Consumption- vs. Production-Based Emission Policies

Michael Jakob[a,b], Jan Steckel[a,b,c], Ottmar Edenhofer[a,b,c]

(a) Potsdam Institute for Climate Impact Research PO Box 601203, 14412 Potsdam, Germany
(b) Mercator Research Institute on Global Commons and Climate Change (MCC), Torgauer Str. 12-15, 10829 Berlin
(c) Technical University of Berlin, Department "Economics of Climate Change", Strasse des 17.Juni 145, 10623 Berlin

October 2013

Abstract

Emission leakage could potentially undermine the effectiveness of unilateral climate policies. Significant emission transfers from developing to developed countries in the form of emissions embodied in trade have been interpreted as an indication of such leakage. In order to reduce leakage and provide an appropriate picture of countries' responsibility for global emissions, it has been proposed to attribute emissions on the basis of consumption instead of production. However, as one unit of imported emissions cannot generally be equated with a corresponding increase of emissions released to the atmosphere, putting a price on an externality equal to its social costs (e.g. by means of consumption-based emission pricing) is not optimal for emissions embodied in imports. Hence, we mandate considering a broad scope of trade measures to reduce leakage, in particular focusing on a few highly traded emission-intensive industries and exploiting the potential of export taxes to alleviate distributional concerns and political resistance. Finally, we argue that the optimal policy portfolio to address leakage may contain not only trade measures but also some form free allocation of emission permits as well as sectoral approaches.

Acknowledgements: We are grateful to Sabine Fuss and Philippe Quirion for helpful comments and suggestions and to Silvia Forin and Hauke Schult for assistance with consumption-based emission data.

1. Introduction

Climate change constitutes a global problem: every unit of long-lived greenhouse gas (GHG) emissions will result in an identical rise of atmospheric concentrations and subsequently global warming, regardless of where it is generated. As a consequence, it is frequently asserted that global externalities, such as greenhouse gas emissions, require global regulation in order to be effectively addressed. The most salient example of this perspective can be seen in 'Durban Action Platform' established at the 18th Conference of the Parties (COP18) of the United Nations Framework Convention on Climate Change (UNFCCC) in 2011, which calls for a global climate treaty to be adopted by the year 2015.

However, such a global agreement seems rather unlikely to emerge in the near future. Therefore, greenhouse gas emissions are currently regulated in a 'fragmented climate regime', in which individual countries or regions pursue unilateral, largely uncoordinated efforts to reduce their emissions (Hof et al. 2009). Perhaps the most prominent is the European Union's emissions trading scheme (EU ETS), which puts a cap on CO_2 emissions generated by energy-intensive industries, such as the power sector or manufacturing, covering about 40% of EU emissions (Ellerman et al. 2010). More recently, Australia has introduced a tax on CO_2 emissions (Jotzo 2012) and several developing countries, including China, Mexico and South Korea, have implemented or announced their own climate polices (Townshend et al. 2013).

While these developments may seem to be promising steps to reduce global emissions, an often voiced concern is that in the absence of a global regulation, emission reductions in one region may increase emissions in regions with less strict (or no) climate policies (van Asselt and Brewer 2010). This process – referred to as leakage – could offset at least some part of the emission reductions achieved by climate policy (Section 2). A related concern is that countries that have committed to reducing their emissions can meet their obligations by importing carbon-intensive goods and services from countries with laxer climate policies without actually reducing global emissions (Peters and Hertwich 2008b). Recent studies have demonstrated substantial and rapidly increasing emissions associated with emissions generated in the production of goods and services exported from developing (non-Annex I) to developed (Annex I) countries (Davis and Caldeira 2010, Caldera and Davis 2011, Peters et al. 2011). This has been interpreted as evidence of 'outsourcing' of emissions from developed to developing countries (Pan et al. 2008) (Section 3).

As a consequence, it has been suggested to shift the attribution of emissions from the current system of territorial accounting, under which countries are regarded as responsible for emissions generated within their national boundaries (so-called production-based accounting) towards emissions associated with their consumption activities (so-called consumption-based accounting) (Peters and Hertwich 2008b). By attributing emissions to final consumers, it is argued, a more appropriate picture of responsibility is obtained by tracking a country's actual 'carbon footprint' (Peters et al. 2009). Furthermore, as consumption-based regulation of emissions reduces the incentive to import carbon-intensive goods and services, it is seen as an appropriate way to reduce or even eliminate carbon leakage (Pan et al. 2008). Consumption-based emissions regulation could be implemented by domestic emission pricing (i.e. a carbon tax or emission trading system) combined with full border tax adjustment (BTA), which charges the domestic carbon price on emissions associated with the production of imported goods and services while reimbursing this price for goods produced domestically but exported to other countries (Ismer and Neuhoff 2007). Thus, by 'leveling the carbon playing field' (Houser et al. 2008), the efficiency of domestic emission regulations is expected to improve (Fischer and Fox 2011).

This overview paper provides a review of the literature on production- and consumption-based approaches to regulate greenhouse gas emissions. We argue that the prominent assertion that consumption-based attribution of emissions provides a more accurate account of responsibility for global emissions and necessarily reduces emission leakage does not take into account the general equilibrium implications that determine global patterns of consumption and production and hence emissions (Section 4). In particular, we emphasize that the correct attribution of global emissions to individual countries is more complex than what can be captured in either production- or consumption-based accounts, such that none of these two accounting schemes can provide a full picture of responsibility for emissions. We also highlight that there is no compelling reason to levy an identical price on domestic and imported emissions, as would be the case under consumption-based emission regulation, as avoiding the import of one unit of emissions is not equivalent to avoiding the release of one unit of emissions to the atmosphere. Besides these insights from trade theory, we also discuss the strategic dimension of measures aiming to regulate emissions embodied in imports (Section 5) and their practical implementation (Section 6). Finally, we provide an overview of alternative policies that have been proposed to reduce leakage (Section 7).

Our analysis provides the following main conclusions: First, neither production- nor consumption-based pricing of emissions are optimal policies from a social welfare point of view. Second, while consumption-based pricing of emissions can potentially reduce carbon leakage, it will not necessarily do so. Third, trade policy can play an important role in reducing carbon leakage, but its actual implementation can be expected to be fraught with serious practical problems, such as insufficient knowledge of relevant effects and parameters and transaction costs. Fourth, trade policy does not only constitute an economic instrument to influence trade partners to reduce their emissions, but also entails a strategic component that has to be taken into account in policy design. Fifth, the optimal policy portfolio to address leakage may contain not only trade measures but also some form of free allocation of emission permits (such as grandfathering or output-based rebates) and linking of emissions trading systems or expanded use of the CDM.

These findings suggest that while consumption-based accounts of greenhouse gas emissions are a valuable complement to conventional production-based approaches as a diagnostic tool, their prominent position in the current debate on how to reduce carbon leakage may be overstated. Instead of focusing on consumption-based pricing of emissions and full border tax adjustment, a broader scope of trade policies to reduce leakage, in particular focusing on few highly traded emission-intensive industries and exploiting the potential of export taxes to alleviate distributional concerns and political resistance, should be considered.

This paper proceeds as follows: Section 2 reviews the theory, empirical evidence and numerical estimates of carbon leakage. Section 3 provides an overview of the literature on shifting from a production- towards a consumption-centered perspective on emissions. Section 4 evaluates different approaches to put a price on emissions from a trade-theoretical perspective and Section 5 analyses trade measure from a game theoretical perspective, in which these policies are applied as strategic rather than economic instruments. Section 6 discusses issues related to their practical implementation and Section 7 provides of a brief overview of alternative policies to address carbon leakage. Section 8 concludes.

2. Climate Policy in Fragmented Regimes

In the absence of a global agreement to mitigate climate change, several countries or regions have implemented or announced unilateral climate measures. In the political arena, the concern that such unilateral emission reductions could – to at least some extent – be offset by increasing emissions elsewhere is frequently used as an argument against such policies (Branger and Quirion 2013). The literature on unilateral climate policies has demonstrated three mechanisms through which such leakage could occur, summarized in Table 1.

The first channel of emission leakage is commonly referred to as 'energy-market leakage' or 'supply-side leakage'. As adoption of climate policy (or strengthening of existing policies) in one part of the world translates into decreased demand for fossil fuels, the latter's world market prices can be expected to decline (Edenhofer and Kalkuhl 2011). These lower prices, in turn, will result in increased consumption of fossil fuels in other countries or regions and hence raise emissions, offsetting some of the reductions achieved in the country implementing the policy (Sinn 2008). Second, climate policy increases the relative domestic price of energy- and emission-intensive goods in the country or region implementing the policy, which will lead to increased demand for imports of these products from the world market (Markusen 1975). As a consequence – unless they have imposed a quantitative ceiling on their emission – production of these goods in other countries rises, resulting in additional emissions (Siebert 1979). This mechanism, which also includes the relocation of industries emphasized in the 'pollution haven' literature (Taylor 2005, Branger and Quirion 2013), is frequently termed 'specialization leakage' (Jakob et al. 2013). Finally, the third channel of emission leakage is free-riding on the provision of the global public good of emission reductions, i.e. 'free-rider leakage'. As it is well known from the public good literature, voluntary provision of a public good commonly is counteracted by decreased provision by other actors (Samuelson 1954). That is, in a strategic setting in which countries decide upon their emissions based on mitigation costs and avoided climate impacts, a reaction to unilateral emission reductions by one country or region can be expected to increase others' emissions (Carraro and Siniscalco 1993, Barrett 1994).

Channel of Leakage	Economic Mechanism	Related Articles
Energy market leakage	Reduced demand for fossil fuels in one region reduces world market price and encourages consumption in other regions.	Sinn (2008), Edenhofer and Kalkuhl (2011)
Specialization leakage	Higher price of emission-intensive goods in one region encourages imports from other regions.	Markusen (1975), Siebert (1979)
Free-riding	Increased contribution of the public good 'mitigation' by one region encourages free-riding in other regions.	Carraro and Siniscalco (1993), Barrett (1994)

Table 1: An overview of the channels of leakage, the economic mechanisms driving them, and related literature.

Quantitative estimates of how global GHG emissions could react to regional regulatory changes mostly rely on numerical modeling. Even though for most industries energy accounts for only a small fraction of total costs, such that leakage could be expected to be a rather minor concern (Hourcade et al. 2008), computable general equilibrium (CGE) models suggest that leakage could seriously undermine unilateral climate policies by offsetting up to 50% of domestic emission reductions (Felder and Rutherford 1993, Babiker and Rutherford 2005, Elliott et al. 2010). One possible explanation for this observation is that not industry relocation but the energy market channel accounts for the largest share of emission leakage (Böhringer et al. 2010, Burniaux et al. 2010, Fischer and Fox 2012a).

In a recent model comparison of 12 CGE models Böhringer et al. (2012c) find rather moderate leakage rates between 5% and 19%, with a mean value of 12%. However, these figures are to some extent sensitive to the employed model structure and assumptions. For instance, leakage rates increase by about one third if not only energy-related, but also process-related greenhouse gas emissions are taken into account (Bednar-Friedl et al. 2012), and by about one half if a trade model with heterogenous firms is employed (Balistreri and Rutherford 2012). The highest estimate of leakage rates in the literature is obtained by Babiker (2005), who uses an oligopolistic model with increasing returns to scale production technologies. For some parameter values, he finds leakage rates as high as 130%, i.e. unilateral climate policy would then even increase global emissions. On the other hand, leakage rates can be significantly lower if technology spill-overs to non-participating regions are taken into account (Bosetti et al. 2008, Golombek and Hoel 2004, Maria and van der Werf 2008). Some recent contributions have demonstrated that leakage can even become negative, either due to a fuel switch in countries carrying out climate policies which decreases the global price of natural gas and thus incentivizes substitution away from coal towards less carbon-intensive natural gas in third countries (Bauer et al. 2013, Curras et al. 2013), or due to higher demand for capital in the countries performing abatement, which lowers capital supply in third countries and reduces their output and emissions (Carbone 2013, Winchester and Rausch 2013). Further, different assumptions on which countries are members of the climate coalition and the ambition of their reduction efforts result in different leakage rates. For instance, Boeters and Bollen (2012) show that leakage rates are the lower the larger the coalition of countries carrying out to emission reductions.[1]

Recently, a number of empirical studies have examined location of energy intensive industries, finding that such industries are indeed more prevalent in regions that are more abundantly endowed with energy resources (Michielsen 2013) or feature lower energy prices (Gerlagh and Mathys 2011). This lends support to the hypothesis that higher energy prices due climate policy could result in some relocation of these industries (Sato and Dechezleprêtre 2013). On the sectoral level, a number of case studies have assessed the impact of carbon pricing in the EU ETS on particular industries. In a review of this literature, Zhang (2012) concludes that "[a]nalysis of cement, iron and steel, aluminium and refinery sectors does not reveal carbon leakage for these trade-exposed carbon intensive sectors during the first phase of the EU-ETS" (p.41).[2]

Other empirical studies take a different perspective, asking in how far increased trade – in contrast to climate polices – has contributed to a geographical shift of polluting industries (e.g. Grossman and Krueger 1993, Antweiler et al. 2001, Levinson 2010). In the context of climate policy, this approach has recently been taken up in the analysis of 'weak carbon leakage' which – in contrast to 'strong

[1] Note that models also differ in their sectoral aggregation. While these differences matter crucially for leakage rates on the sectoral level, their role on the macro-economic level is significantly less important (Alexeeva-Talebi et al. 2012, Fischer and Fox 2012, Kuik and Hofkes 2010).

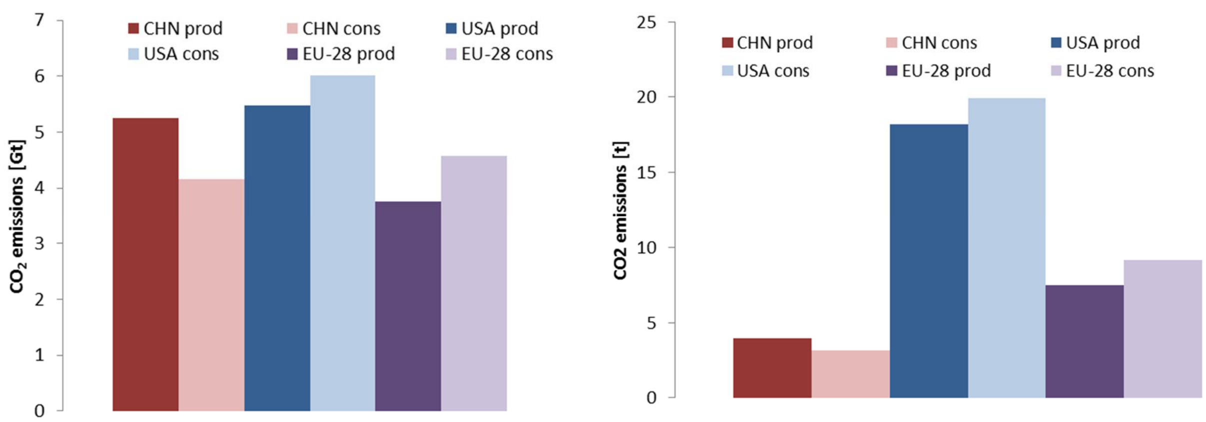
[2] However, the author concedes that "the insights from such analyses are of limited value for the future, because the EU ETS will become a much stricter scheme with a rising share of auctioning on the one hand and a decreasing yearly amount of the overall allowances to be handed out to industries on the other hand […]" (p.41).

leakage' –denotes increases of emissions in third countries for reasons unrelated to climate policy (Davis and Caldeira 2010, Peters and Hertwich 2008b, Peters et al. 2011). The implications of this line of research will be discussed in the following section.

3. Production- and Consumption-Based Climate Polices

The UNFCCC attributes GHG emissions to countries based on geographic origin, i.e. on where these emissions are released (production-based accounting). Alternatively, it has been proposed to put more emphasis on emissions related to a country's consumption activities (consumption-based accounting), in order to attribute emission to consumers based on their 'carbon-footprint' (Peters et al. 2009). Consumption-based emissions can be calculated from production-based emissions by subtracting emissions generated for exports and adding emissions generated abroad to produce imports. The difference between emissions embodied in import and exports – commonly labeled as 'net emissions embodied in trade' (NEET) – can be estimated by combining data on trade flows with multi-regional input/output tables that provide information on the carbon-intensity of imports and exports and are also able to quantify trade flows in intermediate goods (see Peters et al. 2012 for a review).

Applying these methods for the year 2004 reveals that approximately one fifth of global emissions are traded, embodied in goods and services (Davis and Caldeira 2010, Peters et al. 2012). Annex I countries typically are net importers of emissions, with the US (0.7 GtCO2/a) , Japan (0.3 GtCO2/a) and the UK (0.25 GtCO2/a) as the top net importers of emissions (Davis and Caldeira 2010). On the other hand, non-Annex I countries typically 'export' emissions, with China being the single most important exporter (Davis and Caldeira 2010, Peters et al. 2012). Differences between national consumption- and production-based emissions can be significant: Emissions in the US increase by 10.9% when accounting for them on the consumption-based instead of the territorial level, while those of China would decrease by 26.4% (Peters et al. 2012). A very similar picture emerges from Figure 1, which displays consumption- and production-based emissions for the US, the EU28 and China for the year 2008. Considering the growth of emission transfers, Peters et al. (2011) find that net carbon transfers from developing (non-Annex I) to developed (Annex I) countries have increased four-fold between 1990 (0.4 GtCO2) and 2008 (1.6 GtCO2). In the same period, CO2 emissions embodied in traded goods increased from 4.3 GtCO2 (20% of global emissions) to 7.8 GtCO2 (26% of global emissions).

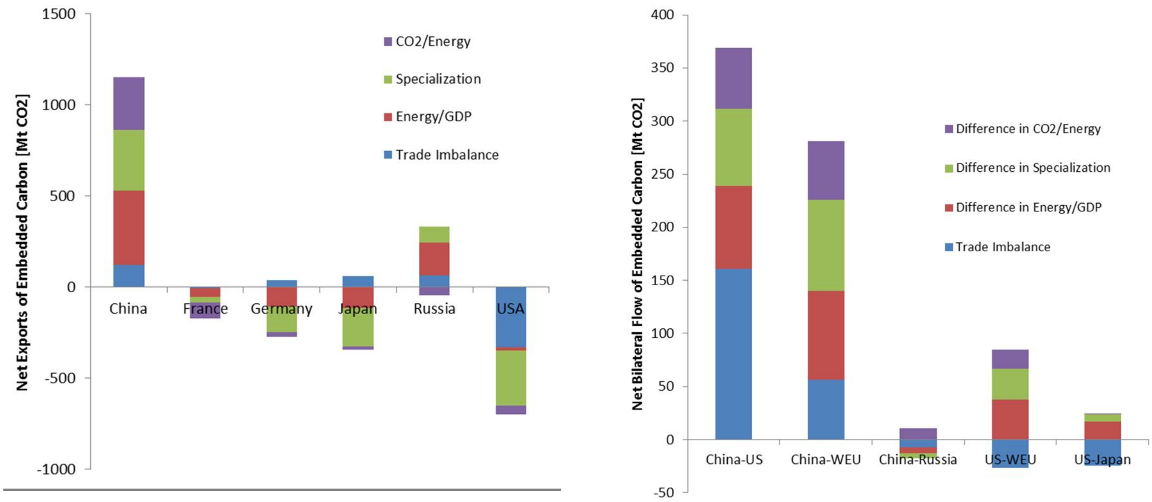


(a) Total CO2 emissions (b) CO_2 emissions per capita

Figure 1: Production- and consumption-based CO_2 emissions for China, the US, and the EU28. Panel (a) displays national emissons, panel (b) per-capita emissions. Calculated using the method described by Lenzen (2001) based on GTAP8 data (Narayanan 2012).

Given this sizable extent of NEET, indicating the substantial fragmentation of production-patterns and supply chains in the global economy (Davis et al. 2011), there is a wide-spread concern that regional climate policies might be rendered ineffective by 'outsourcing' of emissions and that this process might undermine international climate negotiations (Peters and Hertwich 2008a). In particular, the observed increase of NEET has frequently been interpreted as a sign that an increasing amount of emissions are moving beyond the bounds of regulation, resulting in 'weak carbon leakage'. In the literature two definitions of weak carbon leakage are used interchangeably (e.g. Peters and Hertwich 2008a, Davis and Caldeira 2010): first, increases of emissions in third countries due to reasons unrelated to climate policy. Second, an increase of emissions embodied in traded goods. As we will argue below, these two definitions are in general not equivalent, such that attributing emissions in a manner that could be employed as a basis for policy making is more complex than what can be derived from emission accounts.

Following the interpretation that increases in NEET can directly be interpreted as causal for increasing emissions in third countries, Shui and Harriss (2006) conclude that US-China trade has increased global emissions by about 720 million tons. In a similar vein, Aichele and Felbermayr (2012) observe that during the first commitment period of the Kyoto protocol, signatories' NEET increased by more than the reduction of their domestic (production-based) emissions, concluding that the Protocol has had no effect on reducing global emissions. As a consequence, various policy proposals have been brought forth to regulate emissions on a consumption instead of a production basis. It is argued that such schemes could reduce or even eliminate carbon leakage (Peters and Hertwich 2008a, Pan et al. 2008) and result in a more equitable distribution of responsibilities to reduce emissions (Pan et al. 2008, Weber et al. 2008) by lowering developing countries' reduction commitments (Peters and Hertwich 2008a and 2008b, Pan et al. 2008, Shui and Harriss 2006), which would make the latters' participation in an international climate agreement more likely (Peters and Hertwich 2008a and 2008b, Pan et al. 2008, Weber et al. 2008). Some authors have also argued in favor of consumption-based accounting in order to allow consumers in developed countries to more actively control for their emissions, in line with the 'carbon footprint' on the personal level (Peters et al. 2009). These recommendations from the academic community have been picked up by the UK House of Commons (2011) proposing that the UK should employ consumption-based accounting in parallel to production based accounting in order to "acknowledge our responsibility".



(a) Drivers of NEET for individual countries (b) Drivers of NEET in bilateral trade flows

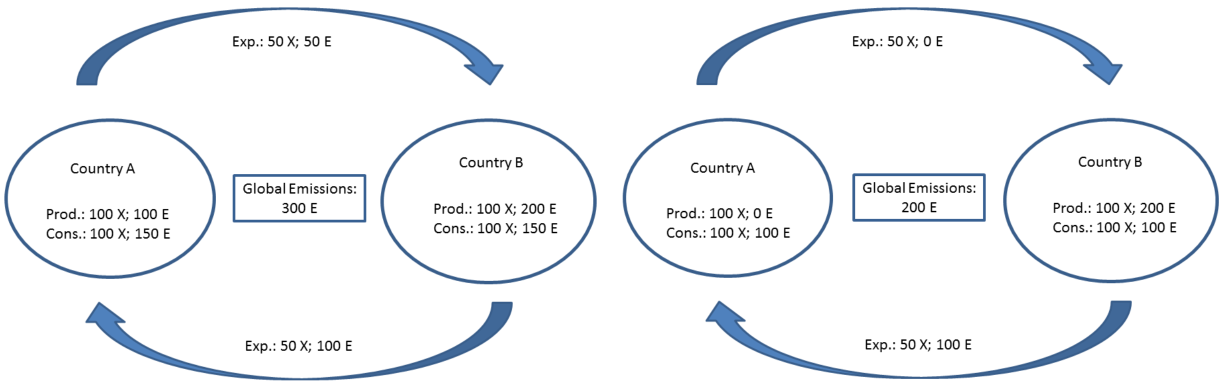
Figure 2: NEET for individual countries (a) and bilateral trade flows (b), decomposed into (i) carbon intensity of energy production, (ii) energy intensity of GDP, (iii) trade specialization, and (iv) trade balance. For instance, 45% of the observed imbalances in carbon trade between the US and China can be attributed to China's current account surplus, while trade specialization accounts for only about 20%. Adopted from Jakob and Marschinski (2013).

However, the interpretation that NEET can be regarded as an indication of direct increases in global emissions – and hence as a measure of the importer's responsibility – has recently been questioned by some authors. Using a decomposition (shown in Figure 2), Jakob and Marschinski (2013) demonstrate that a country can be a net exporter of embodied emissions for several reasons: first, because of a relatively high carbon intensity of energy production. Second, due to relatively a high energy intensity of GDP (i.e. the amount of energy employed to produce one unit of GDP). Third, due to trade specialization in carbon-intensive products. Fourth, because of a current account surplus. From this observation they argue that an understanding of how these factors drive imbalances in carbon trade is required in order to attribute changes in global emissions to individual countries or regions. The trade-theoretic rationale behind this assertion will be considered in the following section.

4. Emissions Pricing From a Trade-Theory Perspective

Jakob and Marschinski (2013) argue that the effect of trade on emissions can only be evaluated in the light of counterfactuals, i.e. by asking what trade partners' emissions would be in the absence of trade. This perspective emphasizes that in order to assess the impact of trade on global emissions, it is not sufficient to compute emissions generated for the production of traded goods. Instead, in order to attribute emissions one has to take into account general equilibrium effects determining the shifts of production and consumption patterns as a response to a change in a country's emission trade balance.

A simple example, displayed in Figure 3a, illustrates this line of reasoning. Consider two countries A and B, each producing 100 units of an identical good X and exporting half of their production to the other country (this corresponds e.g. to a trade in varieties model à la Krugman 1979 or a reciprocal dumping model à la Brander and Krugman 1983). Let both countries be identical on all accounts except their emission intensity (i.e. the amount of emissions E generated to produce one unit of X), which we assume to be twice as high in country B than in A (and normalized to one on A). Then, country A would be found to be a net importer of 50 units of E from country B, putting its consumption-based emission account at 150 units of E (i.e. 100 units of domestically produced E, plus 50 units of NEET). However, A's imports of X from B cannot be said to be the causal factor for an increase in global emissions. If A were to withdraw from trade, its consumption-based emissions would decline from 150 to 100 units, but B's emissions – and hence global emissions – would remain entirely unaffected. Further, suppose country A were to introduce a new technology that would permit it to produce good X free of emissions, as shown in Figure 3b. Then, A's production-based emission account would drop by 100 units (from 100 to 0), but its consumption-based account by only 50 (from 150 to 100). This can be explained by the fact that A's NEET have increased by 50 units, namely from 50 to 100, due to a reduction of its exported emissions. From the observation of increased NEET in A, one could be tempted to conclude that the emission reduction in A has partly been offset by leakage and only resulted in a decrease of global emissions by 50 units. Yet, such a conclusion would clearly be mistaken, as the reduction of emissions in A has not increased territorial emissions in B, and resulted in an actual reduction of global emissions of 100 units (from 300 to 200 units).



(a) Trade in identical goods with different emission intensities

(b) Trade in identical goods after production in country A has become emission free.

Figure 3: Differences between consumption-based emissions and global emissions for the case of two countries A and B producing a single identical good X. Countries are assumed to be identical in all aspects except their emission intensity.

These thought experiments can also be extended towards more practical examples: for instance, under a consumption-based approach to regulate emissions the EU could employ dirty technologies to produce exports without affecting its emission account. Conversely, if China were to introduce an ambitious policy to reduce the emission intensity of production, the consumption-based emissions of the US would decline significantly due to a reduction of emissions embodied in imports from China. In both cases, consumption-based accounts do not provide a direct link between a country's actions and changes in global emissions that could be employed to assess this country's responsibility for emissions. This is confirmed by the finding that despite being substantial net exporters of emissions, China's as well India's emissions would hardly change if these countries were to withdraw from international trade and instead meet their consumption entirely by domestic production (Peters et al. 2007, Dietzenbacher and Mukhopadhyay 2007). That is, even though substantial amounts of emissions are generated to produce exports, imports save a comparable amount of emissions that would arise if these countries were to produce the imported goods domestically, such that trade cannot be regarded as a major driving factor of rising emissions in these countries.[3]

Efficient regulation of emissions requires that the latter are attributed in a way such that changes in emission accounts directly correspond to changes in global emissions. In this case, the socially optimal outcome can be obtained by putting a price on emissions equal to their social costs (Pigou 1920). Under a global regime, production- and consumption-based pricing of emissions would result in identical outcomes (Steckel et al. 2010). In a fragmented regime, in which only some actors have polices that put a price on emissions in place, consumption-based pricing of emissions is equivalent to a production-based policy combined with a full border tax adjustment, which charges the domestic price on emissions associated with the production of imported goods and services while reimbursing this price for goods produced domestically but exported to other countries (Elliot et al. 2010, Monjon and Quirion 2010). As highlighted by Markusen (1975), such measures to tax imports or exports, respectively, cannot directly put a price on emissions in other countries, but can only indirectly affect foreign producers or consumers by influencing world market prices. The optimal policy to regulate trans-boundary emissions can then be obtained by a combination of production-based emission pricing and a tariff on imported goods (Hoel 1994 and 1996, Golombek et al. 1995). Extending Markusen's (1975) model, Jakob et al. (2013) demonstrate that the effect of a change in one country's imports on its trade partners' emissions arise from the interaction of three factors: first, the reaction of world market price to increased or decreased import demand. Second, the reaction of foreign producers to a change in the world market price by shifting their production between exported and domestically consumed goods. Third, the emission intensity of exports relative to the emission intensity of production for the domestic market. This demonstrates that the correct attribution of emissions is more complex than what can be derived from either production- or consumption-based accounts. It also implies that in general the intuition that the Pigouvian rule of putting a price equal to its social costs on an externality cannot be applied to emissions embodied in trade in a straightforward manner (Yonezawa et al. 2012), such that full BTA – and hence consumption-based pricing of emissions – does not constitute an optimal policy (Jakob et al. 2013, Tsakiris et al. 2012, Yonezawa et al. 2012). The basic intuition behind this result is that avoiding the import of one unit of emissions is not equivalent to avoiding the release of one unit of emissions to the atmosphere. Instead, reducing imports of emissions will go hand in hand with general equilibrium changes in production- and consumption-patterns that have to be included in the computation of the applied tariff. This finding also refutes the – on first glance plausible – idea that a policy that 'extends the perimeter of emission pricing' by subjecting a larger quantity of emissions to a price signal, i.e. by means of consumption based emission pricing, necessarily reduces carbon leakage. Such a policy would indeed eliminate one distortion, namely the differences in carbon prices between the country applying the policy and the exported goods of the country against which the policy is applied. However, it also creates a new distortion by introducing a wedge between the carbon price for the latter country's exports and the one for goods produced for the domestic

[3] This is a more general result of the fact that the factor content of trade – i.e. the amount of production factor employed to produce imports and exports, respectively – cannot be applied to assess counterfactual situations (Leamer 1980, Trefler 1995). That is, observing the amount of a production factor embodied in trade does not allow evaluating how exporters' production structure and hence their emissions would be in the absence of trade.

market. The overall effect of these two effects can be a decrease as well as an increase in carbon leakage (Jakob et al. 2013).[4]

Several studies have numerically assessed the effects of BTA on leakage. Kuik and Hofkes (2010) show that full BTA might considerably reduce leakage in the iron and steel industry, but only achieve a modest reduction of the overall leakage rate. A recent comparison of 12 CGE models finds that BTA would decrease leakage rates from on average 12 to 8% (Böhringer et al. 2012c). However, one paper in this comparison exercise also highlights that among the policies analyzed, full BTA is not the most cost-efficient way to reduce leakage (Böhringer et al. 2012b). These results reaffirm that full BTA – and hence consumption-based emission pricing – does not constitute an optimal policy to address emission leakage. However, they also show that in a fragmented climate regime some form of trade measures are required to achieve cost-efficient mitigation. As highlighted by Jakob et al. (2013), the socially optimal tariff would imply strong informational requirements on elasticities of substitution in production and consumption as well as emission intensities of economic sectors even in a highly stylized model. For this reason, it seems reasonable to extend the scope of analyzed policies and consider a broad variety of trade measures that could be put into practice. For instance, putting a tariff on imports of a few selected heavily traded emission-intensive products (such as aluminum, steel, cement, or certain chemicals; see Monjon and Quirion 2010) can be expected to reduce carbon leakage, as they are unlikely to be replaced by the production of goods with a higher carbon-intensity abroad. Finally, trade measures might not only help to alleviate leakage through their effect on relative prices, but might also have strategic repercussions on other countries' environmental policies. This aspect will be discussed in the following section.

5. Trade Measures as Strategic Instruments

As has been demonstrated above, trade measures, including BTA, may have only a limited potential to reduce emission leakage, in particular as they cannot effectively address leakage occurring through the energy market channel (Weitzel et al. 2012; see also Section 2). Yet, it can be argued that trade measures do not only have an economic impact on global patterns of production and consumption by affecting relative prices, but also entail a strategic component (Helm et al. 2012). From this perspective, a tariff can be regarded as a threat to punish other countries without (or with less stringent) climate policies, inducing them to implement climate policies of their own (or strengthen already existing policies). For the case of the Montreal Protocol on Substances that Deplete the Ozone Layer, some authors have identified trade sanctions as an important tool to induce participation (Benedick 1998). For the case of climate policy, Winchester et al. (2011) conclude that BTA is "a costly method to reduce leakage, but may be an effective coercion strategy" (p.20). In order to pose such an incentive, trade measures must fulfill two conditions: first, they must impose sufficiently high costs on the country against which they are employed to make it worthwhile to incur additional mitigation costs in order to escape the punishment (Barrett 2011); second, they must benefit the country imposing the tariff, such that the threat is credible (Kalbekken and Hovi 2007).

[4] As shown by Jakob et al. (2013), the possibility that border measures could also increase leakage had been overlooked by previous studies, which either assume that countries are fully or that there is only one polluting sector (e.g. Markusen 1975, Copeland 1996, Elliot et al. 2010).

In a game theoretic model, in which countries decide to either join a coalition that sets abatement levels in a way to maximize its members' joint payoff, or remain outside the coalition and perform abatement at their business-as-usual level, Barrett (1997) shows that trade sanctions accompanied by a minimum participation clause to coordinate government behavior can contribute to achieving universal participation in the agreement and the socially optimal level of abatement. In a similar vein, using a calibrated multi-regional inter-temporal growth model, Lessmann et al. (2009) find a significant potential for trade sanctions to participate in a climate coalition with a tariff rate of 1.5% to 4% on imports from non-participating countries being sufficient to induce full participation.[5] Finally, Weitzel et al. (2012) use a CGE model to analyze how different schemes to put a price on emissions embodied in imports pose incentives to join the climate coalition. From their policy baseline, in which only Annex-I countries are assumed to adopt climate policies, they find that with full BTA, energy exporters would prefer being in the coalition, while significantly higher import tariffs would be required to make participation attractive for China and an aggregate of other middle income countries.

However, the above models do not allow for the possibility that countries against which tariffs are employed impose countermeasures (i.e. 'retaliate'). Tsakiris et al. (2010) employ a model of two large open economies that can set each of two policy instruments under consideration – a price on emissions and a tariff on imports – either cooperatively (such that their joint welfare is maximized) or non-cooperatively (in which case each country independently aims at maximizing its welfare). They find that regardless of whether they cooperate on emission taxes or not, countries will opt for free trade if they cooperate on tariffs, but implement tariffs if the latter are chosen non-cooperatively. Keen and Kotsogiannis (2011) demonstrate that in a setting in which transfer payments are restricted the globally Pareto-optimal policy consists in applying different carbon prices in different countries in combination with import tariffs. The intuition behind this result is that poor countries benefit more than rich ones from lower mitigation burdens arising from lower carbon prices, and tariffs can be used as an imperfect substitute for transfer payments in order to shift revenues between countries.

To sum up, from a strategic perspective countries may employ trade measures as a complement to their environmental policies in order to influence other countries' behavior. In reality, the tariffs available to policy-makers may be restricted by either international trade agreements in order to prevent that they are applied as a protectionist tool to further the interests of specific industries (Baldwin and Evenett 2009). Moreover, practical considerations, such as availability of relevant information or ease of applicability also need to be taken into account. For this reason, the following section focuses on the practical implementation of such trade measures.

6. Implementing Trade Measures to Address Carbon Leakage

Perhaps the most heavily discussed issue regarding the actual implementation of trade measures to accompany environmental policies is compatibility with international trade law. As has been pointed

[5] Note that in Barrett (1997) and Lessmann et al. (2009) the tariff is independent of the carbon content of imported goods but only depends on whether a country participates in the coalition. It hence should be regarded as a trade sanction rather than a carbon tariff or border tax adjustment (see Section 4). A similar perspective is provided by Turunen-Red and Woodland (2004), who emphasize the role of tariff reform as an incentive to compensate countries for the costs of environmental policy reform.

out in Section 4, moving from a production- towards a consumption-based system of emission pricing can be achieved by means of full BTA, in which the domestic emission price is levied on emissions 'embodied' in imports (i.e. emissions that were generated directly or indirectly for the production of the imported goods or services), while for exported products domestic firms are reimbursed costs paid to cover emissions prices (e.g. an emissions tax or the costs of tradable permits). In general, countries' leeway to regulate trade is closely limited by the World Trade Organization (WTO). However, Art XX of the General Agreement of Trade and Tariffs (GATT) permits exceptions from this general principle if they are undertaken for the "conservation of exhaustible natural resources if such measures are made effective in conjunction with restrictions on domestic production or consumption" and "[s]ubject to the requirement that such measures are not applied in a manner which would constitute a means of arbitrary or unjustifiable discrimination between countries where the same conditions prevail, or a disguised restriction on international trade" (GATT 1947, see Perez 2005). Another possibility to justify putting a price on emissions embodied in imports is the provision of GATT Article II:2(a), which permits to impose "a charge equivalent to an internal tax […] in respect of the like domestic product or in respect of an article from which the imported product has been manufactured or produced in whole or in part" (GATT 1947, see also Pauwelyn 2007).[6]

Against this background, it has been pointed out that – even though WTO legality is eventually only established in the form of case law once a Panel to settle a concrete dispute has reached a decision – there indeed seem to be ways to impose BTA without violating the stipulations of the GATT (Bhagwati and Mavroidis 2011). In any case, this requires that measures are adopted in a way that does not discriminate against importers, either in favor of domestic firms, or in favor of firms from a third country. Ismer and Neuhoff (2007) argue that the so-called 'best-available technology' approach, which calculates emission contents assuming that the country against which BTA is applied uses environmental standards and production technologies equivalent to those required within the area in which the BTA is applied, would stand the highest chance to be regarded as non-discriminatory. Yet, BTA might be politically contentious, as countries against which such measures are applied might not acquiesce to them but instead seek retaliation by raising their own tariffs or technical barriers to trade (Bhagwati and Mavroidis 2011, see also Section 5). Furthermore, it seems likely that countries against which BTA is applied could challenge free allocation of emission permits– which is common practice in e.g. the EU – as giving an unfair competitive advantage to domestic firms (de Cendra 2006).

An additional reason why BTA might face severe political opposition stems from the adverse effects they might have for people living in poor countries. For instance, Mattoo et al. (2009) estimate that if high income countries were to cut their carbon emissions by 17% by 2020 relative to their 2005 level, China manufacturing exports would decline by about 21%, and those of India by about 16%. In a similar vein, Böhringer et al. (2012b) show that BTA would reduce carbon leakage and increase cost efficiency, but also shift the costs of emission reduction towards countries that do not participate in the climate coalition, such that equity concerns might mandate against putting this policy into practice. Arguably, equity concerns as well as political resistance could be alleviated by opting for a jointly agreed system of export taxes. While export taxes (in the exporting country) are equivalent to import tariffs (in the importing country) in terms of their effect on relative prices, and hence on leakage, the crucial difference is which country receives the associated revenues. An export tax might

[6] Such adjustments are common practice e.g. value-added taxes that are levied on imported products once they enter the importer's national territory.

be politically less contentious, as its revenues accrue to the exporter instead of the importer, which would entail fewer negative effects for developing countries (compared to BTA).[7]

Finally, consumption-based policies could involve significant transaction costs related to information and monitoring (Dröge et al. 2009) and be subject to major uncertainties regarding the emission content of traded goods (Sato 2013). Especially if BTA is applied on a basis that estimates emissions embodied in traded product on the process-level, it might be a major challenge to obtain up-to-date information on individual products' emission contents (WTO-UNEP 2009). In addition, such a system could rather easily be undermined by 'creative accounting': for instance, foreign firms that generate electricity for their production of goods and services (i.e. auto-producers) could claim that they employ the relatively clean (e.g. hydro) part of their electricity portfolio for producing exports, while the relatively dirty part (e.g. coal) is used for the domestic market. Dealing with such claims on a case-by-case basis would involve considerable administrative costs and might not even effectively address leakage (as e.g. the firm might split into two distinct legal units, one only using clean, the other one only emission-intensive energy, without altering country-wide or global emissions). Applying the 'best-available technology' approach discussed above, on the other hand, would not only obliterate such incentives to game the system (Ismer and Neuhoff 2007), but would also reduce foreign firms' incentives to switch to cleaner technologies. Complexity could be reduced by applying BTA only in selected emission-intensive sectors that are heavily traded and hence at the greatest risk of carbon leakage (Monjon and Quirion 2010).

7. Alternative Policies

Given that consumption-based emission policies are in general not socially optimal to address leakage and in view of the considerable practical problems related to their practical implementation, several alternatives to increase the efficiency of unilateral emissions reduction policies have been proposed. These are summarized in Table 2 below.

First, one straightforward solution consists in awarding emission permits free of charge to emission-intensive, trade-exposed industries. Through 'grandfathering', i.e. allocation of emission permits in proportion to past emissions (Clò 2010). Even though the regulated firms are still affected by the emission price, they will have an incentive to remain in business if their potential losses are covered (Demailly and Quirion 2009). Further, if future emission permits are assigned by grandfathering using today's emissions as a basis, firms will have fewer incentives to reduce their production in order to receive more of these permits at a later date (Weitzman 1980). Consequently, if the respective industries are less directly affected by a price on emissions, there is less incentive to increase imports in these sectors, such that carbon leakage is reduced (Demailly and Quirion 2006). However, this also reduces these industries' incentive to reduce their emissions, such that more abatement has to be performed in other sectors, where it may come at a higher cost. That is, free allocation of emission permits for these industries can reduce the negative side effects of the regulation (i.e. leakage), but

[7] The perhaps most prominent example of measures to restrict exports is the voluntary export restraints implemented by Japanese car manufacturers in the 1980s to protect the US car industry from import surges. More recently, China has introduced a tax on exports of energy intensive industries, which can be expected to reduce Chinese emissions to at least some extent (Wang and Voituriéz 2009).

will also at the same time to some extent undermine the objective for which the regulation was introduced in the first place (i.e. achieving cost-efficient emission reductions).

Second, output-based rebates (OBRs) constitute a further means to distribute emission permits to firms free of charge. Under such a rebate, the allocation given to a firm would be calculated by multiplying the expected output of a given product with an industry- or sector-specific benchmark. In contrast to an allocation exclusively derived from historical values (such as grandfathering), which poses an incentive to reduce production and results in increased demand for imports and hence leakage, OBRs only incentivize a switch to cleaner technologies (Quirion 2009). Therefore, OBRs would likely be more effective in tackling leakage than free allocation of emission permits based on past emissions. However, with OBRs the price signal for emission-intensive products is not fully passed through to final consumers, such that the incentive to change consumption patterns towards less emission-incentive products is reduced. This effect could raise the economic costs of achieving a certain level of emission reductions above those of grandfathering (Quirion 2009). Comparing OBRs to BTA, Fischer and Fox (2012a) point out that no unambiguous conclusion can be drawn regarding the question which policy is preferable in terms of welfare or reducing leakage. Rather, the total effect of both policies depends on the interplay between creating additional domestic emissions versus avoiding emissions abroad (which, in turn, depends on the specific parameters of the model).

Third, instead of extending emission prices to exports from countries that have no (or less stringent) emission regulations in place, pricing could be extended to certain key sectors of this country's economy. One example is the Clean Development Mechanism (CDM), which allows creating tradable emission permits by abating emissions in e.g. the power sector or industry in countries that do not have reduction commitments under the UNFCCC (i.e. non-Annex-I countries). As it puts a price on emissions arising from emission-intensive sectors, Kallbekken (2007) argues that the CDM will contribute towards leveling the carbon playing field and hence reduce leakage. Rosendahl and Strand (2011), however, argue that by reducing emissions from sectors that are covered by the CDM but increasing emissions from sectors which are not included, the CDM may in fact increase leakage.[8] Beyond CDM, 'sectoral approaches' that limit emissions in some parts of an economy can be employed to equalize emission prices across countries by allowing emission permits issued for the respective sector to be traded within existing schemes, such as the EU ETS (Meckling and Chung 2009). Such sectoral linking of emissions trading systems has the potential to reduce as well as to increase leakage, depending on which sectors are covered and on their relative emission intensities (Marschinski et al. 2012). The above considerations reiterate and expand a finding that has been central for the discussion on BTA in Section 4: extending emission prices to certain parts of an economy (be it to activities covered by the CDM, a sectoral approach, or BTA on exported products) removes one distortion (the original difference between the emission price between the now covered activities in both countries), but at the same time creates a new one (the difference between the emission prices between the sector that is covered by the policy and the one that is not). Hence, emissions from activities covered by CDM, BTA, or a sectoral agreement will decline, while emissions from unregulated activities can be expected to increase. The net effect can be a decrease, but also a net increase in leakage.

[8] Note that Kallbekken (2007) as well as Rosendahl and Strand (2011) abstract from further problems related to the CDM, such as additionality or monitoring and verification (see e.g. Schneider 2009, Wara 2007).

Measure	Description	Related articles
'Grandfathering' of emission permits	Reduces leakage in sectors profiting from the free allocation, but also reduces incentive to lower emissions.	Demailly and Quirion (2006 and 2008), Clò (2010)
Output-based rebates	Provides incentive to lower emission intensity of production, but not its volume.	Quirion (2009), Fischer and Fox (2012a)
Linking and expanded CDM	Puts price on emissions in certain sectors, but may increase emissions in other sectors.	Kallbekken (2007), Rosendahl and Strand (2011), Marschinski et al. (2012)

Table 2: Overview of alternative measures to address carbon leakage.

Finally, it is also conceivable that simply accepting that leakage occurs and compensating the increase of emissions abroad by stricter domestic emission regulation could be a more cost-efficient way to achieve a desired amount of global emission reductions than using BTA. Indeed, some studies find that BTA increases the global costs of achieving a certain level of emission reductions, even if abatement policies are implemented in only a subset of countries (e.g. Annex-I countries) (Winchester et al. 2011). However, as outlined in Section 4, from a purely self-interested perspective, the optimal policy to regulate emissions contains an import tariff. For this reason, trade measures could still be desirable for individual countries or regions, as it shifts part of the costs of emission reductions to others (Böhringer et al. 2012b).

In summary, a variety of alternative polices to consumption-based regulation could help to reduce emission leakage. These policies need to be evaluated in a second-best setting that also takes into account their revenue raising effect and the possibility to lower distorting taxes on e.g. labor or capital (Fischer and Fox 2012b). Against this background, the optimal policy portfolio may consist of a mix of trade measures in combination with free allocation of permits by means of grandfathering or output-based rebates, and further efforts to extend emissions pricing via linking of emission trading systems or the CDM.

8. Conclusions

This article has argued that emission leakage could potentially undermine the effectiveness of unilateral climate policies. In particular, the findings of several recent studies that significant emission transfers from developing to developed countries have been interpreted as an indication of leakage. Hence, it has been suggested that regulating emissions on the basis of consumption instead of production could reduce emission leakage and provide a more appropriate picture of countries' responsibility for global emissions. However, as we have shown, in general one unit of imported emissions cannot be equated with a corresponding increase of emissions released to the atmosphere. Rather, one has to take into account general equilibrium effects that determine how global patterns of production and consumption change as a response to an additional marginal import of one unit of emissions (i.e. by not only considering the emissions content of exports, but also the emissions replaced by imports). Thus, there is no one-to-one link between changes in a given country's consumption-based emission account and global emissions. That is, production and consumption-based emission accounts represent accounting devices, neither of which can directly be employed to assign responsibilities for emissions.

Likewise, for the design of appropriate policies to address carbon leakage, the Pigouvian prescription of putting a price equal to its social costs on an externality (e.g. by means of full BTA) cannot be applied to emissions embodied in imports, as avoiding one unit of imported emissions is not equivalent of preventing the release of one unit of emissions to the atmosphere. This also means that the idea of ‘extending the perimeter of regulation’ by subjecting a larger amount of emissions to a price signal does not necessarily result in less leakage. Such a policy levels the carbon playing field between the economy applying such a policy and its trade partner’s exported products. However, it also creates an additional distortion between the emission price on the trade partner’s exported and its non-exported products. The result can be a decrease but also an increase in leakage. Numerical analyses suggest that full BTA would indeed – at least moderately – reduce leakage. Yet, there is a broad variety of policies that reduce leakage which may be preferable to BTA from a social welfare perspective. For this reason, future research should examine a broad portfolio of trade policies. In particular, a tariff on imports of highly traded emission-intensive industries, such as steel, aluminum and certain chemicals, is likely to reduce leakage (as this production is unlikely to be replaced by more emission-intensive one in the other country) and would be relatively easy to implement and administer. As trade measures also have to be compatible with international trade regulations (e.g. WTO law) and may entail strategic effects (e.g. retaliation), it seems advisable to aim at mutually agreed upon measures. One salient example are export taxes, which have the same effect as import tariffs with regard to leakage, but which permit the exporter to appropriate the revenues, which could ease distributional concerns and alleviate political resistance.

Finally, in addition to trade measures, the literature has identified alternative policies to address emission leakage. These include free allocation of emission permits through e.g. grandfathering or output-based rebates, as well as linking of emissions trading systems or the expanded use of the CDM. Arguably, the relative performance of these measures in a second-best setting will be highly context specific, and it seems unlikely that one measure will be superior in any situation and on all accounts. Rather, the optimal policy can be expected to consist of a mix of these policies.

References

Aichele, R., Felbermayr, G. (2012): Kyoto and the carbon footprint of nations, Journal of Environmental Economics and Management 63(3): 336-354.

Alexeeva-Talebi, V., Böhringer, C., Löschel, A., Voigt, S. (2012): The value-added of sectoral disaggregation: Implications on competitive consequences of climate change policies, Energy Economics 34(S2): S127-S142

Antweiler, W., B.R. Copeland, and M. Scott Taylor (2001), "Is free trade good for the environment?", American Economic Review, 91: 877-908.

Babiker, M.H. (2005): Climate change policy, market structure, and carbon leakage, Journal of International Economics 65(2): 421-445

Babiker, M.H. and T.F. Rutherford (2005). The Economic Effects of Border Measures in Subglobal Climate Agreements. Energy Journal 26(4):99-126.

Baldwin, R. and Evenett, S. (2009): The collapse of global trade, murky protectionism, and the crisis: Recommendations for the G20. Ebook, available online http://www.voxeu.org/content/collapse-global-trade-murky-protectionism-and-crisis-recommendations-g20 [accessed 28 Oct 2013]

Balistreri, E.J., Rutherford, T.F. (2012): Subglobal carbon policy and the competitive selection of heterogeneous firms, Energy Economics 34(S2): S190-S197.

Barrett, S. (1994). Self-enforcing international environmental agreements. Oxford Economic Papers 46:878-94.

Barrett, S. (1997): The strategy of trade sanctions in international environmental agreements Resource and Energy Economics, 19, 345-361

Barrett, S. (2011): Rethinking climate change governance and its relationship to the world trading system The World Economy, 34:, 1863-1882

Bauer N, Mouratiadou I, Luderer G, Baumstark L, Brecha RJ, Kriegler E, Edenhofer O (2013): Global fossil energy markets and Climate Change Mitigation: an analysis with ReMIND, Climatic Change, forthcoming.

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 Economics 34(S2): S168-S180.

Benedick, R.E. (1998): Ozone Diplomacy: New Directions in Safeguarding the Planet. Harvard University Press

Bhagwati, J. and P.C. Mavroidis (2007). Is action against US exports for failure to sign Kyoto Protocol WTO-legal? World Trade Review 6(2):299-310.

Boeters, S., and Bollen, J. (2012). Fossil Fuel Supply, Leakage and the Effectiveness of Border Measures in Climate Policy. Energy Economic 34:S181-S189

Böhringer, C., Bye, B., Fæhn, T., Rosendahl, K.E. (2012a): Alternative designs for tariffs on embodied carbon: A global cost-effectiveness analysis, Energy Economics 34(S2): S143-S153

Böhringer, C., C. Fischer and K.E. Rosendahl (2010). The Global Effects of Subglobal Climate Policies. The B.E. Journal of Economic Analysis & Policy 10(2), Article 13.

Böhringer, C., Carbone, J., Rutherford, T.F. (2012b): Unilateral climate policy design: Efficiency and equity implications of alternative instruments to reduce carbon leakage, Energy Economics 34(S2): S208-S217

Böhringer, C., Rutherford, T. F., & Balistreri, E. J. (2012c). The role of border carbon adjustment in unilateral climate policy: Overview of an Energy Modeling Forum study (EMF 29). Energy Economics 34:S97-S110.

Bosetti, V., Carraro, C., Massetti, E., Tavoni, M. (2008): International energy R&D spillovers and the economics of greenhouse gas atmospheric stabilization, Energy Economics 30(6): 2912-2929

Brander, J., Krugman, P. (1983): A 'reciprocal dumping' model of international trade, Journal of International Economics 15(3-4): 313-321

Branger, F., Quirion, P. (2013): Climate policy and the ‘carbon haven’ effect. WIREs Climate Change. Available online at DOI: 10.1002/wcc.245 [accessed 28 Oct 2013]

Burniaux, J. M., Chateau, J., & Duval, R. (2010). Is there a case for carbon-based border tax adjustment? An applied general equilibrium analysis. Applied Economics, 45(16), 2231-2240.

Caldeira K., and S. J. Davis (2011). Accounting for carbon dioxide emissions: A matter of time, Proceedings of the National Academy of Sciences (PNAS) 108(21): 8533–8534

Carbone, J.C. (2013): Linking Numerical and Analytical Models of Carbon Leakage, American Economic Review 103(3): 326-31

Carraro, C. and D. Siniscalco (1993). Strategies for the International Protection of the Environment. Journal of Public Economics 52:309-28.

Clò, S. (2010): Grandfathering, auctioning and Carbon Leakage: Assessing the inconsistencies of the new ETS Directive," Energy Policy 38(5): 2420-2430

Copeland, B.R. (1996). Pollution content tariffs, environmental rent shifting, and the control of cross-border pollution. Journal of International Economics 40(3-4):459-476.

Curras T.A., Bauer, N., Kriegler, E., Schwanitz, J., Luderer, G., Aboumahboub, Giannousakis, A., Hilaire, J. (2013): Carbon leakage in a fragmented climate regime: The dynamic response of global energy markets. Technological Forecasting and Social Change, forthcoming

Davis, S.J. and K. Caldeira (2010). Consumption-Based Accounting of CO2 Emissions. Proceedings of the National Academy of Sciences of the U.S.A., 107 (12):5687-5692.

Davis, S.J., Peters, G.P., Caldeira, K. (2011). The Supply Chain of CO2 Emissions. PNAS www.pnas.org/cgi/doi/10.1073/pnas.1107409108

de Cendra, J. (2006): Can Emissions Trading Schemes be Coupled with Border Tax Adjustments? An Analysis Vis-á-vis WTO Law, Review of European Community and International Environmental Law 15(2): 131-145

Demailly, D., Quirion, P. (2006): CO2 abatement, competitiveness and leakage in the European cement industry under the EU ETS: Grandfathering vs. output-based allocation, Climate Policy, 6(1): 93-113

Demailly, D., Quirion, P. (2008): European Emission Trading Scheme and competitiveness: A case study on the iron and steel industry, Energy Economics 30(4): 2009-2027

Dietzenbacher, E. and Mukhopadhyay, K. (2007): An Empirical Examination of the Pollution Haven Hypothesis for India: Towards a Green Leontief Paradox? Environmental & Resource Economics 36(4): 427-449

Dröge, S. (2009). Tackling Leakage in a World of Unequal Carbon Prices. Report by Climate Strategies. Available at http://www.centre-cired.fr/IMG/pdf/cs_tackling_leakage_report_final.pdf

Edenhofer, O., Kalkuhl, M. (2011): When do increasing carbon taxes accelerate global warming? A note on the green paradox. Energy Policy (39): 2208–2212.

Ellerman, A.D., Convery, F.J., de Perthius, C. (2010): Pricing Carbon. The European Union Emissions Trading Scheme. Cambridge University Press, Cambridge, UK

Elliott, J., I. Foster, S. Kortum, T. Munson, F. Pérez Cervantes and D. Weisbach (2010), Trade and Carbon Taxes. American Economic Review 100(2):465-469.

Felder, S. and T.F. Rutherford (1993). Unilateral CO2 Reductions and Carbon Leakage: The Consequences of International Trade in Oil and Basic Materials. Journal of Environmental Economics and Management 25(2):162-76.

Fischer, C. and A. Fox (2012). Comparing Policies to Combat Emissions Leakage. Journal of Environmental Economics and Management 64 (2), p.199–216.

Fischer, C., and Fox, A. K. (2011). The role of trade and competitiveness measures in us climate policy. American Economic Review, 101(3), 258.

Fischer, C., Fox, A.K. (2012b): Climate Policy and Fiscal Constraints: Do Tax Interactions Outweigh Carbon Leakage?, Energy Economics 34(S2): S218-S227

GATT (1947): General Agreement on Tariffs and Trade. Available online: http://www.wto.org/english/docs_e/legal_e/gatt47_02_e.htm

Gerlagh, R., Mathys, N. A. (2011). Energy abundance, trade and industry location. Nota di Lavoro 003.2011, Fondazione Eni Enrico Mattei, Milan. Available from: http://www.feem.it/ userfiles/attach/20111171430134NDL2011- 003.pdf. (accessed 14 Sept 2013)

Golombek, R., C. Hagem and M. Hoel (1995). Efficient Incomplete International Climate Agreements. Resource and Energy Economics 17:25-46.

Golombek, R., M. Hoel (2004): Unilateral Emission Reductions and Cross-Country Technology Spillovers. Advances in Economic Analysis & Policy 4 (2), Article 3.

Grossman, G.M. and Krueger, A.B. (1993). "Environmental impacts of a North-American free trade agreement," in P. Garber (ed.) The Mexican–U.S. Free Trade Agreement. Cambridge, MA: MIT Press.

Helm, D., Hepburn, C., Ruta, G. (2012): Trade, climate change, and the political game theory of border carbon adjustments, Oxford Review of Economic Policy 28(2): 368-394

Hoel, M. (1994). Efficient Climate Policy in the Presence of Free Riders. Journal of Environmental Economics and Management 27(3):259-74.

Hoel, M. (1996). Should a carbon tax be differentiated across sectors? Journal of Public Economics 59(1):17-32.

Hof, A., Elzen, M., Vuuren,D. (2009): Environmental effectiveness and economic consequences of fragmented versus universal regimes: what can we learn from model studies?, International Environmental Agreements: Politics, Law and Economics 9(1): 39-62

Hourcade, J.-C., D. Demailly, K. Neuhoff and M. Sato (2008). Differentiation and Dynamics of EU ETS Industrial Competitiveness Impacts. Report by Climate Strategies.

Houser, T., R. Bradley, B. Childs and R. Heilmayr (2008). Leveling the Carbon Playing Field: International Competition and US Climate Policy Design. Peterson Institute and World Resource Institute, Washington D.C.

Ismer, R. and K. Neuhoff (2007). Border tax adjustment: a feasible way to support stringent emission trading. European Journal of Law and Economics 24(2):137-64.

Jakob, M., R. Marschinski (2013): Interpreting CO2 emission transfers. Nature Climate Change,3(1): 19-23

Jakob, M., R. Marschinski, and M. Hübler (2013): Between a Rock and a Hard Place: A Trade-Theory Analysis of Leakage under Production- and Consumption-Based Policies. Environmental and Resource Economics 56(1): 47-72

Jotzo, F. (2012): Australia’s carbon price. *Nature Climate Change* 2: 475–476.

Kallbekken, S. (2007): Why the CDM will reduce carbon leakage, Climate Policy 7(3): 197-211

Kallbekken, S., Hovi, J. (2007): The price of non-compliance with the Kyoto Protocol: The remarkable case of Norway, International Environmental Agreements: Politics, Law and Economics 7(1): 1-15

Keen, M. and Kotsogiannis, C. (2011). Coordinating Climate and Trade Policies: Pareto Efficiency and the Role of Border Tax Adjustments. CESIfo working paper No 3494.

Krugman, P.R. (1979): Increasing returns, monopolistic competition, and international trade, Journal of International Economics 9(4): 469-479

Kuik, O. and M. Hofkes (2010). Border adjustment for European emissions trading: Competitiveness and carbon leakage. Energy Policy 38(4):1741-1748.

Leamer, E.E. (1980). The Leontief paradox, reconsidered. The Journal of Political Economy 88(3):495-503.

Lenzen, M. (2001): Errors in Conventional and Input-Output-based Life-Cycle Inventories, Journal of Industrial Ecology 4(4): 127-148

Lessmann, K., Marschinski, R., Edenhofer, O. (2009): The Effects of Tariffs on Coalition Formation in a Dynamic Global Warming Game, Economic Modeling 641-649.

Levinson, A. (2010), "Offshoring pollution: Is the U.S. increasingly importing polluting goods?" Review of Environmental Economics and Policy 4: 63-83.

Maria, C.D., van der Werf, E. (2008): Carbon leakage revisited: unilateral climate policy with directed technical change, Environmental & Resource Economics 39(2): 55-74

Markusen, J.R. (1975). International externalities and optimal tax structures. Journal of International Economics 5:15-29.

Marschinski, R., C. Flachsland, and M. Jakob (2012): Sectoral Linking of Carbon Markets: A Trade-Theory Analysis. Resource and Energy Economics 34 (4), p.585-606

Mattoo, A., Subramanian, A., van der Mensbrugghe, D., He, J. (2009): Reconciling climate change and trade policy, World Bank Policy Research Working Paper Series 5123

Meckling, J.O., Chung, G.Y. (2009): Sectoral Approaches to International Climate Policy. A Typology and Political Analysis, Belfer Center for Science and International Affairs Discussion Paper 2009-02

Michielsen, T. O. (2013). The distribution of energy-intensive sectors in the USA. Journal of Economic Geography. Available from: http://joeg.oxfordjournals.org/content/early/2013/01/15/ jeg.lbs045. and

Monjon, S. and P. Quirion (2010). How to design a border adjustment for the European Union Emissions Trading System? Energy Policy 38(9): 5199-5207.

Narayanan, B., A. Aguiar, R. McDougall (2012): Global Trade, Assistance, and Production: The GTAP 8 Data Base. Center for Global Trade Analysis, Purdue University. available at: https://www.gtap.agecon.purdue.edu/databases/v8/v8_doco.asp [May 28, 2013]

Pan, J., J. Phillips, and Y. Chen (2008). China’s balance of emissions embodied in trade: approaches to measurement and allocating international responsibility. Oxford Review of Economic Policy 24:354–376.

Pauwelyn, J. (2007): U.S. Federal Climate Policy and Competetiveness Concerns: The Limits and Options of International Trade Law. Duke University Nicholas Institute Working Paper 07-02

Perez, O. (2005). Multiple Regimes, Issue Linkage, and International Cooperation: Exploring the Role of the WTO. University of Pennsylvania Journal of International Economic Law 26:735-78.

Peters, G., Minx, J. Weber, C.L. and Edenhofer, O. (2011): Growth in emission transfers via international trade from 1990 to 2008. Proceedings of the National Academy of Sciences (PNAS) 108(21): 8903-8908

Peters, G., Weber, C.L., Guan, D. Hubacek, K. (2007): China's growing CO2 emissions – a race between increasing consumption and efficiency gains. Environmental Science and Technology 41(17): 5939-5944

Peters, G.P. and E.G. Hertwich (2008a). CO2 Embodied in International Trade with Implications for Global Climate Policy. Environmental Science & Technology 42(5):1401-1407.

Peters, G.P. and E.G. Hertwich (2008b). Post-Kyoto Greenhouse Gas Inventories: Production versus Consumption. Climatic Change 86:51–66.

Peters, G.P., Davis, S.J., Andrew, R. (2012): A synthesis of carbon in international trade, Biogeosciences 9: 3247-3276

Peters, G.P., Marland, G., Hertwich, E.G., Saikku, L., Rautiainen, A., Kauppi, E.P. (2009):Trade, transport, and sinks extend the carbon dioxide responsibility of countries: An editorial essay, Climatic Change 97: 379-338

Pigou (1920): The Economics of Welfare. McMillan and Co.

Quirion, P. (2009): Historic versus output-based allocation of GHG tradable allowances: a comparison, Climate Policy 9(6): 575-592

Rosendahl, K.E. and Strand, J. (2011): Carbon Leakage from the Clean Development Mechanism, The Energy Journal 0(4): 27-50

Samuelson, P.A. (1954): The Pure Theory of Public Expenditure, Review of Economics and Statistics 36: 387–389.

Sato, M. (2013): Embodied Carbon in Trade: A Survey of the Empirical Literature. Journal of Economic Surveys. Available online: http://onlinelibrary.wiley.com/doi/10.1111/joes.12027/abstract [accessed 28 Oct 2013]

Sato, M., Dechezlepretre, A. (2013): Asymmetric industrial energy prices and international trade, Grantham Research Institute on Climate Change and the Environment Working Paper

Schneider, L. (2009): Assessing the additionality of CDM projects: Practical experiences and lessons learned, Climate Policy 9 (3): 242-254

Shui, B. and R.C. Harriss (2006): The Role of CO2 Embodiment in US-China Trade. Energy Policy 34, 4063-4068.

Siebert, H. (1979). Environmental policy in the two-country-case. Journal of Economics 39(3-4):259-274.

Sinn, H.W. (2008). Public policies against global warming: a supply side approach. International Tax and Public Finance 15(4):360-394.

Steckel, J.C., M. Kalkuhl, and R. Marschinski (2010). Should Carbon-Exporting Countries Strive for Consumption-Based Accounting in a Global Cap-and-Trade Regime? Climatic Change Letters 100(3-4): 779-786

Taylor M. S. (2005): Unbundling the Pollution Haven Hypothesis, The B.E. Journal of Economic Analysis & Policy 3(2): 1-28

Townshend, T., Fankhauser, S., Aybar, S., Collins, M., Landesman, T., Nachmany, M. and Pavese, C. (2013): The GLOBE Climate Legislation Study. THIRD EDITION. A Review of Climate Change Legislation in 33 Countries

Trefler, D. (1995): The Case of the Missing Trade and Other Mysteries. American Economic Review 85(5): 1029-46

Tsakiris, N., Michael, M.S., Hatzipanayotou, P (2011). Cross-Border Pollution and Integrated Reforms of Trade and Environmental Tax Policies in Large Economies. Working paper, available online: http://sites.uom.ac.mu/wtochair/Conference%20Proceedings/18.pdf.

Turunen-Red, A.H., Woodland, A.D. (2004): Multilateral Reforms of Trade and Environmental Policy, Review of International Economics 12(3): 321-336

UK House of Commons (2012): Consumption-Based Emission Reporting. Twelfth Report of Session 2010-12. Available online: http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/1646/1646.pdf

Van Asselt, H. and T. Brewer (2010). Addressing competitiveness and leakage concerns in climate policy: An analysis of border adjustment measures in the US and the EU. Energy Policy 38(1):42-51.

Wang, X. and Voituriez, T. (2009): Can unilateral trade measures significantly reduce leakage and competitiveness pressures on EU-ETS-constrained industries, Climate Strategies Working Paper, available online: http://www.climatestrategies.org/research/our-reports/category/32/113.html

Wara, M. (2007): 'Is the global carbon market working?, Nature 445(8): 595–596

Weber, C. L., Peters, G. P., Guan, D., Hubacek, K. (2008): The contribution of Chinese exports to climate change, Energy Policy 36(9): 3572-3577

Weitzel, M., Hübler, M., Peterson, S. (2012): Fair, optimal or detrimental? Environmental vs. strategic use of border carbon adjustment," Energy Economics 34(S2): S198-S207.

Weitzman, M.L. (1980): The "Ratchet Principle" and Performance Incentives, Bell Journal of Economics 11(1): 302-308

Winchester N., Paltsev S., Reilly J. M. (2011): Will Border Carbon Adjustments Work?, The B.E. Journal of Economic Analysis & Policy 11(1): 1-29

Winchester, N., Rausch, S. (2013): A Numerical Investigation of the Potential for Negative Emissions Leakage, American Economic Review 103(3): 320-25

WTO-UNEP (2009). Trade and Climate Change. A report by the United Nations Environment Programme and the World Trade Organization, WTO Secretariat, Geneva, Switzerland, available online: http://www.wto.org/english/res_e/booksp_e/trade_climate_change_e.pdf.

Yonezawa, H, Balistreri, E.J., Kane, D.T. (2012): The suboptimal nature of applying Pigouvian rates as border adjustments. Colorado School of Mines Working Paper 2012-02. Available online: http://econbus.mines.edu/working-papers/wp201202.pdf

Zhang, X.Z. (2012): Competitiveness and Leakage Concerns and Border Carbon Adjustments. FEEM Nota di Lavora 80.2012