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Can Tariffs be Used to Enforce Paris Climate Commitments?

Niven Winchester

MIT Joint Program on the Science and Policy of Global Change

Massachusetts Institute of Technology
77 Massachusetts Ave., E19-411
Cambridge MA 02139-4307 (USA)

T (617) 253-7492 **F** (617) 253-9845
globalchange@mit.edu
http://globalchange.mit.edu/

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Abstract: We evaluate the potential for using border carbon adjustments (BCAs) and welfare-maximizing tariffs to compel non-compliant countries to meet emissions reduction targets pledged under the Paris Climate Agreement. Our analysis employs a numerical economy-wide model with energy sector detail and, given recent actions by the new US administration, considers BCAs on US exports. We find that BCAs result in small reductions in US emissions and welfare. Consequently, the US is better off when it does not restrict emissions and faces BCAs on its exports than when it implements policies consistent with the Paris Agreement. However, targeted welfare-maximizing tariffs could inflict greater cost on the US than if it complied with its pledged emissions reductions. We conclude that BCAs are an ineffective enforcement mechanism but carefully chosen tariffs could be a mechanism to enforce the Paris Agreement.

1 Joint Program on the Science and Policy of Global Change, Massachusetts Institute of Technology, Cambridge, MA 02139, USA. Email: niven@mit.edu.

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1. Introduction

At the 2015 Paris Climate Conference—the 21st Conference of the Parties (COP21) under the United Nations Framework Convention on Climate Change (UNFCC)—representatives from 195 countries set out an agreement to mitigate greenhouse gas (GHG) emissions. The framework required countries representing at least 55% of global GHG emissions to sign up to the agreement for it to take force. This occurred in October 2016 and the Paris Agreement was formally ratified on November 4, 2016.

Nations that are parties to the agreement are required to submit National Determined Contributions (NDCs) that outline future reductions in GHG emissions out to 2030. The US, under the Obama Administration, submitted its NDC on September 3, 2016. This document stated that the US would reduce economy-wide GHG emissions by 26–28 percent below its 2005 level by 2025. However, this pledge, like all NDCs, is not binding under international law and a nation can back out of the deal with four years notice by withdrawing from the agreement (Stutter, 2017) or in one year by leaving the UNFCC (Mathiesen, 2016).

Following the 2016 US presidential election, the future involvement of the US in the global accord is uncertain. Although the carbon pricing scheme recently proposed by an eminent group of Republicans (Baker *et al.*, 2017) and Secretary of State Ross Tillerson's statement that the US should remain a party to the Paris Agreement (DiChristopher, 2017) indicate that the US may meet its NDC goal, other signs from the Trump Administration paint a different picture. In the lead up to the 2016 election, Donald Trump vowed to remove the US from the Paris Agreement (Stutter, 2017) and in 2012 Trump posted on Twitter, 'The concept of global warming was created by and for the Chinese in order to make US manufacturing non-competitive' (Wong, 2016). Trump's actions since taking office have been consistent with his pre-election view on climate change. Significantly, Trump signed an executive order on March 28, 2017 that initiated a review of the Clean Power Plan—an Obama administration policy that aims to reduce carbon dioxide emission from electricity generation—and rescinded the moratorium on coal mining on US federal lands (Merica, 2017).

Other senior Republicans are also dismissive about climate change. For example, Environmental Protection Agency (EPA) Chief Scott Pruitt stated that carbon dioxide (CO_2) is not a primary contributor to global warming and that the Paris Agreement is a 'bad deal' (DiChristopher, 2017). Additionally, House of Representatives Speaker Paul Ryan has stated that 'the Paris climate deal would be disastrous for the American economy' (Doyle and Rampton, 2016).

The 2016 presidential election has also resulted in a change in US trade policy, from actively seeking trade liberalization to a more protectionist stance. Notably, shortly after his inauguration, President Trump withdrew the US from negotiations for the Trans-Pacific Partnership Agreement. The White House also plans to renegotiate the North American Free Trade Agreement and the President has stated that the US will terminate the agreement if a 'fair' deal is not reached (Liptak and Merica, 2017). On April 24, 2017 he announced plans to impose tariffs of up 24% on Canadian lumber entering the US (Gillespie, 2017).

In this paper, we evaluate the role of border carbon adjustments (BCAs) and welfare-maximizing tariffs as a mechanism to persuade a non-compliant country to reduce GHG emissions. BCAs—tariffs on embodied carbon emissions imposed by countries with climate policies on imports from countries without them—have been proposed in policy circles. For example, the directive for the EU Emissions Trading System includes provisions for BCAs, and the American Clean Energy and Security Act of 2009 (US Congress, 2009), which was passed by the House of Representatives but died in the Senate, included import requirements analogous to a tariff on embodied carbon emissions (Winchester *et al.*, 2011).

Most previous studies of BCAs have focused on the impact of BCAs on emissions and consider tariffs imposed by a group of developed countries on imports from other nations (e.g., Felder and Rutherford 1993; Demailly and Quirion 2008; Ponssard and Walker 2008; Mattoo *et al.* 2009; Burniauxet *et al.* 2010; Winchester *et al.*, 2011; Winchester, 2012; and Sakai and Barrett, 2016). Babiker and Rutherford (2005) consider a menu of border measures (e.g., border carbon adjustments and rebates on exports) imposed by countries parties to the Kyoto agreement on imports from other countries and derive the Nash equilibrium over trade instruments. In reviewing the BCA literature, Böhringer *et al.* (2012) note that carbon tariffs shift some cost of reducing emissions from regions that restrict emissions to those that do not. We build on this literature by evaluating the role of BCAs and other trade measures as an enforcement mechanism to persuade a non-compliant country to reduce GHG emissions.

Motivated by recent actions by the US that would make it appear unlikely it would live up to its Paris commitment, our analysis considers a case where all regions except the US implement polices to reduce emissions and US exports face BCAs. Using a global multi-sectoral, multi-region economy-wide model with energy sector detail, we quantify outcomes under this case and compare them to a case where all regions meet their Paris pledges. We also compare the impact of BCAs to the Nash equilibrium of a 'tariff war' where countries impose welfare maximizing tariffs.[1]

1 Our quantification of tariff outcomes does not consider the legal aspects of these measures under international treaties. See Kemp (2016) for a discussion of these issues.

Table 1. Model aggregation.

Sectors		**Regions**	
agr	Agriculture	usa	USA
Cru	Crude oil	anz	Australia & New Zealand
Oil	Refined oil products	can	Canada
Col	Coal	chn	China
Gas	Natural gas	jpn	Japan
ele	Electricity	eur	European Union & EFTA
crp	Chemical, rubber & plastic products	mex	Mexico
nmm	Non-metallic minerals	kor	South Korea
i_s	Iron and Steel	row	Rest of World
Nfm	Non-ferrous metals		
Fmp	Fabricated metals products	**Primary factors**	
Fod	Food processing	cap	Capital
Tcf	Textiles, clothing & footwear	lab	Labor
Trn	Transportation equipment	rcr	Crude oil resources
Eeq	Electronic equipment	rco	Coal resources
Ome	Other machinery & equipment	rga	Natural gas resources
Omf	Other manufacturing		
Ser	Services		

This paper has three further sections. Section 2 describes the structure and data sources for our economy-wide model and the scenarios implemented in our analysis. Our results are presented and discussed in Section 3. Section 4 concludes.

2. Methods

2.1 Modeling Framework

Our analysis employs an economy-model with a detailed representation of energy production that builds on the 'GTAP-Energy in GAMS' model (Rutherford and Paltsev, 2000). The model is a static, multi-sector, multi-region applied general equilibrium model of the global economy that links economic activity to energy production and CO_2 emissions from the combustion of fossil fuels. Regions in the model are interconnected via bilateral international trade flows and sectors are linked by purchases of intermediate inputs.

In each region and sector, there is a representative firm that produces output by hiring primary factors and purchasing intermediate inputs from other firms. There is also a representative agent in each region that derives income from selling factor services and an exogenous net international transfer that reflects the current account balance. A government sector is not explicitly modelled, but taxes and subsidies on transactions are represented, and government purchases are included in household consumption in each region. Net fiscal deficits and, where applicable, revenue from the sale of emission permits are passed to consumers as (implicit) lump sum transfers. Although the model is static, investment is included as a proxy for future consumption and is a fixed proportion of expenditure by each regional household.

Sectors, regions and primary factors included in the model are listed in **Table 1**. The model represents three sectors related to the extraction of fossil fuels (Coal, Crude oil, Natural gas) and two sectors that process these fuels into secondary energy (Refined oil and Electricity). Fossil fuels are also used directly by other sectors and regional households. The representation of manufacturing includes four sectors that use energy intensively (Chemical, rubber & plastic products; Non-metallic minerals; Iron and steel; and Non-ferrous metals) and seven other manufacturing sectors (Food processing; Fabricated metal products, Textiles, clothing & footwear; Transportation equipment; Electronic equipment; Other machinery and equipment; and Other manufacturing). Agricultural activities and services are each included in separate aggregated sectors.

The model represents the US and seven regions that account for a high share of US exports or/and have set out ambitious plans to reduce GHG emissions. Most of these regions are individual countries (e.g., Canada, Mexico, and China), but some regions include an aggregation of nations (Australia & New Zealand and the European Union & European Free Trade Area, EFTA). Remaining countries are included in a composite 'Rest of World' region. Brazil, Russia and India are not represented as separate regions as several studies estimate that 2030 emissions consistent with NDC pledges are close to or above BAU emissions—see, for example, Fawcett *et al.* (2015), Aldy *et al.* (2016), Vandyck *et al.* (2016) and Jacoby *et al.* (2017). Primary factors in the model include capital, labor, and primary resources for the extraction of each fossil fuel.

For computational reasons, we also simulate some scenarios using a more aggregated version of the model (see Section 2.2). This aggregation represents two regions, seven sectors, and the primary factors listed in Table 1. The regional aggregation representing the US and all other countries are included in a composite region that we label the 'Coalition'. Sectors in the more-aggregate version of the model include the five energy sectors in Table 1 (Coal, Crude oil, Natural gas, Refined oil, and Electricity), services, and 'Other industry', a composite of the remaining sectors.

Production in each sector is represented by a multi-level nest of constant elasticity of substitution (CES) functions. Production structures are outlined in panels (a), (b) and (c) of **Figure 1**. Fossil fuel commodities are produced by a CES aggregate of a sector-specific resource and a composite of capital, labor and intermediate inputs. Other sectors combine intermediate inputs, capital and labor. Final consumption in each region is also represented by nested a CES function, as outlined in panel (d). Use of Coal, Refined oil, or Natural gas, either as intermediate inputs or in final consumption, result in the release of CO_2 emissions in fixed proportions with the use of each fuel.

Features of the model that have a large influence on the cost of abating emissions include: (1) substitution among different forms of energy in production and final consumption, (2) substitution between aggregate energy and capital-labor in production, and (3) substitution between aggregate energy and other goods in final consumption. The production structure and elasticity values that, in tandem with input cost shares, govern these substitution possibilities are detailed in the notes to Figure 1 and are guided by those used in the MIT Economic Projection and Policy Analysis (EPPA) model (Paltsev *et al.*, 2005; Chen *et al.*, 2016). To account for the increased penetration of low-carbon generation sources under a carbon price, we set the elasticity of substitution between energy and capital-labor in electricity generation equal to 0.85, compared to 0.6 in Paltsev *et al.* (2005). This higher elasticity of substitution increases the scope for producing electricity with less fuel and more capital in response to rising fuel costs. Implied marginal abatement cost curves in the model are increasing convex functions of the quantity of emissions abated.

International trade in goods and services follows the 'Armington approach' that assumes that goods are differentiated by country of origin (Armington, 1969). Specifically, for each region and commodity, imports are combined using a CES function that aggregates goods from different regions, and aggregate imports are and domestic production are combined using a further CES function.

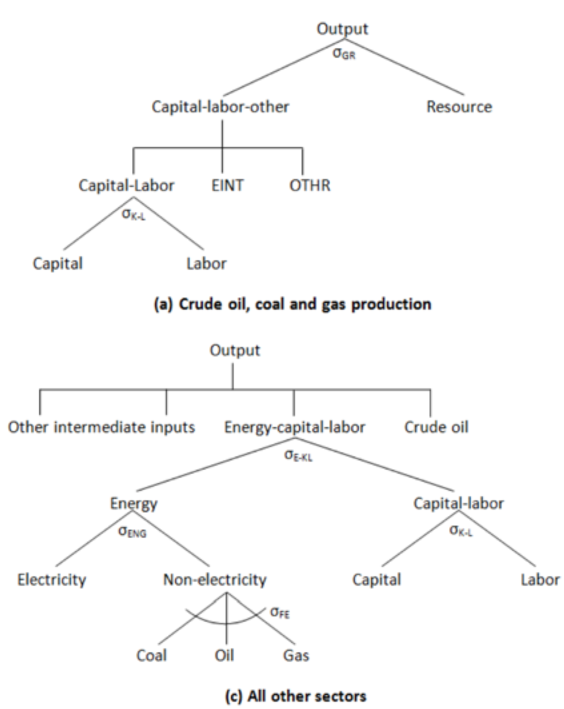

Figure 1. Production and consumption nesting structures.

This two-level CES next produces an 'Armington' supply for each commodity, which is purchased by firms and households and is a composite of domestic and imported varieties. Values for elasticities of substitution in the trade specification are sourced from Hertel *et al.* (2007).

Turning to closure, factor prices are endogenous and there is full employment; factors are immobile internationally, but capital and labor are mobile across sectors; and each region maintains a constant current account surplus/deficit.

The model is calibrated using version 9 of the Global Trade Analysis Project (GTAP) database (Aguiar *et al.*, 2016) and the GTAP-Power database (Peters, 2016). These databases include economic data and CO_2 emissions from the combustion of fossil fuels for 140 regions and 68 sectors, which we aggregate to the elements in Table 1 using tools provided by Lanz and Rutherford (2016). The database provides a snapshot of the global economy in 2011.

The model is formulated and solved as a mixed complementarity problem using the Mathematical Programming Subsystem for General Equilibrium (MPSGE) described by Rutherford (1995) and the Generalized Algebraic Modeling System (GAMS) mathematical modeling language (Rosenthal, 2012) with the PATH solver (Dirkse and Ferris, 1995).

2.2 Scenarios

To focus the analysis on the period when NDCs will have the largest impact, our scenarios estimate outcomes in 2030. As the model is calibrated to 2011 data, we implement a forward calibration simulation to generate a 2030 'business as usual' (BAU) case. Our BAU projection simulates autonomous energy efficiency improvements and endogenous increases in total factor productivity to target estimates of GDP in each region in 2030. We impose autonomous energy efficiency improvements of 1% per year in fossil fuel use, and a 0.03% annual efficient improvement in electricity use. We source estimates of 2030 GDP from the OECD (2014) and report proportional changes in GDP between 2011 and 2030 imposed in the BAU simulation in **Table 2**. In the policy scenarios, total factor productivity parameters are set equal to values derived in the BAU simulation and GDP is endogenous.

Jacoby *et al.* (2017) estimate emissions from the combustion of fossil fuels under a reference (no climate policies) case and a scenario when regions meet their Paris pledges. From these estimates, we calculate proportional reductions from the 2030 baseline projection of fossil fuel CO_2 emissions needed to meet the Paris pledges for each region in our model (Table 2). Estimated proportional emissions reductions due to the accord are largest in Canada, Australia–New Zealand, the US and the EU & EFTA.[2]

We impose emissions reductions in the model using an endogenous price for CO_2 emissions. Each representative household is endowed with emission permits and firms are required to purchase one emission permit for each ton of CO_2 emitted. The quantity of permits endowed to the representative household in region r is equal to $TCO2_r(1 - reduction_r)$, where $TCO2_r$ is total CO_2 emissions from the combustion of fossil fuels in the 2030 BAU equilibrium, and $reduction_r$ is proportional reduction in emissions consistent with the Paris Agreement shown in Table 2. This approach in analogous to implementing a cap-and-trade program in each region with trading of emission permits across sectors, but without international trading of emissions permits.

We explore the impact of BCAs under the Paris Agreement in three policy scenarios, and a further policy scenario (using the aggregated version of the model) is considered to evaluate the outcome of a tariff war. To facilitate welfare analysis without calculating climate damages, global CO_2 emissions are constant at the level consis-

2 The Paris pledge for some countries specifies a reduction in emissions relative to an historic year (e.g., the EU has pledged to reduce its emissions by at least 40% below the 1990 level by 2030). In the modeling exercises, the 2030 baseline is known with certainty, so the reduction in emissions relative to the baseline can calculated to match the emissions reduction relative to a historic year.

Table 2. Baseline GDP projections and 2030 reductions in CO_2 emissions from fossil fuels and industry needed to comply with the Paris pledges.

Region	Change in GDP, 2011 to 2030	Reduction in CO_2 emissions, 2030a
USA	62.4%	-34.3%
Australia-New Zealand	82.3%	-46.4%
Canada	48.1%	-54.0%
China	163.7%	-1.1%
EU & EFTA	41.9%	-30.9%
Japan	23.9%	-11.7%
Mexico	73.3%	-26.0%
South Korea	73.9%	-39.6%
Rest of World	124.3%	-5.1%

tent with implementation of Paris pledges by all regions. In scenarios where the US does not restrict emissions, this is achieved by multiplying the endowment of CO_2 permits in non-US regions by a scaler (λ), so that global emissions equal the level when all regions meet their Paris pledges. That is, the endowment of CO_2 permits is region r is given by $\lambda TCO2_r(1-reduction_r)$. As US emissions are endogenous when it does not meet its Paris pledges, λ is determined endogenously in each scenario.

Policy scenarios considered in the analysis are summarized in **Table 3**. In the first scenario, *Lone-Wolf*, all regions except the US reduce their CO_2 emissions (and there are no BCAs). In the second scenario, *BCA*, all regions except the US restrict emissions and tariffs, based on embodied CO_2, are imposed on US exports of all sectors except services. The third scenario, *Paris*, simulates emissions reductions pledged in NDCs under the Paris Climate Agreement in all regions (including the US).

For computational reasons, our final policy scenario, *Tariff-War*, is only implemented in the two-region, seven-sector aggregation of the model described in Section 2.1. In this scenario, the US does not restrict emissions, the Coalition restricts emissions to meet the global Paris pledge, and the two regions impose welfare maximizing tariffs on each other's exports of Other industry. This simulation is implemented by solving the model for, in one-percentage point increments, US and tariffs on Other industry imports between 0% and 35%, Coalition tariffs on Other industry imports between 0% and 35%, and all combinations of those tariffs.

2.3 Border Carbon Adjustments & Embodied CO_2 Emissions

In the *BCA* scenario, tariffs are used to retrospectively apply the carbon price in each importing region on emissions embodied in goods sourced from the US. The *ad valorem* tariff imposed on imports of good i from the US by region r (τ_{ir}) is given by:

$$\tau_i = PCO2_r E_i^{US}/P_i^{US} \tag{1}$$

where $PCO2_r$ is the price of a permit to release one ton of CO_2 in region r, E_i^{US} denotes tons of CO_2 emissions embodied in each unit of good i, and P_i is the unit price of good i exported from the US.

Following Rutherford and Babiker (1997), our embodied emissions calculations include those from direct and indirect sources. Direct emissions are those that result from the combustion of fossil fuels in the sector in question, and indirect emissions are associated with intermediate inputs. E_i^{US} is calculated as:

$$E_i^{US} = \sum_f D_{fi}^{US} + \sum_j E_j^{US}\alpha_{ij}^{US}\,\delta_j^{US} \tag{2}$$

where D_{fi}^{US} is direct emissions from the burning of fossil fuel f (coal, oil, gas) by industry i, α_{ij}^{US} is the quantity of intermediate input j used by industry i per unit of output, and δ_j^{US} is the share of intermediate input j sourced domestically, all in the US. We multiply α_{ij}^{US} by δ_j^{US} to prevent emissions embodied in imported intermediates from being charged twice—once when they are produced abroad and once when they are (incorporated in other goods) exported by the US. Applying equation (2) to each sector gives rise to a system of i equation and i unknowns. We assign values for D_{fi}^{US}, α_{ij}^{US} and δ_j^{US} using the GTAP database and solve the system of equation simultaneously to determine the value for each E_i^{US}.

3. Results

3.1 Sectoral Emissions Intensities & US Exports

For each sector (except energy production sectors), **Figure 2a** illustrates the emissions intensity of production in the US and separately identifies direct emissions, emissions from electricity use, and emissions associated with other intermediate inputs. The four energy intensive sectors have the highest emissions intensities and electricity is a large source of indirect emissions, especially for Non-metallic minerals. The emissions intensity of production across regions is compared in **Figure 2b**. In general, emissions intensities are highest in developing countries, especially China, and US emissions intensities are high relative to those in other developed countries.

US exports by destination and sector (excluding energy production sectors) are reported in **Figure 3**. Excluding the Rest of the World, the EU (25.9%), Canada (11.7%), China (10.4%) and Mexico (8.6%) account for the largest share of US exports. The data also reveal that Non-metallic minerals (0.7%), Iron and steel (1.5%), and Non-fer-

Table 3. Scenarios.

Name	Description
Lone-Wolf	Emissions reductions in all regions except the US
BCA	Emissions reductions in all regions except the US and BCAs imposed on exports from the US
Paris	Implementation of NDCs by all regions
*Tariff-War**	Emissions reductions in the Coalition and welfare maximizing tariffs imposed by the Coalition and the US

* The *Tariff-War* scenario is only implemented in the two-region, seven-sector aggregation of the model.

rous metals (2.6%)—the three most emissions intensive goods—account for relative small proportions of total US exports. On the other hand, Chemical, rubber & plastic products, which is relatively emissions intensive, accounts for a significant share (14.8%) of US exports.

3.2 Paris Pledges & Border Carbon Adjustments

Results from our modeling exercises are displayed in **Table 4** (CO_2 prices, welfare and US emissions) and **Figure 4** (US exports). In the *Lone-Wolf* scenario, CO_2 prices, in 2011 dollars per metric ton (t) of CO_2, are highest in Canada ($252/t$CO_2$), the EU & EFTA ($181/tCO_2), Australia-New Zealand ($151/t$CO_2$) and South Korea ($144/tCO_2). Conversely, carbon prices are relatively low in China ($5/t$CO_2$) and Rest of World ($15/tCO_2).

Proportional welfare changes reported in Table 4 are annual equivalent variation changes in consumer income relative to GDP (and do not account for benefits from avoided climate damages). Decreases in welfare are largest in Canada (3.1%), Australia–New Zealand (2.9%),

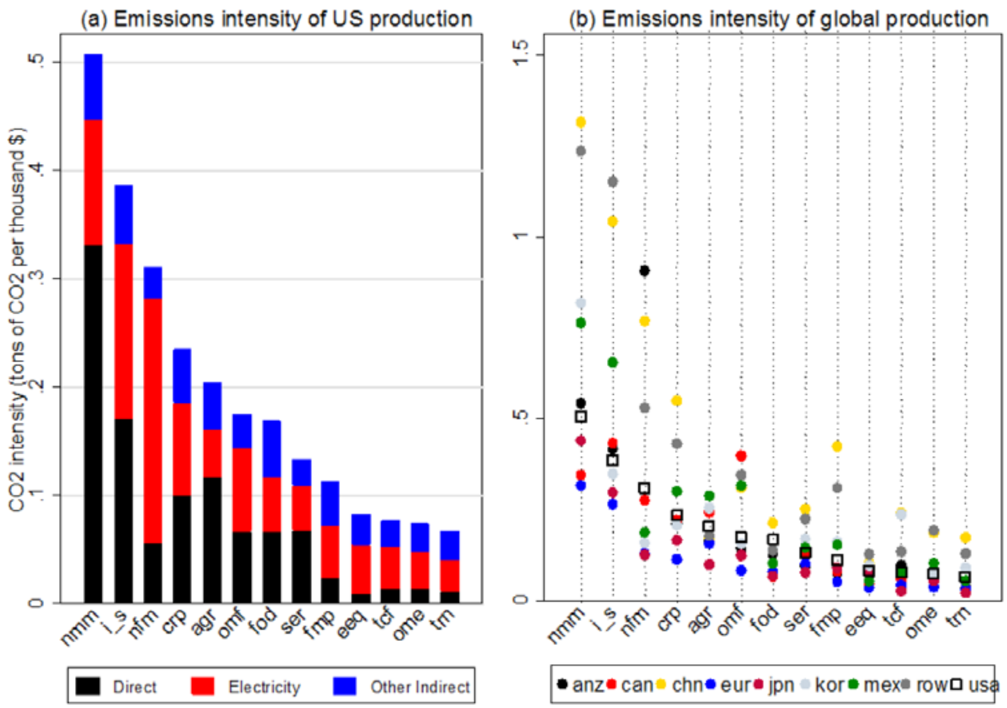

Figure 2. CO_2 emissions intensity of production by sector.

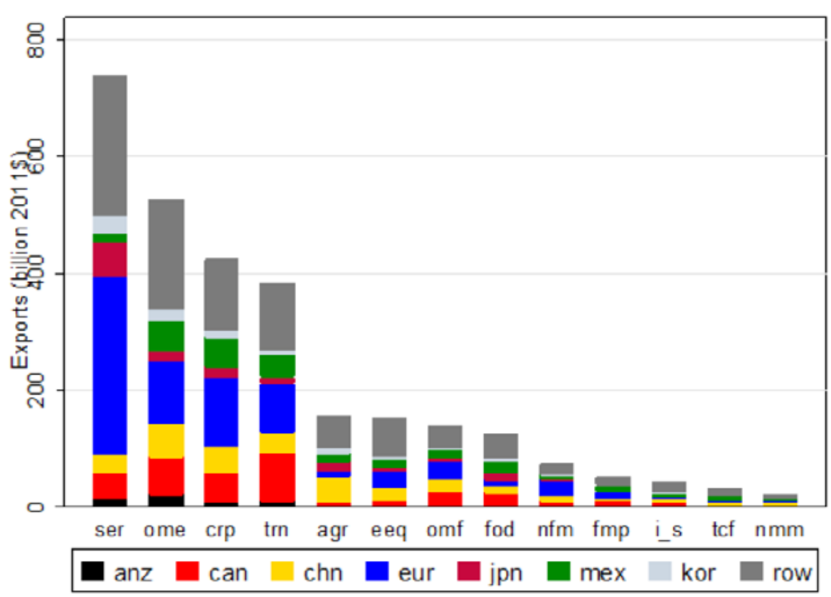

Figure 3. US exports by sector and destination.

Mexico (2.3%) and the EU & EFTA (2.2%). Despite a low carbon price, Rest of World also experiences a relatively large welfare decrease (1.5%) as it includes countries that are major crude oil exporters. Welfare decreases in Japan (0.1%) and Korea (0.9%) are moderate as mitigation costs for these fossil fuel importers are partially offset by decreases in fossil fuel prices.

US welfare increases by 0.21% relative to BAU in the *Lone-Wolf* scenario due to a fall in fossil fuel prices and improved competitiveness in export markets. As illustrated in Figure 4a, exports of Chemicals, rubber and plastic products experience the largest absolute increase in exports, but the proportional change in these exports (2.6%) is less than that for Non-metallic minerals (9.4%), and Iron and steel (9.6%). The largest changes in exports involve US goods shipped to the EU. US emissions increase by 1.9% relative to BAU due to decreased global fossil fuel prices and increased energy-intensive production, indicating leakage of emissions. Proportional emissions reductions in other regions are larger than those under each region's Paris commitment, as these regions pursue deeper emissions reductions to hold global emissions constant.

In the *BCA* scenario, the largest carbon tariff is 12.8% (**Table 5**) and applies to US Non-metallic minerals (the most CO_2-intensive sector) exported to Canada (the region with the highest carbon price). Carbon tariffs on US energy-intensive goods exported to the EU range from 4.4% to 9.3%, and tariffs imposed by China and Rest of World are less than 1%. Carbon tariffs increase the CO_2 prices in most regions as they increase the cost of abating emissions by importing goods from the US. Despite the CO_2 price increases, welfare in all non-US re-

Table 4. CO_2 prices, welfare and emissions.

	Lone-Wolf	***BCA***	***Paris***
CO_2 prices, 2011$/t			
USA	-	-	67.1
Australia & New Zealand	151.2	152.1	125.5
Canada	252.3	251.4	212.5
China	4.7	4.7	1.3
EU & EFTA	181.5	182.3	138.4
Japan	60.7	61.0	37.1
Mexico	67.7	67.5	50.7
South Korea	144.0	144.7	115.7
Rest of World	15.3	15.3	7.5
Welfare change relative to BAU, equivalent variation as percent of GDP			
USA	0.21	0.05	-0.57
Australia & New Zealand	-2.90	-2.85	-2.38
Canada	-3.10	-2.91	-2.91
China	-0.08	-0.07	0.08
EU & EFTA	-2.20	-2.13	-1.62
Japan	-0.09	-0.06	0.06
Mexico	-2.29	-2.15	-2.10
South Korea	-0.95	-0.90	-0.60
Rest of World	-1.54	-1.52	-1.27
Change in CO_2 emission relative to BAU, %			
USA	1.9	1.5	-34.3
Australia & New Zealand	-49.9	-49.9	-46.4
Canada	-57.0	-57.0	-54.0
China	-7.6	-7.5	-1.1
EU & EFTA	-35.4	-35.4	-30.9
Japan	-17.5	-17.4	-11.7
Mexico	-30.8	-30.8	-26.0
South Korea	-43.6	-43.5	-39.6
Rest of World	-11.3	-11.2	-5.1

Table 5. Ad valorem tariffs on US exports in the BCA scenario, %.

	anz	can	chn	eur	jpn	mex	kor	row
Agriculture	3.11	5.15	0.10	3.73	1.25	1.38	2.96	0.31
Chemical, rubber & plastics	3.66	6.06	0.11	4.39	1.47	1.63	3.49	0.37
Non-metallic minerals	7.76	12.84	0.24	9.31	3.11	3.45	7.39	0.78
Iron and Steel	5.89	9.74	0.18	7.06	2.36	2.61	5.61	0.59
Non-ferrous metals	4.74	7.84	0.15	5.68	1.90	2.10	4.51	0.48
Fabricated metals products	1.71	2.82	0.05	2.05	0.68	0.76	1.62	0.17
Food processing	2.55	4.22	0.08	3.06	1.02	1.13	2.43	0.26
Textiles, clothing & footwear	1.17	1.93	0.04	1.40	0.47	0.52	1.11	0.12
Transportation equipment	1.01	1.67	0.03	1.21	0.41	0.45	0.96	0.10
Electronic equipment	1.26	2.08	0.04	1.51	0.51	0.56	1.20	0.13
Other machinery & equip.	1.12	1.85	0.03	1.34	0.45	0.50	1.07	0.11
Other manufacturing	2.64	4.37	0.08	3.17	1.06	1.17	2.51	0.27

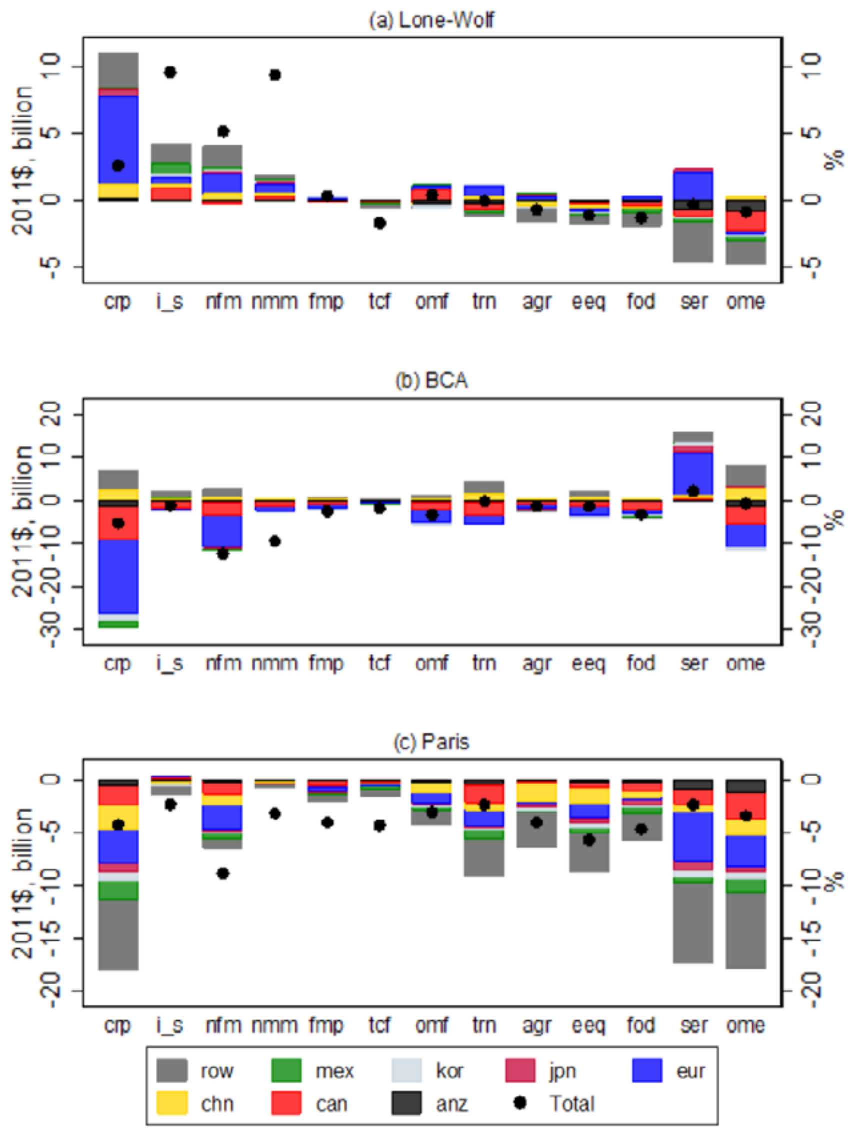

Figure 4. Absolute (right axis, bars) and proportion (left axis, dots) in the value of US exports relative to BAU.

gions increases relative to the *Lone-Wolf* scenario due to terms-of-trade improvements at the expense of the US. Welfare decreases in the US, but there is still a small welfare increase relative to BAU. US exports, relative to BAU, decrease for most commodities, and are proportionally the largest for Non-ferrous metals (12.5%), Non-metallic minerals (9.5%), and Chemical rubber & plastic products (5.4%) (Figure 4b). These changes are driven by decreased exports to Canada and the EU with exports to China and Rest of World, which impose relative low carbon tariffs, increasing. US exports of services, which are not subject to a BCA, increase to all regions. The carbon tariffs result in a small reduction in US emissions and US emissions still increase to relative to BAU.

In the *Paris* scenario, a US carbon price of \$67/tCO_2 is required to meet its NDC emissions reduction target. US exports for all commodities decrease with the largest proportional reductions occurring for the four energy-intensive industries (Figure 4c). Welfare in the US falls by 0.57% relative to BAU. As US welfare in this scenario is significantly higher than in the *BCA* case, this indicates that BCAs would not be sufficient to make it economically advantageous for the US to implement policies to meet its Paris pledges.

Due to emissions reductions in the US, carbon prices decrease elsewhere relative to the *Lone-Wolf* scenario, as less mitigation is required to meet the global constraint on CO_2 emissions. Consequently, welfare is higher in each non-US region in the *Paris* scenario than in the *Lone-Wolf* scenario. Welfare increases due to the constraint on US emissions are smallest for the regions that trade intensively with the US (Canada and Mexico) as US exports become more expensive and the decrease in US income reduces demand for their exports.

3.3 A Tariff War

Welfare changes and CO_2 prices from simulating our scenarios (including the *Tariff-War* case) when the model represents two regions and six sectors are displayed in **Table 6**. Estimated welfare changes in the US from the more aggregated version of the model in the first three scenarios are qualitatively similar to those in Table 4: (1) The US experiences a small welfare gain when it does not restrict emissions and other nations do, (2) BCAs result in a small reduction in US welfare, and (3) meeting its Paris pledge results in a moderate reduction in US welfare. In the *BCA* scenario, the Coalition imposes a 0.28% tariff on Other industry goods produced in the US.

The Nash equilibrium in the *Tariff-War* scenario occurs when the US imposes a tariff of 19% on Other industry imports and the Coalition imposes a 23% tariff on these goods. The tariff war results in a decrease in US welfare that is more than double that in the *Paris* scenario, indicating that when faced with the threat of a tariff war the best play for the US is to meet its Paris pledge (and avoid a tariff war). In the Coalition, welfare is higher when there are BCAs than in the *Tariff-War* scenario, indicating that, in simple one-shot game, the Coalition also has an incentive to avoid a tariff war and the *BCA* scenario represents the Nash equilibrium.

Focusing on the simple one-shot Nash equilibrium, however, ignores other important considerations. First, the Coalition may derive utility by enforcing 'fairness', and this utility gain not considered in our simulations may offset the welfare decrease simulated in the *Tariff-War* scenario relative to the *BCA* scenario. Second, the experimental economics literature has shown that agents that cooperate are willing to punish free-riding, even if it is costly for them (Fehr and Gächter, 2000). Additionally, the US, under the Trump administration, has indicated that it is willing to use trade measures to increase domestic welfare. If the US pursues such policies, the optimal strategy for the coalition is to impose a welfare maximizing tariff.

To illuminate possible outcomes, **Figure 5** reports welfare changes in the two regions for alternative values of the Coalition tariff when the US imposes a welfare maximizing tariff (conditional on the coalition tariff) and the Coalition reduces emission to meet the global Paris pledge. The optimal US tariff is 18% for values of the Coalition tariff

Table 6. CO_2 prices and welfare from the two-region, six sector model.

	Lone-Wolf	*BCA*	*Paris*	*Tariff-War*
CO_2 prices, 2011\$/t				
USA	-	-	\$66.2	-
Coalition	\$18.5	\$18.5	\$10.1	\$18.7
Welfare change relative to BAU, equivalent variation as percent of GDP				
USA	0.02	-0.02	-0.72	-1.50
Coalition	-0.40	-0.39	-0.21	-0.57
Change in CO_2 emission relative to BAU, %				
USA	1.3	1.3	-34.3	-0.8
Coalition	-15.9	-15.9	-9.3	-15.5

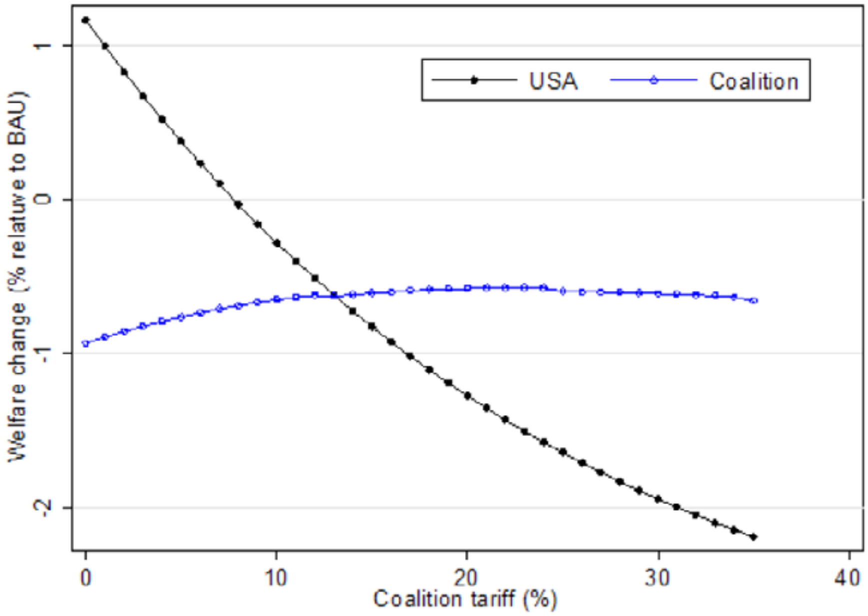

Figure 5. Welfare changes for alternative Coalition tariffs when the US imposes optimal tariffs.

less than or equal to 18%, 19% for Coalition tariff values between 14% and 24%, 20% for Coalition tariffs between 25% and 34%, and 21% when the Coalition tariff is 35%. US welfare is a decreasing function of the tariff imposed by the Coalition and US welfare falls by 2.2% relative to BAU when the Coalition imposes a 35% tariff. The change in Coalition welfare is negative for all Coalition tariffs because this region reduces emissions and faces optimal US tariffs. At low tariffs, an increase in the Coalition tariff leads to relative large increases in welfare in this region. Coalition welfare is maximized when it imposes a 23% tariff and increases in the tariff beyond this value lead to relative small reductions in coalition welfare.

Figure 5 reveals two key outcomes. First, proportional US welfare losses from a tariff are much larger than those in the Coalition. Second, by imposing a tariff higher than the welfare maximizing one, the Coalition can inflict relatively large welfare decreases on the US while incurring small welfare decreases. A uniform response from the Coalition would, however, require a high level of coordination and possibly also income transfers among these regions. Nevertheless, our results indicate that there is scope for the Coalition to use tariffs as a mechanism to enforce the US to implement climate policies.

4. Conclusions

Avoiding undesirable human-induced climate change will require multilateral cooperation between nations. The Paris Agreement attempts to achieve this goal but meeting planned emissions reduction will rely on counties voluntarily agreeing to stay in the accord. The absence of legal channels to enforce this agreement means that other measures will be required to persuade nations to achieve emission reduction targets. BCAs are one such mechanism and this paper quantitatively evaluated the impact of these tariffs using an economy-wide model with energy sector detail. As there are several indications that the current US Administration may withdraw the US from the Agreement or fail to meet its commitments, we considered a case where all countries except the US enact policies to reduce emissions and trade measures—BCAs and welfare-maximizing tariffs—are imposed on US exports.

In our analysis, BCAs imposed by each region were a function of the carbon price in that region and emissions embodied in US exports. The required carbon tariffs were quite low (less than 5%) in most cases, and higher tariffs (up to 13%) only applied to a small share of US exports and could be avoided by re-routing exports to regions with lower BCAs. Consequently, BCAs had only a small negative impact on US emissions and welfare. As US welfare was significantly lower when it met its Paris pledge than when it faced BCAs but did not regulate GHG emissions, we conclude that BCAs will not be effective in enforcing climate commitments.

In contrast, welfare changes were relatively large in the Nash equilibrium of tariff war between the US and the Coalition (the rest of the world). US welfare under a tariff war was significantly lower than when it restricted emissions to meet its Paris pledge (and avoided the tariff war). While the final outcome will depend on the objective of the coalition and the behavior of the US, these results indicate that there is scope to use carefully chosen tariffs as an enforcement tool against regions that fail to meet their Paris pledges.

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T (617) 253-7492 **F** (617) 253-9845
globalchange@mit.edu
http://globalchange.mit.edu/