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Will Border Carbon Adjustments Work?

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Niven Winchester[*,†,‡], Sergey Paltsev[*], and John Reilly[*]

Abstract

The potential for greenhouse gas (GHG) restrictions in some nations to drive emission increases in other nations, or leakage, is a contentious issue in climate change negotiations. We evaluate the potential for border carbon adjustments (BCAs) to address leakage concerns using an economy-wide model. For 2025, we find that BCAs reduce leakage by up to two-thirds, but result in only modest reductions in global emissions and significantly reduce welfare. In contrast, BCA-equivalent leakage reductions can be achieved by very small emission charges or efficiency improvements in nations targeted by BCAs, which have negligible welfare effects. We conclude that BCAs are a costly method to reduce leakage but such policies may be effective coercion strategies. We also investigate the impact of BCAs on sectoral output and evaluate the leakage contributions of trade and changes in the price of crude oil.

Contents

1. INTRODUCTION

There has been longstanding concern about the competitiveness and leakage effects when some countries implement emissions reductions policies while others do not. Early studies of the Kyoto Protocol examined the potential for leakage—an increase in emissions in countries not covered by policy that result from impacts on global energy prices or from relocation of energy intensive industry from countries with controls to those without them (e.g. Bernstein, *et al.*, 1999). Concerns among domestic industries, especially those involved in energy intensive production activities, often are directed towards a loss of competitiveness, fearing that imports of similar products that do not face higher energy prices due to carbon policy will gain an advantage over domestically produced goods. That is one channel of leakage—growth in foreign production of energy intensive goods, and the emissions that go with it, at the expense of domestic production of similar goods. Concerns about such leakage are reflected in the bill passed by the U.S. House of Representatives as the American Clean Energy and Security Act

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(H.R. 2454) of 2009, commonly known as the Waxman-Markey Bill (U.S. Congress, 2009a). Title IV, Subtitle A of H.R. 2454 seeks to “prevent an increase in greenhouse gas emissions in countries other than the U.S.” (p. 1087) by requiring importers of certain products to purchase emission allowances, a measure analogous to a tariff. It is unclear whether border carbon adjustments (BCAs), or tariffs on embodied GHG emissions, are permissible under existing trade laws, but some authors argue that World Trade Organization (WTO) provisions for border tax adjustments (BTAs) provides scope for such charges.

The Bill does not reference competiveness concerns but it appears that members of the House were mindful of such issues when designing the Bill. Indeed, in the discussion draft of the Bill, Subtitle A of Title IV was labeled “Ensuring Domestic Competiveness” with the purpose “to compensate the owners and operators of entities in eligible domestic industrial sectors and subsectors for carbon emission costs” (U.S. Congress, 2009b, p. 537). It is also likely that competitiveness concerns will be important in Senate negotiations. Shortly after the Bill passed the House vote, Michigan Senator Stabenow asserted that keeping BCAs in the legislation was her biggest concern. Similar sentiments were echoed by other senators from states with large manufacturing industries, including Ohio Senator Brown, “I don’t think you can fully take care of manufacturing [and pass the Bill] without some border equalization” (Hale, 2009). Additionally, Democrat Senator John Kerry and Republican Senator Lindsey Graham voiced their support for climate change legislation in a New Your Times Article, providing that BCAs are included (Kerry and Graham, 2009). Senator Graham’s view indicates that Republican support for H.R.5425 in the Senate may hinge on the inclusion of BCA provisions.

Although H.R. 2454 was approved by the House of Representatives in June 2009, political arguments for BCAs are not new. Notably, forerunners to H.R. 2454 – the Bingaman-Specter (S. 1766) and Lieberman-Warner (S. 2191) Bills – included instruments tantamount to tariffs on embodied GHG emissions. Elsewhere, French President Sarkozy has voiced that the EU should impose additional tariffs on imports from countries that do not restrict GHG emissions, a proposal that has be criticized by the EU’s Environmental Commissioner but has reportedly been supported by a number of EU member states (ICTSD, 2009a).

Opposing the view of the U.S. and the EU, countries that do not plan near-term GHG reductions, particularly India and China, have voiced concerns about GHG border measures. At informal climate talks in Bonn, Germany in August 2009, Indian officials put forth a resolution that developed countries shall not resort to any form of countervailing border measures against imports from developing countries (ICTSD, 2009b). If BCAs eventuate, Columbia Economist Jagdish Bhagwati claims that they will lead to massive, justified, WTO-legal retaliation by India and China (Hale, 2009). President Obama is wary of such concerns and has criticized the Bill’s provision for BCAs (Broder, 2009).

Tariffs imposed by nations that restrict GHG emissions (the climate coalition) on imports from regions that do not control emissions (the non-coalition) have been evaluated by a series of computable general equilibrium (CGE) studies.[1] In this literature, BCAs have mixed leakage impacts while there is broad agreement that tariffs will significantly reduce welfare and will be ineffective at addressing competitive concerns.[2] We contribute to the debate by evaluating the economic impacts of BCAs on embodied GHG emissions using the MIT Emissions Prediction and Policy Analysis (EPPA) model, a CGE model tailored to evaluate climate policy questions. We analyze tariffs in the context of a scenario representative of a post-Kyoto climate agreement and the special features of tariff provisions in H.R. 2454. Our study further builds on previous work by evaluating the efficiency of tariffs relative to direct leakage controls, and assessing the relative leakage contributions of trade and the decline in the oil price induced by GHG restrictions.

Section 2 of this paper details provisions for BCAs in H.R. 2454 and discusses international trade rules surrounding these measures. Our modeling framework is detailed in Section 3 and results are discussed in Section 4. Alternative leakage controls are analyzed in Section 5. Section 6 concludes.

2. BCA LEGISLATION

The International Reserve Allowance Program in H.R. 2454 requires importers of covered goods in "eligible industrial sectors" to purchase emission allowances related to the amount of GHG emissions embodied in imported products. Eligible industrial sectors are defined using three concepts: energy intensity, GHG intensity and trade intensity. Energy intensity in H.R. 2454 is calculated by dividing the cost of purchased electricity and fuel costs by the value of output. GHG intensity is determined by multiplying the number of tons of carbon dioxide equivalent emissions from fuel combustion, processing and electricity by 20 and then dividing by the value of output. Trade intensity is defined as the sum of the value of imports and exports divided by the sum of the value of output and the value of imports.

A sector is eligible for the program if it has (i) an energy intensity or a GHG intensity greater than 5%, and a trade intensity greater than 15%, or (ii) an energy intensity or a GHG intensity greater than 20%. Several restrictions circumvent these rules. First, a sector is excluded if 85% or more of U.S. imports in that sector are produced in countries that either have economy-wide GHG reduction programs at least as stringent as in the U.S. as part of an international agreement, or have equal or lower energy or GHG intensities than the U.S. Second, imports sourced from nations responsible for less than 0.5% of global GHG emissions and accounting for less than 5% of U.S. imports in the sector in question are exempt. Third, products from the least-developed nations and refined petroleum products are excluded.

H.R. 2454 requires that the price for international reserve allowances equals the clearing price from the most recent auction of allowances, but does not specify how the GHG content of

[1] See, for example, Babiker and Rutherford (2005), Droge and Kemfret (2005), Peterson and Schleich (2007), Burniux *et al.* (2008), Alexeeva-Talebi *et al.* (2008), and Mckibbon and Wilcoxen (2009).

[2] BCAs are also investigated in partial equilibrium analyses. See, for example, Gielen and Moriguchi (2002), Demailly and Quirion (2008), and Ponsand and Walker (2008).

imports will be calculated. Instead, the Bill requires the administrator to establish "a general methodology for calculating the quantity of international reserve allowances that a U.S. importer of any covered good must submit" (U.S. Congress, 2009a, p. 1123). The administrator must also adjust the number of international emission allowances per unit imported to account for the benefits to eligible industrial sectors from emission allowance rebates and the provision of free allowances to electricity.

One issue is whether the trade provisions of H.R. 2454 are legal under WTO rules and this may depend on how they are classified relative to existing trade-related measures. The extra import charges called for by H.R. 2454 could be branded punitive tariffs, countervailing duties (imposed on the basis that unregulated GHG emissions in foreign countries are illegal subsidies) or BTAs (additional taxes on imports to offset differences in tax structures across countries). A number of studies examine whether BCAs are consistent with rules governing international trade set out by the WTO[3]. The consensus in this literature is that punitive tariffs violate tariff concession rules specified in the General Agreement on Tariffs and Trade (GATT); countervailing duties violate both GATT rules and the WTO's Subsidies and Countervailing Measures agreement; but BTAs may be possible under WTO law. In this connection, a joint report by the WTO and the United Nations Environment Programme (UNEP) (WTO-UNEP, 2009, p. 89) notes that "the general approach under WTO rules has been to acknowledge that some degree of trade restriction may be necessary to achieve certain policy objectives, as long as a number of carefully crafted conditions are respected."

GATT Article II.2(a) details rules governing BTAs on imports, allowing countries to impose a charge equivalent to an internal tax on imports under certain conditions. Indirect taxes (taxes on products such as sales taxes) are eligible for adjustment but direct taxes (levies on producers such as payroll taxes) are not, so a key issue is whether taxes on inputs such as energy are indirect taxes. Article II.2(a) also stipulates that BTAs on imports are only allowed (i) in respect to *articles* from which the imported product has been produced, and (ii) against taxes imposed on "like" domestic products (GATT, 1986, p. 4). Some authors conclude that the wording of (i) restricts the use of BTAs to inputs physically incorporated in the final product, which would exclude emissions charges. However, others argue that (ii) allows BTAs to be used to offset taxes on inputs used during the production process (i.e., applied indirectly on products), which provides scope for WTO-legal BTAs for GHG emissions.

Two historical cases are directly relevant for BCAs. First, in *U.S.-Taxes on Petroleum and Certain Imported Substances* (the *Superfund* case) a GATT dispute settlement panel allowed BTAs on chemicals contained in imported petroleum products. However, the panel did not specifically state that the substance had to be physically present in the final product (Neumayer, 2001). Second, in the late 1980s, the U.S. introduced a tax on ozone-depleting chemicals (ODCs)

[3] See, for example, Bhagwati and Mavroidis (2007), Bordoff (2009), Biermann and Brohm (2005), Frankel (2009), Goh (2004), Green and Epps (2008), Hoerner (1998), Brewer (2008), Pauwelyn (2007), Ismer and Neuhoff (2007), and WTO-UNEP (2009).

in order to implement the Montreal Protocol on Substances that Deplete the Ozone Layer. The tariff was applied to both ODCs and products containing or produced using these chemicals, but the legality of such measures is uncertain as the tariffs were never challenged under WTO rules (Brack *et al.*, 2000).

GATT Article XX, which details general exceptions, provides another avenue to argue for BCAs. Two relevant exceptions include Article XX(b) and Article XX(g). Article XX(b) allows import restrictions that violate trade rules to be applied if they are necessary to protect human, animal or plant life or health, and Article XX(g) relates to the conservation of exhaustible natural resources.[4] The process for determining the legality of GHG border measures is that, once implemented, countries "harmed" by the measures would need to lodge a complaint with the WTO, which would result in a ruling by the Dispute Settlement Body. In the absence of such a judgment, in remaining sections, we set aside legal issues and assume that BCAs are allowable under one or more of the above categories.

3. MODELING FRAMEWORK

We assess the economic and leakage impacts of BCAs using version four of the MIT EPPA model. EPPA is described in detailed by Paltsev *et al.* (2005) and we outline the core features of the model below. EPPA is a multi-regional, CGE model of the global economy that links GHG emissions to economic activity, and is solved through time in recursive dynamic fashion in five-year increments. There is a single representative utility maximizing agent in each region that derives income from factor payments and emissions permits and allocates expenditure across goods and investment. There is also a government sector in each region that collects revenue from taxes and purchases goods and services. Government deficits and surpluses are passed to consumers as lump sum transfers.

As illustrated in **Table 1**, EPPA recognizes Agriculture, five energy sectors (Coal, Crude oil, Refined oil, Gas and Electricity), two manufacturing sectors (Energy intensive industry and Other industry), Transportation and Services. Each good is produced by perfectly competitive firms that assemble primary factors and intermediate inputs. All goods are traded internationally and, following Armington (1969), goods are differentiated by region of origin using a constant elasticity of substitution function, except for Crude oil (which is treated as a homogenous commodity). Alternative electricity generation technologies in EPPA enhance abatement options. Electricity can be produced using conventional technologies (e.g., electricity from coal and gas) and technologies not currently in use but which may become profitable as the emissions price rises (e.g., large scale wind generation and electricity from coal or gas with carbon capture and storage). As also indicated in Table 1, primary inputs include three non-energy resources and seven energy resources. Capital and labor are free to move between sectors and land is specific to agriculture. Each energy resource is sector specific. Crude and shale oil resources are perfect

[4] See Buck and Verheyen (2001) and Heinzerling (2007) for a discussion of legal issues associated with BCAs under Article XX.

substitutes in the oil sector, and the hydro, nuclear and wind & solar resources are specific to electricity generation technologies.

Table 1. EPPA aggregation.

Regions	Sectors	Primary inputs
Annex 1	Agriculture (AGRI)	*Non-energy resources*
United States (U.S.A)	Coal (COAL)	Capital
Canada (CAN)	Oil (OIL)	Labor
Japan (JPN)	Refined oil (ROIL)	Land
Australia-New Zealand (ANZ)	Gas (GAS)	
European Union[a] (EUR)	Electricity (ELEC)	*Energy resources*
Eastern Europe[b] (EET)	Energy intensive industry (EINT)	Crude oil
Former Soviet Union[c] (FSU)	Other industry (OTHR)	Shale oil
	Services (SERV)	Natural Gas
Non-Annex 1	Transportation (TRAN)	Coal
Mexico (MEX)		Hydro
Higher Income East Asia[d] (ASI)		Nuclear
China (CHN)		Wind & Solar
India (IND)		
Indonesia (IDZ)		
Africa (AFR)		
Middle East (MES)		
Central & South America (LAM)		
Rest of World[e] (ROW)		

[a]The EU-15 plus countries of the European Free Trade Area (Norway, Switzerland & Iceland); [b]Hungury, Poland, Bulgaria, Czech Republic, Romania, Slovakia & Slovenia; [c]Russia, Ukraine, Latvia, Lithuania, Estonia, Azerbaijan, Armenia, Belarus, Georgia, Kyrgyzstan, Kazakhstan, Moldova, Tajikistan, Turkmenistan & Uzbekistan; [d]South Korea, Malaysia, Philippines, Singapore, Taiwan & Thailand.

EPPA tracks the use of energy commodities (Coal, Refined oil and Gas) used in each sector measured in exajoules. These data combined with emissions per-exajoule coefficients for each energy commodity allow the model to predict (CO_2) emissions. EPPA also traces non-CO_2 GHGs (e.g., methane, and nitrous oxide) measured in CO_2 equivalent (CO_2-e) units using global warming potential (GWP) weights. GWP weights measure the ability of non-CO_2 gases to trap heat in the atmosphere relative to the heat-trapping capability of CO_2 over a 100 year period. When GHG emissions are restricted, the model calculates a shadow value associated with the emission constraint, which is analogous to an emission price that would develop under a cap-and-trade program. The model is calibrated using economic data from the Global Trade Analysis Project (GTAP) database (Dimaranan, 2006) and energy balance data from the International Energy Agency (IEA).

3.1 Embodied GHGs and BCAs

As noted above, H.R. 2454 does not set out how embodied GHG emissions will be calculated. Following Rutherford and Babiker (1997), we use a comprehensive approach where total GHG emissions embodied in each commodity are the sum of direct and indirect emissions.[5] Direct emissions are immediately linked with production, such as the combustion of fossil fuels to produce energy. Indirect emissions are associated with production of products used as intermediate inputs. For example, total emissions for automobiles equal emissions from the consumption of energy used in automobile manufacturing plus emissions associated with the production of steel and other intermediate inputs. Our calculations employ equation (1):

$$X= AX + D \tag{1}$$

where X is an $N\times1$ vector of total emissions per dollar for each of the N commodities; A is an $N\times N$ matrix, the ij^{th} element of which is the number of dollars of good i used per dollar of good j being produced; and D is an $N\times1$ vector of sectoral direct emissions coefficients per dollar of output.

Assuming that imported intermediate inputs embody the same quantities of GHG emissions as intermediate inputs sourced domestically, total embodied GHG emissions are computed by solving (1) for X:

$$X= (I-X)^{-1}D \tag{2}$$

BCAs are determined by embodied GHG emissions, calculated using equation (2), and carbon prices. For each applicable trade flow, we select an ad valorem tariff on imports of sector i from region s to r, $\tau_{i,s,r}$, so as to increase the price of imports from s by the additional costs incurred by region s producers if they faced the carbon price in r. That is, τ_s is determined simultaneously with the carbon price so that:

$$\tau_{i,s,r}p_{i,s} = pcarb_r x_{i,s} \tag{3}$$

where $p_{i,s,r}$ is the price of sector i in region s, $pcarb_r$ is the CO_2-e price in region r, and $x_{i,s}$ is per-dollar emissions embodied in production of i in s.

Embodied GHG calculations and BCA assignments are updated at the end of each modeling period but we do not adjust BCAs to account for the distribution of emission allowances specified in H.R. 2454, as such allowances are lump-sum transfers and will not influence firm behavior in our model.

3.2 BCA Scenarios

Yardsticks for BCA simulations are provided by business as usual (BAU) and cap-and-trade (CAT) scenarios, which we source from EPPA's evaluation of the Energy Modeling Forum's Climate Change Control Scenario described in Paltsev *et al.* (2009). In BAU, population and labor productivity advance at predetermined rates and there are no GHG restrictions, but autonomous improvements in energy efficiency and responses to rising energy prices as resources deplete lead to GHG emissions growing at a slower rate than GDP. The CAT scenario used in Paltsev *et al.* (2009) gradually reduces U.S. GHG emissions to 80% below 2000

[5] We focus on the impact of BCAs that accurately target embodied GHG emissions and ignore monitoring costs. If monitoring costs are high, broad-brush trade measures may be preferred to targeted instruments (Engle, 2004).

emissions between 2015 and 2050, progressively reduces emissions in other Annex 1 regions except the Former Soviet Union (FSU) to 50% below 1990 levels between 2010 and 2050, and restricts emission in the FSU, China, India and Central and South America beginning in 2030. As it is unlikely that BCAs will be imposed after regions such as China and India begin to price emissions and EPPA has a five-year time step, we focus on the period prior to 2030 when only Annex 1 regions, excluding the FSU, implement climate policy. For ease of reference, we refer to this group as the "coalition" of nations implementing climate policy. In the period we analyze, emission allowances in the CAT scenario for each coalition region in each period match those in Paltsev *et al.* (2009). By 2025, relative to 2000, the U.S. reduces emissions by 31% and other coalition regions curtail emissions by between 18% and 35%. For simplicity, we do not allow banking of emission allowances over time.[6]

Although H.R. 2454 proposes BCAs on imports from regions where GHGs are not taxed with exemptions for some regions, we consider tariffs on imports from all non-coalition regions to simplify the analysis. Also, due to EPPA's coarse sectoral aggregation, no sector in our model meets eligibility criteria for BCAs set out in H.R. 2454. However, the Bill's BCA provisions are clearly aimed at manufactured products, or a subset of these commodities, so we consider BCAs for this sector, where manufacturing is defined as Energy intensive industry and Other industry. To gauge the impact of the sectoral selectivity of BCAs in H.R. 2454, we also simulate tariffs on imports from non-coalition nations for all sectors. Leakage and competitive concerns also exist elsewhere, so in other simulations we consider BCAs imposed by all coalition regions, both on all sectors and manufacturing independently. That is, we analyze four BCA scenarios where, in addition to emission restrictions outlined in CAT, tariffs are imposed on imports from non-coalition regions: U.S. tariffs on all sectors (U.S.-ALL), coalition tariffs on all sectors (CLT-ALL), U.S. tariffs on manufacturing (U.S.-MNF), and coalition tariffs on manufacturing (CLT-MNF).

4. MODELING RESULTS

We focus on results for 2025 as BCAs are largest in this year. To understand what is driving our results, **Table 2** presents total embodied GHG emissions by sector and region in 2025 calculated using equation (2). Emissions are reported in millions of metric tons (Mt) of CO_2-e per U.S. billion dollars of output. Electricity produces significantly more GHG emissions per dollar of output than other sectors in most regions. Electricity GHG emissions per dollar are highest in China, where 34.4 Mt CO_2-e are released per billion dollars of output. Emissions per dollar are also relatively high in Agriculture and Energy intensive industry. The numbers in Table 2 do not distinguish between gases, but unreported calculations reveal that agriculture emissions are largely non-CO_2 gases while emissions from Energy intensive industry are predominantly CO_2. Embodied emissions are also relatively high in Other industry, especially in non-coalition regions.

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[6] Note that these carbon constraints are more stringent than those in the H.R. 2454 because there are no credits from outside the capped sectors in the Energy Modeling Forum scenario.

Comparing carbon emissions across countries indicates that production in China and the FSU is relatively emission intensive and, in general, emissions per dollar are higher in non-coalition regions than coalition regions. However, care should be taken when making cross-country comparisons as the commodity composition of sectors may vary across regions and the number of physical units included in billion dollar bundles depends on the purchasing power of the U.S. dollar relative to local currencies. Nevertheless, emissions per dollar coefficients in Table 2 are appropriate for calculating BCAs. For example, if agriculture production in a region is concentrated in GHG intensive commodities, exports from this region will produce more emissions than exports from a region that specializes in agriculture commodities that are less GHG intensive. Additionally, other factors constant, if a billion dollars buys twice as many units in region A as region B, one billion dollars of imports from A will embody twice the amount of emissions as imports from B.

Table 2. Embodied GHG emissions (CO_2-e millions Mt per billion dollars), 2025.

	AGRI	COAL	OIL	ROIL	GAS	ELEC	EINT	OTHR	SERV	TRAN
USA	0.4	0.2	0.2	1.0	0.2	4.6	0.7	0.2	0.1	0.9
CAN	0.7	0.2	0.2	1.1	0.1	3.2	0.8	0.3	0.2	0.5
MEX	0.1	0.1	-	0.8	0.0	1.8	0.5	0.2	0.1	0.3
JPN	2.2	0.2	0.2	0.9	0.2	8.0	1.1	0.5	0.3	0.8
ANZ	0.5	0.3	0.1	1.2	0.1	4.1	0.5	0.2	0.1	0.5
EUR	1.8	1.0	0.2	1.7	0.4	13.2	2.8	1.4	0.8	1.3
EET	1.9	-	0.3	2.4	0.2	14.6	2.6	1.2	0.3	1.4
FSU	8.5	6.2	0.8	2.1	0.6	24.7	6.0	3.0	1.5	2.5
ASI	5.4	1.4	0.4	1.3	0.4	7.0	2.6	1.4	0.6	2.0
CHN	4.0	11.6	0.8	2.8	0.7	31.8	4.6	2.5	1.6	1.9
IND	4.6	3.2	0.8	2.2	0.9	15.8	4.9	2.7	1.0	2.5
IDZ	3.8	0.9	0.2	1.2	0.3	12.9	4.8	1.8	0.7	1.8
AFR	5.1	2.2	1.1	2.1	1.3	14.4	5.1	2.6	1.5	2.5
MES	6.5	-	0.8	1.7	0.6	12.1	4.6	2.5	1.5	3.8
LAM	4.5	1.9	0.5	1.4	0.4	6.0	1.7	1.3	0.4	1.6
ROW	4.3	13.3	0.9	2.3	0.5	13.8	3.9	2.0	0.8	1.4

4.1 Welfare changes

To focus our discussion, proportional welfare changes relative to BAU, measured as equivalent variation changes in consumption, for the U.S., the coalition (both including and excluding the U.S.), the non-coalition and the world are reported in **Table 3** (and welfare changes for each EPPA region are reported in the appendix, **Table A1**).[7] In the CAT scenario (no BCAs), U.S. welfare falls by 1.16% and aggregate coalition welfare declines by 0.92%. Non-coalition welfare declines by 0.23%, although welfare increases in some non-coalition regions (see Table A1). The largest gainers from coalition climate change policies are intensive exporters of manufacturing products that do not have to pay for GHG emissions, such as China, India and

[7] Welfare changes for composite regions (the coalition, the non-coalition and the world) are GDP-weighted averages of the welfare changes in Table A2. As we do not specify a welfare function to calculate welfare changes for composite regions, figures for composite regions should be interpreted as indicative welfare changes.

Higher Income East Asia. On the other hand, welfare for the Middle East falls by 2.79% due to the decrease in the price of Crude oil, which is also reported in Table 3. In aggregate, global welfare falls by 0.70%. Although results are expressed relative to BAU for all scenarios, unless otherwise stated, welfare changes for remaining simulations are discussed relative to the CAT scenario. Table 3 also reports the U.S. CO_2-e price, which is around $86/Mt CO_2-e in the CAT scenario.

Table 3. Changes in welfare and the price of crude oil relative to BAU (%), and U.S. CO_2-e price, 2025.

	CAT	US-ALL	CLT-ALL	US-MNF	CLT-MNF	OILTAX
Welfare (EV, %):						
USA	-1.16	-1.27	-1.15	-1.26	-1.17	-1.21
Coalition (U.S. included)	-0.92	-0.88	-0.79	-0.90	-0.85	-1.02
Coalition (U.S. excluded)	-0.75	-0.60	-0.53	-0.64	-0.62	-0.89
Non-coalition	-0.23	-0.89	-1.41	-0.74	-1.07	-0.29
World	-0.70	-0.88	-0.98	-0.85	-0.92	-0.79
U.S. CO_2-e price ($/ton)	86.6	86.2	86.3	86.5	86.6	86.1
Crude oil price (%)	-6.2	-11.3	-13.1	-10.1	-11.1	0.0

BCAs influence welfare in three ways. First, as is well known, tariffs create production and consumption inefficiencies. Second, tariffs improve market access for coalition exporters at the expense of non-coalition firms. Third, tariffs generate terms of trade effects, which are considerable when commodities are differentiated by country of origin (Brown, 1987). In the U.S.-ALL simulation, U.S. welfare decreases due to efficiency losses. BCAs also induce a substitution in U.S. purchases towards goods shipped from coalition regions, resulting in a welfare improvement in the coalition and a welfare loss in the non-coalition. Welfare losses are largest in Mexico, Higher Income East Asia and China, all of which export large quantities of goods to the U.S. There is also a large fall in welfare in the Middle East, which is driven by a further decline in the price of Crude oil.

When the coalition imposes tariffs on all products, CLT-ALL, market access and terms of trade gains outweigh efficiency losses in the coalition so welfare for the coalition increases (from -0.92 in the CAT scenario to -0.79). Welfare in the non-coalition falls (from -0.23% in the CAT scenario to –1.41%) and, as in U.S.-ALL, the largest losers are Mexico, Higher Income East Asia, China and the Middle East. It is also interesting to compare welfare changes for the CLT-ALL and U.S.-ALL scenarios. First, U.S. welfare improves when the coalition imposes tariffs relative to when only the U.S. levies tariffs due to market access effects. Second, the numbers reveal that nearly all of the decrease in welfare in Mexico and about two-thirds of that for China is brought about by U.S. BCAs.

Welfare impacts for the U.S.-MNF scenario are qualitatively similar to those for U.S.-ALL, but are smaller in magnitude. That is, BCAs reduce welfare in the U.S. and non-coalition regions and increase welfare in other coalition regions, but by relatively small amounts. In the CLT-MNF scenario, coalition manufacturing tariffs raise welfare in some coalition regions and reduce welfare in non-coalition regions, as in CLT-ALL, and the largest losers are Mexico, Higher Income East Asia, China, the FSU, and the Middle East. The results also indicate that BCAs have little impact on the U.S. CO_2-e price.

4.2 Output changes

Output changes relative to CAT outcomes are presented in **Table 4**. In each sector, producers respond to changes in tariff-inclusive import prices. Tariffs imposed by the U.S. in U.S.-ALL are reported in **Table A2**.[8] In addition to displaying U.S. tariffs on imports from each non-coalition region, the table presents value-weighted U.S. tariffs on imports from the non-coalition group and on imports from all regions (where BCAs on imports from coalition regions are zero). The all-region value-weighted energy intensive tariff is only 4.4% despite large tariffs on Energy intensive industry imports from the non-coalition, as 90% of U.S. imports of this commodity are sourced from other coalition regions (and do not attract BCAs). In contrast, the share of coalition commodities sourced from the non-coalition in U.S. imports of Agriculture, Other industry and Services is 44%, 62% and 57% respectively. As a result, Agriculture attracts the largest value-weighted tariff (19.7%) and value-weighted tariffs for Other industry, Services and Transportation are higher than that for Energy intensive industry. Consequently, U.S. energy intensive output falls and Agriculture production expands in the U.S.-ALL scenario.[9] These results indicate that U.S. BCAs on all products will not be successful in addressing competiveness concerns. However, in CLT-ALL, there is a small increase (0.17%) in U.S. energy intensive production as coalition regions substitute away from non-coalition varieties. If BCAs are only included for manufacturing, as in the U.S.-MNF and CLT-MNF scenarios, Agriculture output decreases, while manufacturing output rises relative to the CAT scenario (by 0.64% for energy-intensive products and 0.60% for Other industry in the U.S.-MNF scenario). Not reported in the table, we also consider scenarios where BCAs are only imposed on energy intensive sectors. As expected, energy intensive output increases by more in these scenarios relative to when BCAs are applied to manufacturing (by 1.8% in the U.S.-only scenario and 2.3% in the coalition scenario). By comparison, energy intensive output falls by 3.6% (not reported in Table 4) in the CAT scenario.

Table 4 also reports production changes in the coalition (excluding the U.S.) and the non-coalition. In the coalition, production changes are a function of tariff-induced import price changes and markets access effects so, relative to other sectors, Agriculture expands by the most when tariffs are applied to all sectors and energy intensive production increases by the largest proportion in the two MNF scenarios. In the non-coalition, in U.S.-ALL there is only a small decrease (0.06%) in energy intensive production. This is because the tariff-induced decrease in U.S. demand is partially offset by increased use of non-coalition energy intensive goods as inputs

[8] As tariffs for other scenarios depend on sectoral GHG emissions and coalition carbon prices, which are similar in all simulations, we do not report carbon tariffs for other scenarios.

[9] In this scenario, as expected, unreported calculations show that domestic consumption of U.S. energy intensive commodities increases (by 1.4%) but, as U.S. exporters face greater competition from non-coalition producers and increased production costs, U.S. energy intensive exports fall by 11.1%.

to energy intensive and Other industry production in coalition regions, which expand exports to the U.S. Other non-coalition output changes are less complicated: in both the U.S.-ALL and CLT-ALL scenarios, the largest proportional sectoral production decline is for Agriculture, which faces high tariffs; and in the two MNF scenarios there are large reductions in energy intensive and other manufacturing production.

Table 4. Output volume changes relative to the CAT scenario, %, 2025.

	U.S.-ALL	CLT-ALL	U.S.-MNF	CLT-MNF
(a) U.S.A				
Agriculture	1.81	1.79	-1.31	-1.71
Coal	-2.79	-3.24	-2.00	-2.65
Oil	-0.58	-1.66	-1.58	-2.17
Refined oil	-1.23	-0.91	-0.39	-0.37
Gas	-0.37	-0.87	-0.54	-0.80
Electricity	-0.09	0.00	-0.03	0.07
Energy int. industry	-0.13	0.17	0.64	1.11
Other industry	-0.11	-0.18	0.60	0.71
Services	-0.20	-0.21	-0.35	-0.39
Transportation	-1.32	-1.37	-2.40	-3.02
(b) Coalition (excluding the U.S.)				
Agriculture	0.49	1.21	-0.58	-1.01
Coal	-2.16	-3.16	-1.48	-2.95
Oil	-1.27	-2.48	-1.41	-2.15
Refined oil	-0.32	-0.25	-0.25	-0.35
Gas	-0.50	-1.28	-0.53	-1.09
Electricity	-0.05	-0.05	0.02	0.08
Energy int. industry	0.09	0.20	0.46	1.01
Other industry	0.07	-0.15	0.40	0.54
Services	-0.09	-0.11	-0.17	-0.27
Transportation	-0.75	-1.03	-1.39	-2.33
(c) Non-coalition				
Agriculture	-0.33	-0.81	-0.58	-0.15
Coal	0.56	0.42	-0.10	0.30
Oil	0.06	0.21	0.25	0.21
Refined oil	-0.32	-0.25	0.13	-0.35
Gas	0.03	-0.10	-0.25	-0.17
Electricity	-0.34	-0.72	-0.05	-0.76
Energy int. industry	-0.06	-0.17	-0.39	-1.36
Other industry	-0.40	-0.33	-0.60	-1.19
Services	0.05	-0.02	-0.79	0.66
Transportation	-0.14	-0.73	0.38	1.64

4.3 Leakage

GHG emissions and the leakage rate, calculated as the increase in non-coalition emissions divided by the decrease in coalition emissions, both relative to BAU, are reported in **Table 5**. The leakage rate is 10.1% in the CAT scenario, indicating that non-coalition emissions increase by about ten CO_2-e tons for every 100 CO_2-e tons of emissions abated in the coalition. The leakage rate is 7.1%, about one-third lower, when the U.S. imposes BCAs on all sectors. In CLT-

ALL, leakage is 3.8%, around 60% lower than in the CAT scenario. Leakage rates for U.S.-MNF (7.0%) and CLT-MNF (4.2%) are similar to those for the corresponding scenarios when BCAs are applied to all sectors. We also calculate leakage rates when BCAs are applied only on energy-intensive sectors (not reported in Table 5). In these scenarios, leakage is 7.9% in the U.S-only case and 5.8% in the coalition scenario, which indicates that around 70% of tariff-induced leakage reductions result from tariffs on energy-intensive products. The leakage calculations also suggest that around one-half of the leakage reduction brought about by BCAs result from U.S. border measures.

Table 5. CO_2-e GHG emissions (100 million Mt) and leakage, 2025.

	BAU	CAT	U.S.-ALL	CLT-ALL	U.S.-MNF	CLT-MNF	OILTAX
Coalition	164.8	113.0	113.0	113.0	113.0	113.0	113.0
Non-coalition	393.5	398.7	397.2	395.5	397.2	395.7	395.7
Leakage (%)	-	10.1	7.1	3.8	7.0	4.2	4.3

Although BCAs reduce leakage by up to 60%, the numbers mask small changes in global emissions. As displayed in Table 5, the coalition's contribution to global emission is 22% and the non-coalition's is 78% in the CAT scenario, so leakage calculations are sensitive to small proportional changes in non-coalition emissions. As a result, the 60% leakage reduction in CLT-ALL – the largest tariff-induced leakage reduction – corresponds to a 0.8% fall in non-coalition emissions and only a 0.6% decrease in global emissions. When combined with the welfare changes reported in Table 3, the leakage calculations indicate that reducing emissions via BCAs is nearly six times as costly as using direct controls. In the CAT scenario, global emissions fall by 4.7 billion tons and global welfare declines by 0.7%, resulting in a welfare reduction of 0.15% per billion tons of abatement. The corresponding number for CLT-ALL is 0.88%.

5. ALTERNATIVE LEAKAGE CONTROLS

At least two other policy measures can be used to address leakage concerns. First, Burniaux *et al.* (2008), Fisher and Fox (2009) and McKibbin and Wilcoxen (2009) claim that the most important source of leakage arises from reductions in the global oil price induced by coalition GHG restrictions, which raise oil-intensive consumption in regions with no GHG controls. Accordingly, in a another scenario (OILTAX), we impose an endogenous tax on Crude oil production, applied uniformly across regions, so that the tax-inclusive Crude oil price is the same as in BAU. Such a tax is an unlikely outcome from climate negotiations but could represent oil producers exercising monopoly power to stabilize the world oil price. Second, direct controls (cap-and-trade system and/or energy efficiency mandates in non-coalition regions) can also reduce leakage. Here one might view the threat of BCAs as a way for the climate coalition to coerce other nations to restrict GHG emissions.[10] To investigate this alternative, instead of BCAs, we impose cap-and-trade programs in non-coalition regions in addition to carbon

[10] Alternatively, unilateral emissions reductions by the coalition may create self-interested emission reductions by the non-coalition (Copeland and Taylor, 2005).

restrictions in the CAT scenario. The emission cap for each non-coalition region in this scenarios is set at emissions observed in the CLT-ALL scenario. In another simulation, we use cap-and-trade systems to determine non-coalition carbon prices that eliminate leakage by returning emissions in each non-coalition region to emissions in BAU.

In our OILTAX simulation, a global tax on Crude oil production of 11.3% is required to equate the tax inclusive Crude oil price in the CAT scenario to that for BAU. As indicated in Table 3, aggregate welfare for the coalition when there is an oil tax is lower than in all of the BCA scenarios. This is because the terms of trade for the coalition (which is a net-importer of oil) improves as a result of BCAs but declines when there is an oil tax. The opposite is true for the non-coalition (which is a net-exporter of oil). Interestingly, the OILTAX leakage rate (4.3%) is higher than the CTL-ALL leakage rate (3.8%). That is, trade measures appear to be as effective at reducing leakage as oil price controls. This finding concurs with and Rutherford (1993) but refutes recent conjectures that, "in practice, the most important source of mechanism through which leakage could occur would be world oil markets, not trade in manufactured goods" (McKibbin and Wilcoxen, 2009, p. 3).

When we apply cap-and-trade policies in the non-coalition, emissions are reduced to levels in the CTL-ALL scenario by CO_2-e prices less than \$0.01 per ton in the non-coalition (except Mexico, where the CO_2-e price is \$0.29) and welfare changes are very small.[11] Indeed, proportional welfare changes are only distinguishable from CAT values at very high levels of precision, so we do not report welfare changes when cap-and trade programs are imposed on the non-coalition. Furthermore, eliminating leakage by non-coalition cap-and trade policies requires CO_2-e prices less than \$0.01 per ton in all non-coalition regions except in Mexico (\$0.48) and the FSU (\$0.02), which also have minor welfare effects. It is likely that near-term non-coalition cap-and-trade policies are infeasible, either because the non-coalition refuses to bind emissions and/or because tiny carbon prices render such systems impractical, so efficiency improvements may be a more feasible way of reducing emissions. In this connection, BCAs reduce Chinese emissions by 3.7 million tons in the CLT-ALL scenario so, assuming replacing a standard light bulb with a compact fluorescent light (CFL) bulb saves 100 kilograms of CO_2-e emissions per year, Chinese leakage could be offset by the same amount if one in ten of China's 360 million households installing a single CFL bulb.

6. CONCLUSIONS

We evaluated the potential for BCAs to reduce leakage using an economy-wide model focusing on 2025. We found that BCAs reduce leakage by around 30% when imposed by the U.S. and about 60% when levied by all coalition countries. However, as the non-coalition accounts for more than three-quarters of global emissions, large proportional leakage changes

[11] Small non-coalition carbon prices reflect low initial emissions reduction costs in this region. As shown by Carbone *et al.* (2009), cheap abatement opportunities in developing countries provide scope for international trade in emissions permits even in the absence of a global cooperative agreement.

mask small changes in emissions – when leakage fell by 60%, non-coalition emissions fell by 0.8% and global emissions declined by only 0.6%.

Although BCAs have small emission impacts, they have pronounced welfare effects. When the coalition imposed BCAs on all products, the change in coalition welfare improved from -0.75% in the CAT scenario to -0.53%, but the change in non-coalition welfare deteriorated from -0.23% to -1.41%. The net result was a worsening in world welfare from -0.70% in the CAT scenario to -0.98% (for an almost negligible reduction in global emissions). As an alternative to BCAs, we considered pricing non-coalition GHG emissions so that, in each region, emission levels equaled those observed when BCAs are employed. CO_2-e prices that achieve this objective were around one-tenth of one cent in nearly all regions and had negligible welfare effects. Cap-and-trade programs with such small carbon prices may not be viable, so the adoption of modest energy efficiency improvements in the non-coalition may be a more practical solution.

These findings suggest that non-coalition regions may wish to adopt emissions controls as part of a global agreement, providing such measures prevent the coalition from adopting BCAs. China recently announced plans to reduce its 2020 GHG emissions to GDP ratio by 45% relative to 2005 through GHG efficiency improvements, so an agreement binding China to this goal (or a slightly more ambitious target) may be a viable alternative to BCAs. However, as leakage reductions achieved by modest non-coalition controls will still leave coalition producers at a cost disadvantage relative to imports from the non-coalition, it remains to be seen whether coalition politicians will be willing to strike out BCAs.

Regarding competiveness concerns, BCAs applied to all sectors will not necessarily increase energy intensive output. This is because, relative to other sectors, a high proportion of coalition energy intensive imports are sourced from other coalition regions and do not attract BCAs. Consequently, the energy intensive tariff value-weighted across sources is lower than value-weighted tariffs for some other sectors. However, BCAs applied only to manufacturing raise domestic manufacturing output but do not fully offset the impact of domestic carbon restrictions. If the U.S. acts unilaterally, BCAs are detrimental to U.S. exports and increase the cost of climate policy.

We also evaluated the conjecture that trade in goods is a minor leakage source compared to the oil-price channel. Contrary to conventional wisdom, we found that comprehensive coalition BCAs reduced leakage to a greater extent than measures that offset the decrease in the price of Crude oil caused by coalition emissions restrictions. Nevertheless, we do not recommend using BCAs to address leakage concerns. Instead, we conclude that although the political landscape in the U.S. and other Annex 1 nations may call for BCAs to control leakage and address competitiveness concerns, BCAs are imprecise instruments that, even when finely tuned to target embodied GHG emissions, cause much collateral damage.

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APPENDIX

Table A1. Welfare changes relative to BAU (%), 2025

	CAT	U.S.-ALL	CLT-ALL	U.S.-MNF	CLT-MNF	OILTAX
U.S.	-1.16	-1.27	-1.15	-1.26	-1.17	-1.21
Canada	-4.40	-3.92	-4.30	-3.90	-4.25	-4.14
Japan	-0.07	0.06	0.15	0.05	0.10	-0.20
Australia-New Zealand	-2.08	-2.03	-2.22	-2.07	-2.32	-2.10
Europe Union	-0.60	-0.46	-0.35	-0.51	-0.47	-0.77
Eastern Europe	-0.96	-0.79	-0.43	-0.89	-0.61	-1.34
Mexico	-0.36	-1.77	-1.98	-1.57	-1.71	-0.32
Former Soviet Union	-0.58	-0.91	-1.52	-0.79	-1.19	-0.30
Higher Income E. Asia	0.18	-0.75	-1.28	-0.65	-1.04	-0.32
China	0.10	-0.90	-1.59	-0.73	-1.24	-0.22
India	0.60	0.15	-0.28	0.16	-0.19	-0.07
Indonesia	-0.24	-0.77	-1.20	-0.62	-0.89	-0.25
Africa	-1.16	-1.59	-2.42	-1.31	-1.67	-0.53
Middle East	-2.79	-3.60	-4.36	-3.25	-3.60	-0.95
Latin America	-0.27	-0.64	-0.86	-0.48	-0.57	-0.24
Rest of World	0.39	0.17	-0.26	0.26	-0.02	-0.10

Table A2. U.S. 2025 carbon tariffs in the U.S.-ALL simulation (%).

	AGRI	COAL	OIL	ROIL	GAS	ELEC	EINT	OTHR	SERV	TRAN
MEX	18.4		-	11.5	0.8	96.3	21.1	10.7	3.2	11.7
FSU	67.2	53.4	-	10.1	4.0	261.4	57.4	28.0	14.1	24.9
ASI	44.6		-	6.3	2.5	45.8	22.3	13.4	6.3	17.9
CHN	38.3	104.1	-	15.5	2.3	221.3	54.8	29.1	21.3	23.6
IND	46.3	21.9	-	11.4		132.9	48.7	31.0	12.9	27.0
AFR	47.5	6.7	-	5.5	1.8		40.6	17.9	6.7	17.3
IDZ	52.1	16.4	-	10.7	7.8	111.1	39.8	23.7	14.7	20.6
MES	48.6		-	7.7	2.9	77.1	36.1	21.5	15.3	29.0
LAM	44.0	17.2	-	6.7	2.7	38.8	15.4	12.2	4.1	14.8
ROW	41.5	115.3	-	11.5	2.6	102.9	33.6	19.2	7.9	12.5
Non-coalition	32.7	13.9	3.2	7.6	6.3	95.0	29.7	17.5	12.1	18.9
All regions	19.7	8.2	3.2	4.5	0.3	5.0	4.4	7.3	5.1	5.1

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