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Border adjustment measures as instruments to reduce emissions leakage

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Abstract

We analyze carbon-related BAMs (focused on imports) as potential instruments to reduce emissions leakage. We combine an approach from international trade law with an economic approach. For the legal aspect we discuss the elements needed to include carbon-related BAMs within the current GATT and WTO frameworks. For the economic aspect, we assess the effects of leakage and of BAMs to tackle it within an optimal climate policy model and a general equilibrium model. We find that the design and implementation of these BAMs would be difficult to bring in compliance with current international trade law and it may entail high transaction costs. Moreover, we observe that the severity of leakage may be amplified by international trade and that BAMs help in reducing it. Finally, we find that welfare effects of introducing carbon-related BAMs are ambiguous and thus they may not represent a credible threat to involve other actors in the international climate regime.

JEL-Classification: H20, F13, F18, F53, Q54

Keywords: international trade, environmental policy, border adjustment measure, CGE model, emissions leakage

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1. Introduction

There is a strong link between international environmental policy making and trade. In particular, this link is apparent whenever trade measures are invoked as instruments to cope with the international environmental regulation involved - e.g. the Montreal Protocol. We find that border adjustment measures (BAMs) are nowadays one of the most discussed instruments in this respect. For instance, in the last few decades, a number of environment-related border adjustment practices have been introduced. BAMs can be applied both by applying internal taxes to imports and by giving tax rebates to exports. However, taxes and other fiscal measures are not the only domestic policy measures used for border adjustment. There are also non-fiscal internal measures, such as standards, regulations and requirements, which countries may apply to imported products at the border.

For instance, in 1986 the US adopted a Superfund Amendments and Reauthorization Act, which, inter alia, introduced export and import border adjustment for an excise tax on certain chemicals used as inputs for producing chemical derivative products (Biermann and Brohm, 2005). Another example of adjustment measures for environmental taxes is export and import border adjustment of an excise tax on certain ozone-depleting chemicals, introduced by the US in 1989 to meet its obligations under the Montreal Protocol. The taxed chemicals were either present in the final product or were themselves a finished product.

In the context of climate policy, BAMs are currently viewed as a way to address competitiveness and carbon leakage concerns associated with a cap-and-trade or any other emission reduction system which imposes additional costs on domestic producers. Furthermore, BAMs may be used to address one of the prominent issues related to climate policy namely, emissions leakage. The IPCC defines leakage as the increase in CO_2 emissions outside the countries taking domestic mitigation action divided by the reduction in the emissions of these countries (IPCC, 2007). Several studies have estimated the size of this leakage. The range in estimations is large and uncertainties seem to be high. But most analyses conclude that the efforts of Annex B countries, which have committed themselves to reduce GHG emissions in the Kyoto Protocol, cause a leakage between 5% and 20% in Non-Annex B countries (IPCC, 2007).

As it was noted in Paltsev (2001) there are several sources of leakage, but two are of particular relevance for our study, the first one is linked to the decrease of energy consumption coming from the regions which are taking commitment in CO_2 abatement, this decrease of fossil energy consumption lead to a lower world energy prices which induces in regions which are not taking into account any commitment an increase of energy consumption and therefore an increase in CO2 emissions. The second source is due to trade effects. The higher cost of fossil energy leads to an increase of production prices in energy-intensive industries in countries, which are implementing a climate policy, this loss of competitiveness induces an increase of imports from other countries and higher emissions level.

BAMs may be applied to either imports, exports or both. Import-BAMs for carbon taxes or carbon-related requirements level the playing field between domestic and foreign firms in the home market by imposing the same costs on imports, as the costs imposed by climate legislation on domestic products. Export-BAMs eliminate competitive disadvantages of domestic firms in the world markets by reimbursing carbon costs when they export their products. Putting domestic and foreign producers on an equal footing prevents relocation of emission-intensive production to countries without emissions restrictions and supports the efficiency of climate change mitigation actions.

There are prominent examples of BAMs applied to climate policy in European Union and the USA. One of the earlier drafts of amendments to the EU ETS Directive contained a more definitive proposal on allowance requirements for EU importers. The so-called FAIR (a future allowance import requirement) program would include imports in the EU ETS beginning from 31 December 2014. The US Waxman-Markey bill, which passed a vote in the House of Representatives in June 2009, provides for inclusion of imports to the US cap-and-trade starting from 2020. It was suggested that US importers would have to buy US “international reserve allowances” to offset lower energy and carbon costs of manufacturing covered goods. The design of these border adjustments is still in process of elaboration.

However, a potential problem with the inclusion of carbon-related BAMs on international climate policy is that the unilateral use of carbon-related import restrictions risks triggering retaliation by trading partners. Moreover, it raises questions about the consistency of such trade measures with countries’ obligations under the WTO. The WTO status is not clear on measures imposed not directly on products but on the methods by which they were produced.[1]

[1] See Holzer (2010a and 2010b) for a good overview of potential challenges and opportunities of climate-related BAMs (both in imports and exports) as instruments for international climate policy.

The objective of this paper is to analyze carbon-related BAMs as potential instruments to reduce emissions leakage. In this paper, we focus our analysis *only* on BAMs that are specifically directed to *imports*, which we labeled as carbon-related BAMs. To attain our objective, we take two approaches: (i) from an international trade law perspective and (ii) from an economic perspective. For the legal aspect, we show the obstacles and opportunities of carbon-related BAMs to comply with the GATT and WTO requirements. Whereas, for the economic part we take two frameworks into the analysis, first, we model the response of countries to an optimal unilateral climate policy and we add carbon-related BAMs as an additional policy instrument for the regulator in order to tackle emissions leakage. Second, we show, by means of a computable general equilibrium (CGE) model, the environmental (emissions reduction and leakage) and welfare effects of an exogenous climate policy objective that resembles current the international climate policy regime.

Early contributions on BAMs (in particular taxes) show that they guarantee trade neutrality if goods are different taxed in differently regions (Bhagwati, 1973). In his seminal paper, Markusen (1975) applies such border measures on environmental problems and showed that import tariffs are part of the optimal policy set for trans-boundary pollution problems. Copeland, (1996) generalizes Markusen's work for variable abatement technologies. His analysis concludes that the affected country should levy a tariff, which varies with the pollution content of the imports. He further shows that even if a country reduces pollution as a respond to another country trade policy, the latter should adhere to the import tariff to maximize rents.

Furthermore, Alexeeva-Talebi et al. (2008) shows with a numerical general equilibrium model that border measures might improve the efficiency of EU's climate policy and increase the competitiveness of European energy-intensive industries. However, the distinction between sectors covered by emission trading and a border tax adjustment scheme and non-covered sectors has some problematic consequences. A BAM causes a shift in emissions and puts a higher burden on non-covered sectors. Since marginal abatement costs in the non-covered sectors are higher, welfare effects are ambiguous. In an earlier contribution Babiker and Rutherford (2005) studied the economic effects of border measures under the targets of the Kyoto agreement. They show that the introduction of carbon-related BAM is welfare improving.

The structure of the paper is as follows. Section 2 describes the legal aspects entailed for integrating carbon-related BAMs into the frameworks of the GATT and the WTO. Section 3 presents our analytical model of optimal climate policy given trade and environmental interactions in two regions and how a carbon-related BAM ay help to reduce leakage in that context. Section 4 presents our analysis of environmental and welfare effects of carbon-related BAMs using a CGE model. Finally, section 5 concludes.

2. Legal aspects of border adjustment measures

Border adjustment of domestic measures linked to an emissions trading scheme or a carbon tax system is likely to get in conflict with a country's obligations under the WTO Agreement. The most vulnerable characteristics of a carbon-related border adjustment is its link to process and production methods (PPMs) which entails discriminatory treatment of products perceived to be like according to the WTO traditional concept of likeness. Moreover, irrespective of the PPM-issue, a violation of WTO non-discriminatory rules may incur if the collection of a carbon tax at the border requires a very complicated bureaucratic procedure or if instead of a carbon tax there is an emissions trading system or the price at which importers buy allowances at the border exceeds the prices of allowances for domestic producers of like products.[2]

As there is a high probability that a carbon-related BAM will be found to violate substantive rules of the GATT, there is a need to assess the possibility of justification of the violations under general exceptions of GATT Article XX and to find institutional solutions to WTO inconsistencies of carbon-related BAMs. The key elements to consider when seeking defense under Article XX include: (i) to demonstrate that a measure was taken with the purpose to achieve one of the legitimate policy objectives indicated in respective paragraphs of Article XX, and (ii) to meet requirements of the Chapeau of Article XX.

2.1 Nexus between a measure and a legitimate policy objective

GATT Article XX contains a list of public policy exceptions which apply to substantive rules of the GATT. The exceptions in Article XX are limited and conditional and may apply to BAMs. For the purpose of carbon-related BAMs, two clauses of GATT Article XX are relevant:

[2] We restrict our analysis to import BAMs, for the analysis of other measures such as export rebates see Holzer (2010a and 2010b).

XX (b) "[measures] necessary to protect human, animal or plant life or health", and

XX (g) "[measures] relating to the conservation of exhaustible natural resources…"

A BAM can be considered under these two paragraphs simultaneously in the case of global warming, we may argue that it can affect exhaustible natural resources (e.g. climate, animals, forests) and it poses a risk to human, animal and plant life and health (e.g. diseases, high temperatures, extreme weather events) –Condon (2009). Justifying a carbon measure under paragraphs (b) or (g) of Article XX is not a simple task. A WTO member must perform a two-tier analysis proving that, first, for paragraph (b), a measure is necessary to protect human, animal or plant life or health or, for paragraph (g), a measure relates to the conservation of exhaustible natural resources and is made effective in conjunction with restrictions on domestic production or consumption. Moreover, as we discuss below, under the chapeau of Article XX, a measure should not constitute a means of arbitrary or unjustifiable discrimination between countries where the same conditions prevail, or a disguised restriction on international trade.

Proving the necessity of a measure under paragraph b) of Article XX is quite challenging. The possible explanation for such a strict threshold is that otherwise it would be quite easy to disguise protectionism under the legitimate objective to protect human, animal or plant life or health. Determining whether there is a risk for life or health of people, animals or plants under paragraph b) is more subjective than determining whether resources are exhaustible or not under paragraph g) - Condon (2009).

The key elements of the necessity test include: (i) the analysis of the contribution of a measure to the achievement of a policy objective and (ii) the check on existence of less trade-restrictive alternatives that provide an equivalent contribution to the achievement of the objective pursued. For the measure to be necessary, it does not need to be indispensable or of absolute necessity or inevitable. Yet, the contribution to the objective should be significant. The recognition of the long-term manifestation of the results of climate policy may suggest that, in the context of climate policy measures, the AB would evaluate the contribution of a measure to the achievement of a policy objective with less strictness. Furthermore, the contribution of a measure into achieving a policy objective has also to be weighed and balanced against other relevant factors, such as trade restrictiveness of a measure, the importance of the common interests or values protected by a measure. Another important consideration relates to the existence of alternatives, for instance, in Thailand-Cigarettes case, the GATT panel, though acknowledging legitimacy of health concerns of the Thai government, pointed to the availability of other measures (e.g. a ban on the advertisement of domestic and imported cigarettes), which could achieve the health policy goals but, at the same time, would be less trade-restrictive than a ban on imports of cigarettes. When considering the existence of less trade-restrictive alternatives, a country's level of development and its financial and technical capacities might be taken into consideration (Low et al., 2010).

The most prominent example of successful justification of a measure under Article XX (g) is the *US–Shrimp* case, in which the AB accepted a justification under GATT Article XX (g) of a modified US ban on shrimps, based on how shrimps were caught abroad. Thus, relevant for carbon-related BAMs is the fact that the measure relates to the conservation of exhaustible natural resources *abroad* and the *PPM character* of the measure. This case showed that the GATT might allow unilateral PPM measures (Hufbauer and Jisun, 2009).

When arguing under an environmental exception of Article XX (g), the first element to consider is whether or not climate may be qualified as an exhaustible natural resource. The simplest argument is that the global community would not have given such a priority to climate change issues, if climate was not an exhaustible resource (Bacchus, 2010). In *US-Shrimp*, the AB explaining the meaning of "exhaustible natural resources" pointed to the "contemporary concerns of the community of nations about the protection and the conservation of the environment". Furthermore, changes in climate lead to the depletion of other exhaustible natural resources, such as forests, fisheries, and biodiversity.

The second element to consider is that a measure is relevant to an environmental objective. At this point, a carbon-related BAM can be challenged as non-relevant. For the particular case of a carbon-related BAM to pass the test on the nexus to the environmental objective, it should be proved that a measure is aimed at reducing emissions and preventing carbon leakage and not at restoring competitive positions for domestic producers (Bacchus, 2010). However, BAMs are traditionally perceived in the WTO as fiscal measures in order to level taxation and domestic regulation systems to create equal competitive conditions for domestic and foreign production. Thus, it would be difficult to escape a competition-related motive of a BAM.

Another requirement necessary to meet under Article XX (g) is that the measure related to the conservation of exhaustible natural resources must be made effective in conjunction with restrictions on domestic production and consumption. In practice, it means that carbon-restrictive measures should be applied to domestic products as well, but there is no requirement of equal application of a measure to imported and domestic products.

2.2 A carbon-related BAM under conditions of the chapeau of Article XX

After passing the necessity test under Article XX (b) and the "relating to" test under Article XX (g), a carbon-related BAM scrutinized under GATT Article XX should also satisfy the provisions of the chapeau of Article XX requiring:

> "… 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…".

Provisions contained in the chapeau are an expression of the principle of good faith. In other words, the chapeau requires that the measure at issue does not abuse or misuse a possibility of exception provided by Article XX and ensures a balance between the right of a member to invoke an exception and the rights of the other members under the GATT. Meeting requirements of the chapeau seems to be crucial for a carbon-related BAM to be justified under Article XX, because recently panels and the AB has moved from focusing on purely technical features of a measure to analyzing the overall design of a measure (Van Calster, 2008). Moreover, the requirement for trade measures not to constitute arbitrary or unjustifiable discrimination is also laid down by Article 3.5 of the UNFCCC. This requirement can be interpreted as a requirement to take account of conditions in different countries.

Pauwelyn (2007) argues that the language of the chapeau allows making distinctions between imports from different countries for as long as "different conditions", such as level of economic development, prevail in those countries. Quick (2000) argues that in the view of the AB, discrimination under the chapeau includes not only the like treatment of different situations but also a different treatment of like cases. It is important to note that comparison on prevailing conditions would be made not only among all countries which export to the country imposing a measure but also among the importing country and the exporting countries.

As follows from the WTO jurisprudence, the AB when testing whether a carbon measure constitutes "arbitrary or unjustifiable discrimination between countries where the same conditions prevail" would likely scrutinize along the following lines:

i. Does a country imposing a measure require that its climate policy being copied by exporting countries or does it accept and take into account climate policy measures previously being taken in exporting countries to combat climate change?

ii. Does the implementation and administration of a carbon measure satisfy the conditions of "basic fairness and due process"?

iii. Did a country, before imposing a carbon measure, try other, less trade restrictive ways to settle the problem, such as "across-the-board negotiations with the objective of concluding bilateral or multilateral agreements" to combat climate change?

For the first line of scrutiny, the US ban on imports of shrimp was originally rejected by the AB as one which has an intended and actual coercive effect on the specific policy decisions made by foreign governments. The US required that all exporting countries adopt essentially the same policy, whereas other specific policies and measures that an exporting country may have adopted for the protection and conservation of sea turtles are not taken into account. At the same time, an import ban, which was later modified by the US so that it no longer required the adoption of essentially the same program but rather the adoption of a program comparable in effectiveness to the US one, has passed the AB test as one which allows for sufficient flexibility in the application of the measure so as to avoid 'arbitrary or unjustifiable discrimination.

Such interpretation of the chapeau by the AB might have the following practical implications. On the one hand, it could give, say, the US the right to exempt the EU imports from a carbon tax, provided that the EU producers already paid the costs of carbon under the EU ETS. On the other hand, climate policy measures of China, such as an export tax on energy-intensive exports or an improved energy intensity target, should also somehow be taken into account, perhaps, through lower carbon tax for Chinese imports. This would require a comparison between emission reduction systems and climate policies in different countries, which would be a very difficult task, especially when comparisons were made between price-based and non-price-based climate policy measures (Low et al., 2010).

Furthermore, to take account of the conditions prevailing in other countries might also imply that a country which imposes a BAM on imports would have to check and insure that the products imported from other countries had not already been taxed with a similar tax on carbon in their home countries and received no tax rebates on exportation. Otherwise, there would be a problem of double taxation as a consequence of ignorance of conditions prevailing in other countries.

Moreover, the requirement of the chapeau to take account of conditions prevailing in different countries might also enable a country imposing a carbon measure to differentiate in strictness of a measure between countries based on their development (as conditions in developing countries are different from developed countries) and even exempt products of least-developed countries from a measure.

For the second line of scrutiny, a WTO adjudicative body may look at the procedure of applying a carbon measure, whether it is transparent and non-discriminatory. In the context of carbon-related BAMs, it might be important to consider the time given by BAM legislation to other countries to respond with "comparable" climate mitigation actions, before their exports are targeted with BAMs. It is usually expected that there is some period of time between a developed country's introduction of an emission trading scheme and its imposition of BAMs against imports from countries not taking "comparable actions". This period should be of reasonable length so that other countries have the possibility to adjust their resources and react.

Zhang (2009) points to the short "grace period" which US draft climate legislation proposes between the establishment of a federal cap-and-trade system and the introduction of an import allowance purchase requirement. In his view, the grace period for developing countries should be at least 10 years after the US emission trading scheme starts working. To take any "comparable actions" within a shorter time-frame would be impossible for developing countries, given their limited resources, weak environmental institutions, relatively high carbon-intensity of production and much time required for designing and preparation of a national cap-and-trade system even for such rich countries, as the EU and the US.

For the third line of scrutiny, a WTO adjudicative body may check whether a country before imposing a unilateral carbon-related BAM made attempts to negotiate on respective climate policy actions with all countries concerned on a non-discriminatory basis. It should be noted, however, that "serious, good faith efforts made ... to negotiate an international agreement" would suffice: the conclusion of the agreement itself is not required. In *US-Shrimp* (WTO, 2001), the AB pointed out to the fact that the US had not ratified three multilateral environmental agreements related to turtle conservation. This note of the AB raises a question in the context of international climate policy: could non-ratification of the Kyoto Protocol or a future international climate change agreement deprive a country of the right to seek justification of a carbon measure under GATT Article XX?

Moreover, Goh (2004) conjectures if a country which is a party to the Kyoto Protocol or a future climate agreement would still have to seek multilateral negotiations with the purpose of reaching an agreement before imposing a unilateral carbon-related measure under exceptions clauses of Article XX. Perhaps, participation in the Kyoto Protocol could count as multilateral efforts taken by a country to find a solution to the problem before imposing a measure. It is worth noting that an effort to negotiate a multilateral agreement with other countries is an obligatory requirement only in disputes (*US-Shrimp*) relating to paragraph g) of Article XX, whereas in disputes falling under other paragraphs of Article XX this requirement is not raised (Condon, 2009)

In sum, the chances of justification of a carbon-related BAM under GATT Article XX exception clauses largely depend upon the ability of a measure to meet the requirements of the chapeau of GATT Article XX. It is especially important to take into account conditions in other countries. In practice, it would mean that the measure needs to be flexible enough to treat more favourably imports from countries, which had taken emission reduction efforts in any form, and to differentiate in treatment depending on a country's level of economic development. It would also mean that a measure had taken into account the rights and obligations of an exporting country under an international climate agreement.

2.3 In search of institutional solutions to the use of BAMs in climate policy

Although justification of a BAM under GATT Article XX is not entirely excluded, it will be difficult to design and implement a carbon-related BAM in a way consistent with the purpose, scope and requirements of Article XX, especially of the chapeau. Furthermore, justification of a measure under Article XX can be made each time only through litigation between the parties to a dispute in the WTO. This implies that the problem of violation of WTO rules will have to be resolved each time anew. Therefore, there seems to be a need for long-lasting institutional solutions to the problem of WTO inconsistency of carbon-related BAMs, which entails high transaction costs.[3]

Proposals have been made to initiate negotiations among the WTO members to reach a multilateral understanding or even an agreement on border adjustment of carbon and energy

[3] For the analysis of other alternatives see Holzer (2010b).

taxes and permissibility of application of PPM-related measures for environmental and other legitimate purposes - Biermann et al. (2003). An alternative approach would be to adopt a protocol or resolution on trade-related climate policy measures among the parties to the UNFCCC (Hoerner and Muller, 1996). Furthermore, another option would be to establish a joint WTO-UNFCCC Working Group on carbon-related BAMs (Abbas, 2008). Whatever track is chosen, it seems unfeasible today to create one global super-regulatory forum for gradual coordination and harmonization of trade-related instruments of climate change policy. Therefore, a partial solution based on bilateral and plurilateral negotiations among countries and inclusion of provisions on the use of carbon-related BAMs in free trade agreements or economic cooperation agreements seems currently most feasible. Alternatively, countries could agree on mutual recognition of climate laws and climate policy actions, which would obviate the need for border adjustment. Such bottom-up initiatives of countries could gradually embrace the majority of the WTO membership and create a multilateral framework for trade-related measures of climate policy.

3. Optimal climate policy and international trade

In this section, we set up a model to analyze the main characteristics of climate policy in open economies and explain the mechanisms behind carbon leakage, the efficiency of border carbon adjustment as measure against leakage, and the opportunity to manipulate terms of trade with climate policy. This analysis helps us understanding the rationale behind the results of the simulations that we further present in section 4. In the following, first we explain the basic settings of our model, second, we extend our analysis to leakage, and third, we analyze the effects of including carbon-related BAMs in our framework.[4]

3.1 Basic settings

We are interested in the interaction between two interconnected regions. These correspond to the two main blocks of countries in climate politics. On the one side, the Annex B countries (mainly members of OECD), which have binding mitigation targets under the Kyoto protocol. On the other side, the Non-Annex B countries that do not have any binding target. Both regions are linked through two channels. First, emissions generate a negative transboundary externality and since mitigation is a public good this creates an incentive to free ride on the

[4] For further simulations of this framework see Schenker and Bucher (2010).

others abatement efforts. Second, the two regions are linked through trade in goods and border measures might affect the flow of goods.

We focus our analysis on two types of commodities: A carbon-intensive, dirty good and a clean good, which is vulnerable to climate change. We suppose that the production of the carbon-intensive good causes an externality and affects the production of the vulnerable good. Examples for goods produced in the carbon-intensive sectors are the production of energy with fossil fuels, cement or steel. All this sectors are responsible for a significant amount of CO_2 emissions from economic activities. The output of the carbon-intensive good in region i can be denoted as:

$$D_i = D(e_i) \tag{1}$$

where e_i are the GHG emissions of region i. As for any other input factor we assume decreasing marginal returns of emissions: $\partial D_i / \partial e_i > 0$ and $\partial^2 D_i / \partial e_i^2 < 0$.

The GHG emissions from producing the carbon-intensive good, regardless of the region, affect the state of the whole climate system and cause a degradation of environmental quality. The second sector, which produces the clean, affected good, uses environmental services as an input and has hence to cope with productivity losses from the GHG emitted by the carbon-intensive sector. Examples are sectors such as agriculture and forestry, which are negatively affected by higher probabilities of droughts and increasing climate variability as consequences of climate change (IPCC, 2007).

The production of the clean, affected good C_i in region i can be denoted as:

$$C_i = C\left(E\left(e_i, e_j\right)\right), \tag{2}$$

with $i \neq j$. The output of the affected good sector depends negatively on GHG emissions from both regions, neglecting other input factors. As it is the case for GHG, we assume that emissions are perfect substitutes in their damage potential, regardless of their origin, i.e. $E\left(e_i, e_j\right) = e_{OECD} + e_{non-OECD}$. From the discussion above it follows that $\partial C_i / \partial E < 0$. We further assume increasing marginal damages with respect to emissions, $\partial^2 C_i / \partial E^2 < 0$. The assumption on increasing marginal damages due to climate change is consistent with most empirical findings on the climate vulnerability of societies - e.g Stern (2007) and Nordhaus and Boyer (2000). Furthermore, it influences the production possibility frontier (PPF) of the regional economies. As shown by Baumol and Bradford (1972), market externalities might often cause non-convex production sets, which aggravate the application of standard microeconomic tools. The above discussed properties of the production function ensure that the production set is convex.

The value of a region's total production can be denoted by a national income function

$$G_i = p \cdot D(e_i) + C\left(E\left(e_i, e_j\right)\right) \quad \text{with } i \neq j \tag{3}$$

where p denotes the world market price of the carbon-intensive good. The world market price of the affected good is the numeraire. For low levels of foreign emissions, G_i is humped shaped, since marginal benefits from emissions are relatively large compared to the damages. Then, G_i is increasing until marginal benefits are equal to the marginal damages. Both regions simultaneously choose their optimal climate policy.

We define the optimal climate policy as the level of emissions, which maximizes welfare within the region. To reach that goal, the climate policy regulator of a region issues e_i emission permits to carbon-intensive producers, such that regional welfare is maximized. In other words: The regulator maximizes the indirect utility function V_i with respect to the number of emission permits e_i:

$$\max_{e_i} V\left(p, G_i\left(p, e_i\right)\right). \tag{4}$$

Then the following first order condition has to hold for an utility maximum:

$$\frac{\partial V_i}{\partial e_i} = \frac{\partial V}{\partial p}\frac{\partial p}{\partial e_i} + \frac{\partial V}{\partial G_i}\left[\frac{\partial p}{\partial e_i} D_i + p\frac{\partial D_i}{\partial e_i} + \frac{\partial C_i}{\partial E}\frac{\partial E}{\partial e_i}\right] = 0 \ . \tag{5}$$

Following Roy's Identity, the domestic demand for the carbon-intensive good $H\left(p, G_i\right)$ is defined as $H\left(p, G_i\right) \equiv -\left(\partial V/\partial p\right)/\left(\partial V/\partial G_i\right)$. So we can rearrange equation (5) to

$$p\frac{\partial D_i}{\partial e_i} + \frac{\partial C_i}{\partial E}\frac{\partial E}{\partial e_i} + \frac{\partial p}{\partial e_i} X_i = 0 \ , \tag{6}$$

where X_i denotes carbon-intensive net exports of region i. Condition (6) represents the standard equimarginal Pigouvian principle, plus a Terms of Trade term. If the domestic demand for the carbon-intensive good is smaller than production, X_i is positive. Thus, assuming that $\partial p/\partial e_i < 0$, a net exporting region has to take into account that an increase in emissions deteriorates the Terms of Trade.

We assume that the different countries, which belong to one group, act as one homogeneous entity. We focus the analysis on responses of Non-Annex B on marginal reductions of Annex B's GHG emissions. This should reflect the current debate about stricter environmental policies in Annex B countries and the respective carbon leakage effect in Non-Annex B countries. Moreover, assuming that trade considerations play no part and that only the effects of the transboundary externality are important (i.e. that $p\frac{\partial D_i}{\partial e_i} + \frac{\partial C_i}{\partial E}\frac{\partial E}{\partial e_i} = 0$). Then country i's optimal response to a marginal change in country j's emissions is

$$\frac{\partial e_i}{\partial e_j} = \frac{-\frac{\partial^2 C_i}{\partial E^2}}{p\frac{\partial^2 D_i}{\partial e_i{}^2} + \frac{\partial^2 C_i}{\partial E^2}} < 0 \qquad (7)$$

In expression (7), the numerator shows the change in marginal damages of i abates an additional unit of emissions. The denominator shows the change of j's marginal profits form a change in its own emissions. We find that the sign of (7) is negative, thus whenever i increase its mitigation efforts, j will increase its GHG emissions – i.e. there is leakage.

3.2 Leakage and trade

As seen in the previous section free-riding counteracts Annex B's mitigation efforts. We relax now the assumption that Annex B countries (abbreviated as B in the following equations) do not affect world market prices, so that $\partial p/\partial e_B = 0$ does not necessarily hold. Now Non-Annex B (abbreviated as NB in the following equations) optimal response if Annex B marginally reduces emissions is now as follows:

$$\frac{\partial e_{NB}}{\partial e_B} = \frac{-\left(\frac{\partial^2 C_{NB}}{\partial E_{NB}^2} + \frac{\partial p}{\partial e_B}\frac{\partial D_{NB}}{\partial e_{NB}}\right)}{p\frac{\partial^2 D_{NB}}{\partial e_{NB}^2} + \frac{\partial^2 C_{NB}}{\partial E^2}}. \qquad (8)$$

There is an additional term that appears in (8) with respect to (7). The second term in the numerator indicates the effect of changing world market prices of the carbon intensive goods due to mitigation in Annex B on marginal emission benefits in the Non-Annex B. From the international market clearance condition for the carbon-intensive good $\sum_i H\left(p, G\left(e_i, e_j\right)\right) - \sum_i D_i\left(p, e_i\right) = 0$, we can show that:

$$\frac{\partial p}{\partial e_B} = \frac{\dfrac{\partial Y_B}{\partial e_B} - \sigma\theta\left(\dfrac{\partial G_B}{\partial e_B} + \dfrac{\partial G_{NB}}{\partial e_B}\right)}{(\varepsilon - \eta) Z}, \tag{9}$$

where σ denotes the income elasticity of the demand of the carbon-intensive good, ε is the price elasticity of the demand and η stands for the price elasticity of the supply of carbon-intensive goods. Furthermore, θ describes the value share of carbon-intensive goods in the utility function and Z denotes the respective market size. It is intuitive and easy to show that equation (9) has a negative sign. Emission taxes or emission trading schemes raise the production costs and prices of carbon-intensive goods.

Note that the elasticities play a crucial role for strengthening of the price change and hence for leakage. Higher demand elasticities cause lower price changes, whereas higher supply elasticities obviously lead to larger price effects. Annex B's emission reduction raises the price of carbon-intensive commodities. This leads to larger marginal profits, which induces leakage. Hence, relative to equation (7), the numerator is larger, so that, Non-annex B's responds more vigorously on mitigation in Annex B.

Figure 1 illustrates the previous findings. Because of decreasing marginal damages, Non-Annex B increases emissions if Annex B intensifies mitigation efforts, since Non-annex B's profits from Annex B contribution to a better climate state. Further, if mitigation in Annex B increases the world market price of carbon-intensive goods, Non-annex B's has additional incentives to raise emissions, since it becomes more profitable to produce carbon-intensive goods. Thus, we find that if Annex B's abatement efforts affect the price of the carbon-intensive good on the world market, Non-Annex B will raise emissions by more than in the absence of those induced price effects. Leakage increases the negative response of Non-Annex B's on Annex B's abatement efforts.

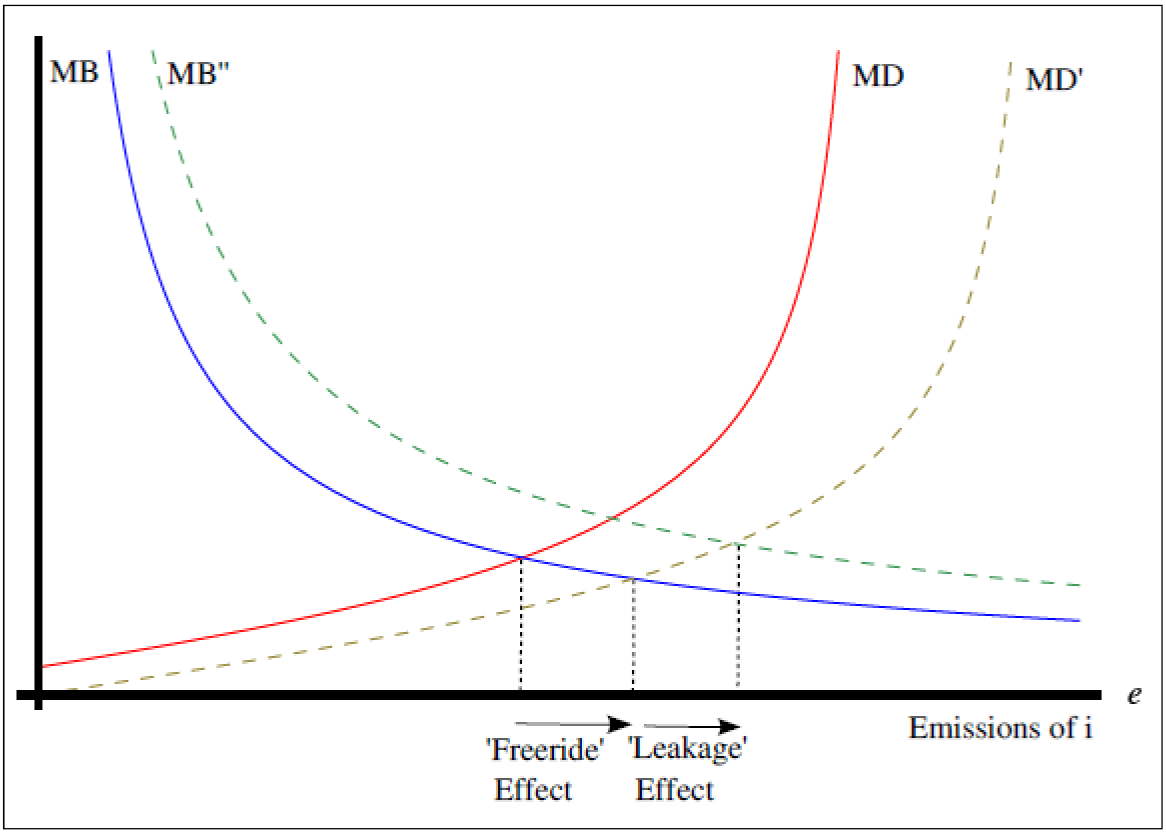


Figure 1. Leakage and free rider effects

Note that if $(\partial p/\partial e_B)\partial D_{NB}/\partial e_{NB} < p(\partial^2 D_{NB}/\partial e_{NB}^2)$, i.e. the increase in marginal benefits of emissions due to the increase in prices is greater than the change in marginal benefits due to increasing emissions, expression (8) can get smaller than -1. Total emissions may increase due to a marginal reduction in the Annex B - but such equilibrium might be unstable.

We define now the leakage rate, i.e. marginal change in Non-Annex B's emission due to marginal changes in Annex B's abatement policy, induced by commodity price change, $L_{NB} = (\partial p/\partial e_B)\partial D_{NB}/\partial e_{NB}$. Thus, the leakage rate denotes the marginal change of the price due to a decrease of emissions in the Annex B times the marginal increase of emissions in Non-Annex B due to the price change and so we get for L_{NB}:

$$L_{NB} = \frac{\frac{\partial D_{NB}}{\partial e_{NB}}\left(\frac{\partial D_B}{\partial e_B} - \sigma\theta\left(\frac{\partial G_B}{\partial e_B} + \frac{\partial G_{NB}}{\partial e_B}\right)\right)}{\left(p\frac{\partial^2 D_{NB}}{\partial e_{NB}^2} + \frac{\partial^2 C_{NB}}{\partial E^2}\right)(\varepsilon - \eta)Z} \quad . \tag{10}$$

Equation (10) indicates that larger marginal profits of emissions ($\partial Y_{NB}/\partial e_{NB}$) in the Non-Annex B cause more leakage. And the higher elasticities of demand the smaller is the leakage rate. And obviously the more vulnerable Non-Annex B's carbon intensive sector is, the lower is leakage. We see as well that increasing market sizes reduced leakage.

As some authors have shown (e.g. Kennedy, 1994), imperfect competition causes a strategic interaction of environmental policies between countries. In the presence of leakage have countries an incentive to set CO_2 taxes below the Pigouvian level to capture additional rents. This environmental dumping effect additionally tempers the ability of climate policy instruments to internalize the pollution problem.

3.3 Optimal climate policy and carbon-related BAMs to Combat Leakage

We analyze the effect of border carbon adjustment on carbon-intensive goods and then we discuss if BMA has the potential to increase the efficiency of unilateral climate policy in open economy regimes. Since the representation of production technologies is as simple as possible in our model, we do not distinguish between different production methods within a region, hence we simply assume that the tax rate by which an imported carbon-intensive good is levied, is based on the domestic carbon intensity. In contrast to a pollution content tariff as in Copeland (1996), the tariff level does not depend on the carbon content of the imported good itself and the production technology abroad. This reduces the policy efficiency of the tariff, since abatement efforts of the exporters do not directly reduce the tariff.

For the analysis of BAMs we concentrate on the case where only Annex B's policy actions influence prices, whereas the Non-Annex B takes them as given. We extend then the model by Annex B's imposition of a border tax τ_B on imported carbon-intensive goods. We assume that Non-Annex B countries are net exporters of carbon-intensive goods. The exports to Annex B are taxed on the border. The first order condition for the optimal emission level in Non-Annex B is now as follows:

$$p\frac{\partial H_{NB}}{\partial e_{NB}} + \left(p - \tau_B\left(e_B\right)\right)\frac{\partial X_{NB}}{\partial e_{NB}} + \frac{\partial C_{NB}}{\partial E}\frac{\partial E}{\partial e_{NB}} = 0\,, \tag{11}$$

where $\partial H_{NB}/\partial e_N$ denotes the change in domestic demand for carbon-intensive goods in Non-Annex B if own emissions marginally change, and $\partial X_{NB}/\partial e_N$ denotes the respective change in net exports. The implementation of carbon-related BAMs in Annex B countries affects the first order condition of Non-Annex B countries. Marginal profits from emissions are now split up in benefits from domestic consumption and in profits from exports. The higher the foreign tariff, the smaller the marginal profits from carbon-intensive exports and hence from emissions.

A small rearrangement of the expression (11) and using of the implicit function theorem leads to the following response of Non-Annex B's on a marginal reduction of Annex B's emissions:

$$\frac{\partial e_{NB}}{\partial e_B} = \frac{-\left(\frac{\partial^2 C_{NB}}{\partial e_{NB}^2} + \frac{\partial p}{\partial e_B}\frac{\partial Y_{NB}}{\partial e_{NB}} - \frac{\partial \tau_B}{\partial e_B}\frac{\partial X_{NB}}{\partial e_{NB}} - \tau_B \frac{\partial^2 X_{NB}}{\partial e_{NB}\partial e_B}\right)}{p\frac{\partial^2 D_{NB}}{\partial e_{NB}^2} + \frac{\partial^2 C_{NB}}{\partial E^2} - \tau_B \frac{\partial^2 X_{NB}}{\partial e_{NB}^2}} . \quad (12)$$

We observe three additional terms in the marginal response expression (12), which are of importance: (i) $\left(\partial\tau_B/\partial e_B\right)/\left(\partial X_{NB}/\partial e_N\right)$ is the tax rate effect of the border measure. If Annex B's marginally reduces his emissions, its carbon-intensive industry produces more carbon-efficiently. Since the assessment basis of the tax rate depends on Annex B's production technology, τ_B is increasing. This reduces the profits from Non-Annex B's carbon-intensive net-exports and hence the incentive to respond with an expansion of GHG emissions. (ii) The term $\tau\left(\partial^2\tau_{NB}/\partial e_{NB}\partial e_B\right)$ captures changes in net-exports due to a decrease in Annex B's emissions. A reduction in its emission affects only the demand side of the net-export balance and is only of second order importance. We ignore therefore this effect for the further analysis and draw our attention on additional terms in the denominator. If we again neglect demand-side effects, we can state $\tau_B\left(\partial^2 X_{NB}/\partial e_{NB}^2\right) = \tau\left(\partial^2 Y_{NB}/\partial e_{NB}^2\right)$. It now becomes obvious that the border measure reduces the marginal profits from emissions for the Non-Annex B countries and hence reduces negative leakage incentives.

Then, assuming that the Non-Annex B region is a net-exporter of carbon-intensive goods and that the changes in climate policy do not affect the demand side of the trade balance carbon-related BAMs reduce the negative response of Non-Annex B on a marginal change in A's GHG emissions.

If we neglect demand-side effects on the trade-balance for carbon-intensive good, then,

$\tau_B\left(\partial^2 X_{NB}/\partial e_{NB}\partial e_B\right) = 0$, $\left(\partial\tau_B/\partial e_B\right)\partial X_{NB}/\partial e_{NB} = \left(\partial\tau_B/\partial e_B\right)\partial Y_{NB}/\partial e_{NB} > 0$, and

$\tau_B \left(\partial^2 X_{NB} / \partial e_{NB}^2\right) = 0$. This reduces the numerator and enlarges the denominator compared to the marginal response on equation (8). Hence, in a regime, where Annex B imposes border taxes to Non-Annex B's carbon-intensive exports, the latter responds to a marginal reduction in Annex B's emissions with a less pronounced emission increase than in absence of border measures.

The numerator in equation (12) on the right hand side shows the limitation of carbon-related BAMs to combat leakage. While mitigation in Annex B influences the world market price and hence the total production of the carbon-intensive goods in Non-Annex B $\left(\partial p/\partial e_B \cdot \partial Y_{NB}/\partial e_{NB}\right)$, the import tariff affects only Non-Annex B's net exports $\left(\partial \tau_B/\partial e_B \cdot \partial X_{NB}/\partial e_{NB}\right)$. Hence, the bigger the export share of the Non-Annex B's carbon-intensive production, the more effective is carbon-related BAMs.[5]

To examine full general equilibrium effects and to get a quantitative assessment of the effects, we turn now our attention to the numerical model. Annex B profits from a better environmental quality, because the incentive of Non-Annex B to increase emissions is smaller than without import tariffs. But at the same time, Annex B suffers from terms of trade changes, depending on trade patterns carbon-related BAMs is only a credible threat, if Non-Annex B is convinced that the Annex B profits in terms of welfare from the measure. However, welfare effects are not captured in our analytical model. We analyze this issue in section 4 by means of a computable general equilibrium model with a more detailed disaggregation concerning production sectors and regions.

4. General equilibrium analysis

In this section we analyze the environmental and economic effects of leakage and the introduction of carbon-related BAMs in our framework. First, we describe the main features of the CGE model (GEMINI-E3) that we use on our analysis. Second, we describe our reference scenario. Third, we present the scenarios that we tested and the main results stemming out from them. Finally, we present how we introduce carbon-related BAMs in our model and the main effects that this have on leakage and welfare.

[5] A possibility to address this problem would be the implementation of export subsidies on carbon intensive goods in the policy implementing region. However, as mentioned in the introduction, we neglect this policy option in this paper.

4.1 Description of the model

GEMINI-E3[6] is a multi-country, multi-sector, recursive computable general equilibrium model comparable to the other CGE models (GREEN, EPPA, MERGE, Linkage, WorldScan) built and implemented by other modeling teams and institutions, and sharing the same long experience in the design of this class of economic models. The standard model is based on the assumption of total flexibility in all markets, both macroeconomic markets such as the capital and the exchange markets (with the associated prices being the real rate of interest and the real exchange rate, which are then endogenous), and microeconomic or sector markets (goods, factors of production).

The model is built on a comprehensive energy-economy dataset, the GTAP-6 database (Dimaranan, (2007), that incorporates a consistent representation of energy markets in physical units, social accounting matrices for each individualized country/region, and the whole set of bilateral trade flows. Additional statistical information accrues from OECD national accounts, IEA energy balances and energy prices and IMF Statistics. Carbon emissions are computed on the basis of fossil fuel energy consumption in physical units, carbon emissions that are not linked to energy combustion, like CO_2 emissions coming from chemical reaction in cement clinker production, are not taking into account. But non-CO_2 greenhouses gases emissions are included in the model, for example the methane released during coal mining is taken into account. For the modelling of non-CO_2 greenhouse gases emissions (CH_4, N_2O and F-gases), we employ region- and sector-specific marginal abatement cost curves and emission projections provided by the Energy Modelling Forum within the Working Group 21.

The nomenclatures - breakdowns by country/region and by sector/product - are framed according to the general context and the targets of each study. For the present analysis, it appeared convenient to disaggregate the main European Union into 6 entities (the 5 most important economies and the rest of the EU) and to retain a nomenclature of 18 products/sectors, with 3 sectors of fossil energy, 6 in the ETS or energy intensive sectors and 9 in the Non-ETS, according to Table 1. We assume that the ETS sector encompasses all of the sectors listed in Table 1. Due to data limitations and to the constraints coming from the initial sectors' classification of GEMINI-E3, we note that this formulation does not exactly fit

[6] All information about the model can be found at http://gemini-e3.epfl.ch, including its complete description.

the EU directive, because: (i) some sectors are in both the ETS sector and in the non-ETS sector; and (ii) within a given sector, some firms under the eligibility threshold should not be accounted in the ETS subgroup.

Table 1. Dimensions of the GEMINI-E3 Model

OECD Countries	***Sectors participating to the ETS***
Germany (DEU)	Petroleum Products
France (FRA)	Electricity
United Kingdom (GBR)	Mineral Products
Italy (ITA)	Chemical, rubber, Plastic
Poland (POL)	Metal and Metal products
Rest of European Union (EUR)	Paper products publishing
Japan (JAP)	
USA (USA)	***Other sectors***
Canada, Australia, New Zealand (CAZ)	Coal
	Oil
non OECD Countries	Gas
Russia (RUS)	Agriculture
India (IND)	Forestry
Brazil (BRA)	Transport nec
China (CHI)	Sea Transport
Rest of the World (ROW)	Air Transport
	Consuming goods
	Equipment goods
	Services
	Dwellings

4.2 The reference scenario

The reference scenario, also called business as usual (BAU), corresponds to a situation where no climate change policy is deemed necessary. Table 2 summarizes the projected annual GDP growth for each region. The World GDP growth will converge in 2030 to 2.8% per year. The growth would be greater in developing and emerging countries. Our price assumptions assumes that oil price reaches 80 US $ per barrel in 2030.

Table 2. GDP Growth in the BAU scenario (%)

	2010-2006	2020-2010	2030-2020
Germany	2.0	1.7	1.5
France	2.4	2.4	2.1
United Kingdom	2.6	2.3	2.1
Italy	1.7	1.9	1.7
Poland	4.3	4.6	3.9
Rest of European Union	3.5	3.1	2.4
Japan	2.2	1.5	0.4
USA	3.9	2.1	2.1
Canada, Australia, New Zealand	2.9	2.2	1.2
Russia	5.9	5.4	5.6
India	4.2	3.7	3.0
Brazil	8.6	8.1	6.5
China	9.6	6.3	5.2
Rest of the World	4.7	3.9	3.0
World	3.9	3.3	2.8

Targets in climate policies are defined relative to a base year for developed countries. The base years have been indicated in the commitments of the countries (see Table 3). For developing countries, the base year is 2005. Currently climate policies are characterized by what is commonly called a fragmented regime. Different countries of Annex 1 were individually engaged in the implementation of various measures (taxes, standards, incentive program, etc.) that result in a set of carbon prices (explicit or implicit) that have little chance to converge toward a common value. Only the EU ETS market does represent a successful attempt to reach a common price for CO2 for a set of economic sectors in different countries. This fragmentation may eventually hinder the development of more ambitious policies and lead to very high disparities in CO2 prices. Furthermore, according to economic theory this is a source of inefficiency, so there is real gain to make these prices converge to a single price (Tirole, 2009). The convergence of these prices necessitates a generalization of the ETS from European countries to other countries in Annex 1 and further, to developing countries. The assumption of the study reported here, is that starting in 2020, a global market for CO2 is in place leading to a single price for CO2. Trading is set up to exchange rights that are equal to the commitments of each country. This assumption represents the best case for achieving cost effectiveness, even though it does not imply necessarily a global market accessible to all (household, business, government). Multiple markets (ETS Global, CDM, carbon market between nations, national tax, etc.) are also possible, provided permeability and monitoring are carried out effectively enough to get a single world price.

Table 3. Base year reference emissions (all GHG)

	Year	Emissions in Gt CO_2-eq	Source
EU	1990	4244	UNFCC exluding LULUCF
USA	2005	7107	UNFCC exluding LULUCF
Australia	2000	495	UNFCC exluding LULUCF
Japan	2005	1358	UNFCC exluding LULUCF
Canada	2006	721	UNFCC exluding LULUCF
Russia	1990	3326	UNFCC exluding LULUCF
China	2005	6739	WEO + estimation EPA
India	2005	2054	WEO 2005 + estimation EPA
Brazil	2005	1011	indicators OMD UN + estimation EPA
ROW	2005	11973	IEO2009 + estimation EPA

In this set of simulations, the quotas allocated within EU are based on the Population in 2001. For industrialized countries, the commitments or proposals made for 2020 and 2050 have been retained (see Table 4). For the intermediate years, the target is obtained by linear interpolation. No international market for tradable emission permits is established before 2020. After 2020 one assumes that an international tradable permit market is gradually established, leading to a single price for carbon.

Table 4. GHG emission abatement commitments (%)

	Year	2020	2050
EU	1990	20-30	75
USA	2005	17	80
Australia	2000	5-25	60
Japan	2005	15	-
Canada	2006	20	65
Russia	1990	20	50

GEMINI-E3 includes 6 European country separately, and assumes that until 2020 Europe will implement the energy-climate package, which means two CO2 price within the European Union: (i) a common carbon price in ETS sector; and (ii) another common CO2 prices within non-ETS sectors, on the basis of allowances specified in the EU-directive on energy and climate. Moreover, starting from 2021 one assumes the participation of the European Union in a global market for CO2. The "burden sharing" of each country must then be defined and be negotiated taking into account the overall objective of -75% in 2050 compared to 1990 level. In this study, the scenarios assessed in the present study assume that the burden sharing between European countries is based on the population of each member.

4.3 Description of scenarios and main results

In this section we describe our scenarios, present the main results from them and assess the effect of leakage.

- *Description of scenarios*

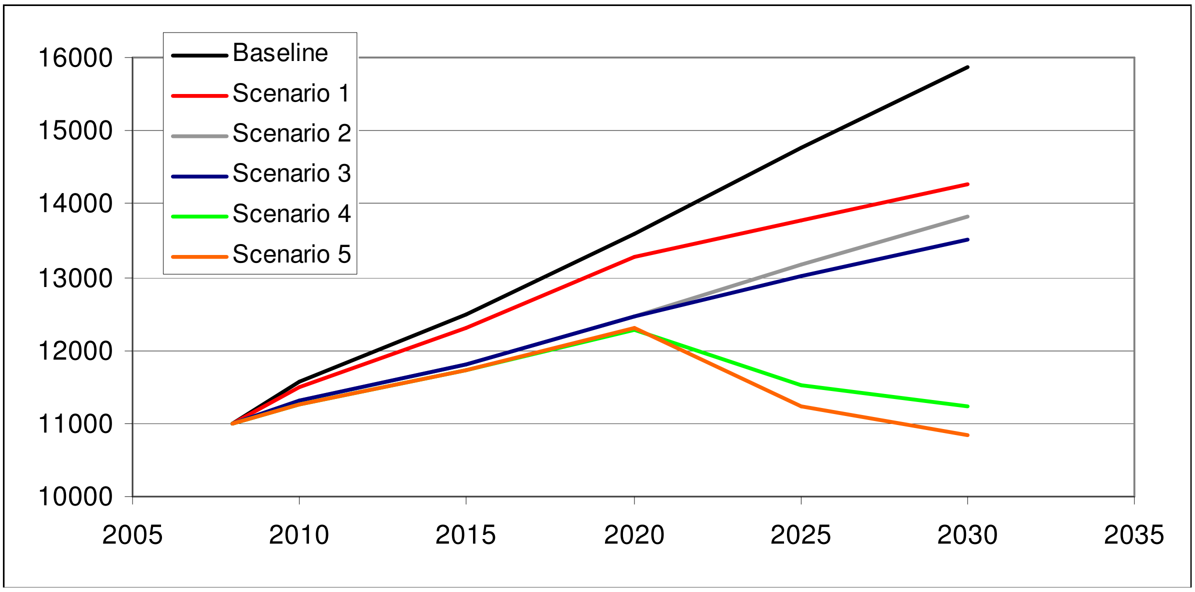
We analyze five scenarios, in Scenario 1 (Failure of Negotiations), countries prefer to emphasize their national interests. The USA abandons their climate policy objectives. Canada, Australia and Japan eventually join the USA. Only EU meets its commitments of -20% in 2020. However, in 2020, the effects of global warming are evident and thus it revives the negotiations. Then, USA, Japan, Canada and Australia decide to reach -20% in 2030 (relative to 2005). The rest of the World does not commit to a binding objective. As regards the European carbon market, we assumed that, within the EU, a market of emission permits is introduced at national level to arrive at a single CO2 price for non-ETS sectors. Two CO2 prices coexist for an ETS sector and another for non-ETS sectors. In Scenario 2 (minimum agreement in OECD countries), we assume that industrialized countries (except Russia) fulfil their commitments in 2020 and set up, gradually from 2021, an international market for emission permits to fulfil commitments consistent with the goals of industrialized countries for 2030. Russia and other countries have no meaningful climate policy until 2030.

Scenario 3 (agreement with OECD and Russia) is practically the same as Scenario 2 with the exception that Russia joins the OECD efforts to tackle climate change. Scenario 4 (G20 agreement) is an extension of Scenario 3 to include major industrialized countries, but with the addition of China, India, Brazil (BRIC block). Countries agreed to set up from 2020 an international market for emission permits. From 2020, China and India are allocated quota as 150% of their 2005 emissions, and Brazil 120%. For industrialized countries, quotas are equal to objectives consistent with their goals for 2050, the European Union deciding to -30% in 2020 given the participation of China, India and Brazil to the agreement. China, India and Brazil participate to the international carbon market. A restriction is imposed on the volume of permits they can sell during the first years (10% of their quotas), this restriction is gradually removed and trade is unlimited in 2030. Finally, Scenario 5 (global agreement) all countries participate in an agreement following the lines of Scenario 4. However, from 2020, the Rest of the World obtains a quota equal to 120% of their 2005 emissions. China, India and Brazil and the Rest of the World participate to the international carbon market. A restriction is imposed on the volume of permits they can sell during the first years (10% of their quotas), this restriction is gradually removed and trade is unlimited in 2030.

- *Main results of the scenarios*

This section presents the main results of the scenarios. Figure 2 presents the GHG emissions in the different scenarios. Only the scenarios 4 and 5 lead to a decrease of GHG emissions, this result shows the importance of the integration of emerging and developing countries in the climate change policy.

Figure 2. World GHG emission in MT C equivalent



We present in Table 5 the CO_2 price in 2020 and in Table 6 the CO_2 price for 2025 and 2030. In the scenario 1, the price of the ETS would be equal to 32 € in 2020 and 73 € for the non-ETS. In the scenario 2, the integration of other OECD countries (USA, Japan, Canada, Australia and New Zealand) leads to a further decrease of world energy demand and therefore a steeper decrease of energy prices (mainly for crude oil and natural gas), this requires an increase in the price of CO_2 in the non ETS sector for European countries (the price reaches 83 €), but not in the ETS sector where coal is the main fossil energy consumed. For non European countries the CO_2 price is around 40 € in the scenario 2 for the year 2020. Scenario 3 does not modified the CO_2 price because the commitment of Russia (-20% in 2020 in respect to 1990 levels) is already reached in the baseline. In scenario 4 and 5 the only difference concerns the European countries, which decides to reach a more stringent commitment (-30% in 2020) this requires an increase of the CO_2 price in the ETS (the price is now equal to 90 €) and in contrary a decrease of the CO_2 price in the other sectors. The raison is that the increase of electricity prices due to the important increase of the ETS price induces a decrease of energy consumption in all sectors and of course a decrease of CO_2 emissions, the prices required to reach the new CO_2 target is therefore less important.

Table 5. Price of CO2 in 2020 (in € 2005)

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
EU					
ETS price	32	33	33	90	90
Non ETS price	73	83	83	71	71
USA	-	37	37	37	37
Japan	-	34	34	33	33
CAZ	-	44	44	44	44
Russia	-	0	0	0	0

After 2020, the implementation of international tradable permits leads to a unique CO_2 price. The table 6 gives this price in 2025 and 2030. It is important to highlight that when the emission abatement increases with a greater participation of regions the CO_2 price decreases over this period. This is due to the lower CO_2 abatement of emerging and developing countries.

Table 6. Price of CO_2 permit in 2025 and 2030 ($€_{2005}$)

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
2025	28	84	64	19	13
2030	83	168	131	39	23

- *Leakage*

We have computed the leakage in the different scenarios. In our analysis, we consider leakage as equal to the increase of GHG emissions in the regions where are not binding by any commitment. In Table 7, we present the leakage in millions tons of carbon and in percentage. The leakage ratio is estimated in the worst case (Scenario 1) to 12% in 2030 concerning CO_2 emissions. Of course when we increase the participation in the climate agreement this reduces the leakage effect and conducts in Scenario 5 to a leakage equal to 0. Furthermore, we observe that when the agreement encompasses the main emerging countries (Brazil, Russia, India and China) the leakage could be reduced to very low level, 3% in 2030. We find that the leakage ratios that we present in Table 7 are in line with the numbers from the literature (e.g. Paltsev, 2001; Babiker and Rutherford, 2005; Metz et al., 2007)

Table 7. Abatement and leakage in Mt C

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
GHG Emissions					
			2020		
Abatement	349	1204	1206	1346	1346
Leakage (total)	43	96	83	86	86
Leakage (%)	-12	-8	-7	-6	-6
			2030		
Abatement	1773	2231	2559	4739	5038
Leakage (total)	154	169	187	97	0
Leakage (%)	-9	-8	-7	-2	0
CO_2 emissions					
			2020		
Abatement	271	930	916	1049	1049
Leakage (total)	43	108	94	100	100
Leakage (%)	-16	-12	-10	-10	-10
			2030		
Abatement	1490	1935	2186	4107	3940
Leakage (total)	172	194	187	106	0
Leakage (%)	-12	-10	-9	-3	0

In the following section, we assess the effects of using carbon-related BAMs to tackle leakage. The introduction of border adjustment measures will be done within the scenario 2 which suppose that only industrialized countries undertake GHG emission reductions. Table 8 presents in the case of the scenario 2 the source of leakage at the regional and industrial level. BRIC countries represent 45% of the leakage and energy intensive industries (including refined petroleum industries and electricity generation) amounting to 81% of the increased emissions.

Table 8. Leakage in Gt C by region and sector in scenario 2 in 2030

Sector	Russia	Brazil	India	China	ROW	**Sum**
Coal	0	0	0	-3	0	**-3**
Oil	0	0	0	0	-2	**-2**
Gas	0	0	0	0	-4	**-3**
Petroleum products	1	6	2	2	35	**45**
Electricity	1	16	5	10	26	**58**
Agriculture	0	0	0	0	1	**0**
Forestry	0	0	0	0	0	**0**
Mineral products	0	1	0	3	7	**12**
Chemical, rubber, plastic	1	3	1	5	14	**24**
Metal and metal products	1	3	1	5	6	**17**
Paper products publishing	0	0	0	0	1	**1**
Transport nec	0	1	1	3	4	**10**
Sea transport	0	0	0	1	1	**3**
Air transport	0	1	0	1	0	**2**
Consuming goods	0	0	0	-1	1	**0**
Equipment goods	0	0	0	0	1	**2**
Services	0	0	0	1	3	**5**
Dwellings	0	0	0	0	0	**0**
Households	0	1	3	0	11	**24**
Sum	**5**	**32**	**14**	**37**	**106**	**194**

4.4 Border Adjustment Measures

We have simulated two different BAMs: (i) an introduction of tariffs to imports and (ii) the inclusion of imports in the domestic permit trading schemes. We focus our assessment on the scenario 2 to analyse the impacts of these instruments. The following simulations will suppose the implementation of BAMs and will be compared to the scenario 2 without any corrective measure

- *Tariff protection*

We first assume that there is a tax on import based on direct CO_2 content. We suppose that in OECD countries a carbon price is imposed on imports coming from non-OECD countries and that this carbon price is based on the price supported by domestic firms. Each OECD government collects their duties. The CO_2 content used to determine the tax is based on the fossil energy consumed by firm in non-OECD countries.

$$\alpha_r^i = \frac{\sum \beta_j En_r^{j,i}}{XD_r^i}, \qquad (13)$$

where α_r^i is the CO2 content of good i produced in region r, β_j the CO2 content of energy j, $En_r^{j,i}$ the energy consumption in toe by sector i in energy j and XD_r^i the production of sector i in region r.

The price of imported good i in region r coming from region t is the following:

$$Pimp_{r,t}^i = pd_t^i * \left({ex_t}/{ex_r} \right) + \alpha_r^i \times Tco2_r^i , \quad (14)$$

where ex is the exchange rate, pd the production price and Tco2 the carbon tax.

Second, we assume that there is a tax on import based on direct and indirect CO2 content. Hence, we take into account not only direct emission but also indirect emissions representing the carbon content of goods used as intermediate input. The coefficient α_r^i is now computed by the following equation:

$$\alpha_r^i = \frac{\sum_j \beta_j \, En_r^{j,i} + \sum_{k,t} \alpha_t^k \, MA_t^{i,k}}{XD_r^i} , \quad (15)$$

where MA_t^k represents the intermediate input in good k used by sector i and produced in region t.

We obtain two sets of results from simulations assuming that the tax on imports is imposed on all goods and not only on goods produced by energy intensive industries (EII). We change this assumption an additional set of results, where only the EII are subject to tariff protection. Concerning climatic impacts the gain coming from tariff imports ranges from 20 to 50 Mt C, which corresponds in the best case to a reduction of 26% of the leakage - as we see in Table 9.

Table 9. Leakage in Mt Carbon and in % in 2030

	Scenario 2	Scenario 2 + BAM based on direct content	Scenario 2 + BAM based on direct and indirect content	Scenario 2 + BAM based on direct and indirect content (only EII)
Leakage (total)	194	174	144	152
Leakage (%)	10	9	7	8

We find that with the adoption of a carbon tariff on imports the price of carbon decrease slightly (from €168 to €166). In Table 10, we report, respectively, the impacts of BAM on the price of carbon and on the welfare cost respectively in 2030. In contrary the impact on welfare is important, as in Babiker and Rutherford (2005) we find that the tariff protection is welfare improving to countries that impose this tariff and in contrary that the other group of countries is worse off[7]. The reason for this welfare impact is the large implicit rent transfer conferred to countries which impose a tax on imports.

Table 10. Welfare cost in % of household consumption in 2030

	Scenario 2	Scenario 2 + BAM based on direct content	Scenario 2 + BAM based on direct and indirect content	Scenario 2 + BAM based on direct and indirect content (only EII)
OECD countries				
Germany	-5.5	-4.4	-3.1	-4.6
France	-1.4	-0.1	0.7	-0.3
United Kingdom	-4.3	-3.4	-2.5	-3.6
Italy	-2.1	-0.6	0.4	-0.6
Poland	-13.3	-10.8	-9.7	-10.9
Rest of European Union	-1.3	1.1	2.5	0.8
Japan	-1.4	-0.5	0.4	-0.6
USA	-1.9	-1.6	-1.6	-1.6
Canada, Australia, New Zealand	-1.1	-0.3	0.7	-0.5
Non-OECD countries				
Russia	-2.0	-8.3	-10.2	-8.9
Brazil	-0.4	-1.0	-2.0	-1.0
India	0.0	-0.1	-1.6	0.2
China	-0.8	-1.4	-5.1	-1.0
ROW	-1.8	-3.6	-4.9	-3.5

[7] We one exception concerning India which has a low welfare gain when the tariff is only applied to Energy Intensive Industries.

- *Inclusion of imports in a national emissions trading scheme*

We consider now that exporters have to buy emission allowances for selling their products in the regions that have adopted binding commitment of GHG emissions, if of course they are not localized in these regions. As our international emissions trading scheme begins at the worldwide level in 2021, we suppose that before 2021, a tariff protection is imposed with the same protocol described above. We assume also that only Energy Intensive Industries are faced to the new rule, the other sectors are exempted to any border adjustment measure. A crucial assumption is linked to the allocation rule of the CO_2 allowances for the foreigner producers, if we suppose that no additional allowances are created, the new demand for emission permits will increase sharply the CO_2 price. We have retained two assumptions: (i) no additional allowances are given, and (ii) allowances are given to exporters which is equal in 2021 to 80% of the CO_2 content of imports for a reference year which is fixed to 2000, and this allocation is equal to 50% in 2050 for this same reference year.

Table 11 reports the CO_2 price and the leakage, whereas Table 12 presents the trading of emission permits. In the case where no additional allowances are given the CO_2 price increases by 50%. The additional demand for permits forced OECD countries to reduce by more than 267 millions of CO_2 their emissions compared to the scenario 2. OECD countries become net sellers of permits and U.S. sell more than half of the demand from the EII exporters. The leakage is equal to 157 Mt CO_2.

Table 12. CO2 permit (€ 2005) and leakage in 2030

	Scenario 2	Scenario 2 + import in emissions trading	Scenario 2 + import in emissions trading + extra allowances
CO_2 price	168	243	218
Leakage	194	157	155
OECD GHG abatement	2231	2498	2387
CO2 buying by EEI exporters	-	267	156

Concerning the welfare cost of OECD countries there is two opposite effects of the inclusion of imports in the national emission-trading scheme, first, the increase of CO_2 price induce a increase of the deadweight loss of the taxation; second, the selling of permits to non OECD producers create extra revenue.

Table 13. Trading of permits (+ selling – buying) in Mt C in 2030

	Scenario 2	Scenario 2 + import in emissions trading	Scenario 2 + import in emissions trading + extra allowances
Germany	-53	-32	-41
France	6	14	11
United Kingdom	-12	1	-4
Italy	6	13	10
Poland	-3	4	1
USA	7	144	88
Japan	16	37	28
Rest of European Union	2	32	19
Canada, Australia, New Zealand	31	52	44
All exporters	-	-267	-156
Sum	**0**	**0**	**0**

Finally, the impact is welfare decreasing for Germany, and USA, and welfare increasing for the other OECD countries. For non-OECD countries the result of the scenario is of course an increase of the costs. When we create extra allowance dedicated to EII imports the increase of the CO_2 price is less important (30% to be compared to 50%), the impact are similar to the previous simulation but with a magnitude less important.

5. Conclusions

We analyze carbon-related BAMs (focused on imports) as potential instruments to reduce emissions leakage. We combine an approach from international trade law with an economic approach. For the legal aspect we discuss the elements needed to include carbon-related BAMs within the current GATT and WTO frameworks. For the economic aspect, we assess the effects of leakage and of BAMs to tackle it within an optimal climate policy model and a general equilibrium model.

From our analysis, we can derive three main results. First, from an international trade law perspective, we find that the design and implementation of carbon-related BAMs would be difficult to bring in compliance with WTO rules and with criteria set for justification under GATT general exceptions. Because of intrinsic competition-related motives of border adjustment, and because of traditionally symmetric application of border adjustment to imports and exports, for the purpose of defence under GATT's Article XX, it would perhaps be more reasonable to apply import carbon tariffs, rather than carbon-related BAMs. Furthermore, a carbon-related BAM might be ineffective to foster global emission reductions. Foreign producers might adjust their costs respectively and choose to pay a carbon tax or surrender emission permits, instead of investing in low-carbon technologies. Moreover, exporting countries may take retaliatory measures.

Second, from the optimal climate policy perspective, we find that leakage indeed is a major problem for unilateral climate policies and BCA is an effective instrument to deal with leakage. Additionally, we observe that the severity of leakage may be amplified through international trade and that BAMs indeed help in reducing such leakage. Third, from our welfare analysis, we find that although leakage may be reduced after the introduction of a BAM, this reduction is not important. We observe that charging a tariff on imports provides better results (in terms of leakage reduction) than forcing exporters to surrender emission permits at the border. Moreover, we find that the welfare effects are not always unambiguous. We show that, when implementing a tariff, welfare in OECD countries is increased (although to a small extent), whereas when exporters have to buy permits at the border the effects on OECD countries is not always positive for all OECD countries. Thus, following our optimal climate policy assessment, we may argue that carbon-related BAMs would not represent a credible threat to involve other actors in the international climate regime.

Finally, as future lines of research, we propose to assess what will be the effects of alternative BAMs (e.g. carbon-intensity standards and export rebates) under our framework and to analyze alternative institutional arrangements (e.g. a combined UNFCCC/WTO framework or bilateral agreements) to tackle both the issues of climate change, in general, and of emissions leakage, in particular.

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References

Abbas, M., 2008. Trade Policy and Climate Change: Options for A European Border Adjustment Measure, *Working Paper LEPII*, Grenoble University, Grenoble.

Alexeeva-Talebi, V., Löschel, A., and T. Mennel, 2008. Climate Policy and the Problem of Competitiveness: Border Tax Adjustments or Integrated Emission Trading, *ZEW Discussion Paper No. 08-061, ZEW,* Mannheim.

Babiker, M., and T. Rutherford, 2005. The Economic Effects of Border Measures in Subglobal Climate Agreements, *The Energy Journal*, 26

Bacchus, J., 2010. Questions in Search of Answers: Trade, Climate Change, and the Rule of Law. Keynote address to the *TAIT second conference Climate Change, Trade and Competitiveness: Issues for the WTO*, Geneva, 16-18 June 2010.

Baumol, W., and D. Bradford, 1972. Detrimental Externalities and Non-convexity of the Production Set, *Economica*, 39.

Bhagwati, J., and T. Srinivasan, 1973. The general equilibrium theory of effective protection and resource allocation, *Journal of International Economics,* 3.

Biermann, F., Böhm, F., Brohm, R., Dröge, S., and H. Trabold, 2003. *The Polluter Pays Principle under WTO Law: The Case of National Energy Policy Instruments*. Environmental Research of the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety, Berlin.

Biermann, F., and R. Brohm, 2005. Implementing the Kyoto Protocol without the USA: the Strategic Rule of Energy Tax Adjustments at the Border, *Climate Policy*, 289.

Condon, B. J., 2009. Climate Change and Unresolved Issues in WTO Law, *Journal of International Economic Law,* 12

Copeland, B. R., 1996. Pollution content tariffs, environmental rent shifting, and the control of cross-border pollution, *Journal of International Economics,* 40

Dimaranan, B. V., 2006. Global Trade, Assistance, and Production: The GTAP 6 Data Base Center for Global Trade Analysis Purdue University

Goh, G., 2004. The World Trade Organization, Kyoto and Energy Tax Adjustments at the Border, *Journal of World Trade*, 38.

Holzer, K., 2010a. Proposals on Carbon related-Border Adjustments: Prospects for WTO Compliance, *Carbon and Climate Law Review*, 1.

Holzer, K., 2010b. Trade and Climate Policy Interaction: Dealing with WTO Law Inconsistencies of Carbon-related Border Adjustment Measures. *NCCR-Climate Working paper 2010/06*, NCCR-Climate, Bern.

Hoerner, J. A., and F. Muller, 1996. *Carbon Taxes for Climate Protection in a Competitive World*. Report for the Swiss Federal Office for Foreign Economic Affairs. Environmental Tax Program of the Center for Global Change. University of Maryland College Park, Maryland.

Hufbauer, G. C., and K., Jisun, 2009. The World Trade Organization and Climate Change: Challenges and Options, *Working Paper Series 2009-09*, Peterson Institute for International Economics, Washington, D.C.

IPCC, 2007. *Climate Change 2007: Mitigation: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.

Kennedy, P., 1994. Equilibrium Pollution Taxes in Open Economies with Imperfect Competition, *Journal of Environmental Economics and Management*, 27.

Low, P., Marceau, G., and Reinaud, J., 2010. The interface between the trade and climate change regimes: Scoping the issue. Background paper written for the *TAIT second conference Climate Change, Trade and Competitiveness: Issues for the WTO*, Geneva, 16-18 June 2010.

Markusen, J. R., 1975. International externalities and optimal tax structures, *Journal of International Economics*, 5.

Nordhaus, W. D., and J. Boyer, 2000. *Warming the World. Economic Models of Global Warming*. MIT Press.

Paltsev, S., 2001. The Kyoto Protocol: Regional and Sectoral Contributions to the Carbon Leakage, *The Energy Journal*, 22.

Pauwelyn, J., 2009, *Testimony before the Subcommittee on Trade of the House Committee on Ways and Means, 24 March 2009*, available at http://www.docstoc.com/docs/9842017/ Statement-of-Joost-Pauwelyn.

Quick, R., 2000. The Community's Regulation on Leg-Hold Traps: Creative Unilateralism Made Compatible with WTO Law through Bilateral Negotiations?, in Marco Bronckers and Reinhard Quick (eds.), *New Directions in International Economic Law: Essays in Honour of John H. Jackson*, Kluwer Law International.

Schenker, O., and R. Bucher, 2010. On Interactions of Optimal Climate Policy and International Trade. An Assessment of Border Carbon Measures, *NCCR-Climate Working paper 2010/04*, NCCR-Climate, Bern.

Stern, N., 2007. *The Economics of Climate Change: the Stern Review*. Cambridge University Press, Cambridge.

Tirole, J., 2009., Politique climatique : une nouvelle architecture internationale, Rapport du Centre d'Analyse Stratégique.

Van Calster, G., 2008. Against Harmonisation – Regulatory Competition in Climate Change Law, *Carbon and Climate Law Review*, 1.

WTO, 2001. Import Prohibition of certain Shrimp and Shrimp Products, *Panel report*, WTO.

Zhang, Z. X., 2009. Encouraging Developing Country Involvement in a Post-2012 Climate Change Regime: Carrots, Sticks or Both?, in *Climate and Trade Policies in a Post-2012 World*, UNEP.