Using Gravity Trade Model to Assess the Impacts of Tariffs and Carbon Tariffs on Trade Flows and Carbon Emissions Embodied in Export*

51-198236 Bei Zhao†

June 2021

*I express my thanks to Professor Taiji Furusawa for his continuous guidance and support throughout this paper. I would also like to thank Dr. Konstantin Kucheryavyy, Dr. Daisuke Fujii, and Shoki Kusaka for their valuable comments. Please note that neither the institution nor the examiners are responsible for the methods and results.

†The University of Tokyo; Email: zhao-bei111@g.ecc.u-tokyo.ac.jp

Abstract

Carbon tariff has been widely studied as a prominent climate policy. This paper assesses tariff, a widely practiced trade policy, and carbon tariff that marries environmental and trade policy together to see their impacts on trade flows and export emissions. First, I adopt the gravity trade model to calculate the trade elasticities across different industries, which is a practice that most environmental researchers hardly take. In the perspective of international trade, trade elasticities have a decisive impact on tariffs' influences. Therefore, in an attempt to evaluate the Carbon tariff, which is also a particular type of tariff, it would be better to consider real trade elasticities. Based on my estimations of trade elasticities, I evaluate the cross-country and cross-industry impacts of tariff and carbon tariff on trade flows and carbon emissions. Moreover, unlike most literature that majorly focuses on total carbon emissions, this paper chooses a specific angle to take a close look at export emissions. To see how tariffs and carbon tariffs affect total emissions is undoubtedly very meaningful. Still, it is also intriguing and noteworthy to get a specific look at the export emissions that reside in the country's total emissions and directly reflect the level of carbon leakages. I find that a 1% increase of tariff reduces world trade flows of 13 industries by 4.04%, which entails a 7.36% reduction of carbon emissions embodied in exports. I also discover that inelastic industries tend to have higher carbon intensities, implying that a higher tariff and carbon tariff should be implemented to target industries with high carbon intensities. Furthermore, my estimations show the threshold carbon tariffs for the 13 industries, which have an average of \$40/tCO2 carbon tariff. This paper suggests that trade elasticities need to be considered when designing tariffs and carbon tariffs to reduce carbon leakage. A detailed analysis of China-US trade is also provided.

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1 Introduction

Climate change driven by human-induced emissions of greenhouse gases has been jeopardizing wildlife and humankind profoundly. Biodiversity is deteriorating; people from small island countries are losing their homes due to accelerated sea levels; countless irreversible consequences induced by climate change are happening daily. Every more greenhouse gas we emit now is putting more pressure on our next generations. Even though many efforts have been made to fight climate change, the accelerating greenhouse gases make it clear that humankind still hasn't found the remedy. As many countries implement stringent environmental policies in an attempt to reduce pollution, manufacturing and production lines that produce a high level of carbon pollution move to other countries. Simultaneously, these countries with stringent environmental policies import large amounts of pollution-intensive products to meet domestic demands. Implementing a carbon tariff on pollution-intensive goods is expected to alleviate this problem. However, it may increase business costs and reduce investment and economic growth, and these are the fundamental reasons many countries avoid implementing such a carbon tariff. The research aims to quantitatively show the impact of tariffs and carbon tariffs on trade and carbon emissions. The results will contribute to the design of carbon tariffs across many countries and even in the negotiation process for the following global climate agreement.

1.1 The Limitation of Existing Multilateral Climate Agreements

In 1992, the first International climate treaty, the United Nations Framework Convention on Climate Change (UNFCCC), urged developed countries to stabilize their greenhouse gas (GHG) emissions. One highlight of the UNFCCC was the principle of "common but differentiated responsibilities and respective capabilities" (CBDR-RC). Under this principle, countries were classified into three groups: the Annex I countries consisted of the industrialized countries that historically contributed to climate change the most and therefore had the responsibility for leading the mitigation of GHG emissions; Annex II countries included all of the Annex I countries except for those in transition to democracy and market economies. In addition, Annex II countries were requested to provide financial resources and technology transfer to developing countries; the third group was the non-Annex I group covering developing countries (UNFCCC, 1992). The non-Annex countries did share the common responsibility of emission reduction. Still, due to the differentiated responsibility, these countries did not have any obligation to take binding emission reduction targets, and their priority was to achieve sustainable development (Izzet, 2017).

The Kyoto Protocol entered into force in 2005 to urge industrialized countries (Annex I countries) to stabilize their GHG emissions at 1990 levels by 2000. One progress that the Kyoto Protocol has made based on the UNFCCC was that the Protocol encouraged developed countries to reduce GHG emissions and obliged them to make a difference with binding commitments under international law (Gallo, 2018). Under the Kyoto Protocol, 36 countries listed in Annex B agreed to reduce emission, and 27 countries out of 36 overachieved their targets between the 2008-2012 period, while the other nine states did not achieve the goals.

Following the Kyoto Protocol, the Paris Agreement adopted by the twenty-first Conference of Parties (COP-21) of the UNFCCC in 2015 seemed to turn a new page of international climate agreements. Instead of sticking with the Annex system to classify countries' responsibilities, the Paris agreement blurred the distinction between developed and developing countries to be in line with the fact that some non-Annex countries have escalated carbon emissions and should also submit plans for emission reductions.

Kortum and Weisbach (2020) think global negotiations cannot achieve a uniform approach to climate change for now. Looking over these international climate agreements' characteristics, according to Zhao(2019), it is not surprising why significant outcomes cannot be achieved. The UNFCCC provides the rationale for Non-Annex countries' resistance to taking emission mitigation targets. Meanwhile, many rising developing countries are experiencing a tremendous increase in carbon emissions, which are colossal enough to undermine the effort of Annex I countries. The following Kyoto Protocol indeed achieves some extends of significance. Still, some Annex I countries' failures of achieving promised goals deteriorate the overall influence of the Protocol by sending the message that free-riding bears no punishment. Thus, the resistance from non-Annex countries and the insufficient efforts from Annex I have led to a failure in the progress of climate change negotiations for the post-2012 regime. With all the unresolved problems, the Paris Agreement brings a new challenge to the attainment of a binding agreement on carbon emission reduction as the preposition of the successful implementation of the Paris Agreement requires clear guidance, rules, and procedures for the definition of developed and developing countries and their responsibilities respectively. The tug of war between developed and developing countries and the conflicts between national interest and global interest prevent effective binding agreements on carbon emission reduction from happening.

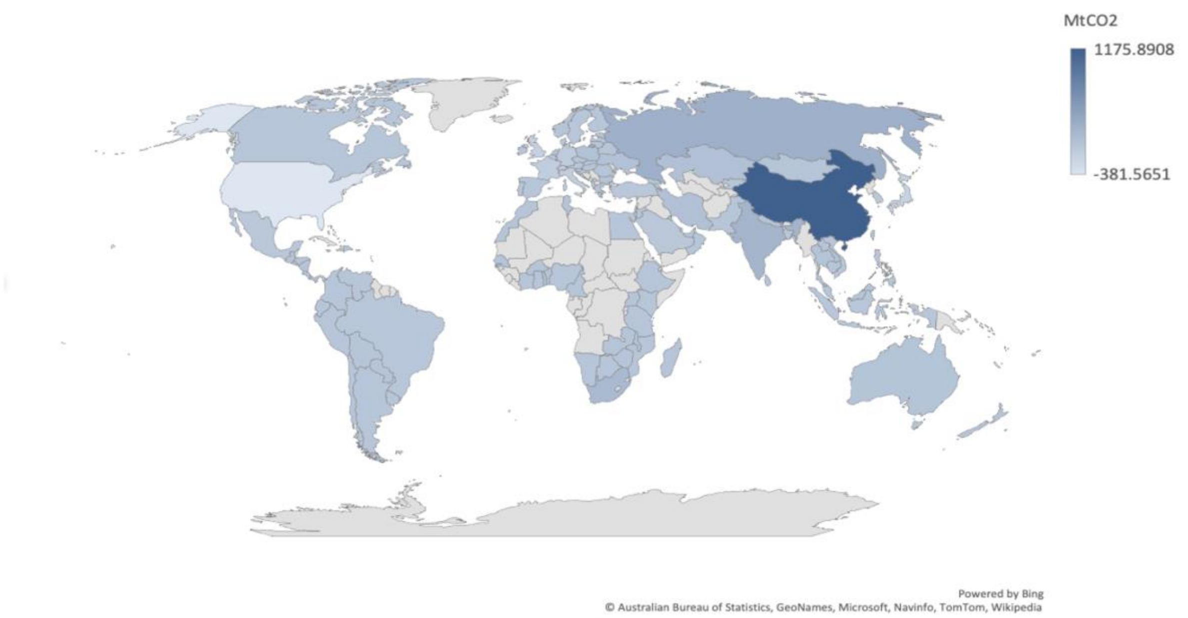
Besides the weaknesses of these multilateral agreements summarized above, another profound loophole is that they only demand countries to reduce their territorial CO2 emissions, which are emissions physically occurring within the national borders, which overlooks the relationship between carbon emissions and international trade. The reality is that the reduction of a country's territorial emissions can be partly offset by importing products from other countries that lead to the increase of other countries' territorial emissions. This phenomenon is known as carbon leakage (Larch, 2017).

1.2 Carbon Leakage and Carbon Tariffs

The relationship between carbon emissions and trade policy has been of significant interest for decades. Felder and Rutherford (1993) conclude that two reasons lead to carbon leakage. The first reason is that a higher carbon price induced by a carbon tax, tradable quotas, or stricter regulation leads to a higher cost of the goods from the country adopting the policy. It can incentivize the carbon emission-intensive productions to shift to countries with lax regulation, increasing emissions in these countries. Secondly, as a higher carbon price can decrease the demand for energy in countries implementing the policy, the world price of energy would fall and lead other countries' production to become more carbon emission-intensive. Many countries, especially developed countries, have witnessed a very outstanding decrease in their territorial carbon emissions. However, it does not mean their consumption emissions that the carbon emissions country consumes have been decreased that much. By importing carbon-intensive products from other countries, especially developing countries, the importing country does not need to burden the allegation for emitting more carbon emissions even though its citizens still live a life with a high carbon footprint. According to Hausfather (2017), the territorial emissions dropped by 11% in Switzerland, but its consumption emissions have actually been increased by 44% since 1990. Meanwhile, China's production emissions have increased by 430%, but their consumption emissions have grown by less than 400%, which means more than 30% increase of Chinese territorial emissions is contributed by foreign demand.

The gap between territorial and consumption emissions is called transfer or carbon emissions embodied in international trade. Figure one shows transfer emissions across countries in 2015. Countries in darker colors are CO2 exporters that bear high transfer emissions, meaning they produce lots of good for foreign demand that their export emissions exceed their import emissions. These countries are mostly non-OECD counties, and among them, the most evident example is China, with 1176 mtCO2. At the same time, countries in lighter colors are CO2 importers that have very small or negative transfer emissions. It means they import large amounts from foreign countries so that their carbon emissions embodied in imports surpass their carbon emissions embodied in exports. United States has the lowest transfer emission, with Japan as the second-lowest and then the U.K. It seems like it is a story that rich countries get goods, poor countries get emissions. However, the reality is way more complex.

Figure 1: World Transfer Emissions



Notes: Transfer emissions data are taken directly from Global Carbon Atlas.

Computable general equilibrium (CGE) models have been widely used to measure the economic and decarbonization impact of the carbon tax. For example, Goulder and Hafstead (2017) estimate that a $40 per ton carbon tax starting in 2020 and growing at 5 percent real annually would reduce GDP by slightly over 1 percent in 2035. Elliott and Foster(2010) adopt an open-source

CGE model called CIM-EARTH. They find out that if Annex B Kyoto countries were to impose a carbon tax on producers of $105 per tonne C($29 per tonne CO2), over 20 percent of reductions made by them would be undone by the increased carbon emissions in developing countries. Adding full border tax adjustments eliminates this leakage and leads to slightly lower global emissions.

Another stream of approach that enables ex-ante investigations of environmental policy scenarios in an international trade context is the use of structural gravity models. These models explain trade flows by country sizes, distances, and multilateral resistance terms (Eaton and Kortum, 2002; Anderson and van Wincoop, 2003). Egger and Nigai(2012) analyze goods trade and services trade by conducting a general equilibrium comparative static estimate of trade policy's trade and welfare effects using the gravity equation. Aichele (2013) estimates a gravity model in Anderson and van Wincoop (2003) to quantify emission relocation in general equilibrium. She finds out that an E.U. emission allowance price of $15 leads to a leakage rate of about 10%. Egger and Nigai(2015) integrate an energy sector into the Eaton-Kortum(2002) type general equilibrium model of international trade to compare different policy measures to reduce a country's energy demand. To the best of my knowledge, Larch and Wanner (2017) are the first to analyze carbon tariffs in a structural gravity model. They follow Shapiro (2016) to add the disutility due to carbon emissions to indicate the multiplicative damages from CO2 pollution. Larch and Wanner(2017) estimate a gravity model with the integration of carbon tariffs and then decompose the emission effects into scale effect, composition effect, and technique effect following Grossman and Krueger(1993) and Copeland and Taylor(1994). By conducting two counterfactuals: carbon tariffs as an isolated measure, and carbon tariffs accompanying other climate policy, they find out that carbon tariffs can reduce carbon leakage and contribute to global decarbonization. Nevertheless, while carbon tariffs reduce welfare in most countries, the welfare loss is more evident in developing countries.

Inspired by Nobel laureate Paul Krugman's comments that trade policy may possess the potential to be a good tool in the case of non-economic objectives such as carbon emissions in his New York Times column in 2009, this paper assesses the possibility of tariffs as a widely practiced trade policy, and in carbon tariffs that marry environmental and trade policy together, in terms of their impacts on trade flows and export emissions. First, I adopt the gravity trade model to calculate the trade elasticities across different industries, which is a practice that most environmental researchers hardly take. For example, Larch and Wanner (2017) also use the gravity trade model in their analysis, but instead of estimating the trade elasticities, they set all industries' trade elasticities as -5. In the perspective of international trade, trade elasticities have a decisive impact on tariffs' influence. Therefore, in the attempt to evaluate the Carbon tariff, which is also a particular type of tariff, it would be better to consider real trade elasticities. Based on my estimations of trade elasticities, not only can I evaluate cross-country differences of the effects, but I also can obtain cross-industry differences of effects. Moreover, unlike most literature that majorly focuses on total carbon emissions, this paper chooses a specific angle to take a close look at export emissions. To see how tariffs and carbon tariffs affect total emissions is undoubtedly very meaningful. Still, I think it is also intriguing and meaningful to get a specific look at the export emissions which reside in the country's total emissions and directly reflect the level of carbon leakages.

This paper finds that a 1% increase of tariff reduces world trade flows of 13 industries by 4.04% and reduces carbon emissions embodied in exports by 7.36%. Furthermore, my estimations show that the threshold carbon tariffs (carbon tariffs that lead to zero export) of the 13 industries range from 0.9738 $/tonCO2 for the manufacture of basic mentals to 110$/tonCO2 for the manufacture of computer, electronic and optical products. This paper finds out that carbon tariff can better target highly emitted industries. For example, an $1/tCO2 carbon tariff can be translated into nearly 13% tariff for the manufacture of basic mentals. Therefore, a reasonable carbon tariff is a better tool than a tariff for environmental purposes, and its negative impact on trade flows is more acceptable than a tariff that leads to the same reduction in export emissions would bring.

After a world analysis, this paper provides a detailed analysis of US-China trade. One progress here is I estimate carbon intensities at the industry level in China and the U.S. separately. We can see how different carbon intensity levels would affect carbon tariff's impacts in these two world largest economies. Every 1% increase of a universal tariff would reduce Chinese exports and American exports by nearly 3% and 4%, respectively. Chinese export emissions would decrease by almost 8%, which is more than American export emissions decrease rate at 6%. Nevertheless, tariffs almost have similar impacts on Chinese export and American export. In contrast, a carbon tariff's influence in China and America are more different because China's carbon intensities in most industries are much higher than that of the U.S. We can see a carbon tariff would hurt Chinese exports more than it does to U.S. exports. I also consider the case when America would impose carbon tariffs that are big enough to stop Chinese exports, what would happen to the domestic carbon emissions in America and some of America's influential trade partners – Canada, Mexico and Japan. I found that that if all Chinese exports are compensated by America's domestic production, America's territorial emissions would increase by 33744361.97 tons CO2, which is only 14% of carbon emissions embodied in Chinese exports to the US. If all Chinese exports to the US are replaced by Canada's exports, its carbon emissions are only 20% of carbon emissions embodied in Chinese exports to the US. In contrast, if America replaces Chinese exports with Japanese exports or Mexican exports, the carbon emissions embodied are actually higher than that in Chinese exports.

2 Dataset

My observations consist of 63 economies, 13 target industries in OECD Inter-Country Input-Output (ICIO) database, and 11 years from 2005 to 2015. This paper will refer domestic carbon emissions for foreign final demand as export emissions or emissions embodied in export.

2.1 Dataset for Gravity Estimations

The gravity control variables, including distance, common language, contiguity, are from the CEPII gravity database. Trade flows are from the BACI(CEPII) database, which provides bilateral trade flows at the HS6 level. BACI is based on UN-COMTRADE, but a feature of the BACI database is that it reconciles Comtrade mirror flows to provide trade flow for each exporter-importer-year t, so that export values and import values are identical in year t. I obtain the bilateral weighted average tariff for each HS6 product from the United Nations Statistical Division, Trade Analysis and Information System (UNCTAD-TRAINS). As the export emissions data is at OECD ICIO level, which overlaps with ISIC4 level, to analyze trade flows and export emissions at the same industry level, I aggregate HS6-level products into ISIC4 level to attain bilateral trade flows and tariffs at the ISIC4 level.

2.2 Dataset for Export Emissions

OECD indicators on Carbon dioxide (CO2) emissions embodied in international trade are derived based on the 2018 editions of OECD Inter-Country Input-Output (ICIO) Database and of International Energy Agency (IEA) statistics on CO_2 emissions from fuel combustion. Carbon dioxide (CO2) emissions embodied in international trade can be divided into export and import emissions. This paper only takes the data of export emissions to construct a dataset with total export emissions of 63 target economies during the period 2005 to 2015. The detailed descriptive statistics of variables used are illustrated below:

Table 1: Descriptive Statistics

Variable	Obs	Mean	Std. dev.	Min	Max
Trade flows ($)	422,906	6091983	1.64E+08	1	3.53E+10
Tariff(%)	421,503	5.575479	6.017623	0	147.33
Distance	422,906	8132.878	4650.492	117.345	19812.04
Language	422,906	0.0917272	0.2886409	0	1
Contiguity	422,906	0.0258781	0.1587718	0	1
Export emissions (tonCO2)	422,906	55061.34	741297.9	0	1.07E+08

3 Estimating Trade Elasticities Across Industries

3.1 Estimation

To estimate how a tariff affects trade flows and carbon emissions embodied in exports, I start by using the gravity model to calculate the industry-level trade elasticities. Let i be the exporter and j be the importer. The structural gravity model is formulated as below following Head and Mayer (2014):

$$X_{ij} = \frac{Y_i}{\Pi_i}\frac{X_j}{P_j}\phi_{ij}$$

According to Anderson and van Wincoop (2013), P_j is defined as inward multilateral resistance representing the importer's ease of market access, along with Π_i is coined as outward multilateral resistance illustrating exporter's ease of market access. Φ_{ij} is here to capture bilateral accessibility of importer j to exporter i. After taking a log of the structural gravity model, it becomes:

$$\ln X_{ij} = \Phi_i + \Omega_j - \theta \ln\phi_{ij}$$

where $\phi_{ij} = \tau_{ij}^{-\theta}\left(1 + t_{ij}\right)^{-\theta}$ with τ_{ji} as the iceberg trade costs and t_{ji} as the import tariffs, hence

$$\ln X_{ij} = \Phi_{it} + \Omega_{jt} - \theta \ln \tau_{ij} - \theta \ln\,(1 + t_{ij})$$

Following Yotov et al. (2016), the standard practice is to proxy for the bilateral trade cost term $\ln\tau_{ji}$ by using a series of observable variables, and here I use distance, contiguity, and common language,

$$\ln\tau_{ij} = \beta_1 \ln Dist_{ij} + \beta_2 CNTG_{ij} + \beta_3 LANG_{ij}$$

By replacing the bilateral trade cost with the observable variables above, the equation that I use to estimate by OLS is as follow:

$$\ln X_{ij} = \Omega_j + \Phi_i - \theta(\,\beta_1 \ln Dist_{ij} + \beta_2 CNTG_{ij} + \beta_3 LANG_{ij}) - \theta \ln\left(1 + t_{ij}\right) + \varepsilon_{ij} \qquad (1)$$

Where θ represents the trade elasticity. According to Yotov et al. (2016), there are some challenges with estimating the gravity equation that need to be carefully addressed. The first obvious challenge is that the multilateral resistance terms P_i and Π_j are not directly observed. To solve this challenge, I follow Hummels (2001), Feenstra (2016), and Olivero and Yotov (2012) to use exporter, importer, and time fixed effects with panel data to account for the multilateral resistance terms. Another challenge to be addressed is the existence of zero trade flows. Many researchers apply the Poisson Pseudo Maximum Likelihood (PPML) estimator to estimate the gravity model to overcome the zero-trade flow problem; however, I still use OLS with the exporter, importer, and time fixed effects for the estimation. The reason is that the trade flows are grouped into 13 big industries by summing subindustries' trade flows for each country pair in each year. Hence, there is no zero-trade flow in my dataset, making OLS estimation feasible. Another reason is that OLS estimation delivers better results in terms of the correctness of the coefficient signs. A detailed comparison between OLS and PPML for some industries can be found in Appendix A.

3.2 Regression Results

Table 2 presents the elasticities for target industries in OECD Inter-Country Input-Output (ICIO) shown in the first column, which also overlaps with the ISIC4 sectors. The second column lists the industry level elasticities, followed by the third column reporting the standard errors. I omit the agriculture and food industries because their elasticities are nearly zero, which renders them almost unaffected by the change of tariff. The elasticities range from -0.953 to 11.719, with a mean of -4.4 that lies in the range of estimates obtained from the literature.[1] All elasticities have a negative sign and meet statistical significance.

I group all industries into the elastic and inelastic sectors based on their rank of elasticities. Among them, the manufacture of basic metals is the most elastic industry, while the manufacture of rubber and plastic is the least elastic one. Industry trade elasticities capture the impact of the tariff on trade flows; in other words, industry trade elasticities are equivalent to the changes rate of industry trade flows given a 1% increase of tariff. For example, if an importing country imposed an extra 1% tariff on an export country's industry of Mining and quarrying, this exporter would experience a 3.072% decrease in their export of Mining and quarrying. With higher elasticities, industries are more sensitive to a change of tariff; consecutively, due to the change of trade flows, the carbon emissions embodied in trade also fluctuate.

[1] Fontagné, Guimbard, and Orefice(2019) obtained trade elasticities centered around -5 after estimating them at the product level(6-digit of the Harmonized System). Larch and Wanner(2017) also adopt -5 as the universal trade elasticity in their analysis.

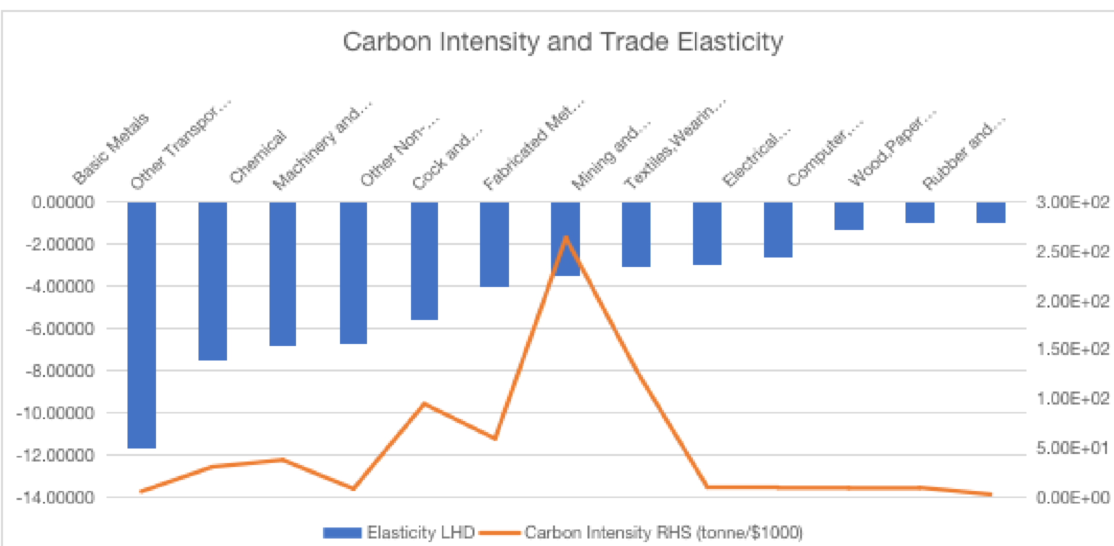
Table 2: Elasticity Estimates

Industry	Elasticity	S.E.	Elastic Level
Mining and Quarrying	-3.072***	(0.62)	Inelastic
Textiles,Wearing apparel and Related Products	-3.022***	(0.20)	Inelastic
Wood, Paper Products and Print	-0.956***	(0.24)	Inelastic
Cock and Refined Petroleum Products	-4.056***	(0.79)	Elastic
Chemical	-6.775***	(0.42)	Elastic
Rubber and Plastics Products	-0.953***	(0.33)	Inelastic
Other Non-metallic Mineral Products	-5.607***	(0.32)	Elastic
Basic Metals	-11.719***	(0.55)	Elastic
Fabricated Metal Products	-3.479***	(0.42)	Inelastic
Computer, Electronic and Optical Products	-1.309**	(0.42)	Inelastic
Electrical Equipment	-2.650***	(0.39)	Inelastic
Machinery and Equipment	-6.692***	(0.45)	Elastic
Other Transport Equipment	-7.500***	(0.51)	Elastic

Notes: *, **, and *** denote statistical significance at the 10, 5, and 1 percent levels, respectively. Among 13 industries, the top 6 absolute values are labeled elastic; the other 7 are labeled inelastic.

The relationships of tariff, trade flows, and carbon emissions are worthy of being explored for trade policy and environmental policy. Let's assume industries' trade elasticities were negatively related to their carbon intensity; in other words, the higher the carbon intensity, the lower the elasticity or vice versa. Therefore, imposing a tariff on an inelastic industry would target high carbon intensity as well. Meanwhile due to the low elasticity of this industry, an introduction of a higher tariff would not hurt the trade flows dramatically. If this assumption is valid in reality, it would be excellent news to policymakers and would likely incentivize the adoption of tariffs for decarbonization purposes. Hence, I carefully examine the relationship between trade elasticities and carbon intensities across industries. The carbon intensity is represented by the ratio of carbon emissions embodied in export and the export values in 2015 at the industry level. I use year 2015's carbon intensities instead of using the average carbon intensities across years because the latest year's carbon intensities can better represent future carbon intensities. The figure 2 presents the carbon intensities and trade elasticities in the 13 industries. An interesting phenomenon is that most inelastic industries do have relatively higher carbon intensities. Therefore, I run a regression with carbon intensity as the dependent variable and trade elasticity as the independent variable. The regression indicates that it is true that industry with lower elasticity has relatively higher carbon intensity and the result is statistically significant. The regression table and regression diagnosis plot can be found in the Appendix C.

Figure 2: Trade elasticities and Carbon Intensities



4 Model

This paper conducts experiments to predict the impact of tariffs and carbon tariffs on trade flows and carbon emissions embodied in exports. First, I develop a model to translate carbon tariff (dollar per tCo2) into standard tariff to simply make use of trade elasticities to predict how a change of carbon tariff affects the change of trade flows and carbon emissions embodied in exports. The latest year in my dataset--2015, is set as the base year. Industries are indexed by k ∈ {1, 2…N}, and importing countries are indexed by j ∈ {1, 2…M}.

4.1 Trade Flows Given a Tariff

For the same industry, I sum up the trade flows in all country pairs to obtain that industry's total trade flow X_k. Hence the total trade flows TX is the sum of industry total trade flow X_k:

$$TX = \sum_{k=1}^{N} X_k \ , \tag{2}$$

θ_k is the industry level elasticities, which is tantamount to the change of industry k's trade flows given a 1% tariff change. Hence, given the change rate of tariff $\frac{\Delta\tau}{\tau}$, Change rate in industry k's trade flows is $\frac{\theta_k \Delta\tau}{\tau}$. In order to simplify the calculation of change rate of total trade flows, $\frac{\theta_k \Delta\tau}{\tau}$ is multiplied with X_k to represent ΔX_k:

$$\frac{\Delta X_k}{X_k} = (X_k \times \frac{\theta_k \Delta\tau}{\tau})/X_k \ , \tag{3}$$

After obtaining the change in all industries' trade flows ΔX_k, the total change of total trade flows ΔTX is given by the sum of ΔX_k, and after divided by the total trade flow TX, the change rate of total trade flow is given below:

$$\frac{\Delta TX}{TX} = \frac{(X_1 \times \frac{\theta_1 \Delta\tau}{\tau}) + (X_2 \times \frac{\theta_2 \Delta\tau}{\tau}) + \cdots + (X_N \times \frac{\theta_N \Delta\tau}{\tau})}{TX}$$

$$\frac{\Delta TX}{TX} = \frac{\frac{\Delta\tau}{\tau} \times \sum_{k=1}^{N} (X_k \theta_k)}{\sum_{k=1}^{N} X_k} \ . \tag{4}$$

4.2 Carbon Emissions Embodied in Export Given a Tariff

Even though carbon intensities vary a lot across different industries, I assume there would not be any drastic change of carbon intensities within the same industry in the short run in this paper. Therefore, I can use the same method for trade flow change rates to predict export emissions' changes. E_k is Industry k's export emissions in 2015, and after summing up all industries' export emissions, I obtain the total export emissions shown as TE:

$$TE = \sum_{k=1}^{N} E_k \ , \tag{5}$$

As industry k's export emissions are simply a function of its trade flows, and each industry's carbon intensity will not change in the short term, industry k's export emissions share the same change rate with its trade flows which is $\frac{\theta_k \Delta\tau}{\tau}$. The only difference is that the weight changes from X_k to E_k:

$$\frac{\Delta E_k}{E_k} = (E_k \times \frac{\theta_k \Delta\tau}{\tau})/E_k \ , \tag{6}$$

Using the same method, I attain the change rate of total export emissions given a tariff:

$$\frac{\Delta TE}{TE} = \frac{(E_1 \times \frac{\theta_1 \Delta\tau}{\tau}) + (E_2 \times \frac{\theta_2 \Delta\tau}{\tau}) + \cdots + (E_N \times \frac{\theta_N \Delta\tau}{\tau})}{TE}$$

$$\frac{\Delta TE}{TE} = \frac{\frac{\Delta\tau}{\tau} \times \sum_{k=1}^{N}(E_k \theta_k)}{\sum_{k=1}^{N} E_k} \ . \tag{7}$$

4.3 Trade Flows and Export Emissions Given a Carbon Tariff

Carbon tariff is very different from normal tariff as it is determined by the carbon emissions embodied in the products. Therefore, different products that emit a different level of carbon emissions bear different carbon tariffs. The nature of carbon tariff makes it harder to implement compared with standard tariff. I develop a simple way to translate carbon tariff into normal tariff, so I can make the most use of the trade elasticities to estimate the impact of a carbon tariff in the possibly simplest way.

Given a carbon tariff equal to p in dollars per ton CO2. The total carbon tariff charged by importing country j in industry k equals p multiplying the industry k's export emissions E_k^j . Therefore, after dividing the total carbon tariff changed by the trade flows, the carbon tariff is translated into a ratio of the trade flows τ_k^j, which is in the same form of a normal tariff. I name τ_k^j the tariff equivalent carbon tariff in industry k:

$$\tau_k^j = \frac{pE_k^j}{X_k^j}, \qquad (8)$$

Following equation 8, the change rate of tariff after the implementation of a carbon tariff p is:

$$\frac{\Delta T_k^j}{T_k^j} = \frac{\Delta \tau_k^j}{T_k^j} = \frac{pE_k^j}{X_k^j T_k^j} \qquad (9)$$

Now, trade flows' change rate $\frac{\Delta X_k}{X_k}$ in industry k should be equal to the change rate of the export emissions in industry k as well because this paper assumes carbon intensity in all industries and countries would not change in short run. Hence trade flows' change rate of industry k equals to the ratio of the aggregation of trade flow changes in all countries and industry k's total trade flows.

$$\frac{\Delta X_k}{X_k} = \frac{\Delta E_k}{E_k} = \frac{\sum_{j=1}^{M} \Delta X_k^j}{\sum_{j=1}^{M} X_k^j}, \qquad (10)$$

The change rate of X_k^j is represented by the change rate of tariff multiplies by the trade elasticity:

$$= \frac{\sum_{j=1}^{M} \theta_k X_k^j \frac{\Delta T_k^j}{T_k^j}}{\sum_{j=1}^{M} X_k^j},$$

Then I plug equation (9) into the above equations, we have:

$$= \frac{\sum_{j=1}^{M} \theta_k X_k^j \frac{pE_k^j}{X_k^j T_k^j}}{\sum_{j=1}^{M} X_k^j},$$

$$= \frac{\sum_{j=1}^{M} \frac{\theta_k pE_k^j}{T_k^j}}{\sum_{j=1}^{M} X_k^j} \tag{11}$$

Equation (11) delivers the final format of how trade flows and export emissions of industry k respond to a carbon tariff. To see how trade flows and export emissions of importing country j, I follow the same method with slight adjustment:

$$\frac{\Delta X_j}{X_j} = \frac{\Delta E_j}{E_j} = \frac{\sum_{k=1}^{N} \Delta X_k^j}{\sum_{k=1}^{N} X_k^j}, \tag{12}$$

$$= \frac{\sum_{k=1}^{N} \frac{\theta_k pE_k^j}{T_k^j}}{\sum_{k=1}^{N} X_k^j}. \tag{13}$$

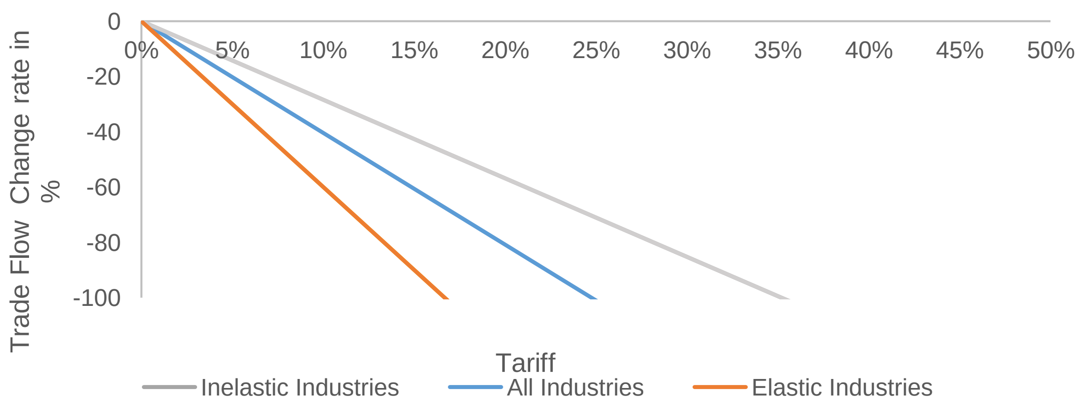
5 Results

5.1 Tariff's Impact on Trade Flows and Export Emissions

As was stated above, given each industry's trade elasticity, I can illustrate how trade flows and export emissions respond to the change of tariff in each sector. Now I consider three scenarios. The first scenario is imposing tariffs on all target industries that include all elastic and inelastic industries. The second scenario assumes there are only elastic industries in the world and then impose tariffs on them. The third scenario is to assume there are only inelastic industries in the world and then impose tariffs on them. I conduct these three scenarios because we can see how tariffs impact the actual trade flows and export emissions through scenario one. Furthermore, we can see how the industry's elasticity influences the tariff's impact by looking at scenarios two and three.

Figure 3 manifests how the three scenarios respond to different tariff rates. The horizontal axis represents tariff in percentage and starts from 0. The vertical axis is the trade flow change rate, which is also in percentage and ranges from 0 to negative 100%. When the trade flow change rate hits -100%, it means trade flows become zero, and there's no trade anymore. The blue line labeled "All Industries" delineates scenario one, the orange and grey lines represent scenarios two and three, respectively.

Figure 3: Trade Flows and Tariffs



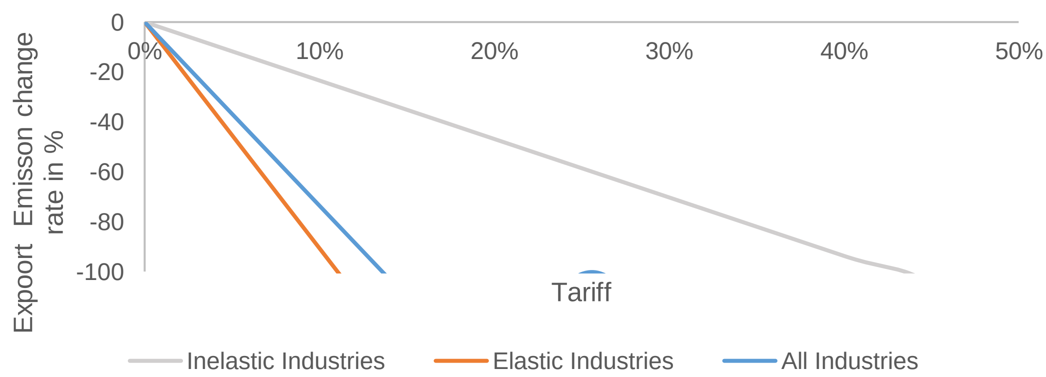
Notes: There are six elastic industries, seven inelastic industries, and 13 industries in total. The trade flow change rates of inelastic industries and elastic industries are calculated as $\frac{\Delta X_{inelastic}}{TX_{inelastic}}$ and $\frac{\Delta X_{elastic}}{TX_{elastic}}$ respectively.

In scenario one, every 1% increase in tariff induces a 4.04% decrease in total trade flows. Thus, with a nearly 25% tariff on all industries, trade flows hit zero. In scenario two, I assume there are only elastic industries in the world. As I stated above, the higher the industry's elasticity, the more trade flows decrease if tariff increases. Based on my analysis, I find that a 1% increase in tariff induces a nearly 6% decrease in elastic industries' trade flows. If with scenario two, where all industries are elastic, total trade flows become zero when a universal tariff is set at nearly 17%.

While for inelastic sectors, a 1% increase in tariff only leads to a 2.84% reduction of inelastic industries' trade flows. Hence, if with scenario three, where all industries are inelastic, total trade flows become zero when the tariff was set at nearly 35%. To conclude, an increase in tariff lead to almost twice as much decrease of inelastic industries' trade flows as elastic industries.

Figure 4 shows how tariffs affect export emissions in the three scenarios. The y axis here represents the export emissions change rate, and it is in percentage. Same as figure 3, blue, orange and grey line delineates scenario one, two and three respectively.

Figure 4: Export Emissions and Tariffs



Notes: There are six elastic industries, seven inelastic industries, and 13 industries in total. The export emission change rates of inelastic industries and elastic industries are calculated as $\frac{\Delta E_{inelastic}}{TE_{inelastic}}$ and $\frac{\Delta E_{elastic}}{TE_{elastic}}$ respectively.

We can see, total transfer emissions decrease by 7.36%, given a 1% increase in tariff. With a nearly 13% tariff on all industries, total transfer emissions hit zero. For elastic industries, a 1% increase in tariff induces an almost 9.07% decrease in elastic industries' total transfer emissions. If all industries are elastic with scenario two, total transfer emissions will become zero when the tariff was set at nearly 11%. While for inelastic industries, a 1% increase in tariff leads to a 2.34% reduction of inelastic industries' total transfer emissions. If under the third scenario that all industries are inelastic, total trade flows become zero when there is a 43% tariff. To sum up, a nearly four times larger tariff needs to be imposed on inelastic industries to achieve the same change rate of carbon emission reductions in elastic industries.

5.2 Carbon Tariff's Impact on Trade Flows and Export Emissions

Compared with a universal tariff, a carbon tariff is directly related to the export carbon intensities of industries. This nature allows carbon tariff better target industries that have higher carbon intensities and emit more carbon emissions. However, industries with higher total export emissions do not necessarily bear higher export carbon intensities. This phenomenon is depicted in figure 5. We can see the manufacture of basic metals has the highest export emissions in 2015, but its carbon intensity is only the second-highest. The manufacture of other non-metallic mineral products is the one with the highest carbon intensity. The reason is that export carbon intensity is also highly related to export values. To be more specific, if an industry's export emissions are not that high, meanwhile, its export values are respectively very low. Its export carbon intensity will be high because, for every one-dollar export, the carbon emissions embodied in it are high. Therefore, a carbon tariff successfully penalizes industries that have high carbon intensities and high export emissions at the same time.

Figure 5: Export Emissions and Export Carbon Intensities in 2015

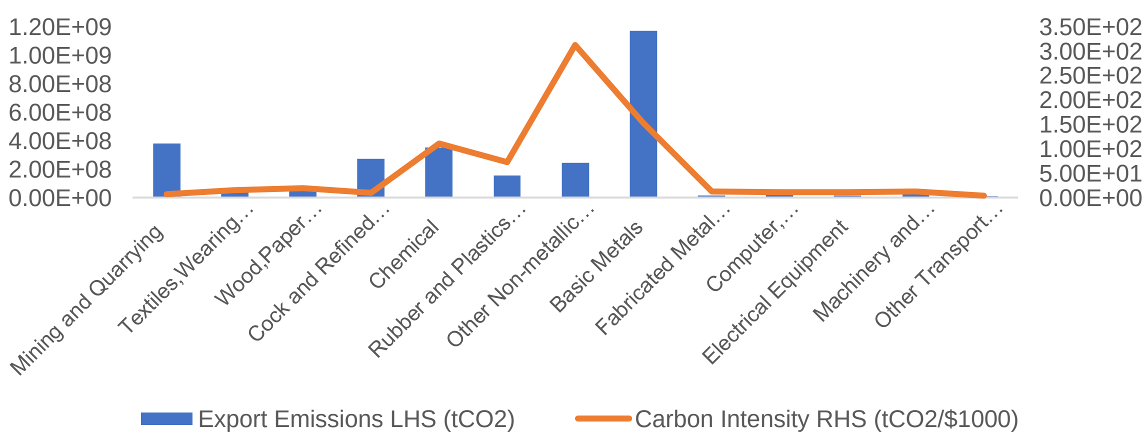


Table 3 delivers a detailed result of how carbon tariff affects trade flows and carbon emissions in different industries. Tariff equivalent carbon tariff τ_k represents how many tariffs that one dollar carbon tariff equals to in industry k. $\frac{\Delta T_k}{T_k}$ is the tariff change rate after imposing one dollar carbon tariff in industry k. We can see, due to the different carbon intensities in various industries, τ_k are distinct. The smallest τ_k is 0.32% tariff for the manufacture of other transport equipment; in other words, a one-dollar carbon tariff on the manufacture of other transport equipment only equals to 0.32% tariff. Whereas, for the manufacture of other non-metallic mineral products, a one-dollar carbon tariff has the same influence that 26% tariff lead to. The impact of a carbon tariff is determined by its carbon intensity and trade elasticity. This renders one dollar carbon tariff higher than a 1% increase of tariff in most industries. We can see the change rates of trade flows and export emissions given every one dollar increase of carbon tariff range from 0.91% in the manufacture of computer, electronic and optical products to 103% in the manufacture of basic metals. Therefore, a one-dollar carbon tariff is high enough to induce its trade flow and export emissions to be zero for the manufacture of basic metals. The reason is that the manufacture of basic metals has the second-highest carbon intensity and the highest elasticities. Therefore, a one-dollar carbon tariff leads to a much higher trade cost, and due to the feature that this industry is highly elastic, there would be no trade of this manufacture. The last column presents the threshold carbon tariffs that would entail zero export and export emissions. We can see the highest carbon tariff can reach is 110$/tCO2 for the manufacture of computer, electronic and optical products, followed by a 86.9 $/tCO2 carbon tariff on mining and quarrying. On the contrary, a nearly 1 dollar per tCO2 carbon tariff will lead to zero export emissions of the manufacture of basic metals and other non-metallic mineral products. The average of the threshold carbon tariff is nearly 40$/tonCO2.

Table 3: Detailed Results given Carbon Tariff

Industry	τ_k	$\frac{\Delta T_k}{T_k}$	θ_k	$\frac{\Delta X_k}{X_k}=\frac{\Delta E_k}{E_k}$	Threshold p ($/ton CO2)
Mining and Quarrying	0.0062	0.0060	-3.072	-0.0115	86.9423
Textiles,Wearing apparel and Related Products	0.0310	0.0283	-3.022	-0.0745	13.4275
Wood,Paper Products and Print	0.0380	0.0360	-0.956	-0.0299	33.4252
Cock and Refined Petroleum Products	0.0089	0.0087	-4.056	-0.0214	46.8009
Chemical	0.0950	0.0905	-6.775	-0.4091	2.4442
Rubber and Plastics Products	0.0597	0.0558	-0.953	-0.0387	25.8472
Other Non-metallic Mineral Products	0.2639	0.2480	-5.607	-0.9087	1.1005
Basic Metals	0.1289	0.1241	-11.719	-1.0269	0.9738
Fabricated Metal Products	0.0105	0.0099	-3.479	-0.0225	44.4660
Computer, Electronic and Optical Products	0.0099	0.0096	-1.309	-0.0091	110.3594
Electrical Equipment	0.0097	0.0092	-2.650	-0.0163	61.2003
Machinery and Equipment	0.0101	0.0098	-6.692	-0.0438	22.8391
Other Transport Equipment	0.0032	0.0031	-7.500	-0.0143	69.9269

Notes: $\tau_k, \frac{\Delta T_k}{T_k}, \frac{\Delta X_k}{X_k}$ are all in decimals.

5.3 Carbon Tariff's Impact in OECD and Non-OECD Countries

In line with many researches, I also discover that overall, OECD countries are more resilient and non-OECD countries are more vulnerable when facing the carbon tariff. Table 4 lists tariff equivalent carbon tariff, export and export emission change rate and threshold carbon tariff of the 13 industries in OECD and non-OECD countries. There are some interesting finds. Firstly, most threshold carbon tariffs are higher for OECD countries. However, for mining and quarrying and the manufacture of other transport equipment, non-OECD countries have higher threshold carbon tariffs, which implies non-OECD countries actually produce these products at lower carbon intensity. I think most people never realize this phenomenon. This paper does not dig deep in the reason here, but my guess is that with many developing countries specialized in industries like mining and quarrying for decades, they gradually build up their comparative advantages in both economic and environmental sense. Still, OECD countries would face less shock when carbon tariff is coming to play in international trade. The average threshold carbon tariff of OECD countries is 54 \$/tCO2 that is nearly 14 \$/tCO2 larger than that of non-OECD countries.

Table 4: Detailed Results given Carbon Tariff in OECD and Non-OECD Countries

	OECD			Non-OECD		
Industry	τ_k	$\frac{\Delta X_k}{X_k}=\frac{\Delta E_k}{E_k}$	Threshold p (\$/ton CO2)	τ_k	$\frac{\Delta X_k}{X_k}=\frac{\Delta E_k}{E_k}$	Threshold p (\$/ton CO2)
Mining and Quarrying	0.0174	-0.0373	26.8323	0.0038	-0.0061	164.5683
Textiles,Wearing apparel and Related Products	0.0107	-0.0212	47.1310	0.0420	-0.1035	9.6626
Wood,Paper Products and Print	0.0327	-0.0249	40.1587	0.0467	-0.0383	26.1205
Cock and Refined Petroleum Products	0.0099	-0.0250	40.0129	0.0081	-0.0185	54.1884
Chemical	0.0831	-0.3214	3.1111	0.1040	-0.4759	2.1011
Rubber and Plastics Products	0.0242	-0.0163	61.5090	0.1035	-0.0663	15.0854
Other Non-metallic Mineral Products	0.1329	-0.4029	2.4822	0.4302	-1.5515	0.6446
Basic Metals	0.0802	-0.6092	1.6414	0.1714	-1.3918	0.7185
Fabricated Metal Products	0.0099	-0.0198	50.5466	0.0112	-0.0260	38.4607
Computer, Electronic and Optical Products	0.0051	-0.0043	234.3542	0.0152	-0.0143	69.9378
Electrical Equipment	0.0072	-0.0110	91.2427	0.0121	-0.0214	46.6271
Machinery and Equipment	0.0075	-0.0308	32.4766	0.0183	-0.0841	11.8864
Other Transport Equipment	0.0036	-0.0156	64.3056	0.0026	-0.0123	81.1546

6 China-US Trade

The world's two largest economies--China and the U.S. have been locked in the ongoing trade war since the former U.S. President Donald Trump accused China of unfair trading practices. The U.S. has imposed tariffs on more than $360bn of Chinese goods; in return, China has retaliated with tariffs on more than $110bn of U.S. products. The economic influences of tariffs on China and the U.S. are well documented and studied. But what about the impact of carbon tariff? As a reasonably new climate policy, carbon tariff has not been widely practiced even though much attention has been paid to it. As far as I know, no country has imposed a carbon tariff on the border yet. Is it possible that the U.S. would utilize carbon tariff as a detrimental weapon to win over this trade war? The answer is unclear yet, but it would be of great importance to have a whole picture of how carbon tariffs would play a role in China and U.S. trade, as well as in their carbon emissions.

6.1 Model

Here I introduce a new model to quantify the net change of carbon emissions of the U.S if it implements carbon tariff on Chinese exports. The decrease of Chinese exports to the U.S in industry k is given by ΔX_{CA}^{k}, and I can obtain the change rate $\frac{\Delta X_{CA}^{k}}{X_{CA}^{k}}$ from the analysis presented before, therefore the decrease is:

$$\Delta X_{CA}^{k} = X_{CA}^{k} \times \frac{\Delta X_{CA}^{k}}{X_{CA}^{k}}, \tag{14}$$

The decrease of Chinese export emissions (US import emissions) to the U.S in industry k is given by ΔE_{CA}^{k}, follow the same method, we have:

$$\Delta E_{CA}^{k} = E_{CA}^{k} \times \frac{\Delta X_{CA}^{k}}{X_{CA}^{k}} = E_{CA}^{k} \times \frac{\Delta E_{CA}^{k}}{E_{CA}^{k}}, \tag{15}$$

I consider two scenarios here. The first is that the U.S would replace the decreased imports with domestic supply. Hence, in this case, this part of U. S's import emissions would become its territorial emissions ΔE_A^k. By multiplying the decreased Chinese exports ΔX_{CA}^k with America's carbon intensity $\frac{E_A^k}{X_A^k}$, we can obtain the carbon emissions occurring in America:

$$\Delta E_A^k = \Delta X_{CA}^k \times \frac{E_A^k}{X_A^k}, \tag{16}$$

The second scenario is that the decreased Chinese exports would be substituted by other countries' exports. The determinant index here would be the carbon intensity if America imposed a universal carbon tariff on all country. Therefore, the new carbon emissions imbodied in new trade would have a range shown as below:

$$\Delta X_{CA}^k \times \min\left(\frac{E_{iA}^k}{X_{iA}^k}\right) < \Delta E_{iA}^k \leq \Delta X_{CA}^k \times \max\left(\frac{E_{iA}^k}{X_{iA}^k}\right), \tag{17}$$

$$\text{Where } \max\left(\frac{E_{iA}^k}{X_{iA}^k}\right) < \frac{E_{CA}^k}{X_{CA}^k},$$

America could choose to import from the country with the lowest carbon intensity, which would entail the lowest carbon emissions in the trade; or any other country that has lower carbon intensity than China's.

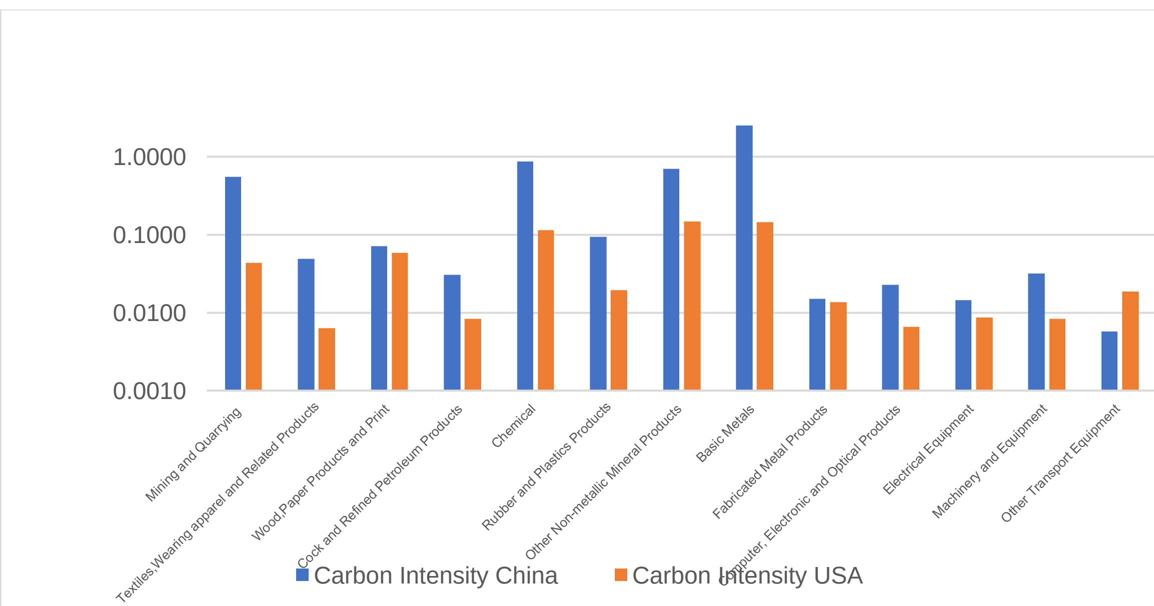
Following two different scenarios, there would be two possible values of the net change of carbon emissions after the US give up on Chinese exports:

$$\Delta \mathrm{TE} = \begin{cases} \sum_{k=1}^{N}(\Delta E_{CA}^{k} + \Delta E_A^k), & if\ replaced\ by\ America'domestic\ production \\ \sum_{k=1}^{N}(\Delta E_{CA}^{k} + \Delta E_{iA}^k), & if\ replaced\ by\ other\ trade\ partners'\ production \end{cases}, \tag{18}$$

6.2 Tariff, Trade Flow and Export Emission between China and America

I design three scenarios to see tariff and carbon tariff's impacts on China and the U.S. The first scenario is for America to only impose a tariff or carbon tariff on Chinese exports; the second is for China to only charge a tariff or carbon tariff on American exports; the third is that both America and China impose a tariff or carbon tariff on each other. The model that I use to calculate the results can be seen in Appendix B. Carbon intensity is a crucial factor that determines how trade flows and export emissions respond to a carbon tariff. Therefore, I carefully calculated the industry level carbon intensities of China and America. Figure 7 presents the comparison of export carbon intensities between China and the U.S. Among 13 industries, China has higher export carbon intensities in 10 industries. On the other hand, export carbon intensities of the U.S. surpass China's in 3 industries: the manufacture of fabricated metal products, electrical equipment, and other transport equipment. A higher export carbon intensity usually entails a higher carbon tariff, which increases the trade cost. Therefore, it is not hard to predict that China will be penalized more by a carbon tariff economically.

Figure 6: Comparison of China-US Export Carbon Intensities



Let's first take a look at the impact of a normal tariff. Table 5 demonstrates the change rates of trade flows and export emissions under the three scenarios. We can see, if only China imposes a higher tariff on American exports, every 1% increase of tariff leads to a 3.9% decrease of American exports to China and a 6.38% reduction of American export emissions. The total trade flows and export emission in China-US trade decrease by 0.66% and 0.42%, respectively. Under the second scenario where there is only a tariff on Chinese exports, China faces a 2.78% decrease in exports and has a 7.55% decrease in export emissions given every 1% increase of tariff imposed by the U.S. Total trade flows and export emissions in China-US trade encounter 2.31% and 7.05% reduction. Under the third scenario, both China and U.S. exports are taxed. Consequently, total trade flows and export emissions bare 2.9% and 7.47% decrease given every 1% increase of a universal tariff. Thus, we can see an increase in tariff affects Chinese exports more than it does to American exports. Chinese export emissions drop faster than American export emissions when facing a higher tariff. The logic underlining these results are easy to comprehend. Firstly, the United States faces a high trade deficient with China. What's more, the average carbon emissions embodied in Chinese exports also surpass America's.

Table 5: Tariff, Trade Flow Changes and Export Emission Changes between China and America

	$\Delta X/X$ $tariff\ on\ US$	$\Delta X/X$ $tariff\ on\ China$	$\Delta X/X$ $universal\ tariff$	$\Delta E/E$ $tariff\ on\ US$	$\Delta E/E$ $tariff\ on\ China$	$\Delta E/E$ $universal\ tariff$
USA	-0.0390	0	-0.0390	-0.0638	0	-0.0638
China	0	-0.0278	-0.0278	0	-0.0755	-0.0755
Total	-0.0066	-0.0231	-0.0297	-0.0042	-0.0705	-0.0747

Notes: the last column labeled "Total" does not mean the sum of the change rates in China and the U.S.; instead, it represents when the U.S. and China are treated as one group.

6.3 Carbon Tariff, Trade Flow and Export Emission between China and America

How would America and China respond when carbon tariffs are in the show? Dong and Walley (2009) find that carbon tariffs imposed by developed countries would bring massive shocks to China's economy, but there is only a minimal contribution to global decarbonization. Ghosh et al. (2012) employs a multi-regional multi-sectoral computable general equilibrium model and finds out that carbon tariffs would result in lower efficiency and unfavorable distribution results in China. Let along the political implication of carbon tariffs, their impacts on US-China trade flows and export emissions across industries are listed below by table 6. Tariff equivalent carbon tariff τ_k not only vary across different industries, but they are also different in American and China within the same industry. Same as stated before, among 13 industries, China has higher τ_k in 12 industries. US surpass China's τ_k in only one industry: other transport equipment. What this implies is that most Chinese industries would be penalized more by a carbon tariff. This is definitely not good news for China. The change rates of exports in Chinese industries also deliver this result. 12 Chinese industries would experience a higher decrease of exports than America's given one dollar carbon tariff imposed. For example, Chinese manufacture of Mining and quarrying would experience a nearly ten times larger decline in exports than American Mining and quarrying. Consecutively, the fewer exports would entail fewer export emissions from China and the U.S., and we will see export emissions from China decrease way faster than that from America.

Table 6: Industries' Carbon Tariff, Trade Flow and Export Emission between China and America

	Industry	X_k	E_k	τ_k	$\frac{\Delta X_k}{X_k} = \frac{\Delta E_k}{E_k}$	Threshold p ($/ton CO2)
China	Mining and Quarrying	63,941,322	35,117,000	0.5492	-1.1727	0.8527
	Textiles,Wearing apparel	1,125,110,748	54,654,000	0.0486	-0.1200	8.3336
	Wood,Paper Products and Print	399,314,058	28,698,000	0.0719	-0.0594	16.8459
	Cock and Refined Petroleum Products	795,753,281	24,065,000	0.0302	-0.0846	11.8211
	Chemical	136,094,507	117,653,000	0.8645	-4.0093	0.2494
	Rubber and Plastics Products	451,925,617	42,350,000	0.0937	-0.0619	16.1487
	Other Non-metallic Mineral Products	153,347,159	107,235,000	0.6993	-2.5350	0.3945
	Basic Metals	164,876,013	416,210,000	2.5244	-20.2636	0.0493
	Fabricated Metal Products	284,157,760	4,258,000	0.0150	-0.0356	28.0757
	Computer, Electronic and Optical Products	680,332,341	15,537,000	0.0228	-0.0212	47.1927
	Electrical Equipment	470,368,763	6,863,000	0.0146	-0.0263	38.0485
	Machinery and Equipment	267,104,286	1,522,000	0.0057	-0.0288	6.7979
	Other Transport Equipment	63,941,322	35,117,000	0.5492	-1.1727	34.6766
	Mining and Quarrying	666469526	29151000	0.0437	-0.0972	10.2914

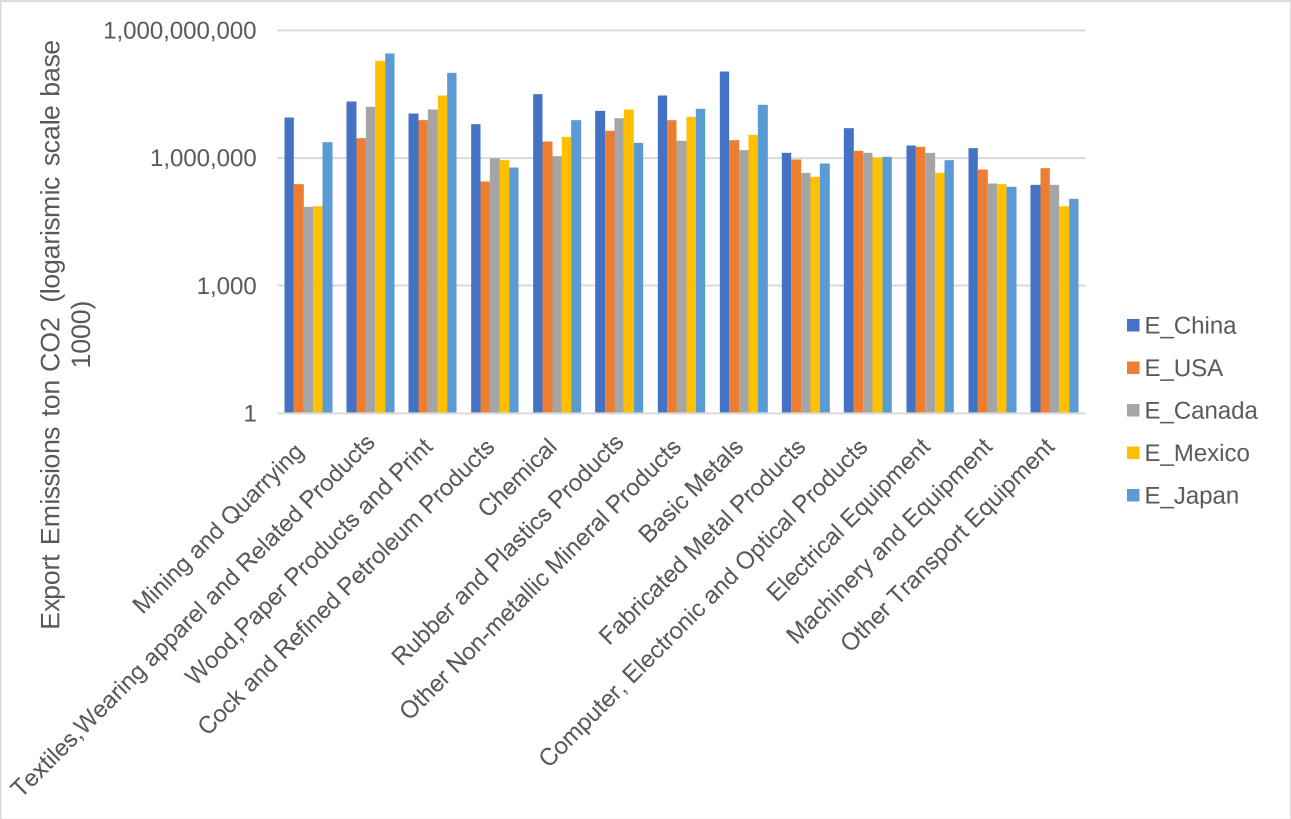
USA	Textiles,Wearing apparel	136542300	867000	0.0063	-0.0157	63.6257
	Wood,Paper Products and Print	312190445	18137000	0.0581	-0.0480	20.8354
	Cock and Refined Petroleum Products	2524310293	21186000	0.0084	-0.0244	41.0642
	Chemical	211777152	24302000	0.1148	-0.5123	1.9520
	Rubber and Plastics Products	202881256	3956000	0.0195	-0.0136	73.3152
	Other Non-metallic Mineral Products	42998542	6394000	0.1487	-0.5668	1.7644
	Basic Metals	157715912	22689000	0.1439	-1.2796	0.7815
	Fabricated Metal Products	121135914	1659000	0.0137	-0.0343	29.1574
	Computer, Electronic and Optical Products	253537052	1676000	0.0066	-0.0058	173.1397
	Electrical Equipment	89308739	770000	0.0086	-0.0162	61.7794
	Machinery and Equipment	332603181	2762000	0.0083	-0.0410	24.3717
	Other Transport Equipment	124921686	2318000	0.0186	-0.0846	11.8272

Inspired by Kortum, S., & Weisbach, D. A. (2020), I examine the scenario when only America adopts unilateral environmental policy to impose a carbon tariff on Chinese exports. I am aware that this policy is against the international trade law as a carbon tariff should not be only implemented to target one country, instead it should be universal for all trade partners. However, based on the recent conflicts between China and the U.S, this practice is definitely not impossible.

With great interest, I dive into this analysis following that model I stated before. I consider four scenarios: the first is that all imports from China are replaced by America's domestic productions; the second to the fourth is that all imports from China are replaced by imports from Canada, Mexico, and Japan respectively; I choose these trade partners as they are among the most important trade partners of the U.S.

Figure 7 shows the export carbon emissions of China to the U.S, America's territorial increase of carbon emissions when it stops importing from China, and the increase of export carbon emissions of Canada, Mexico, and Japan when they replace China to export the same amount. We can see in 10 industries; China has the highest export carbon emissions and the U.S has the lowest territorial carbon emissions. However, in the manufacture of Textiles, wearing apparel and related products and Wood, Paper Products and Print, Canada, Mexico and Japan actually would emit more than China does to produce to same amount of exports. The U.S also would emit the most if it decides to produce all manufacture of other transport equipment at home. So, for only environmental purpose, is it advisable for the U.S to replace all Chinese exports with its own production or with the exports from Canada, Mexico and Japan?

Figure 7: Carbon emissions in China, USA, Canada, Mexico and Japan



Notes: the carbon emissions of China are real export emissions to the U.S; carbon emissions of America, Canada, Mexico and Japan are predicted by the model when they produce the same amount of the Chinese exports.

Table 7 gives us the answer to the question above. This table shows when all Chinese exports to the U.S are replaced by either America's domestic production, or exports from Canada, Mexico and Japan, what would be the change rate of it. For example, for the manufacture of textiles, wearing apparel and related productse, to produce the same amount Chinese exports, America would emit 86% less carbon emissions than China emits. Canada would emit 26% less. But for Mexico and Japan, they actually would emit 8% and 12% more if they produce the same amount of exports for the U.S. If America stops importing from China and produce them at home, Chinese export emissions to the U.S would be zero, and the U.S would only need to emit 86% less carbon emissions to produce the same amount, and this practice would lead to 0.63% decrease of world carbon emissions. In the case that America increases their imports from Canada to substitute all Chinese exports, Canada would only need to emit 80% less carbon emissions to produce the same amount, and this practice would lead to 0.59% decrease of world carbon emissions. In contrast, if Mexico and Japan replace China to export the same amount to America, they actually would emit more than China does. If we take a close look, we can find that Mexico and Japan produce the manufacture of textiles, wearing apparel and related productse and wood, paper products and print with high emissions, and these increased of emissions would offset their decreases of carbon emissions in other industries. Therefore, we can see replacing Chinse products with other countries products have diverse effect on carbon emissions due to the different carbon intensities in different countries.

Table 7: The Change Rate of Carbon Emissions in the USA, Canada, Mexico, Japan

Industry	USA	Canada	Mexico	Japan
Mining and Quarrying	-0.9729	-0.9920	-0.9919	-0.7408
Textiles,Wearing apparel and Related Products	-0.8629	-0.2586	7.9257	12.2840
Wood,Paper Products and Print	-0.3005	0.2407	1.6837	7.9968
Cock and Refined Petroleum Products	-0.9546	-0.8436	-0.8596	-0.9046
Chemical	-0.9204	-0.9646	-0.9003	-0.7539
Rubber and Plastics Products	-0.6650	-0.3189	0.0673	-0.8193
Other Non-metallic Mineral Products	-0.7377	-0.9121	-0.6848	-0.5086
Basic Metals	-0.9749	-0.9857	-0.9667	-0.8300
Fabricated Metal Products	-0.2941	-0.6571	-0.7235	-0.4392
Computer, Electronic and Optical Products	-0.7079	-0.7390	-0.7973	-0.7875
Electrical Equipment	-0.0775	-0.3344	-0.7726	-0.5439
Machinery and Equipment	-0.6867	-0.8541	-0.8567	-0.8802
Other Transport Equipment	1.4746	-0.0158	-0.6795	-0.5228
Total	-0.8582	-0.7970	0.0672	0.8227

Notes: This table compares the change rate of carbon emission of 4 countries with Chinese export emissions to the U.S as the denominator.

7 Conclusion

7.1 Policy Suggestions

Trade policy such as tariffs indeed can be utilized as a tool to prevent carbon leakage. However, there are possible conflicts caused by doing so. According to WTO, one principle is to trade without discrimination, which means countries cannot usually discriminate between their trading partners. Therefore, when a country increases its tariffs on emission-intensive products, they cannot be used to target any individual country. All trading partners should face the same tariff no matter what. Governments and international organizations need to cooperate and supervise to prevent using tariffs as political tools to disturb world order. Unfortunately, we have witnessed many cases in which countries utilize tariffs to curb others' development, such as the US-Japan trade war in the late 20th and the US-China trade war upgoing now. Tariffs are misused political strategy for competing for the status of hegemony.

Let's assume tariff for environmental purpose and carbon tariff were accepted one day. In order to maximize their impacts in decarbonization, it is also vital to take industries' trade elasticity into consideration. Trade elasticities directly determine the effectiveness of tariffs; hence, when targeting specific industries, the tariff rate needs to be adjusted according to industries' trade elasticities. The reason is that inelastic industries comparatively are not very sensitive to the change of tariff; therefore, to achieve a certain level of decarbonization in a highly-emitted inelastic industry, a higher tariff should be considered.

Even though I have accentuated that tariffs and carbon tariffs should not be politicalized, the reality is that they are inseparable from politics. Even though a carbon tariff seems like it is only for environmental goals, but there is no doubt developing countries are indirectly targeted. Many developed countries have passed the phase when their developments were achieved at the cost of the environment, while most developing countries are still experiencing that phrase. Now developed countries possess the most advanced technology and mature capitals, which enable them to achieve high productivity at low CO2 emissions. Once a carbon tariff is imposed, many developing countries will be more vulnerable in trade, which consecutively enervates their development speed. A carbon tariff indeed can discourage countries from importing highly-emitted products from other countries. Still, at the same time, all countries would face welfare loss, and developing countries would definitely burden more loss.

How to solve the conundrum? There is no perfect strategy here. The disadvantages of developing countries will not be eliminated any sooner; simultaneously, climate change will not stop without all humankind's effort. But there are actions that can be taken to make carbon tariff or other environmental policies more feasible. According to UNFCCC, Annex II countries are responsible for providing financial resources and transferring environmentally friendly technologies to developing countries. This regulation should also apply to the implementation of carbon tariffs. What if developed countries used partial carbon tariff revenues to finance and help develop environmentally friendly technologies in developing countries? Would this incentivize all nations to achieve the decarbonization goal? Of course, this design is also difficult to get consensus on. Still, I want to point out that a carbon tariff should be paired with other environmental policies to help developing countries achieve higher productivity at a lower cost to the environment.

7.2 Limitations

When estimating tariffs and carbon tariff's impact on trade flows and export emissions using trade elasticity obtained from the gravity trade model, this paper did not consider the possibility that a universal tariff and carbon tariff would change the multilateral resistance terms.

Thus, a universal tariff would increase the price of the products imported but not change the domestic price. The result is that the change rate of trade flows may be overestimated.

This paper can be improved by integrating carbon tariff into the gravity trade model instead of just utilizing trade elasticities as the bridge to estimate its impact on trade flows and carbon emissions. In addition, it would be intriguing to see the relationship between carbon tariff, price, world welfare, and world carbon emissions. Here remained are many potential research topics in the future.

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Appendix

A Gravity Estimations for Selective Industries

Table 8: Regression Table for manufacture of textiles

	(1) lv	(2) lv	(3) lv	(4) lv	(5) aiv
main					
ldist	-0.150*** (0.0119)	-0.152*** (0.0119)	-0.665*** (0.0247)	-0.668*** (0.0247)	-0.698*** (0.000560)
lt	-3.507*** (0.145)	-3.452*** (0.146)	-3.313*** (0.200)	-3.022*** (0.203)	3.152*** (0.00473)
contig	1.514*** (0.0624)	1.507*** (0.0624)	0.633*** (0.0512)	0.632*** (0.0512)	0.641*** (0.000705)
comlang_off	0.378*** (0.0331)	0.376*** (0.0331)	0.247*** (0.0297)	0.247*** (0.0297)	-0.00962*** (0.000696)
_cons	5.192*** (0.106)	5.483*** (0.113)	6.365*** (0.244)	6.243*** (0.282)	15.43*** (0.0128)
Year FE	No	Yes	No	Yes	Yes
Exporter FE	No	No	Yes	Yes	Yes
Importer FE	No	No	Yes	Yes	Yes
N	69236	69236	69236	69236	69236
R-sq	0.028	0.029	0.437	0.438	

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table 9: Regression Table for the manufacture of Computer, Electronic and Optical Products

	(1) lv	(2) lv	(3) lv	(4) lv	(5) aiv
main					
ldist	-0.187*** (0.0175)	-0.189*** (0.0175)	-0.554*** (0.0230)	-0.553*** (0.0229)	-0.417*** (0.000519)
lt	0.832* (0.375)	0.795* (0.377)	-1.214** (0.410)	-1.309** (0.419)	1.076*** (0.0180)
contig	1.177*** (0.0974)	1.173*** (0.0973)	0.574*** (0.0502)	0.575*** (0.0501)	0.531*** (0.000666)
comlang_off	1.252*** (0.0492)	1.244*** (0.0491)	0.410*** (0.0277)	0.410*** (0.0277)	0.0593*** (0.000584)
_cons	6.148*** (0.155)	6.558*** (0.165)	5.537*** (0.200)	5.583*** (0.202)	14.66*** (0.00792)
Year FE	No	Yes	No	Yes	Yes
Exporter FE	No	No	Yes	Yes	Yes
Importer FE	No	No	Yes	Yes	Yes
N	29367	29367	29367	29367	29367
R-sq	0.039	0.042	0.777	0.779	

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

B Model Used for Estimations between China and America

There are only two countries as importers and exporters, that are China and the U.S. Hence, importer j $\in \{c, a\}$. τ^c is the tariff only imposed on Chinese exports to the U.S. τ^a is the tariff only imposed on American exports to China. Therefore, the change rate of trade flows and export emissions after a tariff only on Chinese exports are equation (14) and (15) respectively:

$$TE = \sum_{k=1}^{N} \sum_{j \in \{c,a\}} E_k^j \quad TX = \sum_{k=1}^{N} \sum_{j \in \{c,a\}} X_k^j$$

$$\frac{\Delta TX}{TX} = \frac{\frac{\Delta \tau^c}{\tau^c} \times \int_{\kappa=1}^{N} X_k^c \theta_k}{\sum_{k=1}^{N} \sum_{j \in \{c,a\}} X_k^j}, \tag{19}$$

$$\frac{\Delta TE}{TE} = \frac{\frac{\Delta \tau^c}{\tau^c} \times \int_{\kappa=1}^{N} E_k^c \theta_k}{\sum_{k=1}^{N} \sum_{j \in \{c,a\}} E_k^j}, \tag{20}$$

Change rate of trade flows and export emissions after a tariff only on U.S. exports are given by equation (17) and (18):

$$\frac{\Delta TX}{TX} = \frac{\frac{\Delta \tau^a}{\tau^a} \times \int_{\kappa=1}^{N} X_k^a \theta_k}{\sum_{k=1}^{N} \sum_{j \in \{c,a\}} X_k^j}, \tag{21}$$

$$\frac{\Delta TE}{TE} = \frac{\frac{\Delta \tau^a}{\tau^a} \times \int_{\kappa=1}^{N} E_k^a \theta_k}{\sum_{k=1}^{N} \sum_{j \in \{c,a\}} E_k^j}, \tag{22}$$

Then after imposing a tariff on both American and Chinese industries, the change rates of trade flows and export emissions are given by:

$$\frac{\Delta TX}{TX} = \frac{\frac{\Delta \tau^a}{\tau^a} \times \int_{\kappa=1}^{N} X_k^a \theta_k + \frac{\Delta \tau^c}{\tau^c} \times \int_{\kappa=1}^{N} X_k^c \theta_k}{\sum_{k=1}^{N} \sum_{j \in \{c,a\}} X_k^j}, \tag{23}$$

$$\frac{\Delta TE}{TE} = \frac{\frac{\Delta \tau^a}{\tau^a} \times \int_{\kappa=1}^{N} E_k^a \theta_k + \frac{\Delta \tau^c}{\tau^c} \times \int_{\kappa=1}^{N} E_k^c \theta_k}{\sum_{k=1}^{N} \sum_{j \in \{c,a\}} E_k^j}. \tag{24}$$

Change rate of trade flows and export emissions after a carbon tariff only on Chinese exports:

$$TE = \sum_{k=1}^{N} \sum_{j \in \{c,a\}} E_k^j, \quad TX = \sum_{k=1}^{N} \sum_{j \in \{c,a\}} X_k^j,$$

$$\frac{\Delta TX}{TX} = \frac{\int_{\kappa=1}^{N} \frac{\Delta \tau_k^c}{\tau_k^c} X_k^c \theta_k}{\sum_{k=1}^{N} \sum_{j \in \{c,a\}} X_k^j}, \tag{25}$$

$$\frac{\Delta TE}{TE} = \frac{\int_{\kappa=1}^{N} \frac{\Delta \tau_k^c}{\tau_k^c} E_k^c \theta_k}{\sum_{k=1}^{N} \sum_{j \in \{c,a\}} E_k^j} \quad . \tag{26}$$

C Further Results

Table 10: Regression Result of Elasticity and Carbon Intensity

Source	SS	df	MS
Model	82023.7699	1	82023.7699
Residual	2.7081e+09	422,904	6403.52998
Total	2.7082e+09	422,905	6403.70879

Number of obs	=	422,906
F(1, 422904)	=	12.81
Prob > F	=	0.0003
R-squared	=	0.0000
Adj R-squared	=	0.0000
Root MSE	=	80.022

ei	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
elap	-.1535482	.0429027	-3.58	0.000	-.2376361	-.0694602
_cons	2.084364	.2090769	9.97	0.000	1.67458	2.494149

Notes: Elasticity is the independent variable and carbon intensity is the dependent variable

Table 11: Country Specific Trade Flows, Export Emissions, Change Rate of Trade Flows and Export Emissions and Threshold Carbon Tariff given Carbon Tariff

Exporter	X_i	E_i	τ_j	$\frac{\Delta X_i}{X_i} = \frac{\Delta E_i}{E_i}$	**Threshold p ($/ton CO2)**
China	5205771376	860952000	0.165384136	-0.899073436	1.112256196
India	1946248940	137384000	0.07058912	-0.449173299	2.22631221
Chinese Taipei	892836803	60963000	0.068280115	-0.43200707	2.314776933
South Africa	1314803514	57782000	0.043947251	-0.351381344	2.845910908
Japan	2344910387	96077000	0.040972568	-0.267481793	3.738572222
Slovak Republic	85436546	9419000	0.110245562	-0.263148255	3.800139202
Germany	1392495616	79120000	0.05681885	-0.226726891	4.410592827
Austria	242886069	13962000	0.057483741	-0.196491907	5.089268117
Korea	3605101094	90909000	0.025216769	-0.169741921	5.891296598
Turkey	509526641	22673000	0.044498164	-0.166030215	6.023000073
Poland	242693395	18222000	0.075082389	-0.165855062	6.029360755
Czech Republic	142353599	10562000	0.074195525	-0.164999945	6.060608082
Thailand	884772612	38157000	0.043126335	-0.143219143	6.982306841
France	729602133	28569000	0.039156958	-0.136548799	7.323389202
United Kingdom	738621249	33789000	0.045746044	-0.128245834	7.797524253
United States	5176391999	135867000	0.026247433	-0.098925576	10.10860931
Brazil	3313209919	48831000	0.014738275	-0.088061347	11.35572002
Spain	604393119	22038000	0.036463023	-0.087328981	11.45095239
Australia	2147676774	37756000	0.017579927	-0.08553967	11.69048229
Canada	5029381206	105671000	0.021010736	-0.078173159	12.79211455
Mexico	2898733445	51859000	0.017890227	-0.075729211	13.20494411
Viet Nam	1354691283	36054000	0.026614182	-0.07531861	13.27693121
Hungary	113828748	4057000	0.03564126	-0.074262619	13.46572484
Italy	1084501977	23981000	0.022112454	-0.071168691	14.05112258
Kazakhstan	2224129927	54428000	0.024471592	-0.061642736	16.22251148
Romania	303188213	6035000	0.019905127	-0.057340992	17.43953076
Russian Federation	10615779236	162951000	0.015349886	-0.055448093	18.03488542
Sweden	406992730	6730000	0.016535922	-0.0525194	19.04058308
Belgium	734545649	16041000	0.021837989	-0.050988484	19.6122717
Finland	332574493	6964000	0.02093967	-0.049263826	20.29886995

Netherlands	1047730524	21057000	0.020097725	-0.04403202	22.71074569
Indonesia	4284193665	51166000	0.011942971	-0.033430559	29.9127514
New Zealand	397469569	2548000	0.006410554	-0.032483166	30.78517652
Portugal	253931698	4640000	0.01827263	-0.031586269	31.65932609
Slovenia	58054430	981000	0.016897935	-0.030221484	33.08904406
Philippines	570750723	4069000	0.007129207	-0.029870068	33.47833003
Argentina	742180407	5959000	0.008029045	-0.029669224	33.70495933
Iceland	42319140	326000	0.00770337	-0.029212928	34.23141945
Greece	519720823	4370000	0.00840836	-0.023241865	43.02580783
Ireland	360389273	2651000	0.007355935	-0.023186839	43.12791433
Denmark	188770326	2369000	0.012549642	-0.021843174	45.78089332
Norway	696271067	12254000	0.017599467	-0.02025003	49.38264287
Costa Rica	76565428	200000	0.002612145	-0.020081936	49.79599657
Singapore	1791421568	11047000	0.006166611	-0.018999178	52.63385643
Malaysia	2788567292	28466000	0.010208109	-0.016570537	60.34807375
Lithuania	162671962	1471000	0.009042738	-0.016484033	60.66476548
Bulgaria	420588404	2491000	0.005922655	-0.012914895	77.42997632
Tunisia	106401374	1394000	0.013101335	-0.012837146	77.8989333
Peru	1164074394	4222000	0.003626916	-0.012788939	78.19257156
Colombia	3603350315	12387000	0.003437634	-0.011754082	85.07682909
Chile	2444520482	11343000	0.004640174	-0.011343626	88.15523074
Switzerland	829763184	2836000	0.003417843	-0.009675167	103.3573939
Luxembourg	235205454	646000	0.002746535	-0.007568022	132.1349262
Israel	790085213	2983000	0.003775542	-0.007412017	134.9160431
Croatia	152252156	872000	0.005727341	-0.006626422	150.9110099
Morocco	736966103	1885000	0.002557784	-0.005669029	176.3970603
Cyprus	112152383	134000	0.001194803	-0.005284997	189.2148686
Hong Kong, China	357996537	1015000	0.002835223	-0.00292245	342.1786448
Saudi Arabia	27536004046	30738000	0.001116284	-0.002714272	368.4228489
Estonia	87492247	191000	0.002183051	-0.002433061	411.0048526
Cambodia	203520998	210000	0.001031835	-0.001661391	601.9051898
Brunei Darussalam	2246303146	1234000	0.000549347	-0.001074149	930.9696469
Latvia	266792231	171000	0.000640948	-0.001009295	990.7908397
Malta	48494567	0	0	0	NA
World	111941049818	2506129000	0.022387935	-0.104729054	9.548448694