Carbon Tariffs and Trade Wars

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Participation in the Paris Agreement is voluntary and countries unilaterally decide on their emission reduction targets. Unilateral climate policy can shift economic activity with little or no impact on global emissions due to carbon leakage. As an alternative to globally coordinated measures, carbon tariffs can limit leakage by shifting the cost of abatement partly from countries with stringent climate policy to countries with lax (or no) climate policy, protect domestic and international competitiveness, and incentivize countries to price emissions. In light of the debates following the announcement of the withdrawal of the US from the Paris Agreement in 2025, using a general equilibrium trade model with cross-border pollution externalities from production, I evaluate the potential for carbon tariffs as an instrument to enforce the Paris Agreement commitments and investigate the strategic interactions across trade partners. I find that welfare-maximizing carbon tariffs are not sufficient to enforce participation in the global emission mitigation efforts. All countries are worse off when retaliation leads to a worldwide trade war. Finally, estimated trade elasticities play a crucial role in determining the industry-level differences across welfare-maximizing carbon tariffs.

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1 Introduction

Voluntary participation in global emission reduction efforts creates a non-cooperative policy environment where participating countries, motivated by both economic and environmental concerns, consider trade restrictions such as carbon tariffs. What are the optimal carbon tariffs in the presence of such legally unbinding environmental agreement where parties unilaterally decide their abatement levels? How do optimal carbon tariffs depend on industry properties like trade elasticities and trade exposure? Optimal carbon tariffs are adopted when imposing countries do not fear any retaliation. Then, another question follows: What happens if other countries retaliate in response to the carbon tariffs imposed on them? If participating countries in turn respond to this threat by increasing their import tariffs, a worldwide tariff war is possible. What are the environmental and economic consequences for both participating and non-participating countries if carbon tariffs lead to a trade war? Focusing on the role of carbon tariffs, my goal in this paper is to investigate the implications of these strategic policy interactions between countries in the context of the Paris Agreement.

Although the environmental and economic effects of alternative carbon tariff designs have been studied in detail in the literature, due to computational and methodological constraints, there are fewer examples that analyse environmental regulations in an optimal policy framework. In particular, previous quantitative analyses mainly focus on carrying out comparative statics of environmental policy alternatives and policy formation among coalition and non-coalition countries. However, detailed exploration of the strategic interactions between countries and the roles of trade and climate policies in these interactions are important to understand how nations should conduct their policy. In the current environmental policy environment, mitigation measures adopted across countries are strongly asymmetric. Countries participating in the Paris Agreement determine their emission reduction rates voluntarily and there is no mechanism in the agreement to enforce participation or commitment. For countries that consider relatively aggressive carbon pricing, this non-cooperative policy formation amplifies the fear for their competitive position in the world economy. Since carbon pricing as a policy instrument cannot be optimally deployed in a cooperative setting under these circumstances, carbon tariffs emerge as a second-best instrument that might have a role to address these environmental challenges. Building on the theoretical framework of Ossa (2014), I investigate the interaction between climate and trade policies and the environmental and economic implications of these interactions in the non-cooperative policy environment provided by the debates around the Paris Agreement.

The international agreement adopted in 2015 at the 21st Conference of Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC) created optimistic expectations for cooperation in international climate policy since both industrialized and developing countries agreed to reduce greenhouse gas emissions (GHG) via voluntary pledges to keep the global mean surface temperature less than 2 degrees Celsius above pre-industrial levels. However, the announcement of the United States, the world's largest economy and the second largest emitter,[1] to withdraw from the agreement created the need to assess the effect of this withdrawal on the compliance prospects of the agreement, and raised the question how other countries should respond. Following the announcement of the US withdrawal, punitive measures, like carbon tariffs have gained supporters among the ratifying parties of the Paris Agreement as an action against non-action.[2] With mechanisms well documented in the literature, when parties do not make commitments comparable with each other on GHG emission reductions, carbon leakage, the reshuffling of emissions to non-regulated regions, can reduce the effectiveness of policies in place. As a second-best alternative to

[1]See Boden et al. (2017) for an analysis of how countries compare in terms of total emissions.

[2]"If Trump wants to withdraw the US from the Paris climate agreement, the rest of the world should impose a carbon-adjustment tax on US exports that do not comply with global standards." J.E. Stiglitz, The Guardian, June 2017. "Further work on developing carbon border adjustments is necessary as a leverage for further efforts by all countries to achieve the objectives enshrined in the Paris Agreement." European Parliament resolution of 3 July 2018 on climate diplomacy. See also Kemp (2017)

globally coordinated measures, carbon tariffs, although complicated and costly to design and implement, can limit this increase in emissions by shifting part of the economic burden to the unregulated regions.[3] In light of the debates following the announcement of the US withdrawal, using a multi-industrial, multi-regional general equilibrium model with emissions from production, I investigate the economic and environmental consequences of a Paris Agreement without the US. In response to the US withdrawal, other countries may choose to impose carbon tariffs on the US imports to encourage cooperation. Therefore, I analyse whether carbon tariffs are effective enforcement instruments in the context of the Paris Agreement. However, the US may in turn take retaliatory action against the countries that impose carbon tariffs on its imports in the form of a more protectionist trade policy. If other countries decide to respond to the US retaliation, this may lead to a worldwide trade war among all parties. I study these strategic interactions across countries and analyse the environmental and economic consequences.

Although the legality of carbon tariffs is still debated, compatibility of such border measures to World Trade Organization (WTO) rules is often defended based on the environmental conservation and public health exceptions outlined in the Article XX of the General Agreement on Tariffs and Trade (GATT).[4] Of particular relevance to the legal debate is also the fundamental requirement of the WTO which states that for a particular environmental policy to be acceptable under the GATT disciplines, it must not lead to unjustifiable discrimination between countries.[5] When analysing the effects of carbon tariffs, the literature generally resorts to a standard approach of calculating carbon tariffs that is most likely to satisfy the regulatory exceptions of the GATT. This involves eliminating the burden on domestic production imposed by environmental tax differentials between countries and imposing tariffs on embodied emissions in imports calculated without discriminating trade partners based on

[3] Fischer et al. (2009) and Frankel and Aldy (2009) review the legal barriers to implementing carbon tariffs based on carbon content of imports. Böhringer et al. (2012) consider alternative designs for anti-leakage measures and compares them in terms of cost effectiveness.

[4] See for example Nordhaus (2015).

[5] For more information on this subject, see GATT Article XX on General Exceptions.

process and production methods. After presenting the results of the benchmark scenario where all ratifying regions including the US achieve their targets as agreed in the Paris Agreement, and also the effects of the US withdrawal, I turn to calculating the "standard" carbon tariffs which are equal to the carbon tax that would have been imposed had the good been produced in the importing region (therefore based on the emission intensity of the importer for GATT consistency). Carbon tariffs imposed by the ratifying regions on US imports are successful in restricting emissions from the US production but I find that the US is better off when it withdraws and faces the carbon tariffs compared to the case where it aims to achieve its Paris Agreement target. Imposing regions gain from the carbon tariffs, both in terms of environmental outcomes and improved terms of trade, however these gains are not large enough to entice the US to restrict its emissions and capture the revenues otherwise accruing to its trade partners.

There are numerous studies investigating the effects of exogenously determined carbon tariffs on carbon leakage, welfare and competitiveness. Condon and Ignaciuk (2013) provide an extensive review of the early literature on carbon tariffs. The main findings of this literature are that carbon tariffs reduce carbon leakage, shift the cost of abatement partly from high carbon tax countries to low carbon tax countries, and reduce competitiveness pressures on emission-intensive and trade-exposed industries in high carbon tax countries. Among the large number of studies that evaluate the efficiency and effectiveness of various carbon tariff designs imposed by a coalition of high carbon tax countries to low carbon tax countries, several incorporate carbon tariffs to existing environmental policy schemes, for example Babiker and Rutherford (2005) show that carbon tariffs can reduce the negative welfare effects on the Kyoto coalition countries by shifting the cost of abatement partly to the non-coalition countries. Using a partial equilibrium model, Monjon and Quirion (2011) investigate whether carbon tariffs can address the competitiveness concerns of the the emission intensive industries regulated under the EU-ETS. A recent example is the work of Larch and Wanner (2017) who find that incorporating carbon tariffs increase the effectiveness of the Copenhagen Accord by lowering carbon leakage. The theoretical literature on optimal environmental tariffs begins with Markusen (1975) who, although not specifically focusing on carbon tariffs, establishes the optimal domestic and trade policy instruments in a two-good, two-country neoclassical general equilibrium model with cross-border production externalities. He shows that import tariffs can be a tool for a sufficiently large coalition of countries to control the externality from foreign production. Building on the analysis of Markusen (1975), Hoel (1996) examines the optimal unilateral carbon taxes in a non-cooperative setting and the corresponding level of import tariffs as a policy response. The main conclusions of his analysis are that optimal carbon taxes should not be differentiated across industries provided that countries are not prevented from using import tariffs as an instrument and that the optimal tariffs must approach zero as international market power approaches zero. The majority of the studies on optimal environmental policy is based on the theoretical framework established by Hoel (1996). And the literature focusing on the optimal carbon tariffs and the quantitative analysis of strategic interactions between countries is relatively recent. Based on the model framework developed by Markusen (1975), Balistreri et al. (2016) study the optimal carbon tariffs imposed by a coalition formed by the Annex I countries on imports from the non-coalition countries in two emission intensive industries. They find that optimal carbon tariffs that arise only from environmental concerns of the coalition is substantially lower than the level of coalition carbon tax. Employing a CGE model, Böhringer and Rutherford (2017), examine the effect of exogenous carbon tariffs imposed on the US after its withdrawal from the Paris Agreement and calculates the retaliating optimal import tariffs as a strategic response by the US on the rest of the world. Similar to the results presented in this paper, Böhringer and Rutherford (2017) find that carbon tariffs do not pose a credible threat to the US and it is better of withdrawing from the agreement. Winchester (2018) studies the same subject and analyses whether carbon tariffs can be used to enforce participation in the Paris Agreement. The results are similar, although carbon tariffs result in small reductions in the US emissions and welfare levels and is better off when it does not restrict emissions and faces the carbon tariffs. Winchester (2018) also analyses a tariff war between the US and an aggregate coalition formed by the committed countries to the Paris Agreement. The results show a tariff war results in a large decrease in the US welfare. The contribution of this paper to the climate policy literature is first of all the comprehensive and flexible framework that can be used to analyse optimal environmental and trade policies in a multi-industry and multi-region set up. The model allows me to calculate non-cooperative optimal policy choices at the industry level for each country and analyse the resulting strategic interactions between countries. The results show that optimal carbon tariffs are substantially higher than the carbon tariffs calculated based on the domestic emission cost differences across countries. This confirms the results of the previous theoretical literature: Countries have motivated to influence the terms of trade in their favour and set carbon tariffs higher than the environmentally optimal levels. The results of the retaliation scenario show that the US would prefer withdrawing from the Paris Agreement, bearing the cost of optimal carbon tariffs and retaliating by imposing import tariffs on exports of other countries to achieving its target under the Paris Agreement. Under a possible worldwide tariff war scenario, all regions take protectionist measures and increase their import tariffs. These are Nash equilibrium tariffs. They substantially differ across countries and industries emphasizing the role of trade elasticities. The results show that a tariff war induced by the US retaliation leaves all countries worse off compared to the Paris Agreement scenario indicating that when faced with the threat of a tariff war, the best play for the US and other countries is to meet their Paris Agreement pledge.

The remainder of the paper is organized as follows. Section 2 presents the basic setup of the model. Section 3 describes the data and the calibration of the model parameters. Section 4 shows the effects of achieving the emission reduction targets adopted by the countries in the Paris Agreement, the consequences of the US withdrawal, then calculates and evaluates the optimal carbon tariffs, finally discusses the implications of retaliation and a worldwide tariff war. The last section concludes.

2 A Quantitative Framework for Optimal Tariffs with Pollution Externalities

I start by outlining a static general equilibrium model of international trade that incorporates emissions from production. The model is then used to analyse the outcome of how economies respond to strategically determined policy interventions that control pollution emissions. The model embeds a variant of other gravity models comprehensively surveyed in Costinot and Rodríguez-Clare (2014) and provides a rich and flexible general equilibrium framework to explore optimal environmental policy alternatives. The setup of the model is based on the theoretical foundation introduced by Ossa (2014) which features imperfect competition and firms differentiated in productivity levels, but builds on it to reflect stylized properties of polluting industries. Specifically, pollution is an increasing function of output and a decreasing function of pollution abatement expenditures, and productivity levels determine pollution intensity of production. All productive processes generate some pollution and firms invest in abatement technologies in response to the stringency of environmental policy. The model serves to introduce a quantitative analysis of optimal carbon tariffs in the presence of pollution externalities in a multi-regional and multi-industrial framework.

The model describes a world of N regions indexed by i and j, and S industries indexed by s. Each region is endowed with a fixed labour force L_i. In each region, consumers have access to a continuum of varieties differentiated by their productivity levels and consumer preferences over these varieties follow a utility function given by

$$U_j = \prod_{s=1}^{S} \left[\left(\sum_{i=1}^{N} \int_0^{M_{is}} x_{ijs}(\nu_{is})^{\frac{\sigma_s - 1}{\sigma_s}} d\nu_{is} \right)^{\frac{\sigma_s}{\sigma_s - 1}} \right]^{\mu_{js}} \left[\frac{1}{1 + \left(\eta_j^{-1} \sum_{i=1}^{N} Z_i\right)^2} \right] \tag{1}$$

Equation (1) describes the nested utility function of consumers in region j with Cobb-Douglas preferences across industries and constant elasticity of substitution (CES) preferences across product varieties within an industry s. All income from wages and pollution control regulations accrues to the consumers and is allocated across varieties of goods, ν_{is}, from the mass M_{is} of industry s varieties produced in region i. $x_{ijs}(\nu_{is})$ represents the quantity of variety ν_{is} goods in industry s exported from region i to j. The share of region j's income spent on industry s varieties is given by μ_{js}, where $\sum_{s=1}^{S} \mu_{js} = 1$. And $\sigma_s > 1$ represents the elasticity of substitution between industry s varieties. The second bracketed term represents the multiplicative damages from pollution. The aggregate stock of transboundary pollution emitted in all regions across all industries is $Z = \sum_{i=1}^{N} Z_i$ and η_j dictates the social cost of emissions.[6] The consumer's decision has two stages. In the first stage, preferences given in equation (1) imply that consumers in region j spend the share μ_{js} of income on industry s goods. In the second stage, consumers allocate their income across varieties in industry s. Therefore, consumers maximize utility subject to the budget constraint,[7]

$$\int_0^{M_{is}} p_{is}\theta_{ijs}\tau_{ijs}x_{ijs} = \mu_{js}X_j \tag{2}$$

where p_{is} is the factory price of an industry s variety from region i and $\theta_{ijs} \geq 1$ is the iceberg trade cost of shipping industry s varieties from region i to j, therefore $p_{is}\theta_{ijs}$ is the before tariff price of the industry s variety imported from region i to region j. Governments can impose tariffs on imports. t_{ijs} represents the industry-specific ad valorem tariff imposed by region j on imports from region i and $\tau_{ijs} = 1 + t_{ijs}$. Finally, X_j denotes the total expenditure in region j.

Subsequently, utility maximization subject to the budget constraint implies that firms in industry s of region i face the demand

[6] I assume that pollution is a pure externality coming from industrial activity and consumers ignore the last term in equation (1) when they make consumption decisions. The parameter η_j captures the regional social cost of carbon and dictates the marginal damages from pollution. The disutility from global emissions is the only feedback loop from environment to economy in this model, therefore changes in environmental quality do not affect productivity or factor endowments. Similar functional forms for climate damages are commonly used in environmental economics to determine the effects of emissions on climate and have recently been adopted by the international trade literature studying various environmental policy alternatives to quantify the impact of regulation on economic outcomes (Shapiro (2016), Larch and Wanner (2017), Kreickemeier and Richter (2018)).

[7] I omit the variety notation (ν_{is}) in the rest of the paper for simplicity.

$$x_{ijs} = \frac{(p_{is}\theta_{ijs}\tau_{ijs})^{-\sigma_s}}{P_{js}^{1-\sigma_s}}\mu_{js}X_j \tag{3}$$

where P_{js} is the consumer price index of industry s varieties in region j. Preferences imply that the consumer price index is given by $P_{js} = \left(\sum_{i=1}^{N} M_{is}(p_{is}\theta_{ijs}\tau_{ijs})^{1-\sigma_s}\right)^{\frac{1}{1-\sigma_s}}$.

Each variety ν_{is} is uniquely associated with an individual firm and in every region, production technology of industry s varieties is homogeneous across firms. Each region has a single productive factor which is inelastically supplied. The inverse production function of firms producing industry s varieties in region i is given by

$$l_{is} = \sum_{j=1}^{N} \frac{\theta_{ijs}x_{ijs}}{(1-\xi_{is})\varphi_{is}} \tag{4}$$

where φ_{is} is the productivity level and l_{is} is the units of labour required at wage w_i to produce industry s varieties. Industrial activity creates pollution and government in region i imposes an environmental policy in the form of a carbon tax, e_i, per ton of pollution emitted on z_{is} tons of pollution emitted as a result of the production in industry s. In order to reduce emissions, firms divert a fraction ξ_{is} of the primary factor, labour, away from production and engage in abatement activities. Then, in region i, the fraction $(1-\xi_{is})$ of this labour is used in production and the remaining ξ_{is} for pollution abatement in industry s.

Following Copeland and Taylor (2013), the production in industry s generates emissions according to the technology given by

$$z_{is} = (1-\xi_{is})^{1/\alpha_{is}}\varphi_{is}l_{is} \tag{5}$$

where z_{is} is the tons of emissions from the production of industry s goods in region i and $\alpha_{is} \in (0,1)$ represents the elasticity of pollution emissions intensity with respect to pollution abatement intensity.[8] From equation (5), pollution is a decreasing function of abatement and an increasing function of output. The level of abatement is determined in equilibrium and I assume that pollution regulations are stringent enough so that all firms engage in some level of abatement. As the government imposes a tax on emissions, e_i, firms engage in abatement activities. The increase in abatement increases firm profits by reducing the pollution tax payments but reduces profits as the share of productive resources allocated to abatement increases.

Given the production technology and the structure of pollution emissions in equations (4) and (5), firms in region i maximize industry profits

$$\pi_{is} = M_{is}\big(\sum_{j=1}^{N} p_{is}\theta_{ijs}x_{ijs} - w_i l_{is} - e_i z_{is}\big) \tag{6}$$

Profit maximization implies that firms producing industry s varieties in region i set prices with a constant markup over marginal costs so that

$$p_{is} = \frac{\sigma_s}{\sigma_s - 1} \quad \frac{w_i^{(1-\alpha_{is})} \quad e_i^{\alpha_{is}}}{\alpha_{is}^{\alpha_{is}}(1-\alpha_{is})^{(1-\alpha_{is})}\varphi_{is}^{(1-\alpha_{is})}} \tag{7}$$

Substituting the expressions in (3), (4), (5) and (7) into equation (6), given carbon tariffs, the industry profits become

$$\pi_{is} = \frac{1}{\sigma_s}\sum_{j=1}^{N} M_{is}\tau_{ijs}^{-\sigma_s}\left(\frac{\sigma_s}{\sigma_s - 1} \quad \frac{w_i^{(1-\alpha_{is})} \quad e_i^{\alpha_{is}}}{\alpha_{is}^{\alpha_{is}}(1-\alpha_{is})^{(1-\alpha_{is})}} \frac{\theta_{ijs}}{\varphi_{is}^{(1-\alpha_{is})}P_{js}}\right)^{1-\sigma_s} \mu_{js}X_j \tag{8}$$

Given the level of import tariffs and equation (7), the equilibrium price index can be

[8] Notice that using equations (4) and (5), ξ_{is} can be eliminated to obtain the joint production technology as $\sum_{j=1}^{N}\theta_{ijs}x_{ijs} = z_{is}^{\alpha_{is}}(\varphi_{is}l_{is})^{1-\alpha_{is}}$ where total industry s output in region i is written as a Cobb-Douglas production function of emissions and labour. Hence, pollution can equivalently be treated as another factor of production even though it is an outcome of the production process. As a result, α_{is} can also be described as pollution tax payments as a share of total production costs in this interpretation. For a detailed discussion of equivalent interpretations of this abatement technology see Copeland and Taylor (2013).

expressed as

$$P_{js} = \left[\sum_{i=1}^{N} M_{is} \left(\frac{\sigma_s}{\sigma_s - 1} \quad \frac{w_i^{(1-\alpha_{is})} \quad e_i^{\alpha_{is}}}{\alpha_{is}^{\alpha_{is}} (1-\alpha_{is})^{(1-\alpha_{is})} \varphi_{is}^{(1-\alpha_{is})}} \theta_{ijs} \tau_{ijs} \right)^{1-\sigma_s} \right]^{\frac{1}{1-\sigma_s}} \tag{9}$$

In equilibrium, labour supply equals labour demand, $L_i = \sum_{s=1}^{S} M_{is} l_{is}$. Using equations (3), (4), (5) and (7), the labour market clearing condition becomes

$$w_i L_i = \sum_{s=1}^{S} \pi_{is} (\sigma_s - 1)(1 - \alpha_{is}) \tag{10}$$

Given the cost of emissions, the level of pollution in region i is determined in equilibrium. Then, the global pollution stock is the sum of pollution emissions in all regions

$$Z = \sum_{i=1}^{N} Z_i \tag{11}$$

where the total cost of emissions in country i is given by

$$e_i Z_i = \sum_{s=1}^{S} \pi_{is} (\sigma_s - 1) \alpha_{is} \tag{12}$$

Finally, total expenditures in region j equals total income given by the sum total factor income, firm profits and lump-sum payments of tariff revenue:

$$\begin{aligned} X_j = {} & w_j L_j + e_j Z_j + \sum_{s=1}^{S} \pi_{js} \\ & + \sum_{i=1}^{N} \sum_{s=1}^{S} t_{ijs} M_{is} \tau_{ijs}^{-\sigma_s} \left(\frac{\sigma_s}{\sigma_s - 1} \frac{w_i^{(1-\alpha_{is})} e_i^{\alpha_{is}}}{\alpha_{is}^{\alpha_{is}} (1-\alpha_{is})^{(1-\alpha_{is})}} \frac{\theta_{ijs}}{\varphi_{is}^{(1-\alpha_{is})} P_{js}} \right)^{1-\sigma_s} \mu_{js} X_j \end{aligned} \tag{13}$$

where total tariff revenue is derived from $TR_j = \sum_{i=1}^{N} \sum_{s=1}^{S} t_{ijs} M_{is} x_{ijs} p_{is} \theta_{ijs}$ using the expressions on x_{ijs} and p_{is}.

The conditions given in equations (8), (9), (10), (11) and (13) define the equilibrium in this economy:

Definition 1. A general equilibrium in this economy is a system of equations (8), (9), (10), (11) and (13) which can be solved for wages $\{w_i\}_{i=1}^{N}$, aggregate stock of emissions $\{Z\}$, total expenditures $\{X_j\}_{j=1}^{N}$, prices $\{P_{js}\}_{j,s=1}^{N,S}$ and industry profits $\{\pi_{is}\}_{i,s=1}^{N,S}$ given the set of import tariffs $\{t_{ijs}\}_{i,j,s=1}^{N,S}$, cost of emissions $\{e_i\}_{i=1}^{N}$, and parameters $\{M_{is}, \theta_{ijs}, \varphi_{is}, \sigma_s, \alpha_{is}\}_{i,j,s=1}^{N,S}$.

The set of parameters $\{M_{is}, \theta_{ijs}, \varphi_{is}\}$ required to solve the equilibrium conditions are difficult to observe and measure. For example, barriers to trade captured by θ_{ijs} are rarely observed. Even when accurate data on freight expenditures are available in monetary terms, these may paint an incomplete picture of trade barriers since risk of damage in transit, communication-based barriers or time spent in transit can rarely be captured.[9] Data on these parameters are not necessary when the equilibrium conditions are expressed as relative changes from the baseline equilibrium. As commonly applied in the literature, following Dekle et al. (2008), rather than attempting to measure these parameters, I rewrite the equilibrium conditions in relative changes. This technique proceeds as follows. Let x denote the value of a variable in the model in the baseline equilibrium and x' denote its value in the counterfactual scenario, then $\hat{x} = x'/x$ is the relative change in x due to the counterfactual. Rewritten in changes, the equilibrium conditions given a change in the set of import tariffs become:

$$\hat{\pi}_{is} = \sum_{j=1}^{N} a_{ijs} \hat{\tau}_{ijs}^{-\sigma_s} \left(\frac{\hat{w}_i^{(1-\alpha_{is})}}{\hat{P}_{js}} \right)^{1-\sigma_s} \hat{X}_j \tag{14}$$

where $a_{ijs} = \frac{Tijs}{\sum_{n=1}^{N} T_{ins}}$ and $T_{ijs} = M_{is}\tau_{ijs}^{-\sigma_s} \left(\frac{\sigma_s}{\sigma_s - 1} \frac{w_i^{(1-\alpha_{is})} e_i^{\alpha_{is}}}{\alpha_{is}^{\alpha_{is}} (1-\alpha_{is})^{(1-\alpha_{is})}} \frac{\theta_{ijs}}{\varphi_{is}^{(1-\alpha_{is})} P_{js}} \right)^{1-\sigma_s} \mu_{js} X_j$ is the expression for bilateral trade flows between country j and i in industry s.

$$\hat{P}_{js} = \left[\sum_{i=1}^{N} \gamma_{ijs} \left(\hat{w}_i^{(1-\alpha_{is})} \hat{\tau}_{ijs} \right)^{1-\sigma_s} \right]^{\frac{1}{1-\sigma_s}} \tag{15}$$

[9] See for example Anderson and Van Wincoop (2003), Evans and Harrigan (2005) and Hummels (2007) for discussions on this subject.

where $\gamma_{ijs} = \frac{\tau_{ijs} Tijs}{\sum_{m=1}^{N} \tau_{ims} T_{ims}}$.

$$\hat{w}_i = \sum_{s=1}^{S} \delta_{is} \hat{\pi}_{is} \tag{16}$$

where $\delta_{is} = \frac{\sum_{j=1}^{N} \frac{(\sigma_s - 1)(1-\alpha_{is})}{\sigma_s} T_{ijs}}{\sum_{t=1}^{S} \sum_{n=1}^{N} \frac{(\sigma_t - 1)(1-\alpha_{it})}{\sigma_t} T_{int}}$.

$$\hat{Z}_i = \sum_{s=1}^{S} \zeta_{is} \hat{\pi}_{is} \tag{17}$$

where $\zeta_{is} = \frac{\sum_{j=1}^{N} \frac{(\sigma_s - 1)\alpha_{is}}{\sigma_s} T_{ijs}}{\sum_{t=1}^{S} \sum_{n=1}^{N} \frac{(\sigma_t - 1)\alpha_{it}}{\sigma_t} T_{int}}$ and the corresponding change in aggregate pollution stock is $\hat{Z} = \sum_{i=1}^{N} k_i \hat{Z}_i$ where $k_i = Z_i / \sum_{n=1}^{N} Z_n$.

$$\hat{X}_j = \frac{w_j L_j}{X_j} \hat{w}_i + \frac{e_j Z_j}{X_j} \hat{z}_j + \sum_{s=1}^{S} \frac{\pi_{js}}{X_j} \hat{\pi}_{js} + \sum_{i=1}^{N} \sum_{s=1}^{S} \frac{t'_{ijs} T_{ijs}}{X_j} \hat{\tau}_{ijs}^{-\sigma_s} \left(\frac{\hat{w}_i^{(1-\alpha_{is})}}{\hat{P}_{js}} \right)^{1-\sigma_s} \hat{X}_j \tag{18}$$

Given the changes in import tariffs, equations (14), (15), (16), (17), and (18) can be solved to obtain $\hat{w}_i$, $\hat{Z}_i$, $\hat{\pi}_{is}$, $\hat{X}_j$, and $\hat{P}_{js}$ for all i,$j \in N$ and $s \in S$. Notice that from equations (8), (10), (12) and (13), the total industry level profits, labour income, pollution tax revenues and trade balance condition across regions can be written in terms of parameters α_{is}, σ_s, import tariffs, τ_{ijs}, and bilateral trade flows, T_{ijs}, such that $\pi_{is} = \frac{1}{\sigma_s} \sum_{j=1}^{N} T_{ijs}$, $w_i L_i = \sum_{j=1}^{N} \sum_{s=1}^{S} \frac{(\sigma_s - 1)(1-\alpha_{is})}{\sigma_s} T_{ijs}$, $e_i Z_i = \sum_{j=1}^{N} \sum_{s=1}^{S} \frac{(\sigma_s - 1)\alpha_{is}}{\sigma_s} T_{ijs}$, and $X_j = \sum_{i=1}^{N} \sum_{s=1}^{S} \tau_{ijs} T_{ijs}$.

Welfare effects of a counterfactual policy that changes total emissions can easily be observed from the model. By substituting utility maximizing levels of x_{ijs} for a given price index and income into the utility function, the indirect utility function in region j is obtained as

$$\bar{U}_j = \frac{X_j}{P_j} \left[\frac{1}{1 + \left(\eta_j^{-1} \sum_{i=1}^{N} Z_i \right)^2} \right] \tag{19}$$

In equation (19), welfare in region j is defined as the product of real income and the damages from pollution. The relative change in welfare can then be calculated from

$$\hat{W}_j = \frac{\hat{X}_j}{\hat{P}_j}\left[\frac{1+\left(\eta_j^{-1}\sum_{i=1}^{N} Z_i\right)^2}{1+\left(\eta_j^{-1}\sum_{i=1}^{N} Z_i'\right)^2}\right] \tag{20}$$

where $\hat{P}_j = \prod_{s=1}^{S}(\hat{P}_{js})^{\mu_{js}}$ and $\sum_{i=1}^{N} Z_i'$ is the total emissions in the counterfactual equilibrium.

The equilibrium described in equations (14), (15), (16), (17), and (18) is based on a balanced trade assumption. Therefore, $NX_i = \sum_{j=1}^{N}\sum_{s=1}^{S}(T_{ijs}-T_{jis}) = 0$ must hold. This condition is violated in the data. I adopt the approach suggested in Dekle et al. (2008) and Ossa (2014) and first purge the raw data from aggregate trade imbalances, then conduct the analyses using the purged dataset. Particularly, I solve a modified system of equations where equation (18) is augmented to include an additional term that captures trade imbalances, $\frac{NX_j \widehat{NX}_j}{X_j}$, where $NX_j = \sum_{i}^{N}\sum_{s}^{S}(T_{ijs} - T_{jis})$ represents the set of trade deficits taken from data. Solving this modified system of equations that define the equilibrium by keeping tariff changes equal to one, such that $\hat{\tau}_{ijs} = 1$ and setting $NX_j' = 0$ delivers a trade matrix without trade imbalances that I use to conduct the analyses presented in section 4. Table A.1 summarizes the effects of this procedure on raw trade data.

3 From Theory to Data

Solving the model in relative changes as presented in section 2 minimizes the data requirements. To calibrate the model and perform the scenarios described in section 4, I need data on bilateral trade flows, existing bilateral tariffs, production and carbon emissions, all at the country-industry level. I aggregate the data into 5 regions and 15 tradable industries. Table C.4 provides a list of industries included in the analysis. To represent the world economy, I include Canada, China, 28 countries in the European Union aggregated as a regional entity, the United States and a constructed rest of the world (RoW). The choice of regions is motivated by the focus of this paper. China, the European Union and the United States are important parties to current and previous climate agreements with their high emissions and international trade exposures. Canada is an important trade partner of the United States and a strategic player in the case of a mutual tariff war. Regional entities are treated as sovereign individual countries. I describe the data in further detail and the construction of key parameters in the rest of this section.

3.1 Trade and Production Data

Data on bilateral trade flows in 2011 are from the United Nations Statistical Division (UNSD) Commodity Trade (COMTRADE) database. The original data is reported in the 2007 Harmonized System classification system, using the concordance tables from the World Bank's World Integrated Trade Solution (WITS) server, I compute the value of trade flows according to the ISIC Rev. 3 industry classification adopted in this paper. I obtain industry level gross output and value-added data for all countries from the World Input Output Database (WIOD). Output and trade data are then used to calculate intra-national trade (production made and sold within each country). All data are expressed in nominal US dollars and no conversion is necessary. Table 3.1 breaks down the average export shares across regions. The US is the primary destination of exports from Canada. Apart from the RoW, the EU and the US are important trade partners for China with export shares amounting to about 25 and 18 percent respectively. The US delivers most of its exports to the RoW while exports to the EU and Canada follows with 20 and 13 percent respectively. Large exports of Canada and China to the US imply high vulnerabilities of these countries for the case of a possible retaliation from US.

3.2 Carbon Emissions

The industry-level emissions cost share of firms in region i, α_{is}, cannot be directly calculated since climate policy stringency is not observable in the data. However, it can be inferred from the data on energy consumption assuming a perfectly linear relationship between energy consumption and emissions. Let $e_i = \frac{ec_i}{z_i}$ denote the

Table 3.1: Average Export Shares (in %)

	Canada	China	EU	US
Canada	-	6.30	8.70	63.28
China	2.36	-	24.55	17.91
EU	0.79	3.67	-	4.70
US	13.45	8.35	20.17	-

Note: Displays the export shares in percentages in the baseline equilibrium from row region to column region.

average implicit cost of emissions in region i where ec_i is the total cost of energy and z_i is total emissions in region i. The WIOD's Energy Use dataset provides detailed data on emission-relevant energy use from different fuels at the industry level for 40 countries plus the RoW.[10] These are given in terajoules. Using annual prices reported in the International Energy Agency (IEA) Energy Prices and Taxes and the conversion factors adopted by the IEA, I calculate energy expenses in each industry for all regions.[11] Industry emissions for each region are calculated from the WIOD Environmental Accounts. Using these data, I construct a region's average implicit cost of emissions as the sum of expenditures on energy sources divided by total emissions.[12] I obtain the corresponding emission cost shares, α_{is}, for each industry in region i by using information on industry emissions and the previously calculated implicit cost of emissions.

Combining the data explained in section 3.1 with the CO_2 emissions data, table 3.2 highlights relative importance and vulnerabilities of each region for carbon tariffs.

[10]This dataset excludes the non-energy use of fuels so provides a direct link between energy use and energy related emissions.

[11]The WIOD uses the IEA data on fuel prices to convert monetary entries on energy use in the input-output tables to physical quantities. I use the energy prices provided by the IEA to be consistent with the WIOD. For more information on the construction of the WIOD Environmental Accounts, see Genty et al. (2012).

[12]This is the average cost of emissions for the industry. Households' energy expenditures and corresponding consumption emissions are not included in the analyses.

Apart from the constructed RoW, the US is the largest economy and the second largest emitter after China. China, Europe and the US account for about 50 percent of the world GDP and 52 percent of global CO_2 emissions. With its large emissions and high export shares, China is the most vulnerable region in the case of a tariff war.

Table 3.2: Shares of GDP, Exports and CO_2 Emissions, (in %)

	GDP Share	Export Share	CO_2 Share
Canada	2.43	36.63	1.85
China	10.33	23.70	27.54
EU	18.58	48.86	10.06
US	21.17	17.72	14.59
RoW	47.49	31.69	45.96

Note: The first column displays each region's share in global GDP. The second column displays exports as a share of regional GDP. The last column displays the share of each region in global emissions. All values are in percentages. First and last columns sum up to 100 percent.

3.3 Trade Elasticities

I estimate trade elasticities using the methodology suggested by Caliendo and Parro (2015). It can be directly applied to the model presented in section 2. Defining the value of trade flows in industry j between region i and j as $X_{ijs} = M_{is}p_{is}\theta_{ijs}x_{ijs}$ and using equations (3) and (7) imply

$$X_{ijs} = M_{is}\tau_{ijs}^{-\sigma_s}\left(\frac{\sigma_s}{\sigma_s - 1}\frac{w_i^{(1-\alpha_{is})} \qquad e_i^{\alpha_{is}}}{\alpha_{is}^{\alpha_{is}}(1-\alpha_{is})^{(1-\alpha_{is})}\varphi_{is}^{(1-\alpha_{is})}}\right)^{1-\sigma_s}\theta_{ijs}^{1-\sigma_s}P_{js}^{\sigma_s-1}\mu_{js}X_j \qquad (21)$$

Consider trade flows in industry s between three countries indexed by i, n, and k. Cross-product of the value of trade between these three countries is $X_{inj}X_{nhj}X_{hij}$. Dividing this cross-product by the same term with the trade flows in the opposite direction and substituting equation (21) yields

$$\frac{X_{inj}X_{nhj}X_{hij}}{X_{nij}X_{hnj}X_{ihj}} = \left(\frac{\tau_{inj}\tau_{nhj}\tau_{hij}}{\tau_{nij}\tau_{hnj}\tau_{ihj}}\right)^{-\sigma_s} \left(\frac{\theta_{inj}\theta_{nhj}\theta_{hij}}{\theta_{nij}\theta_{hnj}\theta_{ihj}}\right)^{1-\sigma_s} \tag{22}$$

In equation (22), all terms specific to a particular country cancel out and only the ones specific to country pairs remain. The trade costs are generally assumed to be composed of four parts, a pair-specific, a destination-specific and an origin-specific component, and a stochastic part, namely $\theta_{inj} = \iota_{inj}\iota_n\iota_i\epsilon_{inj}$. Assuming bilateral trade costs, are symmetric so that $\iota_{inj} = \iota_{nij}$, equation (22) simplifies to

$$\frac{X_{inj}X_{nhj}X_{hij}}{X_{nij}X_{hnj}X_{ihj}} = \left(\frac{\tau_{inj}\tau_{nhj}\tau_{hij}}{\tau_{nij}\tau_{hnj}\tau_{ihj}}\right)^{-\sigma_s} \left(\frac{\iota_{inj}\iota_{nhj}\iota_{hij}}{\iota_{nij}\iota_{hnj}\iota_{ihj}}\right)^{1-\sigma_s} \tag{23}$$

Finally, taking logs and defining the random disturbance term as $\epsilon_{inj} \equiv \frac{\iota_{inj}\iota_{nhj}\iota_{hij}}{\iota_{nij}\iota_{hnj}\iota_{ihj}}$ yields the estimating equation in Caliendo and Parro (2015)

$$\ln\left(\frac{X_{inj}X_{nhj}X_{hij}}{X_{nij}X_{hnj}X_{ihj}}\right) = -\sigma_s \ln\left(\frac{\tau_{inj}\tau_{nhj}\tau_{hij}}{\tau_{nij}\tau_{hnj}\tau_{ihj}}\right) + \epsilon_{inj} \tag{24}$$

The main identifying assumption for equation (24) to yield consistent estimates is that pair-specific tariffs are independent of non-tariff barriers to trade. I estimate this equation for 15 industries using tariff and trade data for a pool of 37 countries. The resulting estimates are displayed in table 3.3.

3.4 Climate Damages

Estimation of the social cost of carbon emissions (SCC) is beyond the scope of this paper. Therefore, I rely on values from multiple sources to determine the parameter, η_j, that governs the regional damages from aggregate emissions. SCC is the the present value of future damages as a result of a ton of increase in emissions in a particular year. It can be calculated at the global scale or for different regions. There is a large variation in the estimates of SCC in the literature due to the uncertainty involved in the sensitivity of the climate to changes in carbon dioxide concentrations, the monetization of damages from these changes and assumed level

Table 3.3: Trade Elasticities

Industry		
Agriculture	$5.43^{\dagger\dagger\dagger}$	(1.19)
Mining	$20.06^{\dagger\dagger\dagger}$	(4.81)
Food Products	$5.06^{\dagger\dagger\dagger}$	(0.61)
Textile	$5.84^{\dagger}$	(0.68)
Wood Products	$34.17^{\dagger\dagger\dagger}$	(3.25)
Paper and Printing	$4.12^{\dagger}$	(3.00)
Petroleum	$14.68^{\dagger\dagger\dagger}$	(6.92)
Chemicals	$9.11^{\dagger\dagger\dagger}$	(1.53)
Plastic Products	$27.29^{\dagger\dagger\dagger}$	(3.31)
Mineral Products	$14.77^{\dagger\dagger\dagger}$	(1.59)
Metals	$11.53^{\dagger\dagger\dagger}$	(1.25)
Machinery and Equipment	$5.02^{\dagger\dagger}$	(2.10)
Electrical and Optical	$15.67^{\dagger\dagger\dagger}$	(0.96)
Transport	$8.09^{\dagger\dagger\dagger}$	(0.73)
Other	$7.93^{\dagger\dagger\dagger}$	(1.35)

Note: Displays the results of the estimating equation (24). The average trade elasticity for all industries is 15.45 with $p < 0.000$ and $se = 1.75$. Standard errors in parenthesis. $\dagger\dagger\dagger$ $p < 0.01$, $\dagger\dagger$ $p < 0.05$, $\dagger$ $p < 0.1$.

of risk aversion.[13] I solve for the values of η_j using various estimates of SCC in the literature. Specifically, I differentiate the welfare equation (19) with respect to total emissions, $\sum_{i=1}^{N} z_i$, and this equals the SCC in region j from a marginal increase in global emissions:

$$\frac{\partial\left(\frac{X_j}{P_j}\left[\frac{1}{1+\left(\eta_j^{-1}\sum_{i=1}^{N} z_i\right)^2}\right]\right)}{\partial\left(\sum_{i=1}^{N} z_i\right)} = scc_j \tag{25}$$

[13]For detailed discussions on the calculation of SCC under different assumptions, see Newbold et al. (2010) and Arrow et al. (2014).

Then, I calculate the derivative and rewrite scc_j as region j's share of global SCC

$$-\frac{X_j}{P_j}\frac{2\eta_j^{-2}\sum_{i=1}^{N}z_i}{\left[1+\left(\eta_j^{-1}\sum_{i=1}^{N}z_i\right)^2\right]^2}=scc_w\frac{sc_jX_j/P_j}{\sum_{i=1}^{N}sc_iX_i/P_i} \tag{26}$$

where sc_j is the share of damage in the GDP of region j due to the warming in climate. From equation (26), η_j can be calculated using data from various sources.

Interagency Working Group on the Social Cost of Carbon (2016) provides estimates of global SCC (scc_w) ranging from \$10 to \$212 under different parameter assumptions. I calculate the values of η_j based on the assumption that a ton increase in emissions decreases global GDP by \$42. This is the estimate of Interagency Working Group on the Social Cost of Carbon (2016) assuming a 3 percent discount rate for the year 2020 and is also consistent with values adopted by other governments and in the range of results estimated under alternative approaches.[14] Nordhaus and Boyer (2000) calculate impacts in 13 regions of a 2.5°C warming in climate measured as percent of GDPs. I rely on their calculations to calculate the share of global costs each region has to bear (sc_j). Nordhaus and Boyer (2000) calculate the percentage of loss in GDP as 0.45% for the US, 0.22% for China, and 2.83% for Europe. Canada is projected to benefit from climate change but the model presented in here does not allow for benefits. Therefore, I assume that Canada faces zero damage to its GDP from climate change. I assume the global average (1.50%) for the ROW. Real GDP values are calculated from the Penn World Table (version 9.0).[15]

[14] The Canadian SCC estimate discounted at 3 percent is \$40.7 for 2020 (Environment and Climate Change Canada, 2016). See also Ricke et al. (2018).

[15] I use expenditure-side real GDP at current PPPs (in mil. 2011$US-$\$) converted to 2009 values from price levels of household consumption. Aggregate prices for EUR and ROW are calculated as weighted averages using expenditures as weights. Data is available at `https://www.rug.nl/ggdc/productivity/pwt/`.

4 Results

In this section, I first present the environmental and economic consequences of the emission reduction pledges in the Paris Agreement. This forms the benchmark scenario where all regions participate. Then, I present the effects of the US withdrawal from the Paris Agreement under two scenarios. First, when the US withdraws, other regions achieve their initial emission reduction targets and as a second scenario, the committing regions choose to compensate for the effect of the US withdrawal on global emissions and increase their efforts to reach the initial emission reduction level in the benchmark scenario. Then, before proceeding with the calculation of optimal carbon tariffs, in order to compare results from this framework to the results of the studies in the current literature, I turn to calculating carbon tariffs using an approach commonly adopted in the literature. Specifically, I calculate the exogenous carbon tariffs as the gap between implicit costs of emissions between regions proportional to the emission intensity of production in the importing region. Again, the effects of these carbon tariffs are evaluated under two scenarios. First, I study the scenario under which committed regions to the Paris Agreement impose carbon tariffs on imports from the US. However, there are large differences across regions in terms of implicit costs of emissions. Paris Agreement pledges are determined unilaterally in each country in a non-cooperative manner and regions like the EU and Canada which already have high implicit emission costs commit to reducing their emissions more than other regions with low implicit costs of emissions. This is a reason for reactions against environmental policies in developed countries. Therefore, regions with high emission costs may decide to impose carbon tariffs on imports from low emission cost regions regardless of the status in the Paris Agreement. In this second scenario, I show the effects when all regions including the US consider imposing carbon tariffs. Then, I calculate optimal unilateral carbon tariffs at the industry level imposed by committing regions on imports from the US. These are the tariffs imposed by regions in a non-cooperative manner without the fear of retaliation from the US. The effects of a possible retaliation from the US in the form of import tariffs are presented in the following section. Finally, I show the effects of a worldwide tariff war where committing regions respond to the retaliation from the US by changing their import tariffs.

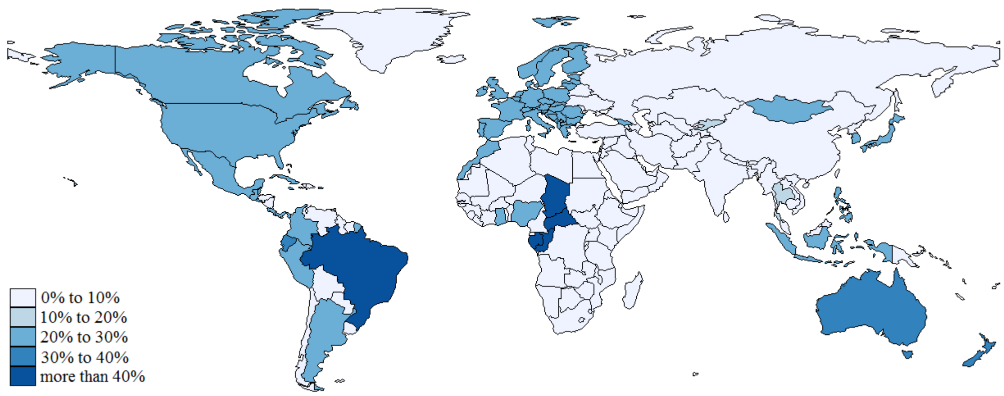
4.1 Effects of the NDCs in the Paris Agreement

Parties to the UNFCCC agreed at the 20th session of the Conference of the Parties (COP20) in December 2014 to set out their "intended nationally determined contributions" (INDCs). When countries formally ratify the Paris Agreement, their INDCs become "nationally determined contributions" (NDCs). I use these national emission reduction pledges published by the UN and calculate the required emission reduction levels in the model base year 2011 using the historical emissions data collected in the UNFCCC National Inventory Submissions.[16] (I)NDCs differ in terms of target years, therefore, a standardization is necessary to make targets comparable. For example, while the US pledges to reduce emissions by 26-28% from 2005 reference levels until the target year 2025, the target year for the EU is 2030. Due to substantial uncertainties involved in GDP projections, I abstain from standardizing emission reduction targets from a business as usual (BAU) scenario in the future. Instead, assuming the data in 2011 as the BAU case, I transform the (I)NDCs into emission reduction targets from 2011 levels using historical data. I use the lower bound of the target when a range of targets are provided in the (I)NDCs. China pledges to reduce its emission intensity by 60-65% below 2005 levels in 2030 and this requires no reduction from the BAU level in 2011. However, I include a mild target of 3% reduction from the BAU path for China to reflect its increasing involvement in climate negotiations. The heterogeneity across countries in terms of emission reduction targets is evident in Figure 1. While most developing countries in Asia and Africa have very small targets or just commit not to increase their emissions, more developed countries and large parts

[16] National pledges are available in the NDC Registry held by the UNFCCC, see https://www4.unfccc.int/sites/NDCStaging/Pages/All.aspx.
Historical emissions are available in National Inventory Reports at https://unfccc.int/process/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/national-inventory-submissions-2018.

of South America commit to lower their emissions by more than 20 percent. In this section, I analyse the economic effects of a scenario in which all regions with (I)NDCs reach their targets and the constructed RoW keeps its emissions constant.[17]

Figure 1: Emission Reduction Targets in the Paris Agreement



Note: Displays the emission reduction targets specified in the (intended) NDCs calculated as reductions below the model base year 2011. The average target is shown for the EU countries.

Employing the model presented in section 2, I quantify the effects of complying with the effective emission reduction targets in each region.[18] Imposing the emission changes in the model delivers a set of changes in the cost of emissions.[19] Results are

[17] 160 (I)NDCs submitted by 2016 cover emissions from 187 parties to the UNFCCC which were responsible for about 96% of world emissions in 2012. Determining what the (I)NDCs will deliver in terms of emission reductions is not straightforward since many countries provide a range of pledges covering different parts of the economy, and for a number of countries (like Russia) the targets suggest emission levels above their no-policy baseline scenarios. This is why I assume that the constructed RoW at least keeps its emissions constant in the counterfactual scenario in which all other regions meet their targets. For more information on how countries compare in their (I)NDCs, see Rogelj et al. (2016).

[18] I assume that each region satisfies the emission reduction pledges by reducing emissions in the industries included in this analysis at the same percentage as described in the NDCs. For example, the effective reduction target of the US is 20% from the BAU levels, I assume that emissions from the tradable industries are reduced by the same percentage. Countries in reality, can satisfy their pledges by targeting certain industry and consumption emissions.

[19] Emission reduction targets can be achieved through different policy instruments like carbon pricing, emission intensity standards, and subsidies on clean technologies. For simplicity, I calculate the total cost of achieving the required reduction rate in each region and assume that the additional cost is imposed on production as a tax on emissions.

presented in table 4.1.

Table 4.1: Effects of Achieving the Paris Agreement Targets across Regions

Region	△Cost of Emissions	△Emissions	△Real Income	△Exports
Canada	$95.4	-26.6	-0.95	-0.69
China	$7.2	-3.0	-0.11	0.14
EU	$185.1	-27.0	-1.41	-1.02
RoW	$2.3	0.0	0.03	0.30
USA	$64.0	-20.0	-0.76	-0.33

Note: Displays the effects of meeting the targets as agreed in the Paris Agreement. Changes in the cost of emissions are in dollars. Changes in emissions, real income and exports are in percentages.

The first column shows the increase in the implicit cost of emitting an extra unit of CO_2 when regions commit to meeting their Paris Agreement targets.[20] Differences across regions reflect both the effective emission reduction targets and the ease of substituting away from carbon intensive goods in consumption and production decisions. High costs in Canada and the EU are related to their relatively ambitious reduction pledges. The second column shows the change in total emissions. Global emissions decrease by 6 percent. In terms of welfare, Canada bears the largest cost of global emission reduction since there are zero benefits to its GDP from a decrease in global emissions. Other regions experience increases in welfare as global emissions decrease. However, measuring the change in welfare this way masks the impact on real income, i.e. the change in welfare net of environmental effects. The isolated change in real income is presented on the third column. The difference

[20]Notice that relatively less emission intensive non-tradable industries such as various services industries are not included in the analysis and Paris Agreement pledges are achieved through reductions in emissions from the production of 15 industries included in this paper. Since introduction of non-tradable industries may change the level of increase in the cost of emissions, these values presented here are informative when compared across regions.

between the change in welfare and real income depends on the size of the global emission reduction and the magnitude of the regional social cost of carbon. All regions lose except the RoW. The RoW with no reduction target experiences a welfare increase from the decrease in global emissions as other regions commit to their pledges and also from the increased comparative advantage in the production of emission intensive goods. Europe experiences the biggest difference between two welfare measures since it enjoys the largest benefit from avoided emissions as explained in section 3.4. The last column shows the changes in total exports. Looking into the change in trade in more detail reveals the effect of some regional features. Canada's total exports decline by 0.69 percent. The primary destination for Canada's relatively emission intensive chemicals industry is the US. While Canada's exports decline in many industries, its chemicals exports increase. This is mainly due to the decrease in production in the US. Even though the increase in the cost of emissions is larger in Canada than in the US, Canada's emission intensity in chemicals production is small compared to other countries. On the other hand, the biggest losers in Canada in terms of production and exports are the mining and petroleum industries. The primary destination for exports in these industries is again the US. However, as the prices increase in Canada, the US increases production and its imports from the RoW. China's mining industry is very emission intensive, but its exports to all other regions increase in the counterfactual equilibrium due to the small change in its cost of emissions compared to its competitors in developed regions. Exports of petroleum products of the RoW increase and this is the main source of increase in the total exports of the RoW.

4.2 Effects of US Withdrawal

A natural question that follows the results of the previous section is the consequences of a possible US withdrawal. In 2017, it was officially announced that the United States will stall all contributions to the United Nations' Green Climate Fund and withdraw from the Paris Agreement. Given that the US is the world's second largest emitter and the largest economy, a possible withdrawal will potentially have consequences for the compliance prospects of the Paris Agreement. In this section, I quantify the effects of a US withdrawal when other regions fulfill their emission reduction requirements by imposing a tax on domestic emissions. I assume that no sanctions are imposed on the US by its trading partners.

Table 4.2 reports changes in the cost of emissions, regional emissions, real income and total exports. The US defects from the Paris Agreement and does not undertake any policies to control its emissions, therefore the change in its cost of emissions is zero. The committed regions then adjust the levels of carbon taxes so that they still achieve the same emission reduction targets. This results in an about 2 percent increase in emissions from the production in the US. Exports of all committed regions are lower because the US is able to provide imports at a lower cost. The increases in average regional price indices are lower compared to the results of the benchmark scenario. Welfare increases in all regions are also lower compared to the benchmark since the achieved global emission reduction is lower. Even though nominal income levels in committed regions are lower than the benchmark scenario, smaller increases in average prices result in higher real incomes in some regions compared to the benchmark scenario.

Instead of aiming for satisfying their initial pledges, the committed regions may step up to make up for the US withdrawal with compensating emission reductions. This way, the global emission reductions can be kept equal to the level consistent with the implementation of NDCs by all parties. This is achieved by multiplying the regional targets by a scalar determined in equilibrium. The results of this scenario is presented in table 4.3.

Results show that proportional decreases in emissions are larger than the ones under the benchmark scenario. When committing regions further limit their emissions to achieve the global emission reduction target of the Paris Agreement, US welfare increases more due to improved competitiveness in export markets. The largest

Table 4.2: Effects of the US Withdrawal

Region	△Cost of Emissions	△Emissions	△Real Income	△Exports
Canada	$94.5	-26.6	-0.95	-0.81
China	$6.8	-3.0	-0.10	0.09
EU	$183.5	-27.0	-1.42	-1.10
RoW	$1.9	0.0	0.03	0.25
USA	$0	2.1	0.01	0.23

Note: Displays the effects of a possible US withdrawal from the Paris Agreement. Changes in the cost of emissions are in dollars. Changes in emissions, real income and exports are in percentages.

increases in exports of the US involve the products imported by the EU. On average, US exports of mining, minerals and chemicals products experience the largest increase. Due to its small contribution to the decrease in global emissions, the RoW still experiences a mild increase in welfare and exports.

4.3 Carbon Tariffs

When the US defects from the Paris Agreement, the remaining regions can either comply with their initial targets but suffer the negative environmental consequences of the US withdrawal or reduce their production emissions more than their initial targets to preserve the global objective of the Paris Agreement and suffer the economic consequences. Both cases create incentive for the US to increase its production and emission levels. To attenuate the emission increase from additional US production, compliant regions may choose to impose carbon tariffs on US imports. Before investigating the consequences of strategic interactions in environmental policy, I first evaluate the effects of exogenous carbon tariffs imposed on US imports. As explained by Böhringer et al. (2012), carbon tariffs are varied along three dimensions: embodied emission coverage, industry coverage and tariff rate differentiation. In this paper, I quantify the economic and environmental

Table 4.3: Effects of the US Withdrawal (with constant global emissions)

Region	△Cost of Emissions	△Emissions	△Real Income	△Exports
Canada	\$97.6	-29.7	-1.24	-1.16
China	\$7.4	-5.0	-0.18	-0.00
EU	\$186.0	-28.8	-1.61	-1.39
RoW	\$2.3	-2.1	0.02	0.17
USA	\$0	2.2	0.05	0.32

Note: Displays the effects of a possible US withdrawal from the Paris Agreement conditional on equal decrease in global emissions with the benchmark scenario. Changes in the cost of emissions are in dollars. Changes in emissions, real income and exports are in percentages.

consequences of carbon tariffs at the region-industry level imposed on direct emissions from imports of all industries. The General Agreement on Tariffs and Trade (GATT) rules require that imports from all parties of the WTO be treated similarly, this implies that imports can be taxed only at a level equal to the gap between policy restrictiveness of two countries. Therefore, I calculate exogenous carbon tariffs as follows:

$$\tau^{c}_{ijs} = \begin{cases} 1 + \epsilon_{js}(e_j - e_i) & \text{if } e_j > e_i. \\ 1 & \text{otherwise.} \end{cases} \tag{27}$$

where ϵ_{js} is the emission intensity of production, e_j is the implicit cost of emissions in the importing region, and e_i is the implicit cost of emissions in the exporting region. Therefore, the larger the difference between two regions' costs of emissions, the higher is the tariff imposed by the importing region. The gap between the restrictiveness of environmental policy is multiplied by the emission intensity of production of industry s in the importer, this means that the emissions embodied in trade flows are calculated based on the emission intensity of the importing region. This is a product-based calculation of carbon tariffs. Since the resulting tariffs do not discriminate between regions based on the production technology abroad, calculating carbon tariffs this way is considered compatible with the WTO law (Böhringer et al., 2012). The resulting tariffs vary across industries and regions. Assessing the average industry tariffs weighted by trade flows yields that the highest average carbon tariff on imports to Canada is in petroleum products with 0.44 percent and on imports to the EU in chemicals with 0.28 percent. The RoW also imposes carbon tariffs on US imports, the highest of which is on petroleum products with 0.31 percent. Table C.2 shows the average trade-weighted tariffs at the industry level on imports from the US. I apply these carbon tariffs calculated from equation (27) on US imports and the revenue from tariffs are recycled lump-sum to consumers in imposing regions. The costs of emissions are held constant.

Table 4.4: Effects of Carbon Tariffs on US Imports

Region	△Emissions	△Real Income	△Exports
Canada	0.1	0.04	0.02
China	0.1	0.01	0.03
EU	0.7	0.04	0.15
RoW	0.7	0.06	0.14
USA	-1.9	-0.30	-0.52

Note: Holding the cost of emissions constant in all regions, the table displays the effects of carbon tariffs imposed on US imports. Changes in emissions, real income and exports are in percentages.

Table 4.4 presents the effects of these carbon tariffs across regions. Comparing with the increase in emissions from the US withdrawal, carbon tariffs are quite effective in attenuating the increase. As a result of the tariffs, US emissions decrease by 1.9 percent. Tariffs also have minor implications for the real incomes of the committing regions. Implicit cost of emissions is lower in China than the US, hence there is no carbon tariff imposed by China in the counterfactual equilibrium, the small change in China's exports is due to the increased competitiveness in the export markets when the US imports are sanctioned. The highest tariffs are imposed by the EU on imports of emission intensive industries like petroleum, chemicals, minerals and plastics. Canada in return increases its exports to the EU in these industries.

Even though the previous analysis establishes that the carbon tariffs imposed on the US imports partly alleviate the negative environmental effects of the US withdrawal, levelling off the carbon playing field on international markets requires equalizing differences in the levels of implicit costs of emissions across regions. In this hypothetical scenario, for each pair of regions, the region with the higher implicit cost of emissions imposes carbon tariffs on imports to eliminate the competitive advantage of the other region. Since carbon tariffs are calculated at the industry level, for a given pair of regions, the resulting tariffs will be higher in industries with higher emissions intensities. Therefore, carbon tariffs in a global scenario function as carbon equivalent taxes between regions with differences in implicit costs of emissions. Table C.3 shows the resulting average trade-weighted carbon tariffs imposed by each region. Since China has the lowest implicit cost of emissions, imports to China are not subject to carbon tariffs. The restrictiveness of environmental policy implied by the implicit cost of emissions is on average higher in the RoW than China. The main reason for the average non-zero carbon tariffs in the RoW is this policy gap between China and the RoW. The EU has the highest implicit cost of emissions, therefore, while the EU imposes tariffs on imports from all regions, China has to pay tariffs. Canada and the US pay tariffs when exporting to the EU and impose carbon tariffs in most of the other cases. Carbon tariffs imposed on imports into the EU are the highest. Among all regions, the highest carbon tariffs are imposed on imports of emission intensive industries like mining, petroleum products, minerals, metals, and chemicals. Table 4.5 presents the effects of these carbon tariffs across regions. The aggregate changes in total emissions show that regions with relatively stricter environmental policies experience an increase in emissions while regions with low costs of emissions reduce their total emissions. The corresponding effect of carbon tariffs is a decrease in global emissions. Therefore, if carbon taxes relocate emissions from regions with strict environmental regulations to low carbon tax regions, carbon tariffs are successful in reversing this relocation. Welfare effects and the changes in real income are similar since the reduction in global emissions is small. The changes in real income are small but positive for regions that on average impose relatively larger carbon tariffs on their trading partners. While the increase in real income is 0.01 percent in Canada, the EU experiences a 0.7 percent increase in real income. China and the US lose about 2 percent of their real income.

Table 4.5: Effects of Global Carbon Tariffs

Region	△Emissions	△Real Income	△Exports
Canada	0.3	0.01	0.02
China	-1.9	-0.18	-0.54
EU	1.1	0.66	1.23
RoW	0.9	0.20	0.08
USA	-0.9	-0.16	-0.44

Note: Holding the cost of emissions constant in all regions, the table displays the effects of carbon tariffs adopted by all regions. Changes in emissions, real income and exports are in percentages.

4.4 Optimal Carbon Tariffs

As presented in the previous section, the purpose of "standard" carbon tariffs is to assure that exporting regions pay the same price on emissions embodied in trade as in the importing regions. However, these "standard" carbon tariffs are not determined by a social planner that seeks to maximize welfare in a region. Emissions arising from the production process affect regions from two channels. First of all, emissions from production are trans-boundary, they accumulate in the atmosphere and reduce social welfare. This creates an environmental incentive for governments when choosing optimal carbon tariffs. Emissions also affect the production possibilities of regions. Governments can also set carbon tariffs in order to influence the terms of trade in their favour. This creates an economic incentive. Considering these channels and the differences in trade elasticities, there can be incentives for the importing regions to deviate from the rates of "standard" carbon tariffs. In this section, to compare the impact of these incentives on economic and environmental outcomes, I present the optimal carbon tariffs imposed by each region on imports from the US. In this scenario, I calculate the unilaterally optimal carbon tariffs for Canada, China, the EU and the RoW on the carbon content of imports from the US. These are calculated in a non-cooperative setting. As in previous scenarios, there are pre-existing import tariffs. Each importing region optimally decides on the industry-level carbon tariffs on embodied emissions in imports from the US calculated at the initial emission intensity of production in the importing region. The revenues are rebated in a lump-sum fashion to the consumers in the tariff imposing region. Table 4.6 presents the results.

Table 4.6: Effects of Optimal Carbon Tariffs

Region	△Emissions	△Exports	△Real Income	
			Own	US
Canada	1.2	0.7	0.6	-0.1
China	1.0	1.6	0.8	-0.2
EU	1.1	3.2	1.2	-0.4
RoW	1.6	2.4	1.3	-0.3

Note: Displays the effects of optimal carbon tariffs adopted by all committing regions on imports from the US. Changes in emissions, real income and exports are in percentages. The column "own" shows the change in real income in each region, the column "US" shows the effect of the optimal carbon tariffs imposed by each row region on the real income of the US.

The results show that committing regions have a large incentive to impose higher carbon tariffs on the US imports compared to the tariffs in the previous section. All countries are motivated by the environmental and economic objectives to impose higher tariffs. This is why contrary to the analysis in the previous section, China also imposes carbon tariffs on the US imports. Production increases for all four regions. Therefore, their exports and production emissions increase. Emissions from the production in the US decrease by 4.1 percent. The last column shows the effect of imposing carbon tariffs individually by each region on the US real income. Changes in real income show that all regions gain at the expense of the US.

4.5 Retaliation of the US and Tariff War

In this scenario, taking the optimal carbon tariffs as given, the US optimally determines import tariffs against the imports from all committing regions. To see if the US has an incentive to retaliate by imposing import tariffs, welfare effects under two scenarios should be compared. Retaliatory tariffs increase the US real income by 1.44 percent and reduces the average real income in other regions by 0.61 percent. The US is better off by withdrawing from the Paris Agreement, bearing the cost of carbon tariffs and retaliating in response, compared to meeting its emission reduction targets under the Paris Agreement. Therefore, carbon tariffs are not effective instruments for enforcing the US to mitigate its emissions.

The retaliation of the US may trigger a worldwide tariff war with the other four regions that commit to meeting their emission reduction targets. I keep the non-cooperative nature of the national policy determination processes, therefore, in a worldwide tariff war scenario, committing regions do not form a coalition against the US. The Nash equilibrium in this scenario is found as follows: Each region observes the industry-level optimal non-cooperative tariffs imposed on its imports and choose its own optimal import tariffs, this process continues until welfare levels are maximized in all regions. Notice that, welfare includes the negative externality from global emissions. Therefore, in each decision step, regions observe the change in global emissions in response to the actions taken in the previous step and decide accordingly. Therefore, although the trade war occurs in a non-cooperative policy environment where all regions maximize welfare at the expense of other regions, increase in emissions is not to the advantage of any region. However, since the EU enjoys the largest benefits to its GDP from a unit reduction in global emissions, it is the region which values a unit reduction in global emissions the most. The results show that the median Nash tariffs is the lowest in the US with 12.55 percent. China imposes the largest median tariff on imports of all other regions with 44.63 percent. Canada's and the EU's median tariffs are 16.06 and 24.23 percent respectively. The tariff war results in a 3.1 percent decrease in the real income of the US. This is substantially larger than the compliance cost to the Paris Agreement. The real income levels decrease also in all other regions. All regions are much worse off in a tariff war situation compared to the Paris Agreement scenario. More importantly, all committing regions are worse off compared to the second scenario presented in section 4.2 in which they increase their emission reduction targets to make up for the withdrawal of the US.

5 Conclusion

This paper explores the interplay between environment and international trade related instruments in a non-cooperative policy environment where participation in a global climate agreement is voluntary and no punishment mechanism exists to enforce commitment. The main question that this paper aims to answer is whether a globally efficient response to climate change can be formed in a non-cooperative framework by employing carbon tariffs as an enforcement mechanism. When carbon tariffs are set in a way to mitigate the distortions that arise from cross-country differences in implicit costs of emissions, inducing participation is not possible. Unilaterally determined optimal carbon tariffs are more aggressive due to the imposing regions' willingness to influence the terms of trade in their favour. However, these are also not sufficient to encourage further mitigation in non-participating regions. Designing globally optimal carbon tariffs would require neutralizing the unilateral incentive to exploit terms-of-trade effects. Optimal carbon tariffs determined based on only environmental concerns would also be legally defensible under the environmental exceptions granted by the WTO. As Balistreri et al. (2016) has shown in a two-good, two-country environment, welfare maximizing carbon tariffs are too aggressive based on purely environmental concerns.

The theoretical framework developed by Ossa (2014) is extended to incorporate a cross-border production externality. To inform policy, the model is used to establish optimal carbon tariffs imposed on emissions embodied in imports (calculated based on the industry level emission intensities of production of the importing regions). The policy experiment that involves the withdrawal of the US from the Paris Agreement indicates that imposing optimal carbon tariffs on the US imports results in retaliation. An alternative scenario worth investigating is changing the way tariff revenues are distributed. As has been discussed in the literature, transferring the tariff revenues to the US may induce cooperation in emission mitigation efforts. Other regions responses to the US retaliation through import tariffs may start a worldwide tariff war. A tariff war makes all regions worse off.

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Appendices

A Eliminating Aggregate Trade Deficits

Table A.1 presents the predicted changes in exports and imports resulting from an elimination of aggregate trade imbalances. The first column displays the trade deficits in the raw data as a share of total trade. The second and third columns show the effects of the procedure described in sector 2. Imports and exports change substantially to eliminate these imbalances. I use this purged data in the quantitative applications presented in section 4.

Table A.1: Effects of Eliminating Trade Deficits

Region	Net Exports (in %)	Imports (in %$\triangle$)	Exports (in %$\triangle$)
Canada	-0.44	-2.41	-1.55
China	0.88	2.35	0.57
EU	-1.21	-2.37	0.02
RoW	1.79	3.93	0.28
USA	-7.00	-15.27	-2.69

Note: Displays the effects of the procedure explained in section 2 on the values of imports and exports. The first column lists the net exports as a share of total trade for each region in the raw data calculated as $100 \times \left(\frac{exports-imports}{exports+imports}\right)$. The second and third columns display the percentage changes in imports and exports as a results of this procedure to eliminate trade deficits.

B Sensitivity Analysis

To investigate the sensitivity of the results with respect to trade elasticities, σ_s, I present the results of this paper assuming all industries have the same elasticity of trade flows with respect to trade costs. The average trade elasticity is equal to 15.45 as presented in section 3.3 which is within the range of estimates in the literature. Tables provided in this section present the results of the scenarios assuming all industries have the trade elasticity equal to 15.45.

Table B.1: Effects of Achieving the Paris Agreement Targets across Regions

Region	△Cost of Emissions	△Welfare	△Real Income	△Exports
Canada	\$98.7	-26.6	-0.97	-0.62
China	\$7.6	-3.0	-0.10	0.14
EU	\$189.3	-27.0	-1.43	-1.01
RoW	\$4.5	0.0	0.03	0.32
USA	\$68.1	-20.0	-0.76	-0.35

Note: Displays the effects of meeting the targets as agreed in the Paris Agreement assuming $\sigma = 15.45$. Changes in the cost of emissions are in dollars. Changes in welfare, real income and exports are in percentages.

Table B.2: Effects of the US Withdrawal

Region	$\triangle$Cost of Emissions	$\triangle$Emissions	$\triangle$Real Income	$\triangle$Exports
Canada	\$94.5	-26.6	-0.95	-0.81
China	\$6.8	-3.0	-0.10	0.10
EU	\$183.5	-27.0	-1.40	-1.10
RoW	\$1.9	0.0	0.03	0.25
USA	\$0	0.9	0.01	0.23

Note: Displays the effects of a possible US withdrawal from the Paris Agreement assuming $\sigma = 15.45$. Changes in the cost of emissions are in dollars. Changes in emissions, real income and exports are in percentages.

C Additional Tables

Table C.1: Trade-weighted Factual Tariffs, by Region and Industry (in %)

Industry	CAN	CHN	EU	USA	RoW
Agriculture	0.03	0.08	0.03	0.14	0.03
Mining	0.00	0.00	0.01	0.01	0.01
Food Products	0.17	0.13	0.09	0.13	0.06
Textile	0.13	0.10	0.10	0.08	0.11
Wood Products	0.02	0.03	0.02	0.04	0.02
Paper and Printing	0.01	0.02	0.00	0.04	0.01
Petroleum	0.01	0.05	0.02	0.03	0.06
Chemicals	0.02	0.06	0.03	0.04	0.02
Plastic Products	0.04	0.08	0.05	0.07	0.04
Mineral Products	0.02	0.11	0.04	0.07	0.04
Metals	0.02	0.10	0.04	0.11	0.04
Machinery and Equipment	0.01	0.06	0.02	0.04	0.01
Electrical and Optical	0.02	0.12	0.05	0.09	0.04
Transport	0.07	0.22	0.09	0.11	0.04
Other	0.04	0.09	0.01	0.04	0.01

Table C.2: Trade-weighted Average Carbon Tariffs on US Imports, by Region and Industry (in %)

Industry	CAN	CHN	EU	USA	RoW
Agriculture	0.11	0	0.11	0	0.13
Mining	0.18	0	0.04	0	0.10
Food Products	0.10	0	0.03	0	0.05
Textile	0.01	0	0.01	0	0.02
Wood Products	0.15	0	0.04	0	0.06
Paper and Printing	0.09	0	0.07	0	0.04
Petroleum	0.44	0	0.18	0	0.31
Chemicals	0.24	0	0.28	0	0.18
Plastic Products	0.06	0	0.05	0	0.24
Mineral Products	0.03	0	0.15	0	0.14
Metals	0.11	0	0.08	0	0.25
Machinery and Equipment	0.03	0	0.03	0	0.03
Electrical and Optical	0.02	0	0.03	0	0.09
Transport	0.03	0	0.04	0	0.02
Other	0.03	0	0.03	0	0.06

Table C.3: Trade-weighted Average Carbon Tariffs, by Region and Industry (in %)

Industry	CAN	CHN	EU	USA	RoW
Agriculture	0.12	0	2.64	0.02	0.18
Mining	0.18	0	3.51	0.01	0.15
Food Products	0.13	0	1.39	0.05	0.11
Textile	0.15	0	1.09	0.41	0.41
Wood Products	0.23	0	0.98	0.41	0.21
Paper and Printing	0.11	0	1.31	0.15	0.09
Petroleum	0.44	0	11.96	0.03	0.46
Chemicals	0.27	0	2.74	0.10	0.48
Plastic Products	0.09	0	0.78	0.06	0.45
Mineral Products	0.06	0	7.17	1.42	1.87
Metals	0.18	0	3.07	0.12	0.88
Machinery and Equipment	0.05	0	0.29	0.06	0.08
Electrical and Optical	0.08	0	0.31	0.04	0.27
Transport	0.03	0	0.34	0.02	0.06
Other	0.13	0	0.69	0.07	0.57

Table C.4: List of Industries

Industry	Description	ISIC Rev. 3
Agriculture	Agriculture, forestry and fishing	1-5
Mining	Mining and quarrying	10-14
Food Products	Food products, beverages and tobacco	15-16
Textile	Textiles, textile products, footwear and leather	17-19
Wood Products	Wood, wood products and cork	20
Paper and Printing	Pulp, paper, paper products, printing and publishing	21-22
Petroleum	Coke, refined petroleum and nuclear fuel	23
Chemicals	Chemicals	24
Plastic Products	Rubber and plastic products	25
Mineral Products	Other non-metallic mineral products	26
Metals	Basic metals and metal products	27-28
Machinery and Equipment	Machinery and equipment n.e.c.	29
Electrical and Optical	Office equipment, electrical machinery and medical instruments	30-33
Transport	Motor vehicles, and other transport equipment	34-35
Other	Manufacturing n.e.c.	36-37

Table C.5: Cost Share of Emissions, α_{is}, by Region and Industry

Industry	CAN	CHN	EU	USA	RoW
Agriculture	0.0290	0.0090	0.0654	0.0335	0.0256
Mining	0.0679	0.0336	0.0685	0.0392	0.0289
Food Products	0.0255	0.0143	0.0360	0.0348	0.0260
Textile	0.0122	0.0126	0.0260	0.0410	0.0300
Wood Products	0.0228	0.0114	0.0212	0.0772	0.0362
Paper and Printing	0.0166	0.0347	0.0343	0.0396	0.0251
Petroleum	0.0873	0.0212	0.0192	0.0254	0.0623
Chemicals	0.0469	0.0457	0.0611	0.0639	0.0882
Plastic Products	0.0106	0.0132	0.0179	0.0089	0.0252
Mineral Products	0.0100	0.0181	0.0133	0.0187	0.0195
Metals	0.0298	0.0735	0.0669	0.0376	0.0111
Machinery and Equipment	0.0073	0.0093	0.0073	0.0135	0.0100
Electrical and Optical	0.0084	0.0030	0.0072	0.0040	0.0206
Transport	0.0063	0.0085	0.0086	0.0191	0.0111
Other	0.0100	0.0066	0.0147	0.0062	0.0151