Can tariffs be used to enforce Paris climate commitments?

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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 4 November 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 3 September 2016. This document stated that the US would reduce economy-wide GHG emissions by 26–28% 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 4 years notice by withdrawing from the agreement (Stutter, 2017) or in 1 year by leaving the UNFCC (Mathiesen, 2016).

In the lead up to the 2016 US presidential election, Donald Trump vowed to remove the US from the Paris Agreement (Stutter, 2017) and in 2012 he famously stated, “The concept of global warming was created by and for the Chinese in order to make US manufacturing noncompetitive” (Wong, 2016). On 1 June 2017, President Trump honoured his pre-election promise by announcing his intention to withdraw the US from the accord. Following this announcement, the US State Department formally notified the United Nations that it would leave the agreement as soon as possible (Meyer, 2017). Since taking office, President Trump has also signed an executive order that initiated a review of the Clean Power Plan—an Obama administration policy that aims to reduce carbon dioxide (CO2) emission from electricity generation—and rescinded the moratorium on coal mining on US federal lands (Merica, 2017).

The 2016 presidential election also resulted in a change in US trade policy, from actively seeking trade liberalisation 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 &
Merica, 2017). Additionally, on April 24, 2017 President Trump announced plans to impose tariffs of up to 24% on Canadian lumber entering the US (Gillespie, 2017).

Kemp (2016) notes that two options for dealing with nations that do not ratify the Paris Agreement include trade penalties, and facilitating the direct involvement of subnational actors, such as states, cities and local governments. In this paper, we evaluate the role of border carbon adjustments (BCAs)—tariffs on embodied carbon emissions imposed by countries with climate policies on imports from countries without them—and welfare-maximising tariffs as mechanisms to persuade a non-compliant country to reduce GHG emissions. BCAs 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, Paltsev, & Reilly, 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 (Burniaux, Château, & Duval, 2010; Demaillé & Quirion, 2008; Felder & Rutherford, 1993; Mattoo, Subramanian, van der Mensbrugghe, & He, 2009; Ponsard & Walker, 2008; Sakai & Barrett, 2016; Winchester, 2012; Winchester et al., 2011). In reviewing the BCA literature, Böhringer, Balistreri, and Rutherford (2012) note that BCAs shift some cost of reducing emissions from regions that restrict emissions to those that do not. As illustrated by Markusen (1975), this results from non-compliant countries sharing some of the burden to reduce emissions, and from terms-of-trade effects that favour nations imposing tariffs.

Several previous studies have empirically evaluated the use of BCAs as strategic trade measure. 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. Weitzel, Hübner, and Peterson (2012) find that nations have incentives to raise BCAs above the standard rate to take advantage of positive terms-of-trade effects. They also show that BCAs can encourage certain regions to join a global climate accord, but they do not provide strong incentives for all regions to participate in such an agreement. Böhringer, Lange, and Rutherford (2014) evaluate a unilaterally abating country (the US or the EU) using carbon prices that differ across sectors as a substitute for optimal tariffs. They find that the terms-of-trade motive has limited potential for strategic burden shifting. Lessmann Marschinski, and Edenhofer (2009) illustrate that, under certain conditions, tariffs can persuade noncompliant countries to join other nations in reducing emissions. Böhringer, Carbone, and Rutherford (2016) show that the threat BCAs imposed by a coalition of Annex-I countries (that restrict emissions) can induce non-coalition countries to reduce their emissions.

Building on this literature, and motivated by recent actions by the US, our analysis considers a case where all regions except the US implement polices to reduce emissions and US exports face BCAs. Using a global multisectoral, multiregion 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/regions impose welfare maximising tariffs (strategic tariffs).

In a contemporaneous study, Böhringer and Rutherford (2017) analyse a similar set of climate policies and trade measures but with several key differences. First, the two studies differ in how they translate Paris GHG pledges into constraints on CO2 emissions. Second, we consider trade measures imposed by all regions while Böhringer and Rutherford (2017) consider strategic trade measures imposed by Europe, China and the US. Third, Böhringer and Rutherford (2017) consider tariffs on all goods and services, whereas we examine tariffs on only merchandise trade. Fourth,
we consider the impact of policies in 2030 whereas Böhringer and Rutherford (2017) impose policies on a database representing the world economy in 2011. Fifth, Böhringer and Rutherford’s (2017) assignment of embodied emissions for BCAs use direct emissions plus indirect emissions from electricity, whereas we calculate embodied emissions calculations as the sum of direct emissions plus indirect emissions from all intermediate inputs. Combined, the two studies form a body of literature to understand the role of tariffs in enforcing Paris climate commitments.

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 | Modelling framework

Our analysis employs an economy-model with a detailed representation of energy production that builds on the “GTAP-Energy in GAMS” model (Rutherford & Paltsev, 2000). The model is a static, multisector, multiregion applied general equilibrium model of the global economy that links economic activity to energy production and CO₂ 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, Aldy et al. (2016), Vandyck, Keramidas, Saveyn, Kitous, and Vrontisi (2016), and Jacoby, Chen, and Flannery.
Primary factors in the model include capital, labour 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 represents the US and all other countries are included in a composite region that we label the “Coalition.” Sectors in the more-aggregated 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 multilevel 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, labour and intermediate inputs. Other sectors combine intermediate inputs, capital and labour. 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 CO₂ 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: (i) substitution among different forms of energy in production and final consumption; (ii) substitution between aggregate energy and capital-labour in production; and (iii) 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 Table 1.

**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 |
| fod     | Food processing | cap | Capital |
| tcf     | Textiles, clothing & footwear | lab | Labour |
| 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 |

(2017).
Figure 1 and are guided by those used in the MIT Economic Projection and Policy Analysis (EPPA) model (Chen, Paltsev, Reilly, Morris, & Babiker, 2016; Paltsev et al., 2005). Elasticity values used in the EPPA model are, in part, informed by the literature review conducted by Cossa (2004). To account for the increased penetration of low-carbon generation sources under a carbon

**FIGURE 1** Production and consumption nesting structures.

Note: Vertical lines signify a Leontief structure where the elasticity of substitution is zero. $\sigma_{GR} = 0.6$, $\sigma_{K-L} = 1$, $\sigma_{E-KL} = 0.85$ in the electricity sector and 0.6 in other sectors, $\sigma_{ENG} = 0.5$, $\sigma_{FE} = 1$, $\sigma_{CN} = 0.5$ and $\sigma_{ENE-FD} = 1$.

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price, we set the elasticity of substitution between energy and capital-labour 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 and domestic production are combined using a further CES function. This two-level CES nest 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, Hummels, Ivanic, and Keeney (2007).

Turning to closure, factor prices are endogenous and there is full employment; factors are immobile internationally, but capital and labour 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, Narayanan, & McDougall, 2016) and the GTAP-Power database (Peters, 2016). These databases include economic data and CO2 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 modelling language (Rosenthal, 2012) with the PATH solver (Dirkse & 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 efficiency improvement in electricity use in all regions.1 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 CO2 emissions needed to meet the Paris pledges for each region in our model (Table 2). Estimated

1Assigned values for autonomous energy efficiency improvements are guided by those used in the EPPA model, which in turn are informed by studies by Schmalensee, Stoker, and Judson (1998) and Webster, Paltsev, and Reilly (2008).

Electronic copy available at: https://ssrn.com/abstract=3264313
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 \(\frac{TCO_2}{1 - \text{reduction}_r}\), where \(TCO_2\) is the total CO\(_2\) emissions from the combustion of fossil fuels in the 2030 BAU equilibrium, and \(\text{reduction}_r\) is proportional reduction in emissions consistent with the Paris Agreement shown in Table 2. This approach is analogous to implementing a cap-and-trade programme 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 consistent 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 \((\lambda)\), so that global emissions equal the level when all regions meet their Paris pledges. That is, the endowment of CO\(_2\) permits in region \(r\) is given by \(\lambda TCO_2/(1 - \text{reduction}_r)\). As US emissions are endogenous when it does not meet its Paris pledges, \(\lambda\) is determined endogenously in each scenario.

Policy scenarios considered in the analysis are summarised 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

### 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, 2030\(^a\) (%) |
|-------------------------|---------------------------------|-----------------------------------------------|
| 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                                          |

Notes. \(^a\)Proportional reductions in CO\(_2\) emissions from fossil fuels and industry needed to comply with Paris pledges relative to the 2030 baseline level. Source: Authors’ aggregation of estimates from OECD (2014) (GDP) and Jacoby et al. (2017) (CO\(_2\) emissions).

\(^2\)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 modelling 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.
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 maximising tariffs on each other’s exports of other industry. This simulation is implemented by solving the model for, in 1-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.

Turning to the compatibility of trade measures considered in the scenarios with World Trade Organization (WTO) legislation, the consensus is that BCAs may be permissible under WTO provisions for border tax adjustments (Bhagwati & Mavroidis, 2007; Kemp, 2016; Veel, 2009; Zhang, 2009). Welfare maximising tariffs, on the other hand, would violate WTO legislation, so the Tariff-War scenario is consistent with a collapse of current trade rules.

2.3 Border carbon adjustments and embodied CO₂ 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 \( r \) \( (\tau_{ir}) \) is given by:

\[
\tau_i = PCO2_r E_{iUS} / P_i,
\]

where \( PCO2_r \) is the price of a permit to release one ton of CO₂ in region \( r \), \( E_{iUS} \) denotes tons of CO₂ 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. \( E_{iUS} \) is calculated as:

\[
E_{iUS} = \sum_f D_{fiUS} + \sum_j E_{jUS} a_{ijUS} d_{jUS},
\]

where, \( D_{fiUS} \) is direct emissions from the burning of fossil fuel \( f \) (coal, oil, gas) by industry \( i \), \( a_{ijUS} \) is the quantity of intermediate input \( j \) used by industry \( i \) per unit of output, and \( d_{jUS} \) is the share of intermediate input \( j \) sourced domestically, all in the US. We multiple \( a_{ijUS} \) by \( d_{jUS} \) to prevent

| 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\(^a\) | Emissions reductions in the Coalition and welfare maximising tariffs imposed by the Coalition and the US |

Note. \(^a\)The Tariff-War scenario is only implemented in the two-region, seven-sector aggregation of the model.
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 \( i \) equations and \( i \) unknowns. We assign values for \( D^\text{US}_{ji} \), \( a^\text{US}_{ij} \) and \( \delta^\text{US}_{ij} \) using the GTAP database and solve the system of equation simultaneously to determine the value for each \( E^\text{US}_i \). 3

3 | RESULTS

3.1 | Sectoral emissions intensities and US exports

For each sector (except energy production sectors), Figure 2a illustrates the emissions intensity of production in the US in the BAU simulation. 4 The figure also separately identifies direct

![Figure 2](https://ssrn.com/abstract=3264313)

**FIGURE 2** CO2 emission intensity of production by sector. (a) Emissions intensity of US production. (b) Emissions intensity of global production.

*Note: Sector abbreviations are defined in Table 1 [Colour figure can be viewed at wileyonlinelibrary.com]*

3The GTAP database combines data on fuel use (in physical units) from the International Energy Agency and with emissions coefficients to estimate emissions from fuel use in each sector (\( D^\text{th}_i \)) in 2011. In the model, technical change that reduces sectoral emission intensities is possible via two channels. First, autonomous energy efficiency improvements reduce emission intensities between 2011 and 2030. Second, substitution among energy sources, and between aggregate energy and capital-labour mean that sectoral emission intensities respond to relative price changes.

4Autonomous energy efficiency improvements in the BAU simulation reduce carbon intensities in all sectors in 2030 relative to those in 2011. Additional changes in sectoral carbon intensities are driven by relative prices changes in the BAU simulation; however, there are no changes in the order of sectoral carbon intensities in 2030 relative to 2011.
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 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-ferrous 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 and border carbon adjustments

Results from our modelling exercises are displayed in Table 4 (CO2 prices, welfare and US emissions) and Figure 4 (US exports). In the Lone-Wolf scenario, CO2 prices, in 2011 dollars per metric ton (t) of CO2, are highest in Canada ($252/tCO2), the EU & EFTA ($181) Australia-New Zealand ($151/tCO2) and South Korea ($144/tCO2). Conversely, carbon prices are relatively low in China ($5/tCO2) and Rest of World ($15/tCO2).

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%), 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 CO₂-intensive sector) exported to Canada (the region with the highest carbon...
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 CO2 prices in most regions as they increase the cost of abating emissions by importing goods from the US. Despite the CO2 price increases, welfare in all non-US regions 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/tCO2 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.

Attributable 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 CO2 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.

Comparing our results to those from the parallel study by Böhringer and Rutherford (2017), reveals several qualitative differences but similar overarching conclusions. Two noteworthy differences include the magnitude of the change in US welfare in: (i) the Lone-Wolf scenario; and (ii) the Paris simulation. In Böhringer and Rutherford’s (2017) Lone-Wolf scenario—which they label USout—the US experiences a small welfare decrease relative to BAU, whereas US welfare increases by 0.21% in our simulations. A likely driver of this result is that Böhringer and Rutherford’s (2017) model represents the global economy in 2011 whereas we our framework is based on a projection to 2030. As a result, the US economy accounts for a smaller share of economic activity in our analysis, resulting in larger declines in fossil fuel prices due to policies elsewhere. The lower cost of US compliance with the Paris Agreement in Böhringer and Rutherford (2017) is likely linked to the lower emissions reduction target imposed in their study (19%) relative to that in our study (34%). Nevertheless, both studies show that US welfare is lower in the Paris scenario than when the US does not restrict emissions and faces carbon tariffs, indicating that BCAs will not be effective in encouraging the US to meet its Paris pledge.

### 3.3 A tariff war

Welfare changes and CO2 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

![Table 5](image)
Table 6 CO₂ prices and welfare from the two-region, six sector model

|                  | Lone-Wolf | BCA    | Paris  | Tariff-War |
|------------------|-----------|--------|--------|------------|
| CO₂ 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 CO₂ emission relative to BAU, % |           |        |        |            |
| USA              | 1.3       | 1.3    | -34.3  | -0.8       |
| Coalition        | -15.9     | -15.9  | -9.3   | -15.5      |

Qualitatively similar to those in Table 4: (i) the US experiences a small welfare gain when it does not restrict emissions and other nations do; (ii) BCAs result in a small reduction in US welfare; and (iii) 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 a 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 from 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 & Gächter, 2000). In such circumstances, the welfare decrease in the Coalition due to climate damages when global emissions are not constrained will likely set a limit on the welfare decrease that the Coalition is willing to endure from a tariff war. Third, under the Trump administration, the US 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 may be to retaliate with welfare-maximising tariffs.

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 maximising 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 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 maximised 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 maximising 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.

Börhinger and Rutherford (2017) consider welfare maximising tariffs imposed by the EU and China on imports from the US and vice versa. Similar to our study, the authors find that US welfare is lower in the tariff war outcome than when the US meets it Paris pledge (and does not face strategic tariffs), and that welfare in the EU and China is lower under a tariff war to when there is a passive response to the US withdrawal from the Paris Agreement. Börhinger and Rutherford (2017) do not report results for their sensitivity analysis but note that simulating their model with a highly aggregated sectoral classification lead to similar qualitative outcomes, even though there are “substantial quantitative deviations.”

Despite the similarities in qualitative outcomes in the two studies, Börhinger and Rutherford’s conclusion differs from ours. Applying a “textbook” one-shot Nash equilibrium analysis, Börhinger and Rutherford (2017, p. 20) conclude that ‘carbon tariffs do not provide a credible threat to the US when accounting for retaliatory tariffs and the possibility of a tariff war’. Our interpretation is more pragmatic and, drawing on results from experimental economics, indicates that the ability for other nations to impose a larger welfare loss on the US than when the US meets Paris pledge, provides scope for tariffs to use tariffs as an enforcement mechanism, even if a tariff warm also harms compliant countries.

3.4 | Sensitivity analysis

Key parameters in our numerical model include: (i) the elasticity of substitution between (aggregate) energy and capital-labour ($\sigma_{E-KL}$); and (ii) sectoral elasticities of substitution in the trade specification (Armington elasticities). To examine the sensitivity of our findings to these parameters, in the more aggregated version of the model, we consider alternative values for $\sigma_{E-KL}$ of 0.5 and 1.2 (compared to 0.85 in the simulations above), and scale Armington elasticities by 0.75 and 1.25.
Proportional welfare changes for all combinations of alternative parameter values considered in the sensitivity analysis are presented in Table 7. When $\sigma_{E-KL} = 0.85$ and the Armington elasticity multiplier is equal to one, the sensitivity analysis reproduces the welfare results in Table 6. In the Tariff-War scenario, holding $\sigma_{E-KL}$ constant, increasing the Armington elasticities reduces US welfare losses under a tariff war as less product differentiation reduces the Coalition’s ability to exploit terms-of-trade improvements. Holding Armington elasticities constant, decreasing $\sigma_{E-KL}$ increases the welfare costs of cutting emissions in the US. These results indicate that for high Armington elasticity values and low values for $\sigma_{E-KL}$, the US may be better off under a tariff war than meeting its Paris pledge. Such an outcome eventuates when Armington elasticities are multiplied by 1.25 and $\sigma_{E-KL} = 0.5$ (although differences in proportional welfare changes across the Paris and Tariff-War scenarios are not visible when reported to two decimal places).

For other alternative values in the sensitivity analysis, our main findings are confirmed: (i) US welfare is higher in the BCA scenario than in the Paris scenario; (ii) the US is worse off in the Tariff-War scenario than in the Paris scenario; and (iii) relative to a tariff war, the Coalition is better off in the Lone-Wolf and BCA scenarios. That is, BCAs are not an effective enforcement mechanism but welfare-maximising tariffs are, providing the Coalition is willing to endure the costs of engaging in a tariff war.

### Table 7  Welfare changes relative to BAU (equivalent variation as a percentage of GDP) for alternative values of $\sigma_{E-KL}$ and the Armington elasticities

| Region          | Lone-Wolf | BCA   | Paris | Tariff-War |
|-----------------|-----------|-------|-------|------------|
| Armington elasticities multiplied by 0.75 |
| $\sigma_{E-KL} = 0.5$ | US        | 0.00  | -0.05 | -0.86      | -1.95      |
| coalition       | -0.31     | -0.30 | -0.17 | -0.55      |
| $\sigma_{E-KL} = 0.85$ | US        | 0.01  | -0.03 | -0.68      | -2.03      |
| coalition       | -0.40     | -0.39 | -0.22 | -0.63      |
| $\sigma_{E-KL} = 1.2$ | US        | 0.03  | -0.01 | -0.60      | -1.98      |
| coalition       | -0.47     | -0.46 | -0.26 | -0.69      |
| Armington elasticities multiplied by 1 |
| $\sigma_{E-KL} = 0.5$ | US        | 0.00  | -0.04 | -0.89      | -1.50      |
| coalition       | -0.31     | -0.30 | -0.15 | -0.49      |
| $\sigma_{E-KL} = 0.85$ | US        | 0.02  | -0.02 | -0.72      | -1.50      |
| coalition       | -0.40     | -0.39 | -0.21 | -0.57      |
| $\sigma_{E-KL} = 1.2$ | US        | 0.04  | 0.00  | -0.64      | -1.51      |
| coalition       | -0.48     | -0.47 | -0.25 | -0.63      |
| Armington elasticities multiplied by 1.25 |
| $\sigma_{E-KL} = 0.5$ | US        | 0.01  | -0.04 | -0.91      | -0.91      |
| coalition       | -0.31     | -0.30 | -0.14 | -0.45      |
| $\sigma_{E-KL} = 0.85$ | US        | 0.03  | -0.02 | -0.74      | -0.81      |
| coalition       | -0.41     | -0.39 | -0.20 | -0.54      |
| $\sigma_{E-KL} = 1.2$ | US        | 0.05  | 0.00  | -0.67      | -1.31      |
| coalition       | -0.48     | -0.47 | -0.24 | -0.61      |
CONCLUSIONS

Avoiding undesirable human-induced climate change will require multilateral cooperation between nations. The Paris Agreement attempts to achieve this goal but meeting planned emission reductions relies 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 the Trump Administration has announced that the US will withdraw from the Agreement, we considered a case where all countries except the US enact policies to reduce emissions and trade measures—BCAs and welfare-maximising 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 a tariff war between the US and the rest of the world. In most model parametrisations, US welfare under a tariff war was significantly lower than when it restricted emissions to meet its Paris pledge (and avoided the tariff war). The tariff war also decreased welfare in the rest of the world. Accordingly, strategic tariffs are only a credible threat if compliant countries are willing to incur welfare losses to punish noncompliant countries. Whether this is the case depends on the utility (if any) derived by the rest of the world from enforcing “fairness,” and if countries that cooperate are willing to punish free-riding even if it is costly for them.

Another interesting political economy aspect of strategic tariffs, although not evaluated in our analyses, is that working class citizens in the US may suffer the most from tariffs imposed by the rest of the world. This raises the possibility that carefully chosen tariffs on certain goods, or the threat of such tariffs, could incentivise the US to meet its Paris commitment.

Overall, we conclude that there is scope to use strategic tariffs as an enforcement tool against regions that fail to meet their Paris pledges.

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