on the tons of CO_2 emitted per dollar of consumption or production. One can interpret the OLS estimates as the implicit carbon tax rate for each region in each industry.

---

[1] I would like to thank Lorenzo Caliendo for his guidance and support throughout this process. I would also like to thank Costas Arkolakis, Sam Kortum, and Michael Peters for their feedback. The most updated version containing all tables, figures, and derivations can be found online here: https://mattmurillo.me/Research.html

I find that the WITS and GTAP 10 data do indeed corroborate the existence of environmental bias for import tariffs. However, the magnitude and significance of the results vary by region and industry. The OLS estimates were negative in every case, implying an implicit subsidy on carbon-intensive goods. The relationship between lower tariffs and higher carbon intensities was most robust among OECD countries in both the manufacturing and the agricultural sectors. I estimate an implicit subsidy of \$34 per ton of CO_2 imported. My findings align closely with those of Shapiro, who uses a sample of 50 countries mostly comprised of OECD members. The OLS estimates for non-OECD countries were not significant, and neither was the pooled regression estimating the global subsidy by industry.

For the second focus of my econometric analysis, I study whether environmental bias extends to domestic tax policy. For the same set of countries and sectors, I use GTAP 10's input-output data and their data on effective taxes paid to construct measurements on the tons of CO_2 emitted per dollar produced/consumed. Taxes on production tend to be lower on more carbon-intensive goods than cleaner goods. Similar to tariffs, the significance and magnitude of these results vary by region and industry. The relationship is strongest in the services sectors, where the implicit global carbon subsidy for producers is \$3.30 per ton of CO_2 produced. The estimates are not significant for manufacturing and agriculture, although they are negative in most settings. A country-level breakdown of this analysis shows that substantial heterogeneity exists in domestic tax policy within OECD and non-OECD countries. This situation contrasts sharply with the taxes paid by households. Taxes to households are very progressive, with much higher taxes on more carbon-intensive goods. This relationship holds in nearly every case. The global implicit carbon tax consumers face in manufacturing is statistically significant and equals \$48 per ton of CO_2 consumed. This estimate is interesting because the social cost of carbon is cited to be around \$40 per ton of CO_2 consumed – suggesting that consumers are paying too much for the cost of carbon. To the best of my knowledge, this is the first study that documents the existence of environmental bias in domestic tax policy in production and an existing asymmetry of implicit carbon tax policy between consumers and producers. Finally, the estimates of environmental bias from intermediate good consumption at aggregated levels are ambiguous, showing an insignificant relationship across every dimension. Similar to production taxes, the variation in environmental bias within regions becomes apparent when analyzing the degree of environmental bias at the country level.

These findings prompt important policy-relevant questions addressing climate change within a global framework. In this paper, I derive a numerical method to study the effects of changes to tax policy from five different channels: imports, production, intermediate goods consumption, final goods consumption, and labor. Using exact-hat algebra, one can implement my numerical method to solve for optimal tax structures under several different constraints. Specifically, I derive a linearized welfare decomposition of Caliendo, Dolabella, Moreira, Murillo, and Parro (CDMMP 2023) to provide a framework for addressing optimal climate policy within the context of international trade. The model is multi-country, multi-sector, with input-output linkages, and multiple factors of production – labor and natural resources. It also captures the heterogeneity of carbon intensities across all countries and sectors, allowing for a granular examination of how policy changes will affect changes in emissions by industry. There are two types of producers in this model: non-extractive and extractive. Extractive sectors such as coal, oil, and gas require natural resources to be processed and used as intermediate goods. The carbon intensities and demand of these extractive sectors are allowed to vary by country and sector. The combustion of fossil fuels from these extractive sectors contributes to global emissions. The model explicitly considers the entire structure of the world economy, providing a comprehensive framework through which one can analyze the effects of carbon policy. Due to the complexity of the problem, it is impossible to predict the effects that a single, let alone simultaneous, change to tax policy can have on emissions and real income. The benefit of the linearized decomposition is that it allows us to numerically solve for changes in the optimal tax and approximate each channel's overall contribution.

Turning to the quantitative results, I use the above methods to explore the national and global welfare implications of the disparity in domestic taxes faced by producers and consumers on carbon-intensive goods. I study the following question – for any given change in the production tax to petroleum, how should the United States adjust its consumption tax to maximize national welfare? My welfare analysis compares two scenarios. The first is how the USA should structure its tax policy given that they are only interested in maximizing domestic welfare. The second imposes an additional constraint where domestic changes in policy cannot make the rest of the world (ROW) worse off. I study 8 sectors: agriculture, coal, electricity, gas, manufacturing, oil, petroleum, and services. The United States tends to have progressive carbon taxes on producers and consumers, with a slightly higher tax faced by producers in most sectors. One notable exception is the petroleum sector, one of the primary sources of global emissions. On the other hand, the baseline taxes for ROW are substantially regressive for producers and progressive for consumers in all sectors. My goal is to provide an illustrative example of what would happen if policymakers in the United States were to reorganize the existing tax structures such that the gap between taxes paid by producers and consumers within the petroleum sector were reduced or even reversed.

I find that households are worse off when consumption taxes rise relative to production taxes, and the optimal tax structure occurs when the production tax exceeds the consumption tax. Not only would households be better off if the USA reduced consumption taxes, but demand would also shift away from carbon-intensive sectors, causing global emissions to fall. In the first counterfactual, the reduction in global emissions is driven primarily by significant reductions in CO_2 from within the USA. This makes sense given that the USA is the second largest source of CO_2 emissions globally, and petroleum is the sixth highest emitting sector. However, this shift in domestic tax policy on petroleum within the USA causes emissions from the ROW to increase slightly. This spill-over effect – known as carbon leakage – is one of the main challenges policymakers face when implementing effective carbon policy. It captures one of the fundamental problems of tackling a global problem in a globally connected economy. Changes to domestic policy may force producers to search for carbon-intensive inputs elsewhere, thus counteracting the intended policy goals. For example, domestic distortions could make less carbon-efficient producers abroad relatively cheaper, thus increasing global emissions. Interestingly, I find no evidence of carbon leakage when the USA's carbon policy is constrained. Policymakers are forced to act in such a way that shifts demand away from domestic and international carbon-intensive sectors.

This paper provides novel findings on existing tax structures and expands on the extensive body of research that assesses carbon policy effects through the lens of general equilibrium trade models. The econometric analysis builds upon the findings of Shapiro [2020], utilizing data from GTAP 10 and expanding his methodology to estimate the environmental bias across three additional tax channels: production, intermediates, and final consumption.

I also build on the burgeoning body of work that deals with environmental trade models. In particular CDMMP extends Caliendo and Parro [2015] and expands upon the work from Egger and Nigai [2015], Shapiro [2016], Shapiro [2020], and Larch and Wanner [2017] by allowing for multiple natural resource sectors with prices varying by country and sector, input-output linkages, taxes to intermediates, taxes to consumption, and taxes to labor use. Each of these papers studies the welfare effects from carbon policies by analyzing different counterfactual policies. I attempt to study this question through the lens of optimal carbon policy.

The classic problem of solving for the optimal tax policy given international externalities was posed by Markusen [1975]. Markusen develops a two country model with tariffs, production taxes, and consumption taxes to analyze how optimal tax structures vary under different conditions. Kortum and Weisbach [2021] expand upon this work by integrating Dornbusch et al. [1977] to solve for the optimal unilateral carbon policy where a country seeks to maximize their welfare by balancing the wedges on extraction, consumption, and exports. Following Kortum and Wiesbach, one of the counterfactuals I consider is for the USA to solve for the optimal tax structure such that welfare in the rest of the world is unchanged. I then compare this benchmark against what would happen if the USA were only concerned with maximizing home welfare, regardless of how domestic shocks affected terms of trade.

The rest of this paper is structured as follows: an econometric analysis estimating environmental bias, a summary of CDMMP, an introduction of the decomposition, and finally, an application of the decomposition to the counterfactuals outlined above. Please refer to the online appendix for more details on data constructions and derivations.

2 Estimating environmental bias

2.1 Data

I use two data sources for the econometric analysis: GTAP 10's environmentally extended multi-regional input-output table (MRIO), which reports expenditures on taxes, and tariffs from WITS TRAINS. All of the data used in the primary analysis covers the year 2014 and spans 121 countries, 20 aggregated regions, and 65 sectors. In this section, I will first describe how I constructed the tax rates using the MRIO, and then I will discuss how I used the MRIO along with the matrix of CO_2 emissions to construct the emissions intensities.

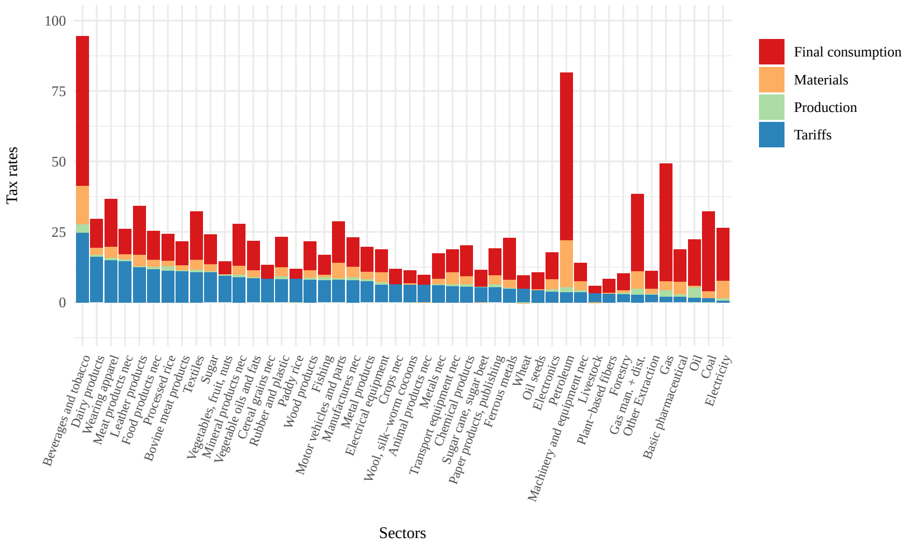
2.1.1 Taxes

An MRIO matrix captures the interactions between different economic sectors and regions. The columns of an MRIO are divided between sales to intermediate goods and sales to households. Reading across the columns can be interpreted as the sales from sector j in country n to each country and sector while reading down a column represents the total expenditures on each country and sector required to produce sector j in country n. The expenditure data also contains information on tax payments, allowing me to construct the effective tax rates for each country in each sector.

Producers pay ad valorem taxes on using materials from other sectors, on materials imported from other countries, on factor payments, and on the value of their production. GTAP only has data on the effective taxes paid, so the material tax that each sector pays for using sector j varies. To construct the uniform, domestic material tax I aggregated the total taxes paid for using sector j in country n divided by the total expenditures on sector j in country n. The taxes on production are constructed by dividing the total production taxes that sector j in country n pays by their total expenditures on production including payments to intermediates, factor use, and their corresponding tax payments. Factor taxes were constructed by dividing the total taxes paid on factors by the total expenditures on factors. Taxes to factors are not considered in the econometric exercise but will be discussed in the quantitative portion. I aggregated the tariffs up from importer × exporter × sectors tuples to importer × sector tuples to construct the average rate paid by producers to import sector j into country n. The second portion of the MRIO is concerned with final goods consumed by the household. We only consider the sales taxes households pay on final goods for this analysis. The effective tax rate on final goods is determined by dividing the tax payments by households to each sector by the total household expenditures in each sector.

Figure 1 shows the average global tax rates in each sector where tariffs are non-zero.

Figure 1: Average tax rate by sector



Source: GTAP MRIO

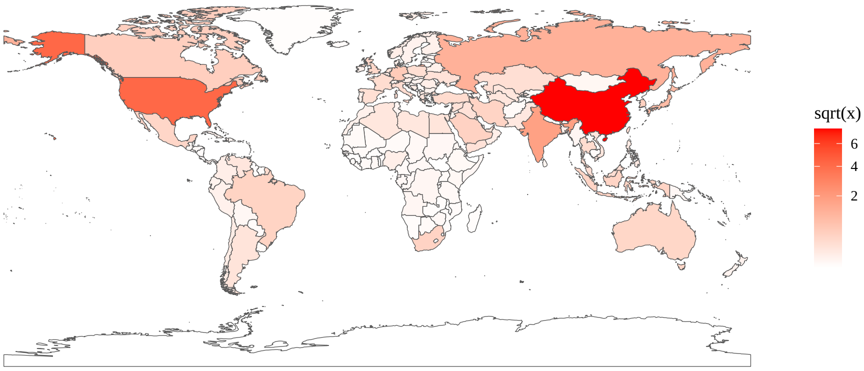
The figure shows that tariffs and production taxes tend to be consistently lower than taxes paid on materials and taxes paid by households. The top 5 highest global tax rates of 59%, 53%, 41%, 28%, and 27% are paid by households on petroleum, beverage and tobacco, gas, coal, and gas distribution, respectively. Final consumption taxes consistently rank among the highest effective tax rates, while taxes to producers via direct production, intermediate inputs, and tariffs tend to be much lower. The highest average tariff rate is on beverages and tobacco products at around 25%. This is followed by dairy production (16%), wearing apparel (14%), meat products (14%), and leather products (12%). In terms of embodied CO_2 emissions, these also tend to be cleaner sectors. Dairy and meat products have high methane emissions, but we are not considering all greenhouse gasses in this analysis, solely emissions directly due to CO_2. This is in strong contrast with the five average lowest tariffs, which are on gas (2%), basic pharmaceutical (1.8%), oil (1.7%), coal (1.6%), and electricity (0.73%). The top five tax rates on intermediate inputs go to petroleum (16%), beverages and tobacco (13%), electricity (6.2%), gas distribution (6%), and motor vehicles and parts (5.4%). Taxes on agricultural products such as wheat (-0.05%) and livestock (-0.28%) tend to be subsidized. Finally, the average global tax rate on production follows a similar pattern to taxes on materials. The top 5 sectors are oil (3.6%), beverage and tobacco (2.9%), gas (2.2%), gas distribution (2.2%), and petroleum (1.7%).

The evidence of environmental bias tends to be most apparent when observing data on tariffs. Average global taxes on production, materials, and consumption tend to be higher on dirtier sectors, suggesting a progressive tax on carbon goods. However, in the econometric section I show that when controlling for country fixed-effects, taxes faced by producers are regressive. This is particularly evident in the services sector. In this next section, I will discuss how I constructed the data on emissions intensities. This will give us information on tons of CO_2 emitted in each sector in each country per dollar spent.

2.1.2 Emissions

GTAP's environmentally extended input-output table captures the CO_2 emitted due to the combustion of fossil fuels in each sector. As in Shapiro [2020], I will refer to these emissions as the "direct" CO_2 emissions from production. Country-level emissions are quite heterogeneous, with a handful of countries contributing to large shares of the global CO_2 content. Figure 2 shows the total level of direct emissions in each country.

Figure 2: Direct emissions due to production



Source: GTAP MRIO

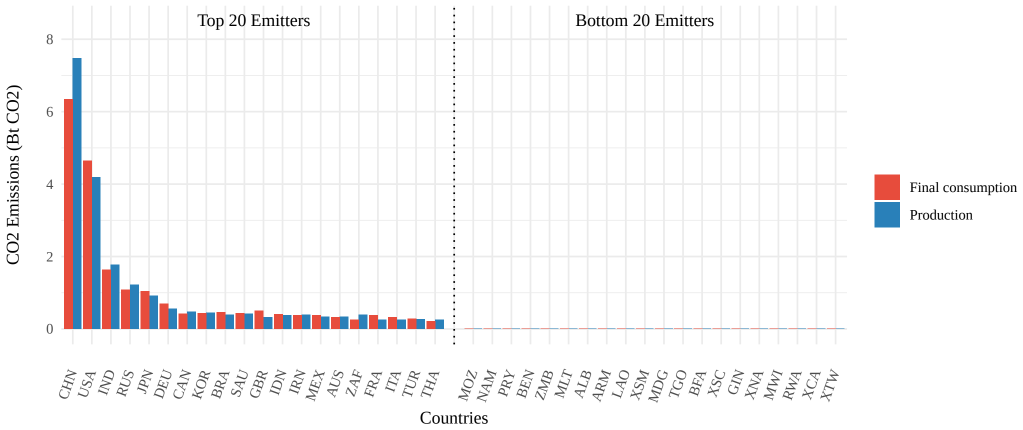
China and the United States are the most significant contributors to global CO_2, with other countries quickly falling behind. "Indirect" emissions are another important measure that captures a good's embodied carbon content. We will first construct the final matrix of embodied emissions which describes the level of direct and indirect emissions produced and consumed for final consumption. Then, we will go over how to use the emissions intensities to construct measures of embodied emissions per dollar imported, per dollar produced, per dollar consumed in materials, and per dollar consumed in final consumption.

Using the accounting identity that gross outputs equal the share of gross output used in intermediate goods production plus the share of gross output used for final demand production, we can say that, $\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{f}$ where $\mathbf{x}$ is an $N \times J$ vector of gross outputs, $\mathbf{A}$ is the $(N \times J) \times (N \times J)$ matrix of input-output coefficients and $\mathbf{f}$ is an $N \times J$ vector of final demand. We can rewrite our expression as $\mathbf{f} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{x}$. The term, $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ is the Leonteiff and each element, L_{in}^{kj} represents the dollar amount of gross production from sector k in country i required to produce one dollar of gross output in country n sector j.

Using GTAP's direct emissions, $E_n^{j,direct}$, along with gross output for each sector, we can construct a vector of emissions intensities where each element is defined as, $e_n^j = \frac{E_n^{j,direct}}{x_n^j}$. The value$e_n^j$ tells us the level of emissions for producing one dollar of gross output in country n sector j. Diagonalizing our vector of emissions intensities, $\tilde{\mathbf{e}} = \mathbf{e}\mathbf{I}$ and premultiplying this object with our Leonteiff matrix gives us, $\Xi = \tilde{\mathbf{e}}\mathbf{L}$, where each element, Ξ_{in}^{kj} tells us the total emissions – direct and indirect – from sector k in country i required to produce one dollar of gross output in country n sector j.

Finally, premultiplying this object by our matrix of final demand sectors, $\mathbf{F}$ gives us our $(N \times J) \times J$ matrix of total embodied emissions, E. Each element, E_{ni}^k is defined as the total level of direct and indirect emissions from sector k in country i consumed by country n. Thus, the summation, $\sum_{i,k} E_{ni}^k$ can be interpreted as the total level of emissions due to final demand consumption in country n, and the summation $\sum_{n,k} E_{ni}^k$ can be interpreted as the total level of emissions due to production from country i. Figure 3 shows the top and bottom 20 emitting countries. We can observe that richer countries tend to be the highest emitters, but we also see that among the top emitters there exists variation in their source of emissions. For instance, China produces more emissions than is being consumed domestically, while the US is a net importer of emissions. This decomposition allows us to observe the changes in carbon emissions resulting from trade.

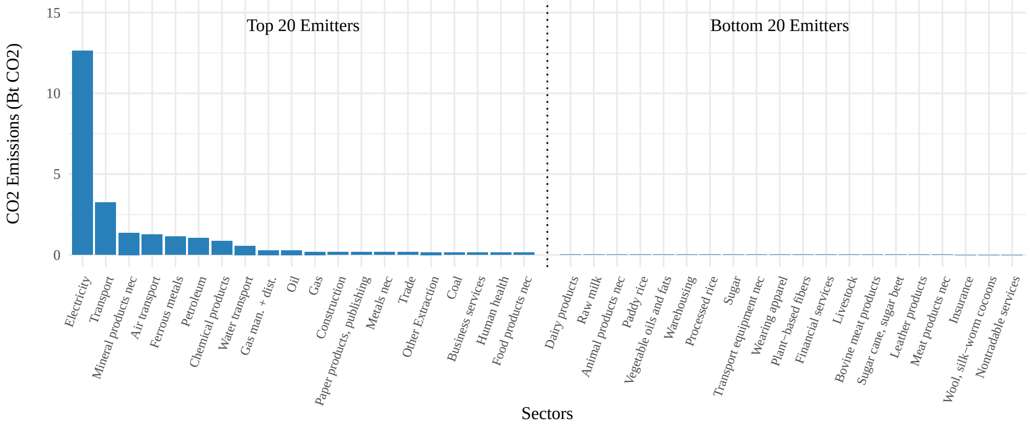
Figure 3: Embodied emissions by country



Source: GTAP MRIO

In Figure 4, we apply the same methodology to study the sectoral impact on global emissions. Here, emissions are balanced because the amount of CO_2 required to produce would be equivalent to the CO_2 embodied in final consumption. Consistent with the literature, electricity is the leading contributor to CO_2 emissions. This is followed by transportation, mineral products, ferrous metals, and petroleum. Cleaner sectors with respect to CO_2 emissions tend to be more agricultural or food processing related sectors. This is due to the fact that this analysis is limited to CO_2 emissions. Agriculture and food processing tend to be sources for other greenhouse gasses such as methane and nitrogen oxides.

Figure 4: Embodied CO_2 emissions by sector



Source: GTAP MRIO

Now, I will go through how to construct the emissions intensities from trade, intermediate consumption, and final consumption. First, let $e_n^j = \sum_{i,k} \Xi_{in}^{kj}$ be the total direct and indirect emissions required to produce one dollar of gross output in country n sector j. Total expenditures from country n on sector k in country i can be decomposed into the trade flows from intermediate goods plus the trade flows from final consumption,

$$X_{ni}^k = M_{ni}^k + F_{ni}^k.$$

Multiplying the total trade flows by our vector of emissions intensities and summing over all exporter countries, $\sum_i e_i^k X_{ni}^k$, gives us the total level of emissions from sector k imported by country n. Following Shapiro [2020], when estimating the environmental bias from tariffs I only consider the emissions imported via international trade and ignore domestic consumption. Thus, the total emissions consumed per dollar of imported good is given by $e_{n,X}^k = \frac{\sum_{i \neq n} e_i^k X_{ni}^k}{\sum_{i \neq n} X_{ni}^k}$. I extend this analysis by constructing measures for material consumption and final demand consumption. I include domestic consumption because domestic expenditures are relevant for carbon tax policy. The measurements for the total emissions per dollar consumed by country n on materials and final consumption given by $e_{n,M}^k = \frac{\sum_i e_i^k M_{ni}^k}{\sum_i M_{ni}^k}$ and $e_{n,F}^k = \frac{\sum_i e_i^k F_{ni}^k}{\sum_i F_{ni}^k}$ respectively.

2.2 Estimation

For each tax mechanism, I estimate the following regression specification,

$$t_n^j = \beta_0 + \beta_1 e_n^j + \delta_n + \varepsilon_n^j \tag{1}$$

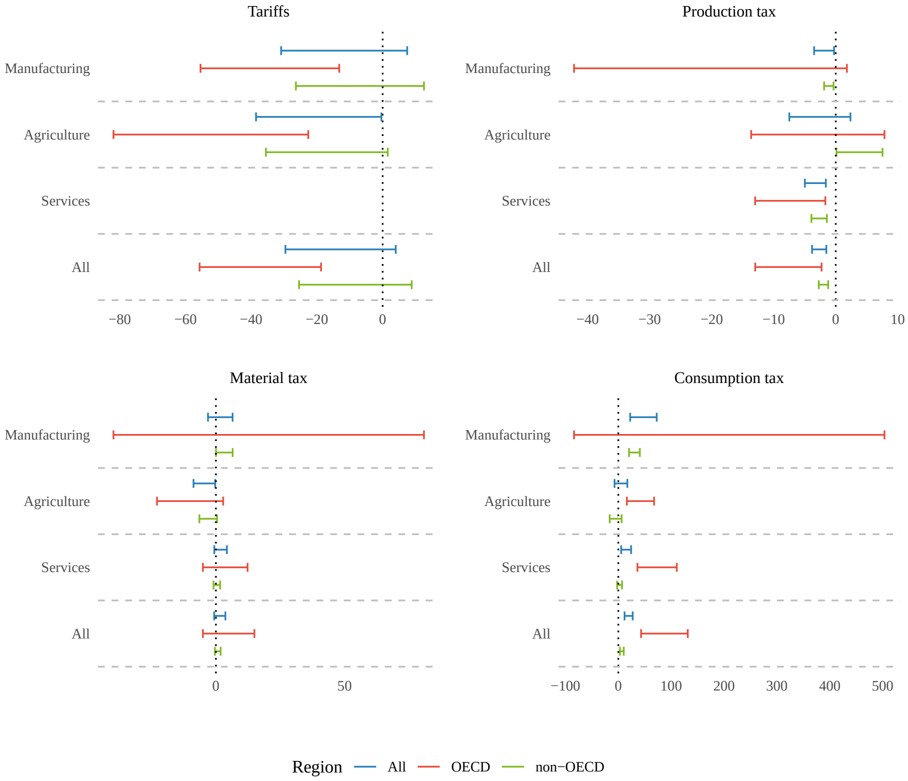
where t_n^j represents the type of tax rate, e_n^j represents the emissions intensities associated with each tax, and δ_n captures the country fixed effects. I group sectors into the following industry level categories: manufacturing, agriculture, and services. Our coefficient, β_1, can be interpreted as the tax dollars raised per ton of associated carbon emissions. Within the context of tariffs, this can be thought of as the implicit carbon tax on imported goods. For materials and final consumption, it represents the implicit carbon tax for consumption by producers and households. Finally, for the production tax, it can be interpreted as the implicit carbon tax from total embodied emissions.

To get an estimate for the implicit tax rate across sectors, I run the following pooled regression,

$$t_n^j = \alpha_0 + \alpha_1 e_n^j + \delta_n + \iota_{n,z} + \tilde{\varepsilon}_n^j \tag{2}$$

where $\iota_{n,z}$ represents the interactions between country and industry-level categories. The primary coefficient of interest, α_1 has the same interpretation as β_1 but speaks more to the implicit carbon tax for all sectors in each country. The results can be found in the Appendix in table A.1. Each panel represents a different subset of countries sampled. For each panel, the results from equation 1 are reported along the first three rows. The final row in each panel reports the results from equation 2. Columns 1 – 4 report the coefficient and standard errors for implicit tax revenues per ton of CO_2 from tariffs, production taxes, material taxes, and consumption taxes respectively. The results from table A.1 are summarized below in Figure 5.

Figure 5: Estimated carbon tax



Note: Table A1 in the appendix reports the coefficient estimates displayed above. The coefficients represent the implicit carbon tax by region and sector. The first three sections – manufacturing, agriculture, and services – represent the results from equation (1) while the final section reports the results from equation (2).

The coefficient plot in the top left represents the estimated implicit carbon tax on tariffs. Among OECD countries, I find an implicit subsidy of \$34.30 per ton of CO_2 imported from manufacturing, \$52.30 from agriculture, and an average of \$37.20 across sectors. All of which are statistically significant. Implicit subsidies tend to be smaller in magnitude and not significant among non-OECD countries at around \$6, \$17, and \$8 collected per ton of CO_2 for manufacturing, agriculture, and both, respectively. There is also strong evidence of environmental bias in the country-level analysis. Most countries, across both industries, tend to exhibit implicit subsidies. Taken altogether together, these findings support the existence of environmental bias in trade policy.

Production taxes are also regressive, but not to the degree that tariffs are. Globally, the implicit subsidy on services is \$3.29 and is statistically significant. The estimates for manufacturing (\$1.88) and agriculture (\$2.56) are not significant but still imply implicit subsidies. The cross-industry global implicit subsidy equals \$2.67. The most robust estimates are from non-OECD countries. Among OECD countries, the country-level analysis reveals substantial heterogeneity, where countries such as Norway and Belgium tend to have more progressive taxes on manufacturers, while countries like France and Italy have higher implicit subsidies to carbon. Implicit taxes on materials are much more ambiguous across all groups. Although they're more progressive for all country samples especially in manufacturing and services, no relationship is significant. The country-level analysis also reveals heterogeneity across countries and industries.

Finally, the most surprising results are that the implicit taxes paid by households are very progressive and much higher in magnitude relative to what producers face. Globally, the average tax revenue collected per dollar of CO_2 consumed in manufacturing by households is \$47 – above the generally accepted social cost of carbon by almost 20%. For all sectors, the average tax collected globally is \$20. In OECD countries, the tax collected from manufacturing is \$208, although not significant. For agriculture and services, the tax revenues collected are \$41 and \$73 respectively and both are significant. In non-OECD countries, implicit taxes collected per ton of CO_2 consumed in manufacturing is \$31 and significant. It's important to note that the costs of goods to households already implicitly contain the different layers of taxes paid by producers. Thus, this sales tax drives an additional wedge between what producers receive and what consumers pay. The country level disaggregation shows that consumption taxes across all industries among OECD and non-OECD countries are clearly much more progressive relative to the other tax channels.

2.3 Robustness

One may question the validity of these estimates outside the context of GTAP's input-output structure. To partly address these concerns, I reran the regression using data from the World-Input Output Database (WIOD) and found the same signs and relative magnitudes for the global, cross-industry estimates of environmental bias for each channel. I aggregated the effective tax rates and the WITS tariffs to a 25 sector classification using a concordance mapping between GTAP 10's sectors and ISIC Rev. 3. The results can be found in the Appendix Table A.2.

The standard errors in Table A.1 are clustered by industry, but I also report the standard errors clustered by importing country in Table A.4. These results tended to report more significant estimates for tariffs and consumption across all country samples. Finally, in Table A.3, I report the results when considering the embodied CO_2 equivalent emissions from all greenhouse gasses (GHG). These results reduce the significance on tariffs, but also makes the relationship between the implicit tax for all tax mechanisms much more regressive. This is most likely due to the fact that taxes on agriculture tends to be low, and often even subsidized, even though these are high GHG emitting sectors.

3 A quantitative model of trade and the environment

The econometric exercise in the previous section revealed two tensions I aim address using existing trade models: environmental bias extends to domestic tax policy and there exists a disparity between the taxes paid by consumers and those paid by producers. To analyze the welfare effects from changes to the current tax structure, I decompose the quantitative model of CDMMP.

3.1 Households

Representative households consist of a measure of L_n workers and landowners who own E_n in natural resources. Households choose the level of final consumption, C_n^j to maximize national utility, U_n^j. Preferences are Cobb-Douglas defined by

$$U_n = \prod_{j=1}^{J} \left(C_n^j\right)^{\alpha_n^j} f\left(Z\right) \tag{3}$$

where $f(Z)$ represents the global damage from emissions which is externally determined and α_n^j represents the share of income spent on final consumption in sector j.

Households generate income by supplying their labor at rate w_n and their natural resources at a renumeration rate r_n^j. The measure of labor and natural resources come in fixed supply in each country, and labor is freely allowed to move across sectors while natural resources are immobile and sector specific. We can write household income as,

$$I_n = \left[w_n L_n + \sum_{j=1}^{J} r_n^j E_n^j + T_n + D_n \right],$$

where T_n represents the total revenue collected due to tariffs and taxes and D_n are deficits.

The consumer purchases final goods at price P_n^j. Consumers also face an ad valorem tax rate $t_{n,c}^j$ for a unit of consumption of final good C_n^j. Solving the utility maximization problem gives us a consumption price index in country n defined by

$$P_n = \prod_k \left(\frac{t_{n,c}^k P_n^k}{\alpha_n^k} \right)^{\alpha_n^k}$$

3.2 Intermediate producers

Producers of intermediate varieties, ω^j, face Cobb-Douglas production functions for all sectors with technology z_n^j. There are two types of producers: non-extractive and extractive. Non-extractive sectors use labor and intermediate inputs from other sectors captured by input-output linkages. Their production technologies are defined by

$$q_n^j = z_n^j \left(l_n^j \right)^{\gamma_{n,l}^j} \prod_{k=1}^{J} \left(m_n^{k,j} \right)^{\gamma_n^{k,j}}$$

where $\gamma_{n,l}^j$ and $\gamma_n^{k,j}$ are the input requirements for labor and intermediate good k used in sector j respectively. Their input cost bundle is given by

$$c_{n,n}^j = \Upsilon_n^j t_{n,p}^j \left(t_{n,l}^j w_n \right)^{\gamma_{n,l}^j} \prod_{k=1}^{J} \left(t_{n,m}^k P_n^k \right)^{\gamma_n^{k,j}}$$

where $t_{n,l}^j$ represents the ad valorem tax for a unit of labor used by producers, $t_{n,m}^k$ is the ad-valorem tax on the demand for intermediate inputs, and $t_{n,p}^j$ represents the ad valorem tax faced by producers in all sectors for the production of q.

In addition to labor and intermediates, extractive sectors also require natural resources. Intuitively, this can be thought of as the oil within in the ground extracted and then used as an intermediate input for the production of petroleum. The production technologies for extractive sectors are defined by

$$q_{n,e}^j = z_n^j \left(l_n^j \right)^{\gamma_{n,l}^j} \left(e_n^j \right)^{\gamma_{n,e}^j} \prod_{k=1}^{J} \left(m_n^{k,j} \right)^{\gamma_n^{k,j}}$$

where $\gamma^j_{n,e}$ are the input requirements for natural resources. The input cost bundles for extractive goods are thus given by

$$c^j_{n,e} = \Upsilon^j_n t^j_{n.p} \left(t^j_{n,l} w_n\right)^{\gamma^j_{n,l}} \left(r^j_n\right)^{\gamma^j_{n,e}} \prod_{k=1}^{J} \left(t^k_{n,m} P^k_n\right)^{\gamma^{k,j}_n}$$

Suppliers in sector j, country n purchase from the lowest cost supplier to produce composite intermediate goods which consist of both final goods and materials used in the production of varieties ω^k.

3.3 International trade

Aggregate trade flows from country i to country n is given by X^j_{ni}. Trade is costly and producers in country i face trade costs for shipping to country i in the form of tariffs $\left(\tau^j_{ni}\right)$ and iceberg costs $\left(d^j_{ni}\right)$. Let $\kappa^j_{ni} = \tau^j_{ni} d^j_{ni}$ denote the trade costs to export from country n to country i. Using properties of the Fréchet distribution, we get that bilateral trade shares follows a gravity equation structurally similar to Caliendo and Parro (2015),

$$\pi^j_{ni} = \frac{\lambda^j_i \left[\kappa^j_{ni} c^j_i\right]^{-\theta^j}}{P^j_n}$$

where the sectoral price index is given by

$$P^j_n = \sum_h \lambda^j_h \left[\kappa^j_{ni} c^j_h\right]^{-\theta^j} .$$

However, trade shares can now be influenced by domestic policy directly via the inclusion of taxes on labor, material demand, and production that enter into the input cost bundle c^j_i. These distortions capture the potential externalities that arise from changes in domestic carbon policy such as "carbon leakage". If domestic production of carbon intensive sectors becomes too expensive than the share of domestic consumption can shift to relative cheaper producers abroad. These relatively cheaper producers abroad can be more carbon intensive thus negating the intended effect of reducing global emissions.

3.4 Equilibrium

Total expenditures in country n on sector j are given by X^j_n and must equal the summation of expenditures on intermediates and on final consumption,

$$X^j_n = \sum_k \frac{\gamma^{k,j}_n}{t^j_{n,m}} \sum_i X^k_i \frac{\pi^k_{in}}{\tau^k_{in} t^k_{n,p}} + \frac{\alpha^j_n}{t^j_{n,c}} \tilde{\alpha}_n \left[w_n L_n + \sum_{j=1}^{J} r^j_n E^j_n + T_n + D_n \right]$$

Where D_n represents deficits in country n and T_n are the total revenues collected from taxes and tariffs and $\tilde{\alpha}_n = \sum_{s=1}^{J} \left[\frac{\alpha^s_n}{t^s_{n,c}}\right]^{-1}$ represents the tax adjusted consumption shares.

To close the model, our factor market clearing conditions for labor and natural resources are given by

$$w_n L_n = \sum_{s=1}^{J} \sum_{i=1}^{N} \frac{\gamma^{l,s}_n}{t^s_{n,l}} X^s_i \frac{\pi^s_{in}}{t^s_{n,p} \tau^s_{in}}$$

$$r_n^j E_n^j = \sum_{i=1}^{N} \gamma_n^{e,j} X_i^j \frac{\pi_{in}^j}{t_{n,p}^j \tau_{in}^j}.$$

3.5 Solving the model in changes

Counterfactuals for the model can be solved in changes using "exact hat-algebra", where x' denotes the counterfactual outcome in levels and $\hat{x} = \frac{x'}{x}$ denotes the change from the baseline. The equilibrium condition in changes are given by

$$\begin{aligned}
\hat{c}_n^j &= \hat{t}_{n,p}^j \left(\hat{t}_{n,l}^j \hat{w}_n\right)^{\gamma_n^{l,j}} \left(\hat{r}_n^j\right)^{\gamma_n^{e,j}} \prod_{k=1}^{J} \left(\hat{t}_{n,m}^k \hat{P}_n^k\right)^{\gamma_n^{k,j}} \\
\hat{P}_n^j &= \left[\sum_{i=1}^{N} \pi_{ni}^j \left(\hat{c}_i^j \hat{d}_{ni}^j \hat{\tau}_{ni}^j\right)^{-\theta^j}\right]^{\frac{-1}{\theta^j}} \\
\hat{\pi}_{ni}^j &= \left[\frac{\hat{c}_i^j \hat{d}_{ni}^j \hat{\tau}_{ni}^j}{\hat{P}_n^j}\right]^{-\theta^j} \\
\hat{w}_n^* &= \sum_{j=1}^{J} \sum_{i=1}^{N} \frac{\gamma_n^{l,j}}{t_{n,l}'^j} X_i' \frac{\pi_{in}'^j}{w_n L_n t_{n,p}'^j \tau_{in}'^j} \\
\hat{r}_n^j &= \sum_{i=1}^{N} \gamma_n^{e,j} X_i' \frac{\pi_{in}'^j}{r_n^j E_n^j t_{n,p}'^j \tau_{in}'^j} \\
X_n'^j &= \sum_{k} \frac{\gamma_n^{k,j}}{t_{n,m}'^j} \sum_{i} X_i'^k \frac{\pi_{in}'^k}{\tau_{in}'^k t_{n,p}'^k} + \frac{\alpha_n^j \tilde{\alpha}_n'}{t_{n,c}'^j} \left[\hat{w}_n w_n L_n + \sum_{j=1}^{J} \hat{r}_n^j r_n^j E_n^j + T_n' + D_n\right]
\end{aligned}$$

4 The welfare implications of environmental bias

To address the heterogeneity in tax structures presented in the data, my goal is to isolate the welfare implication of simultaneous changes in different tax mechanisms. When dealing with carbon policy, there are several competing channels by which tax policy could address climate change. The econometric analysis focused on four – tariffs on imports, taxes on production, taxes on demand for materials, and taxes on final consumption. However, our model also allows for an additional component which are taxes to labor use. Additionally, these taxes can be broken down into their impacts from direct taxes at different stages of production compared to the impacts of direct taxes on the consumer.

The econometric exercise from earlier highlighted the discrepancies that exists within the current tax structure. Sectors with higher embodied emissions tend to be taxed at lower rates with varying degrees of regressivity conditional on the stage being taxed, while taxes on final consumption tend to be higher the more carbon intensive a sector is. Assuming a social cost of carbon equivalent to \$40 per ton of CO_2, final consumption taxes tend to exceed this margin while taxes to various stages of production consistently fall under this benchmark and even equate at times to implicit subsidies.

These different tax mechanisms should serve to price in the damages from carbon into the cost of goods. In an ideal world, we would have a uniform global tax on carbon which equalizes the cost of climate change for consumers and producers. Instead, each country is left to pursue its own "second-best" carbon policies which can lead to international policy concerns such as "carbon leakage" as well as domestic concerns in the form of inefficient tax structuring. Given these potential issues that arise from a decentralized approach to climate change, I aim to characterize the welfare implications of changes to different tax mechanisms.

4.1 Welfare decomposition

Solving for the indirect utility function allows us to characterize the welfare in country n as,

$$U_n = \frac{I_n}{P_n} f(Z)$$

Due to the nonlinearity of the welfare function, one cannot discern the simultaneous impacts due to changes from different instruments. The taxes can affect welfare via changes to consumption as well as changes to global emissions. Moreover, changes to each instrument can affect each of these channels differently.

To address this, I log-linearize the utility function to derive an expression for how welfare changes in response to changes in consumption versus changes in income.

$$d\ln U = \mathbf{W}_\tau d\ln\tau + \mathbf{W}_{t_p} d\ln t_p + \mathbf{W}_{t_m} d\ln t_m + \mathbf{W}_{t_c} d\ln t_c + \mathbf{W}_{t_l} d\ln t_l$$

The expression for changes in real income and changes to welfare due to global emissions can be further decomposed to isolate how they respond to changes in policy. Changes welfare due to changes in real income are given by

$$d\ln I - d\ln P = \mathbf{W}^I_\tau d\ln\tau + \mathbf{W}^I_{t_p} d\ln t_p + \mathbf{W}^I_{t_m} d\ln t_m + \mathbf{W}^I_{t_c} d\ln t_c + \mathbf{W}^I_{t_l} d\ln t_l \tag{4}$$

and changes in welfare to changes in global emissions are given by

$$d\ln f(Z) = \mathbf{W}^Z_\tau d\ln\tau + \mathbf{W}^Z_{t_p} d\ln t_p + \mathbf{W}^Z_{t_m} d\ln t_m + \mathbf{W}^Z_{t_c} d\ln t_c + \mathbf{W}^Z_{t_l} d\ln t_l \tag{5}$$

where $\mathbf{W}^I$ and $\mathbf{W}^Z$ are matrices governing the interactions between each tax mechanism and it's overall effect on real income and utility from emissions respectively.

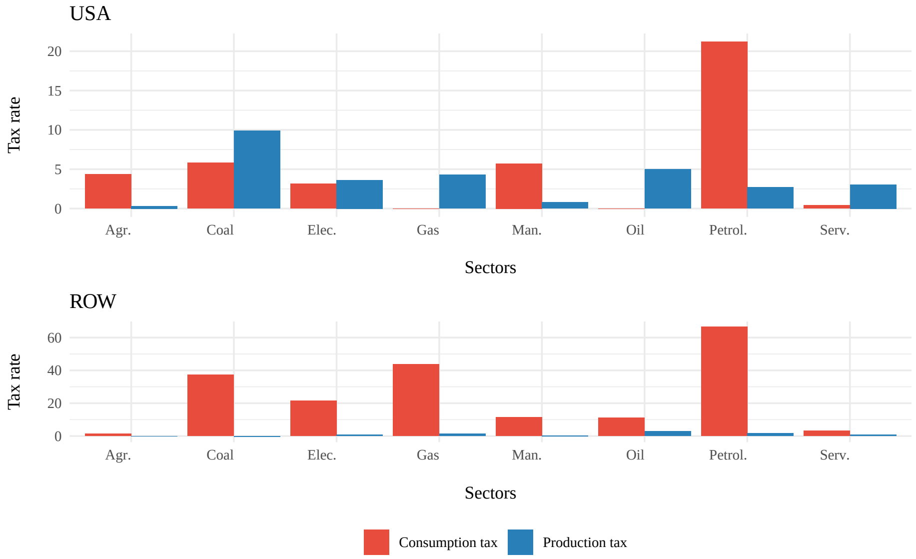
4.2 Counterfactuals

We can use the decomposition to answer questions pertaining to the effects of different tax mechanisms on national welfare. The following section studies the welfare implications for the United States and the world when reducing the gap in taxes paid by producers and consumers on carbon intensive sectors. The input-output data, tax data, and environmental data are the same data used in for the econometric exercise except aggregated up to two regions – United States and the rest of the world (ROW) – and for 8 sectors: agriculture, coal, oil, gas, manufacturing, petroleum, electricity, and services.

The combustion of fossil fuels used in the production and final consumption of petroleum are responsible for 3%, or approximately 1 billion tons, of global CO_2 emissions. Suppose the US government aims to address the environmental bias enjoyed by producers in the petroleum sector while also relieving the tax burden faced by consumers. Intuitively, an increase in the production tax to petroleum could increase the sectoral price index and thus decrease real income. However, because petroleum is more expensive, it could also lead to a reduction in global emissions. Concurrently, the reduction in the consumption tax could also negate the pass-through effects from the production tax on petroleum while also counteracting any welfare gains due to a potential increase in global emissions. Shocking the price of production could also effect trade flows, making domestic producers import petroleum from different sources having uncertain effects on global emissions and prices. Clearly there are a multitude of general equilibrium outcomes one has to keep in mind.

Figure 6 below shows the baseline tax rates for the ROW and the USA by sector.

Figure 6: Baseline taxes

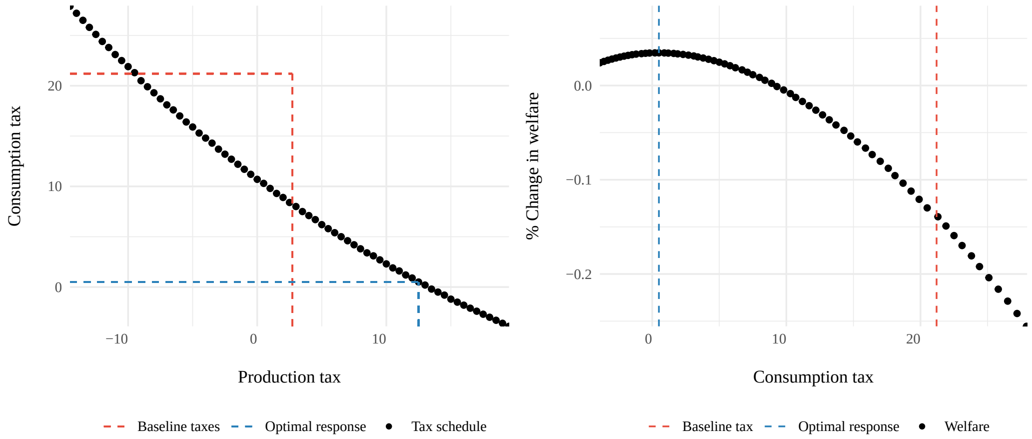


We see the evidence described in the econometric section when focusing on the petroleum sector for both the USA and the ROW. The tax rates paid by producers of petroleum in the USA is 3% while the taxes paid by US households for petroleum consumption is 21%. The difference is even more stark for the ROW. Consumers on average are paying 66% in taxes on petroleum while producers are only paying 2%.

The welfare decomposition outlined above allows us to analyze two key statistics: welfare under optimal changes in the consumption tax given changes to production tax and the relative impacts on welfare due to changes in each instrument. For the first statistic, I consider incremental changes in production tax and given this change I solve for the optimal, simultaneous change in consumption tax until $d \ln U_{USA} = 0$. I iterate this process for a range of production taxes. In this counterfactual, the USA does not care how their domestic policy affects the rest of the world.

Figure 6 below shows the schedule of optimal consumption tax responses given changes to the production tax on the left and the corresponding changes in welfare on the right. Each black dot represents the welfare maximizing consumption and production tax. The blue dashed line indicates the welfare maximizing production tax and its corresponding optimal consumption response. The red dashed line represents the baseline level of taxes.

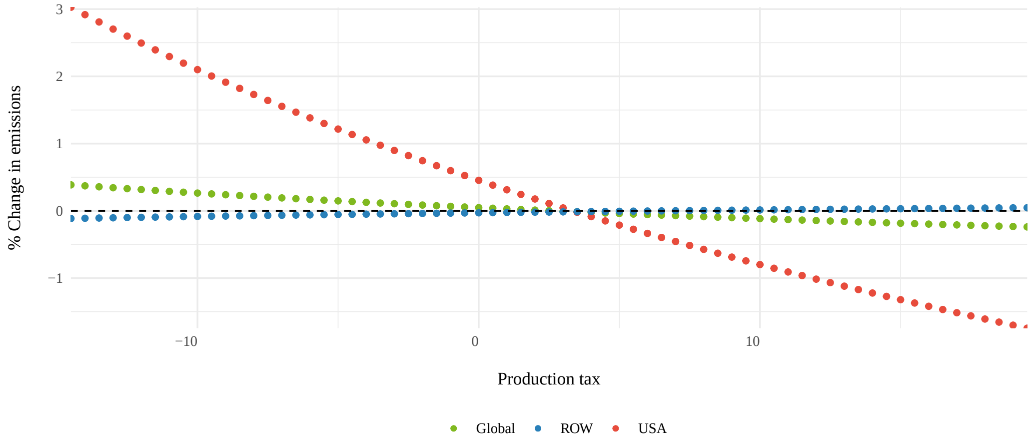
Figure 7: Optimal consumption response



The welfare curve on the right tells us that minimizing the distance between consumers and producers is not only optimal, but also that their magnitudes should be flipped. Notice that the welfare maximizing taxes occur when the production tax is 12%, a 9 percentage point increase, and when consumption taxes fall by 20 percentage points to approximately 1%. Moreover, even if we start at the initial production tax of 3%, then the optimal consumption tax should be approximately 8%, a 13 percentage point decrease from their current level.

The most interesting result for carbon policy is that the tax schedule above also coincides with a reduction in global emissions. Figure 8 below shows the changes in emissions levels as production taxes change with consumption responding optimally. The dotted green line represents the USA changes in emissions, the dotted red is for the ROW, and the dotted green represents global emissions.

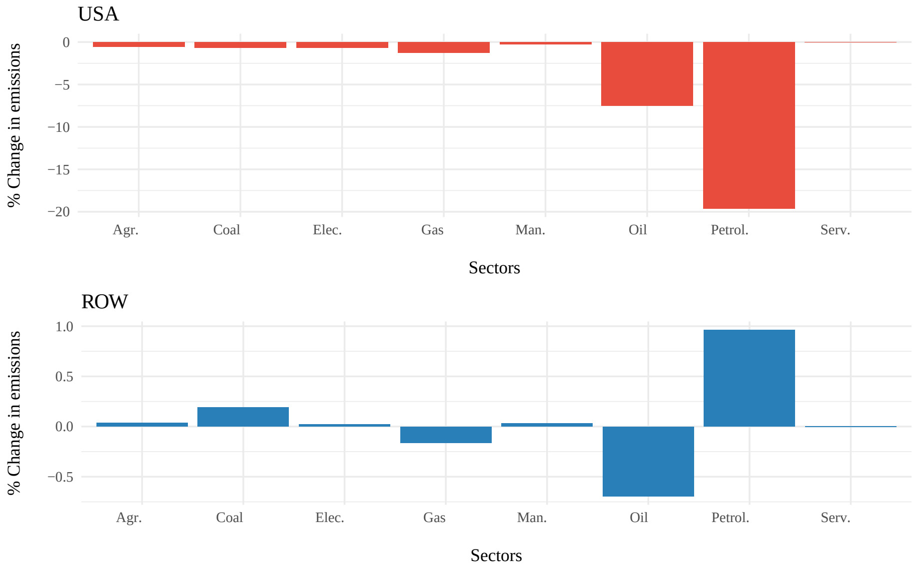
Figure 8: Changes in emissions



The reduction in USA emissions suggest that the demand for petroleum has fallen and agents are turning to other sources for their petroleum or for less carbon intensive substitutes. It's clear that the reduction in USA emissions is contributing to the overall decline in global emissions as production taxes increase. However, we also see evidence of carbon leakage. As domestic production becomes more expensive, demand shifts towards cheaper sources of production abroad. In this example, the carbon leakage is not enough to offset the reduction from the USA, but it still speaks to a core issue when attempting to address carbon policy in globally connected economy.

Figure 9 summarizes how the policy distorted emissions by sector in each country.

Figure 9: Changes in emissions by sector



We see a 20% reduction in emissions from petroleum in USA met with a 1% increase in emissions from petroleum from the ROW.

We can now use our decomposition to determine how much each channel is contributing to the welfare gains. Table 1 describes the share of welfare gains, real income, gains, and emission disutility at the optimal response that is due to production versus consumption for the USA and for the ROW.

Table 1: Utility decomposition: without constraint

	USA		ROW	
	% Δ P Tax	% Δ C Tax	% Δ P Tax	% Δ C Tax
% Δ Utility	70.63%	29.37%	-87.6%	12.4%
% Δ RI	69.99%	30.01%	-88.19%	11.81%
% Δ $f(Z)$	99.69%	0.31%		
% Δ Wage	1.11%	-98.89%		
% Δ Rent Coal	-91.03%	8.97%	99.73%	0.27%
% Δ Rent Oil	-79.29%	20.71%	-65.48%	34.52%
	% Δ RI	% Δ $f(Z)$	% Δ RI	% Δ $f(Z)$
% Δ Utility	97.84%	2.16%	-94.25%	5.75%

Notes: This table illustrates the percentage change in different economic variables given simultaneous changes to production taxes and consumption taxes in the petroleum & coal sector. The values represent the share of the total changes in utility, real income, utility from abatement, wage, oil and coal rents due to changes in either tax channel within the United States (USA) and the rest of the world (ROW). The % Δ $f(Z)$ is a global measure, so it's equal for USA and the ROW which is why it's left blank under the ROW column. The % Δ Wage is blank for the ROW because it's normalized to one. The sub-table provides an additional detailed look at specific impacts on RI and $f(Z)$.

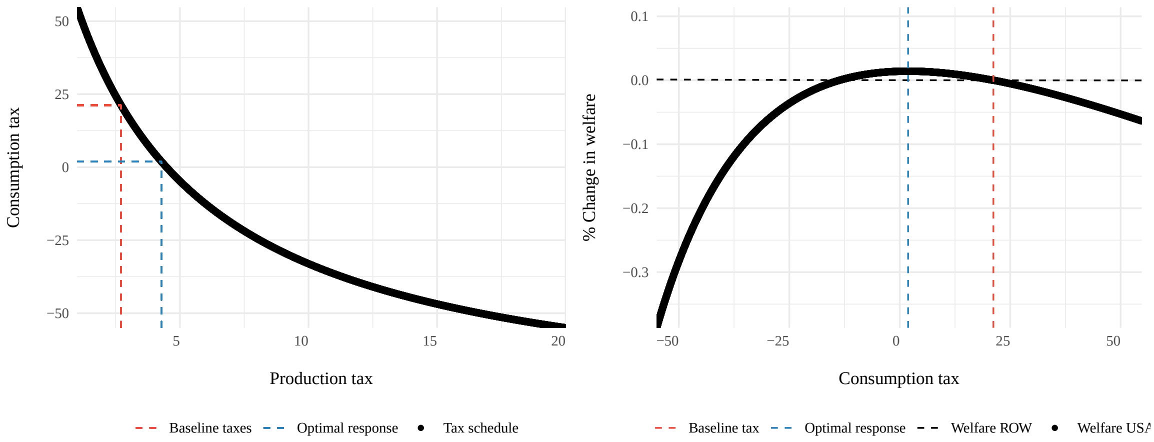
The table[2] above suggests that most of the changes to total welfare which incorporates changes in real income and changes in emissions come from the changes to real income. We also see that for the USA, 70.63% of the increase in national welfare is due to the increase in production tax and a 29.37% increase is from consumption. However, changes in the production tax in the USA are also responsible for 87.6% of the total welfare loss in the ROW. Moreover, the increase in the production tax accounts for 99.69% of the reductions in emissions. These results suggest that taxes directly to producers are potentially more effective instruments in promoting climate objectives than sales taxes to households under these conditions.

I now follow Kortum and Weisbach [2021] and consider a counterfactual where the USA changes their domestic policy such that the ROW's welfare is unchanged. To do so, I impose that $d\ln U_n = 0$ and use the corresponding ratio between USA production and consumption taxes to numerically solve for welfare maximizing policy. Let n and i represent the ROW and the USA respectively, then the problem is characterized by the null space of our system. In this simple example, it's equivalent to the following,

$$\begin{aligned} d\ln U_n &= W_{n,t_p} d\ln t_{i,p} + W_{n,t_c} d\ln t_{i,c} \\ 0 &= W_{n,t_p} d\ln t_{i,p} + W_{n,t_c} d\ln t_{i,c} \\ d\ln t_{i,c} &= -\frac{W_{n,t_p}}{W_{n,t_c}} d\ln t_{i,p} \end{aligned}$$

Using this relationship for changes in consumption tax given changes to production tax, I plot the same tax schedules and welfare curve as below. The dashed black line in the right plot reflects how the ROW's welfare is unchanged given different tax structures.

Figure 10: Optimal consumption response



The conclusion from the first counterfactual still holds when considering the constrained optimization problem. The current tax structure is sub-optimal and households would gain if the production tax were raised while simultaneously decreasing taxes to consumption. Moreover, as in the first counterfactual, the tax structure that maximizes national welfare is one where production taxes are higher than consumption taxes. The two counterfactuals differ in that in the constrained optimization problem, the taxes faced by

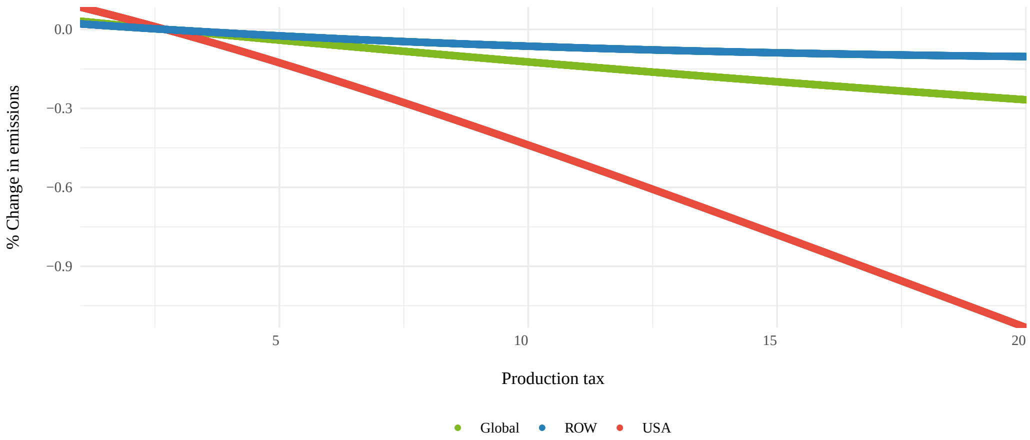
---

[2] The values represent the direction of the total movement due to each tax channel. For example, the percentages for real income in row 1, column 1 reflect the following: $\%\Delta \text{Real Income} = \frac{\mathbf{W}^I_{t_p} d\ln t_p}{\left|\mathbf{W}^I_{t_p} d\ln t_p\right| + \left|\mathbf{W}^I_{t_c} d\ln t_c\right|}$. Thus, of the total movement in real income for the USA, regardless of direction, approximately 70.63% was due to changes in the production tax.

both agents are much closer together. The optimal tax is reached when consumers are paying a 2% tax and when producers are paying a 4% tax.

Since the US is adjusting it's tax structure in such a way that does not manipulate the terms of trade in favor of home, the gains to welfare are in part coming from the reorganization of domestic production as well as the reduction in global emissions. Figure 10 shows the effects that this tax structure has on global emissions.

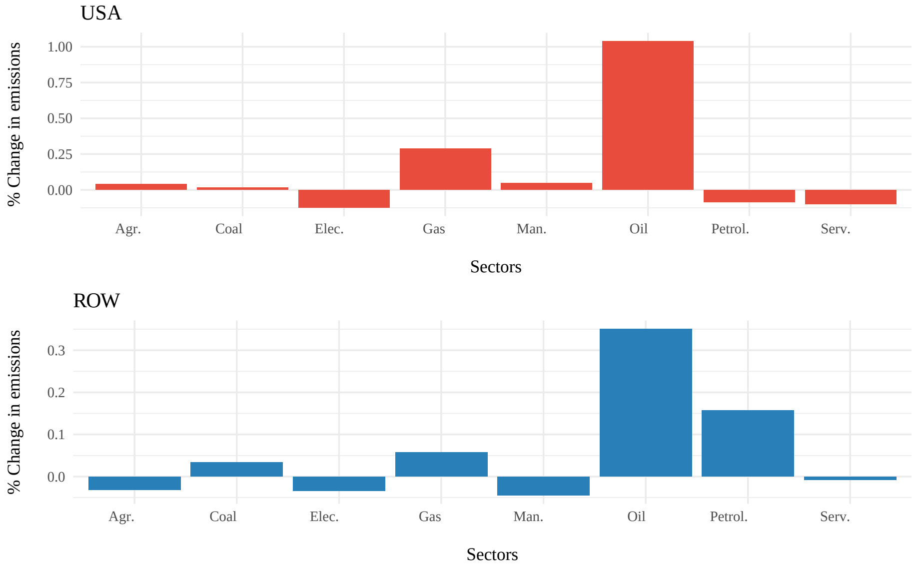
Figure 11: Changes in emissions



In the constrained problem, carbon leakage is addressed but the reduction in global levels of emissions is less than in the first counterfactual. Here, at the optimal, we see a 0.02% reduction in global emissions while in the first we saw a .15% reduction. However, it still may be the case that the second strategy is preferred because the reduction in global emissions came with the reduction in welfare from the ROW which could induce retaliation.

Figure 11 below shows how the tax distortions reorganized domestic production by sector. Interestingly, unlike in the previous scenario where emissions fell across all sectors in the USA, reductions in emissions from high intensity sectors such as electricity, petroleum, and services are met with increased emissions in the extractive sectors. These distortions, however, result in overall reduction in emissions for both the USA and the ROW.

Figure 12: Changes in emissions by sector



The welfare decomposition reveals that the source of welfare gains differ between the constrained problem and the first counterfactual. The table below shows that 70.70% of welfare gains in this scenario are generated by a reduction in the consumption tax while the remainder are from the increase in production taxes. Moreover, gains due to emissions reductions accounted for only 0.91% of the overall change in welfare.

Table 2: Utility decomposition: with constraint

	USA		ROW	
	% Δ P Tax	% Δ C Tax	% Δ P Tax	% Δ C Tax
% Δ Utility	29.3%	70.7%		
% Δ RI	28.66%	71.34%		
% Δ $f(Z)$	98.24%	1.76%		
% Δ Wage	0.19%	-99.81%		
% Δ Rent Coal	-63.61%	36.39%	98.46%	1.54%
% Δ Rent Oil	-39.75%	60.25%	-24.63%	75.37%

	% Δ RI	% Δ $f(Z)$	% Δ RI	% Δ $f(Z)$
% Δ Utility	99.09%	0.91%		

Notes: This table illustrates the percentage change in different economic variables given simultaneous changes to production taxes and consumption taxes in the petroleum & coal sector. The values represent the share of the total changes in utility, real income, utility from abatement, wage, oil and coal rents due to changes in either tax channel within the United States (USA) and the rest of the world (ROW). The % Δ $f(Z)$ is a global measure, so it's equal for USA and the ROW which is why it's left blank under the ROW column. The % Δ Wage is blank for the ROW because it's normalized to one. The The % Δ Utility is blank for the ROW because in there are no changes in the nonlinear version. The sub-table provides an additional detailed look at specific impacts on RI and $f(Z)$.

The two exercises highlighted above show how different policy objectives can have vastly different welfare implications. Further research is required to understand why consumption taxes play a larger role on welfare gains in the constrained optimization problem. It's also unclear why the constrained problem eliminates carbon leakage for large increases to production tax. For sufficiently large changes, welfare falls in both country, but there always exists gains from the overall reduction in emissions. A caveat of the model is that it only has dirty energy sectors, and a rich area for future research would be to extend the CDMMP framework allowing for innovation and clean energy.

5 Conclusion

There is a consensus in the literature that policy makers need to take immediate action if we are to meet our climate goals. Reducing emissions can potentially come at a cost and the goal should be to incentivize the reallocation of production towards more efficient means while simultaneously improving the livelihood of households. We have several instruments at our disposal to enact such policy. However, in a globalized economy where shifting the price of goods domestically can have impacts on producers abroad, determining the appropriate policy is in no way trivial.

In light of these challenges, this paper documents evidence that the current tax structure is suboptimal. Tariffs on imports and taxes to production tend to implicitly subsidize the use of carbon intensive sectors while the opposite holds true for households. These taxes on final goods places a heavier burden on consumers and may not adequately address the problem of carbon mitigation. I decompose the environmental trade model of CDDMP to analyze the impacts of simultaneously adjusting production taxes and consumption taxes. I first quantify the effects for when the USA is self-interested and seeks to maximize welfare regardless of how it may effect the ROW. I then rerun the exercise but constrain USA policy such that domestic changes do not effect welfare abroad. Under both conditions, households in the USA gain when production taxes exceed consumption taxes on carbon intensive sectors like petroleum. Additionally, the constrained problem always results in the elimination of carbon leakage.

The environmental trade model of CDMMP provides a comprehensive framework for which to study the intricacies of climate change. However, allowing for numerous instruments to vary quickly makes the problem intractable. The decomposition outlined in this paper can thus serve as a valuable benchmark to identify the origins of potential distortions that arise both domestically and internationally from changes to climate policy.

References

International standard industrial classification of all economic activities (ISIC).

Angel Aguiar, Maksym Chepeliev, Erwin Corong, and Robert Mcdougall. The GTAP data base: Version 10. 4(1), 2019.

Kathy Baylis, Don Fullerton, and Daniel H. Karney. Negative leakage. 1(1):51–73, 2014. ISSN 2333-5955, 2333-5963. doi: 10.1086/676449. URL https://www.journals.uchicago.edu/doi/10.1086/676449.

Chad P Bown, Lorenzo Caliendo, Fernando Parro, Robert W Staiger, and Alan O Sykes. Reciprocity and the china shock. 2023.

L. Caliendo and F. Parro. Estimates of the trade and welfare effects of NAFTA. 82(1):1–44, 2015. ISSN 0034-6527, 1467-937X. doi: 10.1093/restud/rdu035. URL https://academic.oup.com/restud/article-lookup/doi/10.1093/restud/rdu035.

Lorenzo Caliendo and Fernando Parro. The quantitative effects of trade policy on industrial and labor location. 2020.

R Dornbusch, S Fischer, and P A Samuelson. Comparative advantage, trade, and payments in a ricardian model with a continuum of goods. 1977.

Jonathan Eaton and Samuel Kortum. Technology, geography, and trade. 70(5):1741–1779, 2002. ISSN 0012-9682, 1468-0262. doi: 10.1111/1468-0262.00352. URL http://doi.wiley.com/10.1111/1468-0262.00352.

Peter Egger and Sergey Nigai. Energy demand and trade in general equilibrium. 60(2):191–213, 2015. ISSN 0924-6460, 1573-1502. doi: 10.1007/s10640-014-9764-1. URL http://link.springer.com/10.1007/s10640-014-9764-1.

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

Mario Larch and Joschka Wanner. Carbon tariffs: An analysis of the trade, welfare, and emission effects. 109:195–213, 2017. ISSN 00221996. doi: 10.1016/j.jinteco.2017.09.003. URL https://linkinghub.elsevier.com/retrieve/pii/S0022199617301186.

Marcel P. Timmer, Erik Dietzenbacher, Bart Los, Robert Stehrer, and Gaaitzen J. de Vries. An illustrated user guide to the world input-output database:. 23(3):575–605, 2015.

James R Markusen. International externalities and optimal tax structure. 5(1):15–29, 1975.

Mauricio Mesquita Moreira and Marcelo Dolabella. Does trade policy help or hinder global warming? a case study of latin america and the caribbean. 2023. ISSN 0378-5920, 1467-9701. doi: 10.1111/twec.13449. URL https://onlinelibrary.wiley.com/doi/10.1111/twec.13449.

William Nordhaus. Climate clubs: Overcoming free-riding in international climate policy. 105(4):1339–1370, 2015. ISSN 0002-8282. doi: 10.1257/aer.15000001. URL https://pubs.aeaweb.org/doi/10.1257/aer.15000001.

Joseph S. Shapiro. Trade costs, CO $_2$, and the environment. 8(4):220–254, 2016. ISSN 1945-7731, 1945-774X. doi: 10.1257/pol.20150168. URL https://pubs.aeaweb.org/doi/10.1257/pol.20150168.

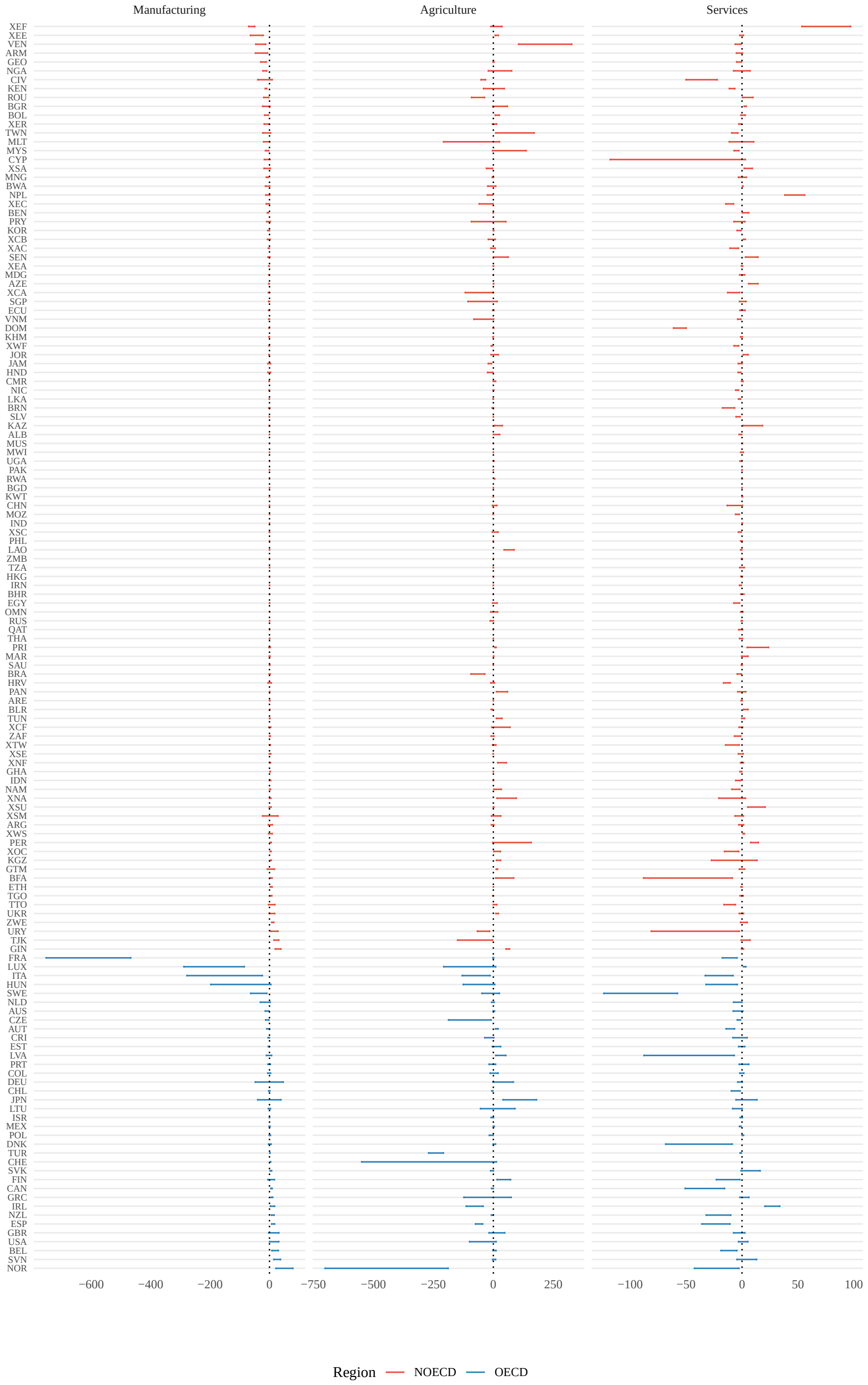
Joseph S Shapiro. The environmental bias of trade policy. 2020.

6 Appendix

Figure A1: Tariffs by country

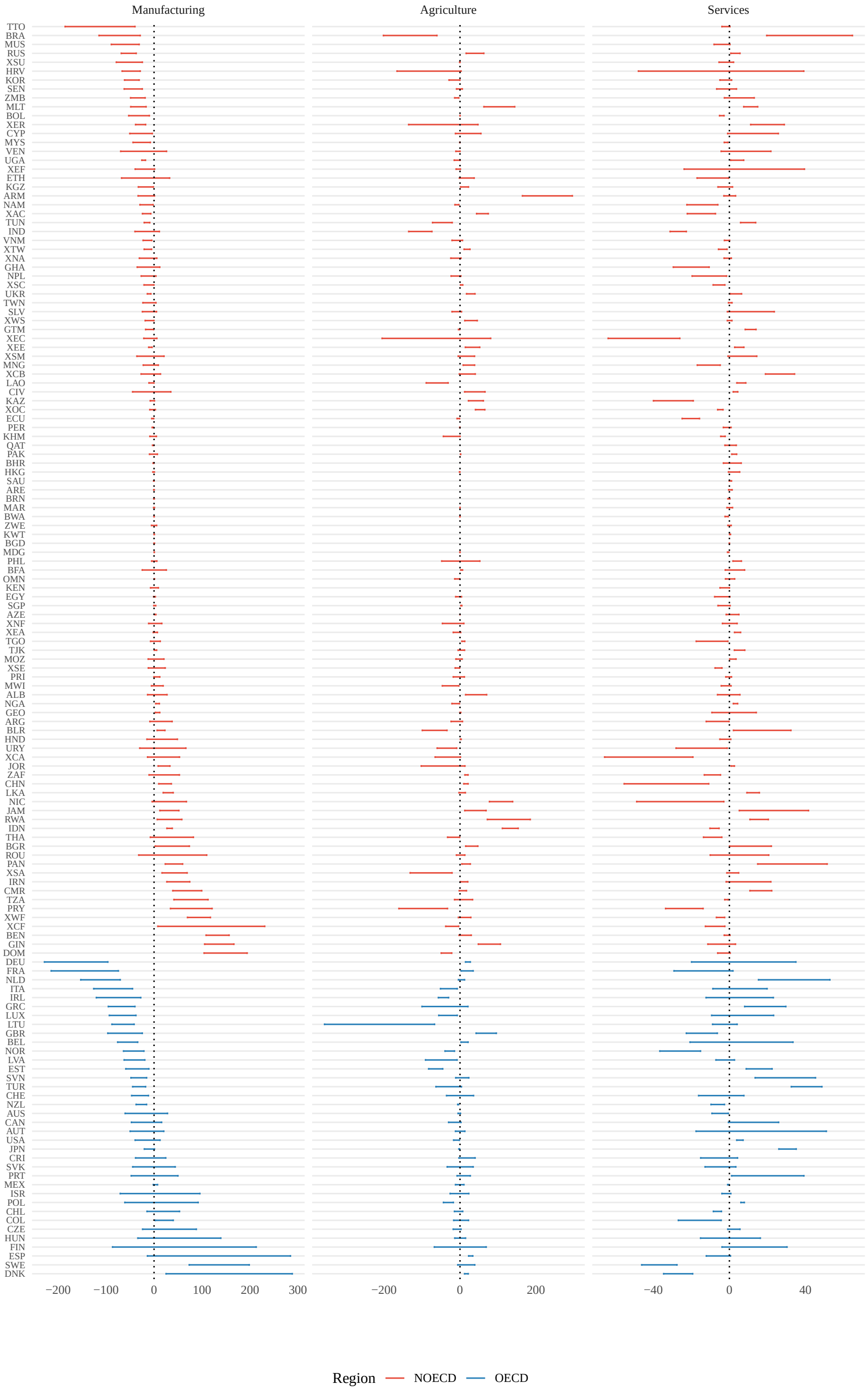
Note: The coefficients represent the implicit carbon tariff by country and sector. The left graph represents the coefficients for manufacturing and the right represents agriculture. Standard errors are clustered by industry and error bars are one standard error.

Figure A2: Production taxes by country



Note: The coefficients represent the implicit carbon tax on production by country and sector. The left graph represents the coefficients for manufacturing, middle is agriculture, and right is services. Standard errors are clustered by industry and error bars are one standard error.

Figure A3: Material taxes by country



Note: The coefficients represent the implicit carbon tax on materials by country and sector. The left graph represents the coefficients for manufacturing, middle is agriculture, and right is services. Standard errors are clustered by industry and error bars are one standard error.

Figure A4: Consumption taxes by country

Note: The coefficients represent the implicit carbon tax on consumption by country and sector. The left graph represents the coefficients for manufacturing, middle is agriculture, and right is services. Standard errors are clustered by industry and error bars are one standard error.

Table A1: Tax revenue vs CO2 intensities

	Dependent Variable: Tax revenue per ton of CO2							
	Tariff		Prod. Tax		Mat. Tax		Cons. Tax	
	Est.	s.e.	Est.	s.e.	Est.	s.e.	Est.	s.e.
All Countries								
Manufacturing	-11.71	(19.18)	-1.88	(1.61)	1.71	(4.78)	47.5*	(25.07)
Agriculture	-19.46	(19.08)	-2.56	(4.93)	-4.48	(4.21)	4.95	(12.13)
Services	–	–	-3.29**	(1.69)	1.83	(2.44)	14.8	(9.41)
All	-12.8	(16.79)	-2.67**	(1.15)	1.51	(2.18)	19.49***	(7.7)
OECD Countries								
Manufacturing	-34.32*	(21.11)	-20.2	(22)	20.51	(60.27)	209.8	(293.57)
Agriculture	-52.28*	(29.64)	-2.89	(10.75)	-10.02	(12.85)	41.91*	(25.72)
Services	–	–	-7.34	(5.66)	3.63	(8.67)	73.38**	(37.22)
All	-37.23**	(18.48)	-7.64	(5.35)	4.95	(10)	87.15**	(44.14)
Non-OECD Countries								
Manufacturing	-6.92	(19.49)	-1.12	(0.76)	3.27	(3.24)	30.5***	(10.2)
Agriculture	-16.99	(18.54)	3.83	(3.71)	-2.98	(3.43)	-5.08	(11.27)
Services	–	–	-2.68**	(1.25)	0.36	(1.29)	2.39	(4.67)
All	-8.31	(17.14)	-1.98***	(0.76)	0.72	(1.12)	6.58*	(3.66)

Notes: Table shows regressions from different tax sources on CO2 emissions intensities. Each panel represents a different subset of countries estimated. Each row in each panel subsets a different sector. The columns from left to right are the dollars of tariff revenue collected per ton of CO2 imported ($/ton), dollars of production tax revenue per ton of CO2 produced, dollars of material tax revenue collected per ton CO2 from intermediate good consumption, dollars of final good tax revenue collected per ton of CO2 from final good consumption. The top 1% of tariffs/taxes and emission rates were removed from the analysis. Total emissions are measured in million tons of CO2 and output is measured in millions of dollars 2014 US$. All data is from 2014 and standard errors are clustered by sector. p-value: $* < 0.1$, $** < 0.05$, $*** < 0.01$

Table A2: Tax revenue vs emissions intensities

	Dependent Variable: Tax revenue per ton of emissions			
	Tariff	Prod. Tax	Mat. Tax	Cons. Tax
Panel 1: CO2				
CO2	-0.51	-0.22	0.72	2.34
Standard Errors				
COMM	(0.18)	(0.34)	(0.86)	(2.93)
DST	(0.05)	(0.19)	(0.46)	(1.98)
Panel 2: GHG				
GHG	-0.57	-0.32	0.02	-0.09
Standard Errors				
COMM	(0.19)	(0.26)	(0.63)	(2.47)
DST	(0.06)	(0.22)	(0.39)	(1.45)

Notes: Table shows regressions from different tax sources on CO2 and GHG emissions intensities. Each panel represents a different subset of emissions estimated along with the standard errors when clustered by industry versus by reporting country. The columns from left to right are the dollars of tariff revenue collected per ton of CO2/GHG imported ($ton), dollars of production tax revenue per ton of CO2/GHG produced, dollars of material tax revenue collected per ton CO2/GHG from intermediate good consumption, dollars of final good tax revenue collected per ton of CO2/GHG from final good consumption. The top 1% of tariffs/taxes and emission rates were removed from the analysis. Total emissions are measured in million tons of CO2/GHG and output is measured in millions of dollars 2014 US$. WIOD MRIO and tariff data is from 2010 and the environmental and tax data is from 2014.

Table A3: Tax revenue vs GHG intensities

	Dependent Variable: Tax revenue per ton of GHG							
	Tariff		Prod. Tax		Mat. Tax		Cons. Tax	
	Est.	s.e.	Est.	s.e.	Est.	s.e.	Est.	s.e.
All Countries								
Manufacturing	5.35	(5.52)	-1.52	(1.89)	-4.79***	(1.27)	-5.16	(5.42)
Agriculture	-1.5	(1.55)	-0.06	(0.07)	-0.28***	(0.07)	-0.43***	(0.11)
Services	–	–	-2.94**	(1.5)	1.94	(2.39)	14.56	(9.38)
All	-0.52	(1.84)	-0.17	(0.13)	-0.44**	(0.2)	-0.17	(0.64)
OECD Countries								
Manufacturing	-4.03	(7.42)	-30.09	(38.26)	-8.85	(6.48)	-5.78	(35.9)
Agriculture	0.75	(2.85)	-0.32	(0.53)	-1.68**	(0.85)	-7.55***	(1.9)
Services	–	–	-6.59	(6.36)	3.64	(8.61)	71.87**	(37.1)
All	0.26	(2.59)	-1.18	(1.15)	-1.79	(1.54)	2.05	(10.05)
Non-OECD Countries								
Manufacturing	7.16	(5.14)	-1.07	(1.84)	-4.15***	(0.87)	-4.16	(3.08)
Agriculture	-1.63*	(0.89)	0.01	(0.06)	-0.1**	(0.05)	-0.2*	(0.11)
Services	–	–	-2.29**	(0.98)	0.48	(1.24)	2.33	(4.56)
All	-0.46	(1.6)	-0.06	(0.09)	-0.28*	(0.16)	-0.32	(0.28)

Notes: Table shows regressions from different tax sources on GHG emissions intensities. Each panel represents a different subset of countries estimated. Each row in each panel subsets a different sector. The columns from left to right are the dollars of tariff revenue collected per ton of GHG imported ($/ton), dollars of production tax revenue per ton of GHG produced, dollars of material tax revenue collected per ton GHG from intermediate good consumption, dollars of final good tax revenue collected per ton of GHG from final good consumption. The top 1% of tariffs/taxes and emission rates were removed from the analysis. Total emissions are measured in million tons of GHG and output is measured in millions of dollars 2014 US$. All data is from 2014 and standard errors are clustered by sector. p-value: $* < 0.1$, $** < 0.05$, $*** < 0.01$

Table A4: Tax revenue vs CO2 intensities

	Dependent Variable: Tax revenue per ton of CO2							
	Tariff		Prod. Tax		Mat. Tax		Cons. Tax	
	Est.	s.e.	Est.	s.e.	Est.	s.e.	Est.	s.e.
All Countries								
Manufacturing	-11.71***	(3.46)	-1.88	(1.27)	1.71	(3.44)	47.5***	(11.88)
Agriculture	-19.46***	(7.7)	-2.56	(5.8)	-4.48	(4.09)	4.95	(13.23)
Services	–	–	-3.29***	(1.1)	1.83*	(1.01)	14.8***	(3.38)
All	-12.8***	(3.35)	-2.67***	(0.85)	1.51	(1.05)	19.49***	(3.68)
OECD Countries								
Manufacturing	-34.32***	(5.65)	-20.2	(19.52)	20.51	(12.99)	209.8***	(51.34)
Agriculture	-52.28***	(9.45)	-2.89	(8.42)	-10.02	(7.33)	41.91	(29.38)
Services	–	–	-7.34***	(2.54)	3.63	(2.96)	73.38***	(12.97)
All	-37.23***	(5.42)	-7.64**	(3.18)	4.95	(3.2)	87.15***	(15.66)
Non-OECD Countries								
Manufacturing	-6.92**	(3.48)	-1.12	(0.95)	3.27	(3.44)	30.5***	(10.65)
Agriculture	-16.99*	(9.93)	3.83	(4.2)	-2.98	(4.61)	-5.08	(13.52)
Services	–	–	-2.68**	(1.15)	0.36	(0.87)	2.39	(1.88)
All	-8.31***	(3.38)	-1.98***	(0.8)	0.72	(1.03)	6.58***	(2.66)

Notes: Table shows regressions from different tax sources on CO2 emissions intensities. Each panel represents a different subset of countries estimated. Each row in each panel subsets a different sector. The columns from left to right are the dollars of tariff revenue collected per ton of CO2 imported ($/ton), dollars of production tax revenue per ton of CO2 produced, dollars of material tax revenue collected per ton CO2 from intermediate good consumption, dollars of final good tax revenue collected per ton of CO2 from final good consumption. The top 1% of tariffs/taxes and emission rates were removed from the analysis. Total emissions are measured in million tons of CO2 and output is measured in millions of dollars 2014 US$. All data is from 2014 and standard errors are clustered by destination. p-value: $* < 0.1$, $** < 0.05$, $*** < 0.01$