Energy Policy 92 (2016) 102–110

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Border carbon adjustments: Addressing emissions embodied in trade

Marco Sakai*, John Barrett

Sustainability Research Institute, School of Earth and Environment, University of Leeds, LS2 9JT Leeds, UK

HIGHLIGHTS

- We estimate the volume of emissions that could be potentially taxed by BCAs.
- We study the effects of trade provisions and country and sectoral coverage on BCAs.
- Trade provisions can significantly reduce the scope and effectiveness of BCAs.
- Best available technology and exclusion of electricity reduce tariffs considerably.
- BCAs are not optimal policy tools to address carbon leakage concerns.

ARTICLE INFO

Article history:
Received 23 July 2015
Received in revised form
15 January 2016
Accepted 25 January 2016

Keywords:
Border carbon adjustments
GHG emissions
International trade
Embodied emissions
Carbon leakage
Best available technology

ABSTRACT

Approximately one fourth of global emissions are embodied in international trade and a significant portion flows from non-carbon-priced to carbon-priced economies. Border carbon adjustments (BCAs) figure prominently as instruments to address concerns arising from unilateral climate policy. Estimating the volume of emissions that could be potentially taxed under a BCA scheme has received little attention until now. This paper examines how a number of issues involved in the implementation of BCAs can affect their ability to cover emissions embodied in trade and thus address carbon leakage. These issues range from ensuring compliance with trade provisions and assumptions on the carbon intensity of imports, to determining which countries are included and whether intermediate and final demand are considered. Here we show that the volume of CO_2 captured by a scheme that involved all Annex B countries could be significantly reduced due to these issues, particularly by trade provisions, such as the principle of 'best available technology' (BAT). As a consequence, the tariff burdens faced by non-Annex B parties could dwindle considerably. These findings have important policy implications, as they question the effectiveness and practicalities of BCAs to reduce carbon leakage and alleviate competitiveness concerns, adding further arguments against their implementation.

1. Introduction

Previous studies have focused on estimating the amount of greenhouse gas (GHG) emissions that are generated during the production of goods and services destined to be traded internationally (Davis and Caldeira, 2010; Kainuma et al., 2000; Peters and Hertwich, 2008; Peters et al., 2011). One consistent finding in this literature is that industrialised nations (i.e. Annex B) tend to import more emissions embodied in the foreign-made products that they consume than those they export, consequently becoming net-importers (Peters and Hertwich, 2008). Net emissions transfers from non-carbon-priced to carbon-priced economies via international trade have increased by a factor of 4 during the last two decades, from 0.4 Gt in 1990 to 1.6 Gt of CO_2 in 2008 (Peters et al., 2011). Some authors consider that these growing transfers undermine mitigation commitments, since it can be argued from this perspective that emissions reductions in Annex B countries are in fact lower than what is specified in their national emissions inventories (Kanemoto et al., 2014; Peters et al., 2011).

Net emissions transfers constitute a phenomenon that has been labelled as 'demand-driven' carbon leakage, in order to differentiate it from its other variant, better known as 'policy-induced' leakage (Peters, 2010). The latter can be defined as the increase of emissions in countries with no abatement obligations due to climate policy implemented in nations subject to binding targets (Felder and Rutherford, 1993; Paltsev, 2001). The Intergovernmental Panel on Climate Change (IPCC) provides a more general definition, stating that carbon leakage relates to "*phenomena*

* Corresponding author.
E-mail addresses: m.a.h.sakai@leeds.ac.uk (M. Sakai), j.r.barrett@leeds.ac.uk (J. Barrett).

http://dx.doi.org/10.1016/j.enpol.2016.01.038

whereby the reduction in emissions (relative to a baseline) in a jurisdiction/sector associated with the implementation of mitigation policy is offset to some degree by an increase outside the jurisdiction/sector through induced changes in consumption, production, prices, land use and/or trade across the jurisdictions/sectors" (Allwood et al., 2014; p. 1265). Existing studies have been unable to reveal meaningful empirical evidence of 'policy-induced' carbon leakage (Reinaud, 2008; Sartor, 2012), whereas the existence of 'demand-driven' leakage is clearly reflected on the significant rise of net emissions transfers and constitutes an important matter.

It is believed that carbon leakage is associated with the loss of competitiveness of trade-exposed and carbon-intensive industries located in nations subject to costly carbon restrictions with respect to similar foreign industries situated in countries not constrained by climate policy (Kuik and Hofkes, 2010; van Asselt and Brewer, 2010). In order to alleviate carbon leakage and competitiveness concerns, it has been argued that emission pricing should be extended unilaterally to cover imported goods and services by applying border carbon adjustments (BCAs) (Helm et al., 2012; Ismer and Neuhoff, 2007; Lockwood and Whalley, 2010; Stiglitz, 2006). Applying a price on the carbon content of imported goods at the border, in this manner, could contribute to levelling the playing field between carbon-priced and non-carbon-priced economies.

The effectiveness of BCAs is a contested issue. Several studies suggest that these instruments can contribute to ameliorate the risk of carbon leakage (Bednar-Friedl et al., 2012; Kuik and Hofkes, 2010). Other examinations, however, have been more critical, highlighting the major drawbacks of these policy tools (Jakob et al., 2014). This paper, in this sense, aims to shed light on the matter by quantifying the volume of emissions that could be actually levied by BCAs, an aspect that has not received the proper attention in the literature. For this purpose, we take into account issues involved in BCA implementation related to trade provisions, carbon intensity of products and sectoral and country coverage. We then examine how these issues influence the tariff burdens faced by non-carbon-priced economies. This allows assessing the ability of BCAs to reduce leakage and their true contribution to climate policy.

The analysis involves the hypothetical case of a BCA scheme implemented by Annex B nations, given that this country grouping is suitable to illustrate the paper's objectives. However, we acknowledge that this particular group constitutes one of many potential scenarios. This is relevant given the introduction of other emissions trading schemes (ETS), apart from the Kyoto Protocol and the European Union ETS, such as the recent launch of South Korea's cap-and-trade programme, the first to be in operation in Asia, as well as the progress made towards setting up a Chinese trading system. The implications for our analysis of considering new abatement schemes in Non-Annex B countries are discussed later in the paper.

This research adds to the literature by showing that some aspects related to BCA implementation, particularly trade provisions, substantially reduce the volume of emissions along the supply chain that could be potentially taxed and contribute to seriously diminish the tariff burdens faced by exporting economies. The results offered in this paper thus confirm other existing studies in the sense that the benefits generated by BCAs would be small, while its implementation could prove to be extremely costly and difficult (Izard et al., 2010; Liu, 2015; McKibbin et al., 2008; Winchester et al., 2011). The findings essentially cast doubts on the practicality and effectiveness of these policy tools. This is relevant, as there has been an increasing discussion about adopting BCAs in some Annex B countries and other industrialised economies. The US represents a particularly pertinent example, since it has explicitly stated that any future climate legislation involving reduction targets would contain a provision for BCAs to protect its national industries. However, given their ineffectiveness, we argue that other options should be sought. The literature offers examples of alternative measures to address leakage and competitiveness concerns that could be more effective to support major polluting economies to intensify their mitigation actions, rather than to unilaterally penalise them for their inaction (Böhringer et al., 2012; Droege, 2011; Jakob et al., 2014). Some of these examples are presented later in the paper when we address the policy implications.

The paper is structured as follows. Section 2 provides additional background on BCAs and clarifies some conceptual aspects that are adopted in the analysis. Section 3 describes the method and data used. The empirical results are presented in Section 4, which are then discussed in Section 5. Section 6 offers the conclusions derived from the study, as well as the policy implications.

2. BCAs: background and conceptual approach

As has been mentioned, this section succinctly covers some key background information about BCAs and clarifies the conceptual approach followed in the analysis. It addresses aspects such as the objectives, implementation, compatibility with trade law, and efficiency of BCAs.

2.1. The objectives of BCAs

Advocates of BCAs generally regard them as a trade instrument to internalise a global externality (Markusen, 1975). The literature, however, identifies more specific objectives that can be pursued by implementing BCAs, such as ensuring an effective carbon price domestically, creating incentives to improve carbon efficiency among foreign producers, or from the standpoint of a coercion strategy to penalise free-riders (i.e. non-carbon-abating economies) and persuade them to assume legally binding targets (Neuhoff, 2011).

If carbon prices are asymmetrical among members of a region bound by carbon constraints, applying BCAs to fellow trade partners within the international agreement can ensure an efficient domestic price, given that adequate carbon equalisation measures are in place (e.g. assuming average carbon intensity, best available technology, etc.). BCAs can also encourage emissions reductions abroad by motivating foreign producers outside the scheme to become more carbon efficient, or even to punish non-participation in abatement efforts (Barrett, 1997; Irfanoglu et al., 2015; Lessmann et al., 2009; Li and Zhang, 2012; Winchester et al., 2011). However, it has been suggested that carbon equalisation can hinder the achievement of these two last objectives (Neuhoff, 2011). Depending on the adjustment rate after equalisation, BCAs can contribute to either shift carbon-intensive production to non-exports sectors in the producing country, or even risk blocking future involvement from non-participating nations in climate policy negotiations. In this paper, we argue that carbon equalisation can significantly reduce the tariff rates faced by exporting nations, thus affecting the effectiveness of BCAs. In our analysis, we assume that there is a homogeneous carbon price among the participants of the BCA scheme (and additionally that there is no internal leakage), which seeks not only to improve carbon efficiency outside the region (i.e. reduce net emissions transfers), but also serve as a coercive tool.

When regarded as an instrument of persuasion, BCAs have been often considered as a potential 'game changer' in deadlocked international climate negotiations (Helm et al., 2012). Developing nations, however, have historically experienced border adjustments being imposed against them, with adverse effects on their development efforts. Consequently, they generally oppose to their utilisation, claiming that these policy tools represent a justification for protectionism by industrialised economies and go against the spirit of free trade (Holmes et al., 2011; Kaufmann and Weber, 2011). Moreover, developing economies tend to contest BCAs, asserting that they conflict with the UNFCCC principle of 'common but differentiated responsibilities'. According to this perspective, the developing world should carry less onerous abatement obligations and, consequently, should not be subject to additional mitigation costs via BCAs (Davidson Ladly, 2012). Along these lines, it is commonly stated that BCAs downplay the environmental and social injustices that arise from uneven development (Eckersley, 2010; Steininger et al., 2014). For this reason, authors such as Neuhoff (2011) propose that in the case of implementing BCAs, it should be done under close international cooperation with the purpose of generating trust and understanding among parties about the desired outcomes delivered by the scheme.

2.2. Implementation of BCAs

Regarding the implementation of BCAs, they can be applied from a priced-based (e.g. tariff, tax) or a quantity-based approach (e.g. allowances) (Neuhoff, 2011). In the first case, importers are required to pay at the border a tax or tariff that is equal to the current carbon tax or price multiplied by the carbon embodied in the imported good and then divided by its value. In the latter, importers acquire allowances in the market or through an auction to cover for the carbon embodied in the imports, while exporters would be exempted from surrendering allowances. Monjon and Quirion (2010) suggest that it makes sense to follow the quantity-based approach in systems that already have a trading scheme.

The manner in which emissions allowances are allocated to domestic emitters is also an important element that is essential in the design of BCA schemes. To date, existing emissions trading programmes have provided most allowances for free. The rationale behind this action responds mainly to political reasons, as this method can ameliorate adverse costs (e.g. production, employment, etc.) in polluting sectors. Since the allowances are not paid for, allocating allowances freely ultimately represents a subsidy to production or investment and, as a result, polluters earn a profit (Böhringer and Lange, 2005). As follows, free allocation has also been considered as a potential option to address risk of carbon leakage (Monjon and Quirion, 2011a). However, it has been recognised that this method is less efficient than BCAs (Monjon and Quirion, 2011b) and can create undesired distortions (Neuhoff, 2011). These range from distributional impacts, since costs are shifted to the consumer, to the creation of perverse incentives if free allowances are allocated repeatedly over time. Monjon and Quirion (2010) assert that applying BCAs under free allocation would be difficult to justify, as assigning free allowances to foreign producers would be politically unlikely. The authors, however, believe that a better solution is to combine BCAs with a full auctioning of allowances. This idea is supported by Neuhoff (2011) and Sato et al. (2015), who suggest that this combination would allow countries to pursue ambitious carbon pricing without creating distortions.

The selection of a particular allocation method influences the carbon price. Nevertheless, in this paper we do not model a particular method for allocating allowances nor its price effects. We argue that issues involved in BCA implementation, related to trade provisions, assumptions on the carbon intensity of products and sectoral and country coverage (explained in detail in Section 4), seriously affect the volume of emissions captured by the scheme irrespective of how allowances are allocated or how the domestic carbon price is determined. Here we assume that allowances are allocated for free, but assume that BCAs are applied in the form of tariffs. We use an illustrative carbon price of $50 USD per ton, which has been suggested as a reasonable target for highly-developed economies in the short term in order to elucidate our argument (Atkinson et al., 2011).

2.3. Compatibility with trade law

Numerous efforts have been made to examine the legal aspects behind BCAs and their compatibility with World Trade Organisation (WTO) law (Frankel, 2005; Goh, 2004; Kaufmann and Weber, 2011). Some authors maintain that BCAs are not necessarily in violation of the General Agreement on Tariffs and Trade (GATT), which represents the basis of the WTO framework (Biermann and Brohm, 2004; Holmes et al., 2011; Monjon and Quirion, 2011b; Sheldon, 2011). GATT holds a provision of non-discrimination between foreign and domestic 'like' products. Members of the WTO are not allowed to restrict imports of 'like' products on grounds of environmental impact, such as higher embodied emissions. Exemptions exist, with the protection of global resources being stipulated in Article XX of GATT. Hence, the potential implementation of BCA schemes would mainly hinge on whether they are designed in a manner that avoids being challenged under WTO law. Equalisation measures, in this respect, can ensure that the import of 'like' goods receives a fair and similar treatment than domestic products. This requires not taxing them in excess of the domestic rates even if their carbon content is larger (Monjon and Quirion, 2011b). This implies, for example, the application of the principle of 'best available technology' (BAT), according to which imports are supposed to have been manufactured with at least the best technique existent in the country or region of consumption (Ismer and Neuhoff, 2007).

The influence of trade regulations, such as BAT, on the effectiveness of BCAs to address leakage and competitiveness concerns has received little attention and the evidence is inconclusive. Some studies have suggested that leakage is not necessarily increased by BAT (Demailly and Quirion, 2008; Monjon and Quirion, 2011b). Other authors have indicated that when border tariffs are based on the carbon content in domestic production, rather than in imports, BCAs would broadly address the competitiveness concerns of producers in consuming nations without seriously damaging exporting countries (Mattoo et al., 2009). Others have intuitively expressed that BAT would contribute negatively to global emissions reductions (Kuik and Hofkes, 2010). In this paper we examine the effects of BAT and offer more decisive evidence, illustrating that its application could significantly limit the scope and effectiveness of BCAs to ameliorate risk of leakage.

2.4. Efficiency of BCAs

Several modelling studies suggest that BCAs could address competitiveness concerns by discouraging the relocation of industries to regions with laxer climate policies and overall by reducing net emissions transfers (Bednar-Friedl et al., 2012; Kuik and Hofkes, 2010; McKibbin et al., 2008; Winchester, 2012; Winchester et al., 2011). However, reviews of different models have found that the decrease in carbon leakage would be moderate (Böhringer et al., 2012; Branger and Quirion, 2014). It is worth noting, nonetheless, that modelling efforts mainly involve the use of computable general equilibrium (CGE) models, which can produce a wide range of leakage rates, depending on the level of sectoral and country aggregation (see: Caron, 2012) and to different assumptions, such as type of emissions, allocation of emission allowances, product and firm heterogeneity, among others (see: Balistreri and Rutherford, 2012; Bednar-Friedl et al., 2012; Winchester, 2012).

As has been said, other examinations have stressed the limitations of these policy tools (Jakob et al., 2014). In general, it is argued that addressing leakage in an effective manner requires detailed knowledge, not only about the exact carbon content of products, but also about how world market prices would react to the imposition of BCAs, and how this affects production and consumption choices (Jakob and Marschinski, 2013). It has been suggested, in this sense, that under incomplete information a full BCA scheme (i.e. whereby a price is levied on imports according to their carbon content and a rebate offered to exports to exempt them from the domestic carbon price) could actually lead to an increase in emissions and ultimately to a rise in leakage (Jakob et al., 2013). This could be due to the decision by producers to export their emission-intensive products to other unregulated markets, or because production could shift from low-carbon-intensive export sectors towards more carbon-intensive non-export sectors.

In this paper we adhere to this latter perspective, since our findings question the effectiveness of BCAs to address emissions embodied in trade. The specific method and data that we used to conduct our analysis is described next.

3. Methods and data

Multi-Regional Input-Output (MRIO) analysis is a widely used technique to calculate emissions embodied in trade (see: Wiedmann, 2009). This method is consequently employed in this paper to estimate the volume of emissions that could be potentially taxed by BCAs, and specifically to examine how their scope is affected by trade provisions, assumptions on the carbon intensity of imports, and sectoral and country coverage.

In standard input-output notation, total output (X) is given by the following expression:

$$X = (I - A)^{-1}Y = LY \tag{1}$$

where I is an identity matrix and A is the technical coefficient matrix. In the MRIO framework, matrix A accounts for sectoral requirements within a region to produce goods domestically, as well as inter-regional sectoral requirements to produce goods with imported intermediate inputs. In this sense, A contains a domestic component and an imports component. The term $(I-A)^{-1}$ is known as the Leontief inverse (further identified as L), which indicates the requirements of a given sector to deliver a unit of output. In turn, X and Y represent total output and final demand, respectively, of the sectors located in all regions. Regarding Y, it incorporates all the components of final demand (i.e. private and public consumption, gross capital formation and change in inventories) for domestically produced goods and services within a region, as well as for imports. Moreover, goods and services produced domestically, but destined for final consumption in other regions (i.e. exports) are equally included in Y.

In order to determine the amount of emissions embodied in products of intermediate and final demand, the MRIO database was reconfigured as an Emissions Embodied in Bilateral Trade (EEBT) model (see: Peters, 2008). The main difference between MRIO and EEBT is that in the latter the A matrix just includes the domestic components, while intermediate exports are appended as column vectors along with Y.

3.1. Estimating emissions embodied in trade flows

Both MRIO and EEBT can be extended so as to include a row vector of sectoral CO_2 emissions. The emissions generated by sector i are divided by the corresponding output (X_i) in order to obtain a row vector of carbon intensities. These intensities can then be expressed as a diagonal matrix ($\hat{C}$). In order to determine the amount of emissions associated with a given level of output, $\hat{C}$ is post-multiplied by X.

$$C = \hat{C}X \tag{2}$$

By substituting X into the standard IO Eq. (1), this is equal to:

$$C = \hat{C}LY \tag{3}$$

In this sense, the model is able to determine the amount of direct and indirect CO_2 emissions that are associated with a certain level of final demand (Y). The term C in the equation represents a rectangular matrix of CO_2 emissions, with i^*s rows and i columns, where i is the number of countries and s the number of sectors. Expressed in compact form, the C matrix is constituted by domestic and trade-related components. In the case of two regions, m and n, this matrix is equal to:

$$C = \begin{Bmatrix} c^{mm} & c^{mn} \\ c^{nm} & c^{nn} \end{Bmatrix} \tag{4}$$

where each component (c) in this matrix stands for a column vector with an s number of rows. In this sense, c^{mm} and c^{nn} are the emissions required to satisfy the domestic production of goods consumed within regions m and n, respectively. In turn, c^{mn} are the emissions necessary to manufacture products in m that are consumed in n (i.e. exports from m to n). Accordingly, c^{nm} are the emissions required to produce goods in n that are consumed in m (i.e. imports from n to m). The total sum of the rows in this matrix (i.e. domestic plus exports) yields direct production emissions. Conversely, the total sum of the columns (i.e. domestic plus imports) represents consumption-based emissions. If region m corresponds to a group of economies subject to legally-binding emissions targets (i.e. Annex B nations), the column vector c^{nm} then represents the emissions embedded in their imports manufactured in region n, which could therefore be levied by a BCA scheme. On the other hand, c^{mn} stands for emissions already priced that are embedded in products manufactured in region m to be consumed in n. These are the exports that can be subject to a rebate.

BATs, on the other hand, were calculated as the average carbon intensities ($\hat{C}$) of the 33% most carbon efficient countries under the scheme. Individual nations were ranked, once for every economic sector, according to their intensities. BATs were then estimated as the mean carbon intensity of the most efficient tercile.

3.2. Estimating value added embodied in trade flows

Value added is understood as the value that is added to a product during each stage of its production process along the global supply chain. Studies have emerged detailing the input–output methods required to measure the amount of value added that is embodied in traded goods and services (Daudin et al., 2011; Hummels et al., 2001; IDE-JETRO and WTO, 2011). In this study, trade in value added was calculated following the same procedure as in the case of CO_2 emissions.

A row vector of value added per sector is divided by the total output of each sector. The resulting vector ($\hat{V}$) is then diagonalised. In order to determine the amount of value added (V) that is generated directly and indirectly given a level of output, $\hat{V}$ is post-multiplied by X.

$$V = \hat{V}X = \hat{V}LY \tag{5}$$

Expressed in a compact form, V is a rectangular matrix composed of domestic and traded components.

$$V = \begin{Bmatrix} v^{mm} & v^{mn} \\ v^{nm} & v^{nn} \end{Bmatrix} \tag{6}$$

In the case of two regions, m and n, each of the individual elements (v) represents a column vector with s number of rows, where s is the number of sectors. The vectors v^{mm} and v^{nn} indicate the value added per sector that is generated within the regions to satisfy domestic consumption. In turn, v^{mn} is the value added created within region m to produce exports consumed in region n. The same logic applies to v^{nm}.

3.3. Estimating tariff rates

The tariff rates faced by region n depend on the price for carbon (p). In order to calculate the tariffs, p is multiplied by the amount of emissions embedded in imports. This is then divided by the value of those same imports, expressed in terms of their value added. The tariff is calculated according to the following expression:

$$\text{tariff} = p(c^{nm})'\left(\hat{v}^{nm}\right)^{-1} \tag{7}$$

where p is a scalar (i.e. price for carbon), $(c^{nm})'$ represents the transposed vector of emissions embodied in imports and $(\hat{v}^{nm})^{-1}$ is the inverse of the diagonalised values of those imports.

3.4. Data

The MRIO table was assembled with data from the Global Trade Analysis Project (GTAP), version 8 (Narayanan et al., 2012), consisting of a large square transactions matrix that represents the structure of the global economy. It includes 110 countries and 19 regions depicting the rest of the world, each encompassing 57 economic sectors. This matrix is accompanied by another one representing final demand and an additional row vector for value added. GTAP data for CO_2 emissions was complemented with figures taken from the Carbon Dioxide Information Analysis Center (CDIAC), comprising emissions derived from the use of solid and liquid fuels, gas, and cement production. These data were incorporated into the model as a row vector following the sectoral breakdown provided by GTAP.

4. Empirical results

Annex B countries generated around 45% of global emissions from 2005 to 2010, but were accountable for a larger amount of CO_2 by consuming products manufactured in other regions (Davis and Caldeira, 2010; Peters et al., 2011). Using data for 2007, we estimated that approximately 5.3 Gt of CO_2 (i.e. 17.9% of global) were embodied in imports destined to Annex B nations, while 3.5 Gt (i.e. 11.8% of global) were embodied in exports to the rest of the world. The net emissions transfer or deficit (i.e. imports minus exports) in Annex B nations thus amounted to about 1.8 Gt (i.e. 6.1% of global). As can be seen in Fig. 1, about 2.4 Gt of traded emissions were embodied in intra-Annex B trade flows and consequently would not be included in a BCA scheme. It is only the CO_2 traded with non-Annex B nations that could be covered, assuming that both imports and exports were considered. The emissions, represented in Fig. 1 as the bars within the dotted lines, represent the volume of emissions that are embodied in inter-regional trade flows. This includes 1.1 Gt or 31.5% of the total export emissions produced in Annex B, and 2.9 Gt or 54.8% of total import emissions from Non-Annex B. It is worth mentioning that almost half of imported emissions (1.3 Gt) correspond to China and almost another fourth (0.8 Gt) to the rest of the emerging economies (see Table A.1 in the appendix).

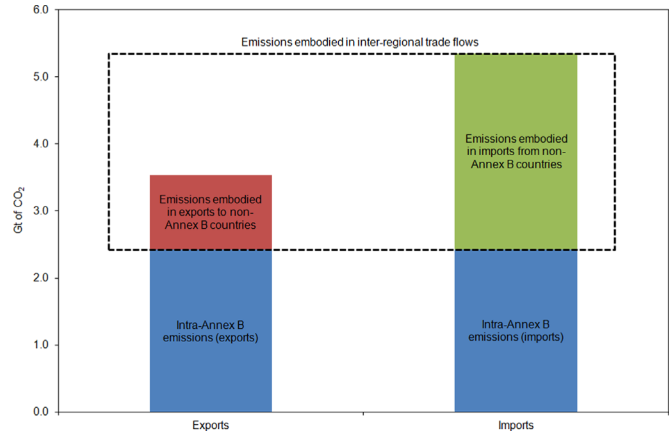

Fig. 1. Emissions embodied in exports and imports in Annex B nations. Approximately 5.3 Gt of CO_2 were embodied in imports destined to Annex B nations in 2007, while 3.3 Gt were embodied in exports from Annex B to the rest of the world. About 2.4 Gt of traded emissions were embodied in products traded within Annex B nations and consequently are not subject to BCAs. The bars within the dotted lines represent the emissions embodied in inter-regional trade flows. These comprise 1.1 Gt or 31.5% of export emissions and 2.9 Gt or 54.8% of import emissions.

4.1. Trade regulations

The scope for BCAs is influenced by a number of factors, such as trade law under the WTO framework. In order to comply with GATT's provision of non-discrimination, and thus ensure that imports receive a fair and similar treatment than domestic products, not all types of imports can be levied. BCAs can only be applied to comparable products that are covered domestically in the region of consumption by the existing abatement scheme. In this manner, 17.0% (0.5 Gt) of the emissions embodied in imports cannot be included under the existing provisions. These are associated with sectors not currently considered in the Kyoto Protocol and the EU ETS, and are therefore not priced (see Table A.2 in the appendix)[1]. As can be seen in Fig. 2, only 2.4 Gt could be potentially taxed by BCAs. We call this volume of emissions the hypothetical scope of BCAs, which is illustrated in Fig. 2 as the bar within the dotted lines.

GATT's provision of non-discrimination also requires not taxing imports in excess of the domestic rates, even if their carbon content is greater. It is assumed that non-Annex B nations would defend this provision. This implies the application of carbon equalisation measures, such as BAT. Imports are thus assumed to have been manufactured with at least the best clean technology existent in the region of consumption. The determination of an appropriate BAT is, however, complicated. It has been suggested that product-specific benchmarks should be used, like the ones developed in the EU ETS for industry products (Monjon and Quirion, 2010). In the case of this analysis, BATs were calculated for each economic sector as the average carbon intensity of the most carbon-efficient tercile of countries under the scheme. As illustrated in Fig. 2, the scheme's breadth decreases significantly when BATs are applied. They cause a reduction of 1.3 Gt or 55.8% of the hypothetical scope. This evidences, on the one hand, the high carbon intensities of some non-Annex B nations and, on the other, the undermining effects that BATs could have on the effectiveness of BCAs.

[1] The Kyoto Protocol also details in its Annex A emissions from agriculture, waste and deforestation, which have been central in international negotiations. However, we have not taken these into account in our analysis, which represents a limitation.

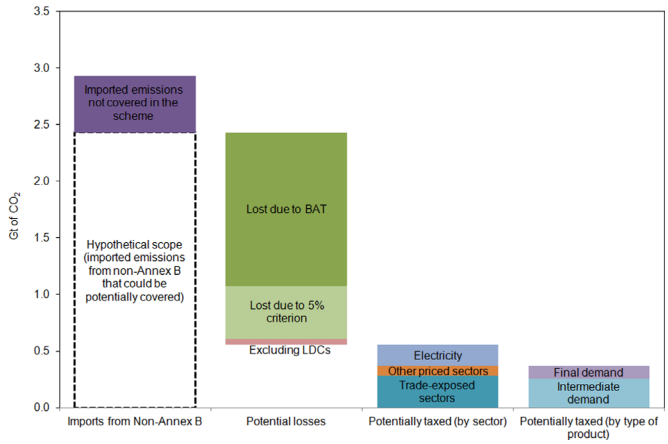

Fig. 2. Decomposition of the hypothetical scope. 17.0% of emissions embodied in imports from Non-Annex B are not priced domestically and cannot be levied. BATs cause a reduction of 55.8% of the hypothetical scope. Excluding activities that contribute with less than 5% of total imports in a given sector reduces the scope by 19.1%. Excluding LDCs causes a minimal impact. The volume that could be taxed amounts to 22.9% of the hypothetical scope. Two thirds correspond to priced sectors, including those that are exposed to foreign competition. The remaining third is related to electricity. Around 69.8% of these emissions are associated with intermediate inputs, while the rest relates to products for final demand.

4.2. Country and sectoral coverage

Country and sectoral exemptions constitute one more factor that can influence the scope of BCAs. There have been proposals to exclude those activities that contribute with less than 5% of the total imports in a given sector of the consuming country or region (Cosbey et al., 2012; van Asselt and Brewer, 2010). Exempting sectors based on the 5% criterion reduces the amount of captured emissions by approximately 0.4 Gt or 19.1% of the hypothetical scope.

Certain proposals, such as the ones initiated in the US, also contemplate exempting least developed countries (LDCs), as long as they are responsible individually for less than 0.5% of global CO_2 (Monjon and Quirion, 2010; Winchester et al., 2011). It is assumed that these economies do not represent a risk of leakage and loss of competitiveness. As is shown in Fig. 2, the implications of excluding LDCs are minimal. The CO_2 captured from these nations amounts to barely 0.5% of total emissions in Annex B countries.

The volume of CO_2 that could be potentially taxed after taking into consideration trade provisions and country and sectoral exemptions thus amounts to 0.56 Gt, about 22.9% of the hypothetical scope and barely 1.8% of global emissions. Around two thirds of these (0.37 Gt) correspond to sectors priced by the Kyoto Protocol and the EU ETS, including six that are characterised by being carbon intensive and exposed to foreign competition (i.e. lime and cement, basic iron and steel, refined petroleum, aluminium, inorganic basic chemicals, and pulp and paper). The latter are considered as particularly relevant in terms of competitiveness and carbon leakage, and represent the sectors that are most likely to be taxed by future BCA schemes (Stephenson and Upton, 2009). However, just focusing on these last sectors would imply capturing 0.28 Gt or 11.5% of the hypothetical scope (i.e. 0.9% of global emissions).

In turn, a third of the emissions that could be potentially taxed (i.e. 0.19 Gt or 7.7% of the hypothetical scope) relate to the on- and off-site generation of electricity used to manufacture the products that are consumed. Electricity is not always traded between countries, but it is embedded into them during production. Including electricity can be challenging, as it would require calculating the direct and indirect electricity contributions along the global supply chain.

Table 1
Average tariff rates on imports at $50 USD per ton.

Coverage	China	India	Emerging economies	Other high income	LDCs
All sectors	11.1%	7.8%	4.7%	3.2%	2.9%
Only priced sectors (hypothetical scope)	15.0%	19.4%	6.4%	5.1%	4.9%
With BAT	2.1%	3.6%	2.4%	4.2%	3.3%
With BAT and 5% criterion	2.1%	3.4%	1.8%	3.0%	1.2%
With BAT and 5% criterion and excluding electricity	1.2%	2.2%	1.5%	2.7%	1.1%

Finally, tracking the emissions associated with final and intermediate products poses a similar problem. The results reveal that around 69.8% of emissions from priced sectors are associated with intermediate inputs, while the rest is embodied in products for final demand. A precise estimation of the emissions generated along the global supply chain to produce final goods can be a daunting task that would elevate the complexity and the operating costs of a BCA scheme, as will be discussed.

4.3. Average tariff rates

Table 1 shows the average tariff rates faced by different countries and regions based on an illustrative carbon price of $50 USD per ton, finding that they are mostly consistent with those estimated previously by Atkinson et al. (2011). If all sectors were taxed, regardless of their treatment by the existing emissions trading schemes, China and India would face average rates of around 11.1% and 7.8% due to their high carbon intensities (see Table A.3 in the appendix). In turn, emerging economies and other high-income nations with no binding targets would face average rates of 4.7% and 3.2%, respectively. Nonetheless, the tariffs would increase if only the priced sectors were taken into account (i.e. hypothetical scope), since these are more intensive in carbon. China and India would face taxes of 15.0% and 19.4%, respectively, while these would vary from 6.4% to 4.9% in the other country groups. The use of BATs, however, drastically reduces the burdens, with tariffs ranging between 4.2% and 2.1% among different nations. This measure would particularly favour China, who would observe an 85% decline in its tariff with respect to the hypothetical scope, the lowest rates among the country groups. The inclusion of the 5% criterion, in turn, has a minor effect, but it would specifically benefit LDCs by halving their tariffs with respect to the option that only includes BAT. Excluding electricity also produces a significant effect in relation to the most carbon intensive economies, especially in the case of China, whose tariff would drop to about 1.2%. India would equally register an important reduction, facing a tariff 2.2%. The influence of electricity is less striking in the rest of the country groups and has a very small effect in LDCs.

5. Discussion

The results presented in the previous section evidence the challenges involved in the implementation of BCAs. Some of the issues analysed here contribute to substantially diminish the breadth of these policy tools, and thus to reduce the tariffs faced by the major non-priced polluting economies. Trade provisions, and especially the use of BATs, undermine the tariff rates. Low tariffs would hardly level the playing field between nations and would do little to alleviate competitiveness concerns among domestic producers who are subject to a carbon price. Moreover, low rates weaken the incentive for foreign carbon-intensive exporters to adopt cleaner technologies.

Our findings contradict those obtained by other authors who suggest that BATs might not necessarily cause an increase in carbon leakage (Demailly and Quirion, 2008; Monjon and Quirion, 2011b). According to the calculations offered in this paper, countries like China and India could register decreases in their BCA rates of up to 85% due to BAT. We argue that tariffs of 2% to 4%, based on carbon price of $50 USD per ton, could not be enough to protect domestic industries from foreign competition and, more importantly, to halt the increasing transfer of emissions from non-priced to priced economies. Furthermore, rates of this calibre would offer very limited support to curb global emissions, as has been insinuated by other studies (Kuik and Hofkes, 2010).

The developing world, however, would certainly offer less resistance to some trade provisions, like the proposal to exclude those activities that contribute with less than 5% of the total imports in a given sector of the consuming country. Likewise, LDCs would welcome being totally exempted from any BCA scheme. These two factors, the 5% criterion and the exclusion of LDCs, could lead to reductions of about 19.1% and 2.2%, respectively, of the emissions captured by BCAs (i.e. the hypothetical scope). However, they would particularly favour the smallest and weakest economies, as well as low-carbon and not highly trade-exposed economic sectors located in more affluent nations. These provisions could be implemented on grounds of ensuring fairness and avoiding shifting the mitigation burden to the most unprotected countries and sectors. Meanwhile, these measures would have limited influence on the tariffs faced by highly carbon-intensive and export-oriented emerging economies, like China, India and South Africa, to whom these provisions have little effect.

The results also corroborate the difficulty of addressing the complexity of the global supply chains in terms of fully capturing the carbon embodied in products along the different stages of the production process (Izard et al., 2010). The exclusion of electricity exerts an important effect on the volume of captured emissions and thus on the reduction of leakage. Estimating the specific emissions contributed by electricity use can be technically complicated, particularly when integrated electricity systems are involved, as the origin of specific electricity inputs is difficult to track (Ismer and Neuhoff, 2007). However, the effectiveness of a BCA scheme would be weakened if electricity was not taken into account, especially for electricity-intensive sectors that are exposed to international competition, such as aluminium (Monjon and Quirion, 2010). The findings presented here indicate that electricity accounts for around a third of the emissions which could be potentially taxed (i.e. 7.7% of the hypothetical scope), after considering the reductions caused by trade provisions. Failing to capture this volume would lead to important reductions in tariff rates, especially in the case of those countries, like China, who have benefited heavily by using low-cost, but high-carbon sources for power generation. China, India and the rest of the emerging economies would face tariffs as low as 1.2%, 2.2% and 1.5%, respectively, hardly high enough to level the playing field.

A similar problem comes to the fore when estimating the amount and origin of emissions that are embodied in products. This task can be simpler in the case of intensive primary commodities, but it can become a challenging undertaking with regards to more elaborate products, such as electronic or mechanical components. In the case of final demand goods, such as cars or heavy equipment, the complexity is even greater. Calculating the direct and indirect emissions of elaborate or final products requires a comprehensive and transparent carbon accounting procedure that takes into account the intricacy of global supply chains. The results show that by just covering basic commodities and intermediates, BCAs could capture around 10.5% of emissions included in the hypothetical scope without considering electricity, while a further 4.5% could be lost by not capturing all the emissions embodied in final demand goods. Doing so, however, is difficult and costly. For example, requiring exporters to provide certified information about the carbon embodied in their goods can imply a heavy burden, especially for small producers. Applying a rigid rate, on the other hand, could be considered as a fixed import or anti-dumping tariff, irresponsive to improvements in carbon intensity (Winchester, 2012). This fixed rate could reduce the effectiveness of the tax in encouraging producers to modify their practices, unless it is considered as a fall-back rate and importers can choose to provide evidence about the specific carbon content of their products.

The low tariffs estimated here, nonetheless, could be less damaging to the developing world, but there is still the risk that they could prove be trade-distorting and could create adverse distributional impacts in terms of welfare in net exporting countries, as has been suggested in the literature (Atkinson et al., 2011; Dissou and Eyland, 2011). BCAs levied by industrialised countries generally change the terms-of-trade against the developing world, thereby shifting the burden of emission abatement and exacerbating existing income inequalities (Böhringer et al., 2012). These effects could be ameliorated by abandoning free allowance allocation or given that the revenues obtained from the schemes were remitted back to the exporting nations in the form of aid, technology transfer or assistance for adaptation efforts (Böhringer et al., 2012; Steininger et al., 2014). However, even if these low tariffs could be imposed, they might still be a cause of opposition from non-priced economies, mainly on grounds of contravening the spirit of free trade.

In environmental terms, the contribution of BCAs is minimal. It is uncertain if tariffs as low as those determined in this paper could still maintain some coercive power. It can be assumed that they would be too weak to stimulate unregulated economies to strengthen their mitigation efforts. Rather, they could represent a cause of trade disputes and could deepen the stalemate in international climate negotiations. Furthermore, it has been recognised that taxing one unit of imported emissions is not always equal to avoiding the release of one unit of emissions to the atmosphere (Jakob et al., 2014). Even if it were technically and politically possible to calculate the exact amount of emissions released in the production of imports and a corresponding carbon price could be applied, it is inconclusive if BCAs can contribute to reduce emissions on a global scale. It is argued, however, that combining BCAs with full auctioning could deliver added benefits for mitigation (Sato et al., 2015).

6. Conclusions and policy implications

Given the increasing net emissions transfers from non-carbon-priced to carbon-priced economies via international trade, some countries have considered extending emission pricing in a unilateral manner to cover imported goods and services by applying BCAs. It is argued that this course of action could level the playing field between nations and reduce carbon leakage. The objective of this paper is to quantify the volume of emissions that could be actually levied by BCAs, and determine how the tariff burdens faced by non-carbon-priced economies are shaped by issues related to trade provisions, carbon intensity of products, and sectoral and country coverage. In summary, it can be concluded that BCAs could prove to be complex, costly and ineffectual policy tools, which complements and confirms other similar existing findings in the literature (Izard et al., 2010; Liu, 2015; McKibbin et al., 2008; Winchester et al., 2011). This paper makes a contribution by estimating that trade provisions substantially reduce the volume of emissions that could be potentially taxed and contribute to seriously diminish the tariff burdens faced by exporting economies. The implementation of BAT more than halves the scope of captured emissions, while the tariffs faced by high carbon-intensive countries, like China, could drop by around 85%. Furthermore, proposals to exclude activities that contribute with less than 5% of the total imports in a given sector of the consuming country can cause a further reduction of about 19.1% of the initial scope. Failing to capture the complexity of global supply chains also has important effects. Not including the full contribution of electricity to the production process and only focusing on levying intensive primary commodities and intermediates can cause added reductions of 12.3%. After taking into account all these issues, countries like China and India could end facing tariffs of around 1.2% and 2.2%. Tariffs as low as these ones would do little to protect domestic industries from foreign competition and stop the increase in carbon leakage.

It can be concluded that BCAs are not optimal policy tools. This statement supports similar claims made, for example, by Jakob et al. (2014), who assert that putting a price on an externality equal to its social costs via BCAs is not an adequate measure for emissions embodied in imports. This has important policy implications, especially for nations like the US, who has stated that any future climate legislation involving reduction targets would contain a provision for BCAs to protect its national industries. The Kerry-Lieberman and the Waxman-Markey climate bills, which failed to obtain approval by the US congress, considered the use of these policy instruments. In the light of the results presented in this paper, we argue that US policy makers should seek other more effective strategies if they intend to alleviate their carbon leakage concerns.

The latest UN climate summit in Paris constituted an important effort towards engaging developed and developing nations in limiting the global average temperature to below 2 degrees with respect to the pre-industrial era before the end of the century (UNFCCC, 2015). Nonetheless, the world is still far from achieving a true universal climate agreement that includes an internationally harmonised price on carbon, as well as setting legally binding targets for all major polluters. If this was attained, then carbon leakage and competiveness would cease being considered as issues of concern. Presently, the implementation of emissions trading schemes in Non-Annex B nations constitutes good news. The case of the Chinese scheme is of particular relevance, since a considerable share of global emissions would thus be covered and priced. This could represent up to an additional 25% according to the figures used in this analysis, but subject to the breadth of sectoral coverage that is considered. This would also mean that up to half of Annex B imported emissions could be priced, as has been discussed in Section 4. The operation of additional abating schemes, such as the Korean and Chinese programmes, however, does not undermine the relevance of this paper's findings. Carbon leakage and competitiveness would still represent matters of concern between carbon-priced and non-carbon-priced economies, and issues like trade provisions and country and sectoral coverage would continue affecting the volume of captured emissions and the tariffs faced by importing nations.

Given the inefficiency of BCAs, alternative options should be sought if leakage concerns are wished to be addressed. The literature offers examples of measures that can prove to be more efficient to deal with emissions transfers and which can support global emissions reductions. It has been recognised that there is not a magic bullet that can solve these issues on its own, but rather a mix of different policies could prove to be more optimal. Some authors have suggested that if a BCA scheme were to be implemented, it would need to cover just a few trade-exposed and carbon-intensive commodities (Droege, 2011; Lininger, 2015). In addition, it would require close international cooperation to create trust and avoid disputes and harmful outcomes (Neuhoff, 2011). This could be also combined with state aid to sensitive sectors (domestic and foreign). Moreover, full auctioning of allowances would be mandated (Sato et al., 2015) or continuing with free allocation in the case of emission-intensive industries, but based on output levels, as has been suggested by some scholars (Jakob et al., 2014; Monjon and Quirion, 2011a). Lastly, emissions could be partially levelled by a wider implementation of carbon offset policies, such as the Clean Development Mechanism, which are more cost effective than BCAs and provide direct incentives for emissions reductions abroad (Böhringer et al., 2012; Jakob et al., 2014). However, future research should evaluate a broader portfolio of measures and assess their relative performance in terms of climate and energy policies. This is vital to ensure a more equitable, fair and swifter transition towards a low-carbon future.

Acknowledgements

The authors appreciate the input of two anonymous reviewers, as well as the contribution of Anne Owen and Robin Vanner in the early stages of the analysis. Paola Sakai, Julia Steinberger and Tim Foxon are also acknowledged for providing useful insights and assistance. This work was supported by the Research Councils UK (RCUK) Energy Programme's funding for the Centre for Industrial Energy, Materials and Products (CIE-MAP), grant reference EP/N022645/1. Additional funding was provided by the UK Energy Research Centre (UKERC), supported by the RCUK under EPSRC award EP/L024756/1.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.enpol.2016.01.038.

References

Allwood, J.M., Bosetti, V., Dubash, N.K., Gómez-Echeverri, L., von Stechow, C. Glossary, 2014. In: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T., Minx, J.C. (Eds.), Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge United Kingdom and New York, NY, USA.
Atkinson, G., Hamilton, K., Ruta, G., Van Der Mensbrugghe, D., 2011. Trade in 'virtual carbon': empirical results and implications for policy. Global Environ. Change 21, 563–574.
Balistreri, E.J., Rutherford, T.F., 2012. Subglobal carbon policy and the competitive selection of heterogeneous firms. Energy Econ. 34 (Suppl 2), S190–S197.
Barrett, S., 1997. The strategy of trade sanctions in international environmental agreements. Resour. Energy Econ. 19, 345–361.
Bednar-Friedl, B., Schinko, T., Steininger, K.W., 2012. The relevance of process emissions for carbon leakage: a comparison of unilateral climate policy options with and without border carbon adjustment. Energy Econ. 34 (Suppl 2), S168–S180.
Biermann, F., Brohm, R., 2004. Implementing the Kyoto Protocol without the USA: the strategic role of energy tax adjustments at the border. Clim. Policy 4, 289–302.
Böhringer, C., Balistreri, E.J., Rutherford, T.F., 2012. The role of border carbon adjustment in unilateral climate policy: overview of an Energy Modeling Forum study (EMF 29). Energy Econ. 34 (Suppl 2), S97–S110.
Böhringer, C., Lange, A., 2005. Economic implications of alternative allocation schemes for emission allowances. Scand. J. Econ. 107, 563–581.
Branger, F., Quirion, P., 2014. Would border carbon adjustments prevent carbon leakage and heavy industry competitiveness losses? Insights from a meta-analysis of recent economic studies. Ecol. Econ. 99, 29–39.
Caron, J., 2012. Estimating carbon leakage and the efficiency of border adjustments in general equilibrium — does sectoral aggregation matter? Energy Econ. 34 (Suppl 2), S111–S126.
Cosbey, A., Droege, S., Fischer, C., Reinaud, J., Stephenson, J., Weischer, L., Wooders, P., 2012. A Guide for the Concerned: Guidance on the Elaboration and

Implementation of Border Carbon Adjustment, Policy Report. ENTWINED, Stockholm, Sweden.
Daudin, G., Rifflart, C., Schweisguth, D., 2011. Who produces for whom in the world economy? Qui produit pour qui dans l'économie mondiale?. Can. J. Econ./Revue Can. d'économique 44, 1403–1437.
Davidson Ladly, S., 2012. Border carbon adjustments, WTO-law and the principle of common but differentiated responsibilities. Int. Environ. Agreem. 12, 63–84.
Davis, S.J., Caldeira, K., 2010. Consumption-based accounting of CO_2 emissions. Proc. Natl. Acad. Sci. 107, 5687–5692.
Demailly, D., Quirion, P., 2008. Leakage from climate policies and border-tax adjustment: lessons from a geographic model of the cement industry. In: Guesnerie, R., Tulkens, H. (Eds.), The Design of Climate Policy. The MIT Press, Cambridge, Massachusetts, US.
Dissou, Y., Eyland, T., 2011. Carbon control policies, competitiveness, and border tax adjustments. Energy Econ. 33, 556–564.
Droege, S., 2011. Using border measures to address carbon flows. Clim. Policy 11, 1191–1201.
Eckersley, R., 2010. The politics of carbon leakage and the fairness of border measures. Ethics Int. Aff. 24, 367–393.
Felder, S., Rutherford, T.F., 1993. Unilateral CO_2 reductions and carbon leakage: the consequences of international trade in oil and basic materials. J. Environ. Econ. Manag. 25, 162–176.
Frankel, J., 2005. Climate and trade: links between the Kyoto Protocol and WTO. Environ.: Sci. Policy Sustain. Dev. 47, 8–19.
Goh, G., 2004. The World Trade Organization, Kyoto and energy tax adjustments at the border. J. World Trade 38, 395–423.
Helm, D., Hepburn, C., Ruta, G., 2012. Trade, climate change, and the political game theory of border carbon adjustments. Oxf. Rev. Econ. Policy 28, 368–394.
Holmes, P., Reilly, T.O.M., Rollo, J.I.M., 2011. Border carbon adjustments and the potential for protectionism. Clim. Policy 11, 883–900.
Hummels, D., Ishii, J., Yi, K.-M., 2001. The nature and growth of vertical specialization in world trade. J. Int. Econ. 54, 75–96.
IDE-JETRO, WTO, 2011. Trade Patterns and Global Value Chains in East Asia: From Trade in Goods to Trade in Tasks. World Trade Organisation, Geneva, Switzerland, p. 132.
Irfanoglu, Z.B., Sesmero, J.P., Golub, A., 2015. Potential of border tax adjustments to deter free riding in international climate agreements. Environ. Res. Lett. 10, 024009.
Ismer, R., Neuhoff, K., 2007. Border tax adjustment: a feasible way to support stringent emission trading. Eur. J. Law Econ. 24, 137–164.
Izard, C., Weber, C., Matthews, S., 2010. Scrap the carbon tariff. Nat. Rep. Clim. Change, 10–11.
Jakob, M., Marschinski, R., 2013. Interpreting trade-related CO_2 emission transfers. Nat. Clim. Change 3, 19–23.
Jakob, M., Marschinski, R., Hübler, M., 2013. Between a rock and a hard place: a trade-theory analysis of leakage under production- and consumption-based policies. Environ. Res. Econ. 56, 47–72.
Jakob, M., Steckel, J.C., Edenhofer, O., 2014. Consumption- versus production-based emission policies. Annu. Rev. Resour. Econ. 6, 297–318.
Kainuma, M., Matsuoka, Y., Morita, T., 2000. Estimation of embodied CO_2 emissions by general equilibrium model. Eur. J. Oper. Res. 122, 392–404.
Kanemoto, K., Moran, D., Lenzen, M., Geschke, A., 2014. International trade undermines national emission reduction targets: new evidence from air pollution. Global Environ. Change 24, 52–59.
Kaufmann, C., Weber, R.H., 2011. Carbon-related border tax adjustment: mitigating climate change or restricting international trade? World Trade Rev. 10, 497–525.
Kuik, O., Hofkes, M., 2010. Border adjustment for European emissions trading: competitiveness and carbon leakage. Energy Policy 38, 1741–1748.
Lessmann, K., Marschinski, R., Edenhofer, O., 2009. The effects of tariffs on coalition formation in a dynamic global warming game. Econ. Model. 26, 641–649.
Li, A., Zhang, A., 2012. Will carbon motivated border tax adjustments function as a threat? Energy Policy 47, 81–90.
Lininger, C., 2015. Design Options for Consumption-Based Policy Approaches: A Literature Review, Consumption-Based Approaches in International Climate Policy. Springer International Publishing, Switzerland, pp. 205–226.
Liu, L., 2015. A critical examination of the consumption-based accounting approach: has the blaming of consumers gone too far? Wiley Interdiscip. Rev.: Clim. Change 6, 1–8.
Lockwood, B., Whalley, J., 2010. Carbon-motivated border tax adjustments: old wine in green bottles? World Econ. 33, 810–819.
Markusen, J.R., 1975. International externalities and optimal tax structures. J. Int. Econ. 5, 15–29.
Mattoo, A., Subramanian, A., van der Mensbrugghe, D., He, J., 2009. Reconciling Climate Change and Trade Policy, Policy Research Working Paper. The World Bank, Development Research Group, p. 46.
McKibbin, W.J., Wilcoxen, P.J., Braathen, N.A., Tao, H., Levinson, A., 2008. The economic and environmental effects of border tax adjustments for climate policy [with comments]. Brook. Trade Forum, 1–34.
Monjon, S., Quirion, P., 2010. How to design a border adjustment for the European Union Emissions Trading System? Energy Policy 38, 5199–5207.
Monjon, S., Quirion, P., 2011a. Addressing leakage in the EU ETS: border adjustment or output-based allocation? Ecol. Econ. 70, 1957–1971.
Monjon, S., Quirion, P., 2011b. A border adjustment for the EU ETS: reconciling WTO rules and capacity to tackle carbon leakage. Clim. Policy 11, 1212–1225.
Narayanan, G., Dimaranan, B., McDougall, R.A., B.V., 2012. Guide to the GTAP data base. In: Narayanan, G., Badri, Aguiar, A., McDougall, R.A. (Eds.), Global Trade, Assistance, and Production: The GTAP 8 Data Base. Center for Global Trade Analysis. Purdue University, Indiana, US (Chapter 2).
Neuhoff, K., 2011. Climate Policy after Copenhagen: The Role of Carbon Pricing. Cambridge University Press, New York, USA.
Paltsev, S.V., 2001. The Kyoto Protocol: regional and sectoral contributions to the carbon leakage. Energy J. 22, 53–79.
Peters, G.P., 2008. From production-based to consumption-based national emission inventories. Ecol. Econ. 65, 13–23.
Peters, G.P., 2010. Policy update: managing carbon leakage. Carbon Manag. 1, 35–37.
Peters, G.P., Hertwich, E.G., 2008. CO_2 embodied in international trade with implications for global climate policy. Environ. Sci. Technol. 42, 1401–1407.
Peters, G.P., Minx, J.C., Weber, C.L., Edenhofer, O., 2011. Growth in emission transfers via international trade from 1990 to 2008. Proc. Natl. Acad. Sci. 108, 8903–8908.
Reinaud, J., 2008. Issues Behind Competitiveness and Carbon Leakage: Focus on Heavy Industry. IEA information paper. International Energy Agency (IEA), Paris, France.
Sartor, O., 2012. Carbon Leakage in the Primary Aluminium Sector: What evidence after 6½ years of the EU ETS? USAEE Research Paper Series. CDC Climat Research Paris, France.
Sato, M., Neuhoff, K., Graichen, V., Schumacher, K., Matthes, F., 2015. Sectors under scrutiny: evaluation of indicators to assess the risk of carbon leakage in the UK and Germany. Environ. Resour. Econ. 60, 99–124.
Sheldon, I., 2011. Is there anything new about border tax adjustments and climate policy? Am. J. Agric. Econ. 93, 553–557.
Steininger, K., Lininger, C., Droege, S., Roser, D., Tomlinson, L., Meyer, L., 2014. Justice and cost effectiveness of consumption-based versus production-based approaches in the case of unilateral climate policies. Global Environ. Change 24, 75–87.
Stephenson, J., Upton, S., 2009. Competitiveness, leakage, and border adjustment: climate policy distractions? Organ. Econ. Co-op. Dev., 36.
Stiglitz, J., 2006. A New Agenda for Global Warming. The Economists' Voice 3.
UNFCCC, 2015. Adoption of the Paris Agreement. United Nations Framework Convention on Climate Change, Paris, 30 November to 11 December 2015.
van Asselt, H., Brewer, T., 2010. Addressing competitiveness and leakage concerns in climate policy: An analysis of border adjustment measures in the US and the EU. Energy Policy 38, 42–51.
Wiedmann, T., 2009. A review of recent multi-region input–output models used for consumption-based emission and resource accounting. Ecol. Econ. 69, 211–222.
Winchester, N., 2012. The impact of border carbon adjustments under alternative producer responses. Am. J. Agric. Econ. 94, 354–359.
Winchester, N., Paltsev, S., Reilly, J.M., 2011. Will border carbon adjustments work? B E J. Econ. Anal. Policy 11.