LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Department of Economics

Seminar "Empirical Issues in Trade"

Summer Semester 2024

Carbon Tariffs, a Comprehensive Analysis

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1 Introduction

Climate change and its consequences are one of the greatest challenges of our time. Human activities, with the emission of greenhouse gases, have unequivocally caused global warming (IPCC 2023). To keep global warming within a manageable path, numerous mitigation and adaptation actions and policies are needed. If applied on a large scale, economic instruments can also help reduce emissions, and among these, carbon taxes and their various implementations play an important role. As the report of IPCC (2023) reveals, in 2020, over 20% of global greenhouse gas emissions were covered by carbon taxes or Emission Trading Systems. These instruments have proven to be effective in reducing emissions and, in addition, carbon tax revenues are often redistributed to low-income households to address equity issues.

In this context, Larch et al. (2017) study the impacts of introducing carbon tariffs on trade flows, welfare, and emissions. To do so, they implement a widely used framework in the international trade literature, such as a structural gravity model. Moreover, taking advantage of the work of Copeland et al. (2003), they are also the first to isolate the effects that influence emissions in this framework. Not only this, Larch et al. (2017) also assess the rate of carbon leakage that arises when only a subset of countries commit to their climate commitments, with and without carbon tariffs.

This seminar paper proceeds as follows: Chapter 2 summarizes the paper of Larch et al. (2017), Chapter 3 reviews the literature on carbon tariffs and compares results, Chapter 4 proposes two extensions to the paper of Larch et al. (2017), Chapter 5 concludes.

2 | Analysis of Carbon Tariffs impacts

2.1 Theoretical Model

In a series of counterfactual analyses, Larch et al. (2017) study the consequences of introducing carbon tariffs on trade flows, welfare, and carbon emissions, by decomposing the changes in emissions into three effects: scale, composition, and technique. To do so, they take advantage of a gravity model, which is a workhorse framework employed in the field of international trade. The power of this tool lies in the gravity equation, which can describe the link between trade flows and the size, distance, and border resistance of countries.

Firstly, they introduce the presence of more sectors: a non-tradable sector S and L tradable ones (l) in all N countries. This enables the detection of how sectors with different carbon intensities respond and interact with each other when a carbon tariff is levied. The utility the representative consumer from country j gains when consuming in sector l is shown in Equation 2.1 (a):

$$(a)\ U_l^j = \left[\sum_{i=1}^{N} (\beta_l^i)^{\frac{1-\sigma_l}{\sigma_l}} (q_l^{ij})^{\frac{\sigma_l-1}{\sigma_l}}\right]^{\frac{\sigma_l}{\sigma_l-1}} \qquad (b)\ U^j = (U_S^j)^{\gamma_S^j} \left[\prod_{l\in\mathcal{L}} (U_l^j)^{\gamma_l^j}\right] \left[\frac{1}{1+(\frac{1}{\mu^j}\sum_{i=1}^{N} E^i)^2}\right] \tag{2.1}$$

where σ_l is the elasticity of substitution of sector l, β_l^i is a sector and country-specific distribution parameter, and q_l^{ij} is the quantity of goods from tradable sector l and imported from country i that the representative consumer j consumes. Additionally, Equation 2.1 (b) measure the total utility of the country's representative consumer j that comes from both types of sectors, S and L, discounted for the disutility arising from global carbon emissions. The γ^j are elasticities and sum up to 1, E^i are the emissions produced by country i, and μ^j is the Social Cost of Carbon (SCC) for the affected country j, denoting the economic damage caused by an additional unit of emissions.

To afford consumption, the representative consumer in country j earns income Y^j from selling energy, providing labor, and a number of other factors $\mathcal{F}$. Furthermore, the revenues from carbon tariffs imposed on imports from country i, i.e. $\sum_{l\in\mathcal{L}}\sum_{i=1}^{N}(\tau_l^{ij} - 1)X_l^{ij}$, are redistributed to the consumer and also feed its income equation. Let's assume that all income in each country is spent, so-called balanced trade assumption, i.e. $Y^j =$

$\mathfrak{X}^j = \mathfrak{X}^j_S + \sum_{l \in \mathcal{L}} \mathfrak{X}^j_l$, we can now find the demand of country j for goods from country i in sector l, as in Equation 2.2 (a):

$$(a)\ q_l^{ij} = \left(\frac{\beta_l^i p_l^{ij}}{P_l^j}\right)^{-\sigma} \left(\frac{\beta_l^i \mathfrak{X}_l^j}{P_l^j}\right) \quad (b)\ P_l^j = \left[\sum_{i=1}^{N} (\beta_l^i p_l^{ij})^{1-\sigma_l}\right]^{\frac{1}{1-\sigma_l}} \tag{2.2}$$

where $\mathfrak{X}_l^j$ is the total expenditure of country j in sector l, p_l^{ij} is the price in country j for goods from sector l coming from country i. Instead, P_l^j is the sectoral price index, giving an overall measure for the prices in sector l. Therefore, from Equation 2.2 (a) we can see, for instance, that demand q_l^{ij} increases either if $\mathfrak{X}_l^j$ increases (e.g. thanks to an increase in country income Y^j) or if goods from i are more competitive and cheaper relative to the overall price index P_l^j (i.e. a lower $\frac{p_l^{ij}}{P_l^j}$).

Now that we have an endogenous demand function for goods, let's define trade flows.

$$X_l^{ij} = \underbrace{\frac{Y_l^i \gamma_l^j Y^j}{Y^W}}_{(1)} \underbrace{\left(\frac{T_l^{ij}}{\prod_l^i P_l^j}\right)^{1-\sigma}}_{(2)} \underbrace{(\tau_l^{ij})^{-\sigma_l}}_{(3)} \tag{2.3}$$

Equation 2.3 is the extended gravity equation. The trade flows in sector l from country i to j depend: (1) on the relative size of sector l in both countries, the larger the production in this sector and the more is traded; (2) given transport costs T_l^{ij} between the two countries, more is exchanged if the two multilateral resistance terms (i.e. $\prod_l^i$ outward, P_l^i inward) are smaller; (3) larger carbon tariffs τ_l^{ij} for products coming from i reduce imports. In particular, the two multilateral resistance terms, calculated by taking each pair of countries, play a crucial role in explaining how conditions in all other countries interact with trade between i and j.

After welfare (Equation 2.1 (b)), income, and trade flows (Equation 2.3), the last key variable investigated is carbon emissions produced. The authors start shaping total emissions for each country as $E^i = (\alpha^i_{SE} Y^i_S + \sum_{l \in \mathcal{L}} \alpha^i_{lE} Y^i)/e^i$, where α^i_{lE} and α^i_{SE} are the energy cost shares for each sector, and e^i the enegy price in country i. Intuitively, the authors treat emissions as a byproduct of the energy used, and the numerator suggests that if energy costs are a significant component of the production costs, production is more energy and carbon-intensive. After some transformations, we can rewrite the total emissions for country i as in Equation 2.4 (a):

$$(a)\ E^i = \bar{\alpha}^i_E \frac{\tilde{Y}^i}{P^i}\left(\frac{e^i}{P^i}\right)^{-1} \quad (b)\ dE^i = \underbrace{\frac{\delta E^i}{\delta(\tilde{Y}^i/P^i)} d(\tilde{Y}^i/P^i)}_{\text{(1) scale effect}} + \underbrace{\frac{\delta E^i}{\delta \bar{a}^i_E} d\bar{a}^i_E}_{\text{(2) composition effect}} + \underbrace{\frac{\delta E^i}{\delta(e^i/P^i)} d(e^i/P^i)}_{\text{(3) technique effect}} \tag{2.4}$$

here, emissions are expressed in real value terms of production and energy prices, while the weighting factor $\bar{\alpha}^i_E$ reflects the average energy costs share. Therefore, total emissions E^i in country i can increase if the real value of overall production increases, but also when production sectoral shares change. The various effects resulting from changes to the variables of the model can be decomposed by taking the total derivative of Equation 2.4 (a), as shown in Equation 2.4 (b).

$$(1)\ \frac{\delta E^i}{\delta(\tilde{Y}^i/P^i)} = \frac{\bar{a}^i_E}{e^i/P^i} > 0 \quad (2)\ \frac{\delta E^i}{\delta \bar{a}^i_E} = \frac{\tilde{Y}^i}{e^i} > 0 \quad (3)\ \frac{\delta E^i}{\delta(e^i/P^i)} = -\frac{\bar{\alpha^i_E}\tilde{Y}^i/P^i}{(e^i/P^i)^2} < 0 \tag{2.5}$$

Equation 2.5 represents a key contribution of Larch et al. (2017) and describes how total emissions behave when certain variables in the model change, for example, as a result of the introduction of carbon tariffs. In Equation 2.5, (1) represents the "scale effect" and indicates that an increase in real value production increases emissions, (2) is the "composition effect" and reflects the sectoral composition of production and its carbon intensity, for example, a carbon-intensive sector increasing its share will result in an increase in total emissions, (3) illustrates the "technique effect", where an increase in real energy prices leads to a decrease in emissions, because higher energy costs encourage producers either to use energy more efficiently or to switch to less energy-intensive (and therefore less carbon-intensive) sectors.

2.2 Empirical Strategy

The analysis of Larch et al. (2017) compares a benchmark and a counterfactual case without and with carbon tariffs, respectively. To achieve this, they utilize several data sources, outlined in Section 2.3, from which they extract or calculate data such as for the benchmark production levels (Y^i_b) or the energy cost shares (α^i_{lE}). However, there isn't a unique and overarching measure for trade costs T^{ij}_l, thus they must be approximated as a function of observable factors and estimated using the gravity equation, Equation 2.3.

First, the authors approximate T_l^{ij} giving it the form of an exponential function of K observable variables, which results in $T_l^{ij} = \exp\left(\left(\boldsymbol{z}_l^{ij}\right)' \boldsymbol{b}_l\right)$. The K variables they employ are (1) distance, (2) contiguity, whether they have (3) bilateral Regional Trade Agreements (RTA), (4) a common language, (5) a direct colonial link or (6) a common colonizer in the past. Once this formulation for T_l^{ij} is plugged into the gravity equation and after some transformations, Equation 2.6 is used to estimate the coefficients of the factors influencing trade costs:

$$X_l^{ij} = \frac{1}{Y^W} \exp\left(\left(\boldsymbol{z}_l^{ij}\right)' \boldsymbol{\beta}_l\right) \left(\tau_l^{ij}\right)^{-\sigma} n_l^i m_l^j u_l^{ij} \tag{2.6}$$

where trade flows X_l^{ij} is the dependent variable, $\boldsymbol{z}_l^{ij}$ is the vector of the mentioned independent variables for each pair of countries, $\boldsymbol{\beta}_l$ is the vector of coefficients to estimate, u_l^{ij} is the random error term, and n_l^i and m_l^j are fixed effects for the exporter and importer country, respectively. As fixed effects, they allow to control for unobserved heterogeneity that is constant over time, and since they are a function of the outward and inward resistance terms, they can capture the overall trade resistance faced by each country.

Secondly, to estimate Equation 2.6 the authors use the Poisson Pseudo-Maximum-Likelihood (PPML) estimator. This methodology solves two major issues highlighted by Silva et al. (2006) and which arise when using an OLS to estimate a log-linearised version of the gravity equation, namely: (1) the heteroskedasticity in the error term, (2) the presence of many zeros in the datasets.

Lastly, in Equation 2.6, in the benchmark case without tariffs, the term τ_l^{ij} has value 1, while in the counterfactual scenario Larch et al. (2017) model τ_l^{ij} as follows: $1 + \frac{E_l^j}{Y_l^j}(\lambda^j - \lambda^i)$ if $\lambda^j > \lambda^i$, 1 otherwise, where λ^i is the implicit carbon tax in each country. This implies that if the importing country j has a higher carbon tax, it will levy a carbon tariff equal to the difference between the two countries, adjusted for the carbon intensity of sector, i.e. a pure and product-based carbon tariff.

2.3 Data

Before moving on to the results, let's examine the datasets employed by Larch et al. (2017). The main resource used is the Global Trade Analysis Project (GTAP) 8 database by Narayanan et al. (2012). The reference year is 2007, it covers 128 regions and 57 sectors, aggregated down to 15 tradable and non-tradable sectors. The authors collect most of the necessary data from here, e.g. sectoral trade flows and production or energy cost share. They extrapolate that, on average, a country's total production amounts to 839 billion US-$ (with a standard deviation of 2617 billion US-$) and produces 207 million tonnes of CO2 (s.d. 698 mT). Interestingly, in some countries, the implicit carbon tax is even negative, indicating that the energy input is subsidized. In addition, they set the SCC at 29 US-$, as estimated by the US Interagency Working Group on Social Cost of Greenhouse Gases (2010), and use the work of the OECD (2016) to find the implicit carbon tax λ^i for each country.

Table 2.1: Model variables at sector-level, excerpt from Larch et al. (2017)

	Production (Y) (billion US-$)	Emissions (E) (mT of CO2)	Energy cost share (α)	Carbon tariffs (τ) (product-based)	Avg. Trade flows X_l^{ij}
Agriculture	25,498	4.62	0.04	0.002	21.89
	(67,654)	(15.61)	(0.04)	(0.004)	(186.21)
Mineral	32,605	73.55	0.51	0.019	44.06
	(86,679)	(258.70)	(0.23)	(0.032)	(330.14)
Service	288,220	48.79	0.09	0.003	143.65
	(976,964)	(159.90)	(0.06)	(0.006)	(867.00)

Note: standard deviations in parentheses.

Table 2.1 displays some sector-level variables used to solve the model. Among others, the "Service" sector is the largest contributor to overall production, while "Mining" (which comprises the production of coal and refined petroleum products) is the most polluting. Finally, the last column contains the average sectoral trade flows between each country pair and, of these, "Services" is the sector with the highest average value of trade flows.

2.4 Results

Firstly, Larch et al. (2017) feed the observed data for production and trade flows into the gravity model and use them to calibrate the model in the benchmark scenario. In Table 2.2, the coefficients of the variables influencing sectoral trade flows are listed, and a high R^2 implies that the independent variables (e.g. distance, language) can explain the variance of the dependent variable (i.e. sectoral trade flows) very well. For example, in all sectors, the distance coefficient is statistically significant and always negative, suggesting that trade flows decrease when countries are more distant. The impact is greatest for the

Table 2.2: Estimation results for the gravity equation (PPML), excerpt from Larch et al. (2017)

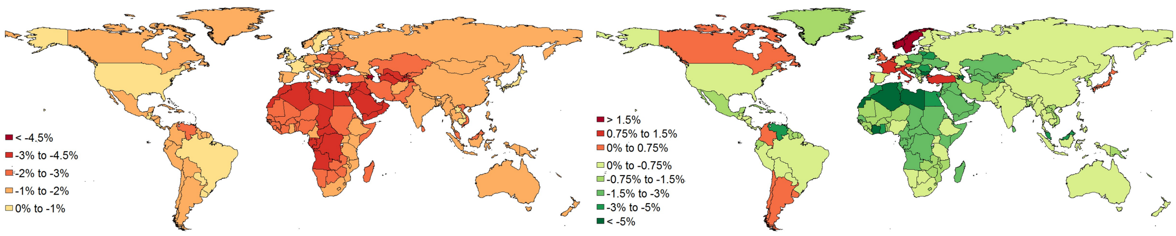
dep. var.	X_{agr}	X_{che}	X_{food}	X_{met}	X_{mine}	X_{mini}	X_{ser}	X_{tex}	X_{wood}
ln DIST	-1.14**	-0.92**	-0.92**	-0.93**	-1.22**	-1.33**	-0.35**	-1.08**	-0.93**
	(0.052)	(0.038)	(0.040)	(0.043)	(0.062)	(0.11)	(0.032)	(0.052)	(0.098)
RTA	0.22*	0.40**	0.52**	0.19	0.11	0.100	0.14*	0.26**	0.43**
	(0.088)	(0.069)	(0.067)	(0.085)	(0.11)	(0.16)	(0.059)	(0.087)	(0.15)
LANG	0.32**	0.24	0.29**	0.098	0.24*	0.036	0.14*	0.52**	0.12
	(0.11)	(0.093)	(0.083)	(0.11)	(0.11)	(0.20)	(0.060)	(0.086)	(0.13)
COMC.	0.49**	0.20+	0.74**	0.43**	0.71**	-0.25+	0.72**	-0.54**	0.63**
	(0.16)	(0.12)	(0.14)	(0.14)	(0.41)	(0.41)	(0.15)	(0.15)	(0.15)
Pseudo-R^2	0.776	0.901	0.849	0.920	0.886	0.769	0.929	0.894	0.849

Note: robust standard errors in parentheses.

mining industry, where a 1% increase in distance reduces trade flows by 1.33%, and least for the services sector, where trade flows decrease only by 0.35%. Conversely, having in place bilateral Regional Trade Agreements or a language in common increases trade flows by 0.3% and 0.22% on average, respectively.

2.4.1 Pure Carbon Tariffs

Figure 2.3: Left: percentage changes in normalized trade flows with pure carbon tariffs, Right: percentage changes in carbon emissions with pure carbon tariffs, Larch et al. (2017)



Trade flows - The first result is that introducing pure carbon tariffs (i.e. equal to the country-pair differential in implicit carbon taxes λ^i) reduces global trade flows by 1.9%. In particular, countries with lower implicit carbon taxes suffer a stronger reduction in trade flows since (1) they will be asked the highest tariffs (their goods become more expensive and lose competitiveness), and (2) as can be seen in the gravity Equation 2.3, tariffs negatively affects trade volumes.

Welfare - Larch et al. (2017) measure welfare using the total utility function shown in Equation 2.1 (b). Introducing pure carbon tariffs reduces welfare for the majority of countries, and most of them are developing countries in Africa and Asia. Utility falls as carbon tariffs increase the price p_l^{ij} of tradable goods, negatively affect the budget constraint, and reduce the quantity q_l^{ij} of goods consumed.

Carbon emissions - Lastly, carbon tariffs reduce global carbon emissions by 0.5%. As can be seen in Figure 2.3 on the right, they alter where emissions are produced. Previously, we mentioned that countries with low implicit carbon taxes see their trade flows decrease, since the production of those goods is shifted back to states with higher carbon taxes ("composition effect" between countries). By decomposing the effects on emissions, it can be seen that the decline in emissions is driven by a negative scale effect for all countries, which means that production in real terms declines everywhere. However, the composition effect appears to be the main driver of the reduction. In fact, it is negative for 80% of the countries and accounts for 66% of the global carbon emission contraction, meaning that most countries shift to less energy-intensive sectors, while the other share, consisting mainly of high carbon tax states, increases their emissions.

2.4.2 Copenhagen Accord

Larch et al. (2017) also use their model to investigate the welfare and emissions impacts if a subset of countries, the Annex I group, were to meet the targets set in Appendix I of the Copenhagen Accord, signed in 2009 during the 15th session of the Conference of the Parties (COP). However, the partial adoption of emission targets and policies can lead to carbon leakage, therefore, the authors measure emissions that have not been cut, i.e. offset by non-committing countries, with the Leakage Rate (LR).

Without tariffs - Solving the counterfactual scenario given that Annex I countries fully commit to their emissions pledges results in a global carbon emission reduction of 8.4%. Responsible for 83.4% of the global emissions reduction, the largest effect comes from the technique effect. In fact, exogenous emission commitments directly increase real energy prices, encouraging more efficient energy use. Leakage Rate reaches 13.4%.

With tariffs - Now, Larch et al. (2017) include carbon tariffs to study their impact on the LR. Conversely from Section 2.4.1, they now amount to the real energy prices differential between committing and non-committing countries. With completely fulfilled targets by the committing countries and new carbon tariffs in place, the global carbon reduction is now stronger reaching 9.3%. This further increase is caused by a weaker composition effect (which typically increases emissions) and a stronger technique effect on average between the countries. Leakage Rate is reduced to 4.1%.

3 | Literature Review

Attention to climate change issues is on the rise both among the public and scholars, and Larch et al. (2017) also join the growing literature on international trade that studies the impacts of carbon tariffs on trade flows, welfare, and carbon emissions. To this end, they are the first to build on the work of Copeland et al. (2003) to isolate the forces impacting carbon emissions in a multi-sectoral, multi-factor gravity model. Hence, the work of Larch et al. (2017) is a valuable contribution to the literature, and, in this Section, I first argue the key role of carbon tariffs, then briefly report initial findings on the impacts of implementing a carbon tariff in the real world, and finally explore other methods used in the literature.

3.1 Why Carbon Tariffs

The environment and its components, such as the atmosphere or the oceans, are examples of public goods and, therefore, non-excludable and non-rivalrous. While everyone wants to breathe the clean air and drink clean water, the production of goods and services is polluting and produces carbon emissions, ultimately negatively affecting public goods consumption.

There is broad consensus among economists that an efficient and effective way to internalize the externality caused by emissions is to implement a (Pigouvian) carbon tax (Heal et al. 2019). In order to quantify the "marginal cost of externality" caused by an additional unit of emissions, the social cost of carbon (SCC) is estimated and the Pigouvian tax is set equally (Pindyck 2017). Mechanically, pricing the carbon intensity of a good increases its price, inducing, for example, producers to improve their energy efficiency or switch to cleaner sectors.

Moreover, environmental protection suffers from the problem of free-riding. Namely, after signing an international agreement to tackle carbon emissions, such as the Copenhagen Accord of 2009, countries do not fully commit to their pledges and rely on the emission reductions of others, ultimately leading to a sub-optimal outcome. In this context, carbon leakage is a failure, and in the analysis of Larch et al. (2017) it reaches a level of 13.4% in the base case without tariffs, and drops to 1.41% when both Annex I and

Annex II countries meet their targets and tariffs are in place. These rates are very similar and are further supported by King et al. (2021) where, when countries act alone, the leakage amounts to 16.1%, while, when the majority of countries complies with agreements (in their case the 2015 Paris Agreement), the leakage decreases to about 3%. All in all, these outcomes confirm the validity of carbon tariffs as a tool to tackle carbon leakage.

3.2 The World's First Carbon Tariff and Climate Club

Although the broad consensus and the analyses of Larch et al. (2017) and King et al. (2021) highlight the ability of carbon tariffs to reduce carbon emissions and carbon leakage, no country in the world had implemented such a system before October 2023.

Indeed, it was only with the European Regulation 2023/956, which came into force on 17 May 2023, that the European Union declared the introduction of a Carbon Border Adjustment Mechanism (CBAM) as of 1 October 2023. Without going into too much detail, the goal of this instrument is to restore the competitiveness of European goods and address carbon leakage by setting a price on carbon emissions from goods entering the European market. As it is designed, it resembles the well-known 'climate clubs' proposed by Nordhaus (2015), indeed Szulecki et al. (2022) calls it a "de facto" climate club, analyses their common features, and points out the governance challenges this instrument will have in the future.

Exploiting the model of Larch et al. (2017) described in the previous section, Korpar et al. (2023) analyse the impact of the European CBAM on exports, real GDP, welfare, and carbon emissions. Since both base their analysis on the same multi-regional and multi-sectoral structural gravity model, their results are easily comparable. In terms of trade flows, both find a contraction: Larch et al. (2017) estimate a decrease in aggregate world trade flow of 1.9%, while Korpar et al. (2023) find a decrease in global exports of 0.11%. This small negative effect on European exports is explained by the lower demand for imports from non-EU countries, in fact, non-EU countries experience a slight decrease in their real GDP and, consequently, welfare. In contrast, both European real GDP and welfare increase by about 0.02%, due to higher domestic production. The same conclusions come from Larch et al. (2017) where, in terms of welfare and real income, most (developing) countries are found to be negatively impacted by the redistribution of production between states, while countries with high carbon taxes benefit. Lastly, the European CBAM slightly increases European emissions by 0.24% and decreases global emissions by 0.08%, confirming its (modest) effectiveness in addressing carbon leakage and reducing emissions globally.

3.3 Other Models and Decomposing Carbon Leakage

So far, we have reviewed the results of papers that have developed their analyses on the basis of a structural gravity model to estimate the impact of a carbon tariff on trade flows. However, a few other frameworks are also used in the international trade literature to achieve this goal, for example, the Dynamic Computable General Equilibrium (DCGE) model, as in Zhang et al. (2019), in which the authors study the impact of US carbon tariffs on China's trade flows, carbon emissions, and welfare.

Another particularly interesting example is the work of Tan et al. (2018), which uses a multi-regional Computable General Equilibrium (CGE) model to investigate and decompose the channels through which a carbon tax (in their case a regional Emissions Trading System) generates carbon leakage. Their hypothesis is that carbon leakage occurs mainly through three different channels: 1) competitiveness, which causes the relocation of energy-intensive sectors to regions with more permissive policies; 2) energy, the reduction in production lowers energy prices by sparking fossil fuel consumption in other regions; 3) demand, due to income variation. To this end, they use data from the Hubei ETS and find that the trading scheme succeeds in reducing carbon emissions by 6731 kt CO_2, but the surrounding regions increase emissions by 892 kt, causing a carbon leakage of 13.25%. Isolating the forces, it turns out that the competitiveness channel is the main driver of carbon leakage, accounting for 41.98% of the increase, while energy and demand account for 7.61% and 6.21% respectively. To conclude, the authors propose the introduction of a carbon price on imports from Hubei's neighboring regions, as the competitiveness channel is the main source of carbon leakage, effectively supporting the effectiveness of a carbon tariff on imports to tackle carbon leakage.

4 | Extension

Let's now delve into some possible extensions or improvements that can be done to the work of Larch et al. (2017).

4.1 Enhanced Trade Costs Estimates

As described in Section 2, since trade costs T_l^{ij} are not directly observable, to measure the trade flows X_l^{ij} between each pair of countries, Larch et al. (2017) approximate and estimate them using a vector of seven variables. Among others, they include the distance between the two countries or the presence of Bilateral Trade Agreements, and their coefficients (excerpt in Table 2.2) appears to be statistically significant and with a large average Pseudo-R^2 of 0.86.

However, I believe that also another key factor can determine the trade costs between two countries: currency. More precisely, whether both countries officially adopt the same currency nationally. For example, some minor costs could arise from exchanging and storing different currencies or being subject to the volatility of the rates. This hypothesis is further supported by Anderson et al. (2003), where they find out that the barriers arising from using different currencies may account up to 14% of all trade costs. Similarly, analyzing the case of the European Economic and Monetary Union (EMU), Rose et al. (2001) highlight the huge positive impact that a common currency can have on reducing trade barriers.

Therefore, using the data of the International Standard ISO 4217, which regulates currency codes worldwide, we can create a dummy variables taking values as follow:

$$z^{ij} = \begin{cases} 1 & \text{if } currency^i = currency^j \\ 0 & \text{otherwise} \end{cases} \tag{4.1}$$

where, the variable takes value 1 if both countries adopt the same currency. Now, we can include it in the vector $\boldsymbol{z}_l^{ij}$ of regressors (see Equation 2.6), and run again the regression for the PPML estimator to estimate the updated measure for trade flows, hopefully now with an even higher R^2.

4.2 Reinforced Low-Carbon Consumer Preferences

In Equation 2.1 (b), Larch et al. (2017) include in the total utility of the representative consumer a damage factor that reduces utility based on the social cost of carbon μ^j and the total emissions E^i produced by all other countries, i.e $(\frac{1}{\mu^j}\sum_{i=1}^{N} E^i)^2$.

As it is modeled, pollution is treated as a pure externality and does not directly enter into consumer choice. Nowadays, I believe that consumers actively choose ex-ante a low-carbon consumption bundle, and not only do they suffer the pollution ex-post. This behavior is fostered also by the presence of carbon labels on the products (as highlighted by Vanclay et al. (2011)), or information regarding the place or production methodology (e.g. bio vs conventional agriculture, recycled vs virgin paper, recycled vs virgin rare earth elements). The two elements work in the same direction and, to my mind, this extension provides an additional micro-foundation to the model.

The new underlying mechanism is as follows: 1) the consumer gains a greater utility from consuming low-carbon goods, 2) therefore, thanks to elasticity in consumption, the expenditure in low-carbon sectors increases and falls in the others, 3) since the balance trade assumption applies, i.e. $Y^j = \mathfrak{X}^j$, everything produced is consumed, a higher share of low-carbon goods is produced, 4) ultimately, the production-share-weighted average energy cost term $\bar{\alpha}_E^i$ is smaller in Equation 2.4, thus reducing emissions E^i. To obtain a closer approximation of this consumption behavior and mechanism, I propose an extension of the utility function previously illustrated in Equation 2.1 (a).

$$U_l^j = \left[\sum_{i=1}^{N}(\beta_l^i)^{\frac{1-\sigma_l}{\sigma_l}}\left(\frac{q_l^{ij}}{\boldsymbol{1+\delta_l^j I_l^{ij}}}\right)^{\frac{\sigma_l-1}{\sigma_l}}\right]^{\frac{\sigma_l}{\sigma_l-1}} \tag{4.2}$$

In Equation 4.2 is illustrated the extended utility function. The new parameters are: 1) δ_l^j, which captures the preference for low-carbon intensive goods in sector l and country j, 2) I_l^{ij}, the carbon intensity of goods from sector l produced in country i and consumed in country j.

δ_l^j serves as a weight: a more environmentalist consumer gives more importance (and weight) to the carbon intensity of the goods she consumes and therefore will have a higher δ_l^j and, depending on I_l^{ij}, a larger denominator, and a lower U_l^i. Conversely, an egoist consumer does not value at all carbon intensity, and her δ_l^j is 0.

I_l^{ij} accounts for the emissions emitted during the production of a unit of a good in country i, and is defined as follows: $I_l^{ij} = E_l^i/q_l^i$. Here, when the representative consumer buys a good with a low carbon intensity I_l^{ij}, the denominator is smaller, and the utility U_l^i is larger.

In the context of the decomposition analysis of Larch et al. (2017), I expect this extension to further increase the composition effect, i.e. $\frac{\delta E^i}{\delta \bar{a}_E^i}$. This effect was already the main driver of emission reductions and now, as consumers have even more incentives to switch to low-carbon consumption, it will increase the share of low-carbon output and, ultimately, reduce emissions.

In conclusion, besides fulfilling the main role of providing additional micro-foundation, I believe this extension can also correct the often underestimated social cost of carbon. Indeed, a too low estimate of the SCC cannot capture the real damage suffered by the consumer due to pollution and diminishes the attractiveness of a low-carbon consumption bundle. The American Interagency Working Group on the Social Cost of Carbon is the main and most famous research team evaluating such a measure. For instance, Larch et al. (2017) use a social cost of carbon μ^j of 29 US-$ for 2007, in line with Nordhaus (2017) which uses a SCC of 31 US-$ for 2010 with a discount rate of 3%. However, in 2021, while the Interagency Working Group on Social Cost of Greenhouse Gases (2021) estimated a SCC of 51 US-$ for 2020, in 2022, Rennert et al. (2022) estimated a mean SCC of 185 US-$ per ton of CO2. Still, in 2023, Interagency Working Group on Social Cost of Greenhouse Gases (2023) found a SCC of 120 US-$ for 2020 at a 2.5% discount rate. It is clear that the social cost of carbon is constantly evolving, as are the techniques to measure it. Hopefully, this micro-founded extension, together with the disutility factor, can extensively account for the negative impact of carbon emissions.

5 | Conclusion

Larch et al. (2017) analyze the impacts of introducing carbon tariffs on trade flows, welfare, and emissions effects. Moreover, building on the work of Copeland et al. (2003), they decompose the forces influencing emissions into three effects: scale, composition, and technique. To this end, they are the first to implement such analysis by exploiting a structural multi-sector and multi-factor gravity model.

Firstly, to address the externalities of carbon emissions, they estimate the consequences of introducing a pure carbon tariff on imports, that is, a tax equal to the carbon tax differential between each pair of countries. They find: 1) global trade flows decrease by 1.9%, 2) 79% of the countries experiences a welfare loss, and developing countries suffer the most, 3) however, world carbon emissions decrease by 0.50%. Breaking down the forces behind the change in emissions, they reveal that the main driver is the composition effect, which means that low-carbon sectors have increased their share in global production.

Secondly, they estimate once again the impacts of carbon tariffs on trade, welfare, and carbon emissions, in case a subgroup of countries (Annex I from the Kyoto Protocol) fully reaches its climate pledges. The goal is to explain whether carbon tariffs can also reduce carbon leakage, a major problem when it comes to meeting the targets of international agreements. They point out that: 1) in the case where the Annex I group reaches its pledges but carbon tariffs are not in place, carbon leakage amounts to 13.4%, and emissions decrease by 8.4%, 2) on the other hand, with carbon tariffs, carbon leakage falls to 4.14%, and emissions shrink by 9.3%.

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Declaration of Authenticity

I hereby declare that I have prepared this seminar paper independently and without the use of aids other than those specified, that I have not yet submitted it to another examination authority and that it has not yet been published.

In the case of the use of generative models for the creation of texts, illustrations, calculations and other services, I am fully responsible for the selection, adoption and all results of the generated output used by me. In the list "Overview of tools used" I have named all generative models used with their product name and indicated how, to what extent and for what purpose they were used.

Overview of tools used

ChatGPT: Used in the reading/comprehension phase to assist with understanding complex sections and explaining statistical instruments.

10/06/2024 Giovanni Remonti