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DIPARTIMENTO DI ECONOMIA

COOPERATIVE AND NON-COOPERATIVE SOLUTIONS TO CARBON LEAKAGE

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Cooperative and non-cooperative solutions to carbon leakage

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Abstract

A modified version of the CGE GTAP-E model is developed for assessing the economic and carbon emissions effects related to alternative policy measures implemented with the aim of reducing carbon leakage. We explore a set of scenarios, comparing solutions where Annex I countries introduce exogenously or endogenously determined carbon border taxes in order to solve the carbon leakage problem unilaterally. Results provide evidence on the scarce effectiveness of carbon tariffs in reducing carbon leakage and enhancing economic competitiveness, while they have large negative welfare effects not only on the Non-Annex countries, but also on certain Annex I countries.

Keywords: Carbon Leakage, Carbon Border Tax, GTAP-E model

J.E.L. codes: Q430; Q470; Q540

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1. Introduction

In recent years, a large body of the international literature as well as the policy debate have expressed increasing interest in measures to mitigate the negative externalities of climate change policies. As a matter of fact, the imposition of stringent climate policies may produce substantially distortive effects in terms of displacement and re-allocation of carbon intensive production processes in countries where no climate policies are in force, a phenomenon also known as carbon leakage effect (OECD, 2006). However, the extent of carbon leakage is controversial and there is considerable debate on the design of the correct policy mix to reduce it.

Generally speaking, the potential outcome of unilateral climate change policies may be a reduction in carbon emissions of abating countries partially undermined by an increase in carbon emissions by non-compliant countries. This negative outcome may be explained by relative changes in the comparative advantages between non-compliant and abating countries, whose climate policies will reduce competitiveness of domestic firms with respect to foreign production. Consequently, some forms of border adjustments have been invoked in order to restore a level playing field between domestic producers facing abatement policies (e.g., carbon tax or emission trading) and foreign exporters subject to a carbon tariff (Moore, 2010; Wooders and Cosbey, 2010).

The jury is still out on the exact design and practical implementation of these adjustments, since there are several unresolved issues. In this respect, we will elaborate on the existing studies providing further evidence about the extent of carbon leakage and the impact of different forms of Carbon Border Tax (CBT). However, the major focus of the paper is on the ambiguities regarding the possible goal(s) to be achieved through a CBT. As a matter of fact, carbon tariffs are often justified both as instruments to reduce the leakage rate or to restore the competitiveness of domestic firms: our results show that the two goals are not necessarily overlapping.

In order to quantify in a more realistic way how CBTs influence emission behaviours of non-compliant countries we develop a modified version of the computable general equilibrium GTAP-E model (Burniaux and Truong, 2002; McDougall and Golub, 2007) in order to assess the potential economic and carbon emissions effects related to CBT adjustment schemes. We refer to the Kyoto objectives as our climate policy framework, to be able to depict a world where two groups exist, abating and non abating countries. Our regional aggregation includes the 11 Annex I countries/regions featuring country-specific CO_2 emission reduction commitments listed in the Kyoto Protocol and the largest emerging economies within the Non-Annex list, including Brazil, China, India and Mexico, that are expected to be the most likely source of carbon leakage. In terms of sectoral aggregation, we distinguish 21 sectors in order to simulate the impact of alternative policies in energy intensive and non-intensive sectors.

In order to build a benchmark for investigating the effectiveness of alternative forms of CBT, we first assess the carbon leakage implied by an international emission reduction agreement such as the Kyoto Protocol, modelling two scenarios with and without emission trading. We then compare a cooperative scenario featuring global emission trading where Non-Annex countries also play an active role with several approaches to deal with the carbon leakage effect introducing different carbon tariff schemes (hereafter referred to as non-cooperative scenarios).

On the one hand, in the cooperative scenario Annex I countries face their emission targets as defined in the Kyoto agreement whereas Non-Annex countries are constrained to a zero-increase in domestic emissions.

On the other hand, in the non-cooperative scenarios, carbon tariffs are either based on the domestic carbon tax or endogenously computed as *ad valorem* equivalents. In the former case, a specific carbon tariff is computed by multiplying the carbon tax either by the actual carbon content of imports or by the carbon content of the corresponding domestic good. In the latter case, the *ad valorem* tariff equivalent is set either with the aim of eliminating (or at least reducing) the carbon leakage or with the aim of keeping the competitiveness of Annex I countries in satisfying their domestic demand.

By applying the exogenously given CBT based on the domestic carbon tax, we assess the economic impacts of the unilateral policies that are currently discussed in the political debate especially in the European Union. The effects produced by an exogenous carbon tariff on competitiveness, welfare changes and emission levels of Non-Annex countries are compared with those resulting from 'endogenous tariffs' (i.e., tariffs computed in order to achieve a given objective either in terms of leakage or competitiveness). The distance between the exogenous and the endogenous carbon tariffs gives an idea of the distance between the policy schemes actually discussed and the motivations put forward by the proponents of these policies.

The economic and environmental effects resulting from alternative policies applied unilaterally by Annex I countries are compared with the results from the cooperative - or zero-leakage - scenario. Such a comparison highlights the advantage for Non-Annex countries of changing their conservative position in the climate negotiations.

The rest of the paper is structured as follows. In Section 2 we provide a literature review on carbon leakage and border adjustments. In Section 3 we describe the computable general equilibrium model, the 2012 baseline and the non-cooperative and cooperative scenarios. In Section 4 we present the main simulation results and Section 5 provides some final remarks.

2. The carbon leakage issue

2.1 The measurement of carbon leakage

A global solution to climate change has not been implemented yet, since the output of Copenhagen meeting in 2009 was a non-binding agreement. Cancùn negotiations in 2010 represented a step forward for reaching a cooperative solution, but global international cooperation for fighting climate change still seems a difficult goal to be achieved. For this reason, policy actions to mitigate climate change and reduce emissions still remain unilateral. It has already been noted that the efficiency of CO2 reduction policies could be undermined by the presence of carbon leakage (Hamasaki, 2007). The use of economic instruments for greenhouse gas (GHG) emission reduction with a non-global approach is likely to have negative impacts on the international competitiveness of some industrial sectors, for example, the steel and the cement sectors (OECD, 2003, 2005). If only a few countries are involved in the implementation of climate change policies, non-abating countries may have comparative advantages in producing and exporting energy intensive goods, risking to nullify the efforts of abating countries. Veenendaal and Manders (2008), for instance, point out that if a coalition of countries committing themselves to reducing GHG emissions remains limited in its coverage, carbon leakage is likely to occur, partly offsetting the reduction efforts made by the coalition. The vast and growing literature on this issue distinguishes two typologies of leakage: the first one is caused by a shift in the location of production towards non-compliant regions and the second one is related to an increase in energy consumption in non-abating regions due to the lower prices resulting from the reduced demand for fossil fuels on the international markets by abating countries.

Imposing stringent climate policies in certain countries may produce substantially distortive effects in terms of displacement and development of carbon intensive production processes in countries where no climate policies are in action, in a well consolidated literature strand referring to the so-called pollution haven effect (Copeland and Taylor, 2004). The pollution haven hypothesis explains the first type of leakage where carbon/energy intensive firms will move from abating countries to non-abating countries in order to exploit relative comparative advantages arising from heterogeneous environmental standards.

Carbon leakage due to production relocation is related to the fact that leakage increases with the intensity of international competition in energy-intensive goods. If this competition is strong and energy intensive goods are perfectly substitutable in terms of production location, this will bring production of carbon intensive goods to countries with lower energy costs. In other words, when countries have different environmental regulatory stringency, production will be located where environmental costs are lower. As emphasized by Babiker (2005), in extreme situations where energy-intensive goods produced in different countries are perfectly homogeneous, the relocation of the production of carbon intensive goods to non-abating countries is almost complete, leading to carbon leakage rates that can even exceed 100%.

In addition to the leakage resulting from a shift in production location, a second type of leakage could result from a substitution effect induced by decreasing carbon-energy demand in the abating countries and the consequent fall in international energy prices (Gerlagh and Kuik, 2007). This second type of carbon leakage can be explained by referring to the energy market model: the reduction in fossil fuel demand in abating countries leads to lower prices on the world energy markets, which in turn fosters energy demand in non-abating countries (Burniaux and Oliveira Martins, 2000; Felder and Ruherford, 1993). As a matter of fact, the relative magnitude of the taxing countries' energy demand combined with the elasticity of the energy supply curve are key drivers in determining different types of leakage (Kuik and Gerlagh, 2003). According to Gerlagh and Kuik (2007), the energy market model seems to be the prevalent explanation of carbon leakage estimates from simulation analyses.[2]

The rate of carbon leakage is usually computed as the ratio between the increase of CO2 emissions in non-abating countries and the reduction of CO2 emissions in countries implementing GHG abatement policies. As reported by the Energy Modeling Forum (2000) and Kuik and Verbruggen (2002), carbon leakage rates vary widely according to the model used: 5% (GREEN), 8% (G-Cubed), 9% (GTEM), 11% (Gemini-E3), 14% (WorldScan), 26% (MS-MRT), 34% (MERGE4).

In addition to these macro leakage rates, sectoral leakage rates can be computed as the ratio of the additional emissions in each productive sector of Non-Annex I countries to the emission reduction achieved in Annex I countries in the same sector (Kuik and Ofkes, 2010). Sectoral rates are useful for understanding which sectors are most responsible for the leakage rate and which should consequently be targeted by specific trade policy measures.

Even if the implications for international trade of emission abatement policies are crucial,

[2] It is also worth noting that this is likely to be the main available mechanism in all models where only a partial international reallocation of factor endowments is allowed, such as the static GTAP-E used in this paper.

especially when considering their acceptability and feasibility, few studies have adopted a global approach and tried to quantify simultaneously the effects on emissions, sectoral exports and output of all countries, as well as distributional welfare effects at country level.

Babiker and Jacoby (1999) use the EPPA-GTAP model and find a global leakage rate of 6%: 30% of the leakage is related to China alone and more than 60% to only five countries: Brazil, China, India, Mexico and South Korea. McKibbin *et al.* (1999) use the G-Cubed general equilibrium model and focus on the effects of the tradable emissions permit system proposed in the Kyoto Protocol on international trade and capital flows. Their results show a significant carbon leakage effect. Initially, over half of this leakage is due to the lower oil demand from Annex I countries, and in particular from the US, and the fact that non-abating countries buy and burn more oil. In the long run, it is economic growth that produces most of the increase in Non-Annex emissions.

In the analysis developed by Haaparanta *et al.* (2001) using a modified GTAP-E version, the leakage rate also decreases when emission permit trading is allowed between Annex I countries compared to the case where Kyoto targets are only introduced on a national basis. This result is mainly due to the crucial role played by the Former Soviet Union (FSU), where emissions increase by 3.2% in the scenario with domestic implementation whereas with emission permit trading, they are dramatically reduced by almost 60%. Among the factors that potentially affect carbon leakage, little attention has been paid to changes in import tariffs. Kuik and Verbruggen (2002) compare a scenario where emissions of Annex I are constrained to the Kyoto objectives with no change in import tariffs and a similar one in which tariffs are adjusted to implement the Uruguay Round and find that the leakage rate increases with trade liberalization.

Carbon leakage estimates seem to be very sensitive to different model settings. Two key parameters emerge as the driving factors of highly heterogeneous leakage rates: the Armington elasticities in the import demand module and the substitution elasticities in the energy nests of the production module (Gerlagh and Kuik, 2007). In particular, if lower Armington elasticities values are assumed, there will be fewer opportunities for Non-Annex countries to expand their exports towards compliant countries thus resulting in lower leakage (McKibbin *et al.*,1999). Moreover, as a consequence of price impacts of emission reduction targets, non-abating countries will import less carbon-intensive commodities from Annex I countries due to changes in their comparative advantages. At the same time, given a certain value of Armington elasticities, non-abating countries will easily substitute imported intermediates from Annex I countries with intermediates from other non-abating countries and substitute aggregate imports with domestic intermediates (Wang *et al.*, 2009) eventually producing a demand-driven leakage effect. In this respect, higher substitution elasticities in the production function between energy and other inputs, as well as between alternative fossil fuels, would lead to larger drops in world energy price and hence to larger leakage rates (Kuik, 2001).

2.2 *Alternative carbon border tax designs*

Positive analysis on the existence and potential causes of the carbon leakage effect paved the way for a growing strand of literature dealing with policies that could solve the problem. We can provide a real-world example: European energy-intensive sectors, facing a price for carbon emissions, could be at a competitive disadvantage compared with regions with a less stringent, or inexistent, climate policy, and they are exposed to negative effects in terms of loss of production and jobs. CBTs could then be introduced with the aim of restoring competitive fairness and preventing carbon leakage.

Abating countries may decide to impose two forms of CBT: full or partial adjustment. Full adjustment refers to a carbon tariff (in other words, a carbon border tax) applied to imported goods from non-compliant countries plus a tax rebate for domestic goods which are exported.[3] Partial adjustment refers to the application of border carbon tariffs without rebates on exports (Fischer and Fox, 2009). For example, in the European Union (EU), since it is a net exporter of energy-intensive products, a refund on exports is a more effective means of supporting employment in sectors covered by the Emission Trading System (ETS) than a levy on imports (Veenendaal and Manders, 2008).

There is growing concern over CBT as a feasible and effective unilateral policy measure for preventing carbon leakage. In particular, three major issues arise from the international literature. The first issue is how to design a CBT which is consistent with WTO rules, feasible in its implementation, and fair from the point of view of the heterogeneous exporting countries facing the carbon tariff. Relative to this, there is an open debate on the possibility of designing CBT adjustments consistent with WTO rules, since trade measures might contravene WTO's Article I on most-favoured nation treatment. The question is whether tons of carbon from domestic or international sources should be treated in the same way and whether goods are subject to similar treatment. On the other hand, based on Article XX of the WTO dealing with environmental issues, the absence of a carbon policy in non-abating countries could be considered an implicit production and export subsidy by abating countries (Dong and Whalley, 2008). Because of the legal uncertainty, a CBT regime will be

[3] In the rest of the paper, the terms "carbon tariff" or "carbon border tax" will be used interchangeably.

controversial and probably lead to a number of disputes between WTO countries (Messerlin, 2010; Moore, 2010; Wooders and Cosbey, 2010), but we will not be dealing with this issue in this paper.

More importantly, against the expected benefits of a CBT, there are at least two expected costs of border adjustments. First, there is a risk that the border adjustment system could be abused for purely protectionist reasons by compliant countries, and second, there is a real risk that border adjustments could lead to retaliatory tit-for-tat trade wars, particularly with developing nations who may believe that developed nations bear a greater responsibility for curbing climate change (Bordoff, 2008).

While the vast majority of scientific and political documents agree on the value of the specific tariff which should be taken as equivalent to the specific carbon price in the abating countries (i.e., equal to the domestic carbon tax or to the net equilibrium permits price if an emissions trading scheme is allowed), there are different opinions about how to quantify the embedded carbon in traded goods from non-compliant countries. Two alternative computation methods are often proposed (Elliot *et al.*, 2010a). The first one is to apply a best available technology (BAT) approach in the importing country. In this case, the carbon content for each good produced in the compliant countries is applied to imported goods coming from non-abating economies. The second one considers the effective carbon content of the imported goods, thus relying on the production technique applied by the producing country. This second method could introduce a high degree of uncertainty for exporting countries and lead to a heterogeneous treatment and a relative penalty for less developed economies. According to Ismer and Neuhoff (2007), the CBT based on the carbon content of the imported good as if it would be produced with the BAT in the levying country seems to be the only trade measure that should be WTO compatible. Moreover, the two computation methods may be applied twofold: if a direct approach is considered, only carbon emissions related to the production process are accounted for. If an indirect accounting approach is implemented, all CO_2 emissions related to the production process of all intermediates are considered for the application of the CBT, leading to substantially higher implementation difficulties.[4] Choosing the indirect emission accounting approach strongly affects carbon leakage estimates. Atkinson *et al.* (2010) analyse the total embodied carbon emissions in goods produced and consumed by different countries, combining the GTAP model with both the Bilateral Trade Input-Output (BTIO) and Multi-Region Input-Output (MRIO) approaches. They find that the carbon tariff equivalent to a carbon price of 50$ per ton of

[4] Despite the indirect emissions approach seems to be the most promising from an environmental point of view, it should bring to high implementation costs at the administrative level.

CO_2 amounts to 10% of the value of the average export bundle of non-abating countries, but tariffs may be two to three times higher for specific sectors. This suggests that CBTs – when also indirect emissions are considered – present an higher risk of being trade distorting and being associated with losses in efficiency and welfare, particularly in low and middle income countries.

The second question concerns the effectiveness of CBT in preventing carbon leakage (Schenker and Bucher, 2010). As a matter of fact, empirical analyses provide contrasting results on the effective capacity of CBTs to reduce emissions from non-abating countries, depending both on model settings and alternative CBT designs. For example, Mattoo *et al.* (2009) show that carbon leakage is a very limited phenomenon, while introducing a CBT based on the carbon content of imports would seriously damage Non-Annex trading partners. Such an action would impose average tariffs on merchandise imports from India and China of over 20 percent and would lower manufacturing exports of these countries towards Annex I by between 16 and 21 percent. On the contrary, Dong and Whalley (2009) simulate CBTs based on the emissions generated by comparable domestic production in the importing country (BAT approach). In this case CBTs effects are generally small, depending on the emission targets of abating countries, and CBTs contribute to alleviating the carbon leakage effects.

Adopting a sector-based approach, the picture of the effectiveness of CBTs becomes even more complex. Kuik and Hofkes (2010) explore the implications of CBTs on the EU ETS, distinguishing between sectoral and macro rate of leakage. In this case, CBTs impose significant reductions in sectoral leakage rates and more modest ones in the macro leakage rate. This is due to the fact that CBTs preserve sectoral competitiveness in abating countries but do not directly affect the emissions increase by non-compliant countries driven by the fall in energy prices and the substitution effect which accounts for the largest part of the macro rate of leakage. At the general level, empirical contributions find that CBTs are not very effective from an environmental point of view.

A third issue relates to welfare implications of a CBT approach. The degree of political acceptance of a policy is very likely to depend on its perceived "fairness" in terms of welfare changes for the different economic agents or countries affected by its implementation (OECD, 2006). It is worth noting that CBTs clearly represent a second best solution compared with the implementation of global climate policies which would establish a similar carbon price for all countries (Stern, 2006).

3. Model and Scenario Setting

3.1 Model description

The Computable General Equilibrium GTAP-E model is an energy-environmental version of the standard GTAP model specifically designed to simulate GHG emissions mitigation policies. It includes an explicit treatment of energy demand, the possibility of inter-factor and inter-fuel substitution, information on carbon dioxide emissions accounting and the possibility of introducing market-based policy instruments such as carbon taxes or emissions trading (Burniaux and Truong, 2002; McDougall and Golub, 2007).

As far as the production structure is concerned, GTAP-E adds several substitution nests such as between a capital-energy composite and other production factors or between capital and a energy-composite where the latter is obtained by substitution across different energy commodities.

Carbon taxation is modelled with different tax wedges for firms, private and government consumption of domestic and imported energy products. An international emissions trading (IET) scheme, as described in Article 17 of the Kyoto Protocol, is modelled by defining bloc-level emissions and emissions quotas in the abating (Annex I) countries. Carbon dioxide emission permits can be traded in an international market where only compliant countries are allowed to to buy or sell permits. Accordingly, once Kyoto targets for each Annex I country are established, the model computes the carbon tax required to reach the emission reduction objectives. The carbon tax represents the marginal cost of abatement equalized between regions that participate in IET and at equilibrium coincides with the permits price. If emission trade is not allowed, the carbon tax represents the domestic cost of abatement in each Annex I country. If we consider the GTAP-E structure, the carbon tax reduces CO_2 emissions by augmenting the cost of fossil fuels as inputs in the production and consumption functions (for firms and private households, respectively).

In this paper, we introduce some changes in the GTAP-E model. First of all, some substitution elasticities - namely the substitution elasticity between the capital-energy composite and the other endowments and the substitution elasticity between capital and energy in all the nests related to the energy composite - were replaced with those proposed by Beckman and Hertel (2010). The Armington elasticities were also changed as in Hertel *et al.* (2007).[5] This specific choice allows a better assessment of carbon leakage implications since the literature agrees on the crucial role of substitution elasticities in the quantification

[5] For a comprehensive discussion on substitution elasticities in the energy sector, see Koetse *et al.* (2008), Okagawa and Ban (2008), while Panagarya *et al.* (2001) and Welsch (2008) discuss the role of import demand elasticities in international trade.

and geographical distribution of leakage rates.

A second set of changes refers to the data. We updated the GTAP-E dataset using the latest version of the GTAP Database version 7.1 (base year 2004) as well as the latest version of the combustion-based CO_2 emissions data provided by Lee (2008) for all GTAP sectors and regions. It is worth mentioning that we introduced some adjustments to specific sectors and regions where emissions were not consistent with data provided by the main international energy agencies (EIA-DOE and IEA). Since CO2 emissions data are assigned to each region/sector on the basis of energy input volumes and emission intensity factors, we analysed country/sector specific data in order to understand which factors were driving these distortions the most. We found that for some sectors and regions the emission intensity factors were indeed much higher than the average leading to a substantial overestimation of the corresponding emissions reported in the official IEA data on CO2 emissions from fossil fuels combustion. In order to reduce this bias, we replaced the emission intensity factors for those sectors and regions whose values were out of the range -1/+1 compared with the official IPCC emission intensity factors (Herold, 2003). On the basis of these new emission intensity factors, we computed adjusted CO2 emissions, obtaining new values for those sectors/regions characterized by outlier emission factors.

In order to include CO2 emissions in the GTAP-E model, some preliminary changes had to be made to adapt data to model requirements. Since the most recent CO2 emissions database do not distinguish between domestic or imported sources, we computed these shares as proportional to the volumes of domestic production and imports, respectively. Such a choice is consistent with the methodological assumptions described in Ludena (2007) and Lee (2008) where CO2 emissions data are calculated from the energy volume data of the GTAP Version 6 database.[6] It is worth noticing that emissions in our version could not account for all other GHG emissions since they only relate to fossil fuels combustion, thus providing a lower bound estimate of total emissions and abatement targets. Even if the missing emissions amount to 15% of total GHG, the underestimation is quite homogeneous across regions and sectors with the exception of the agricultural and chemical sectors, thus not influencing the distributive effects of our simulations.

Finally, CO2 emissions are directly linked to the energy commodities considered in the model such as coal, crude oil, natural gas, refined oil products and gas manufacture and distribution. CO2 emissions are produced by energy consumption by firms, government and private households. These direct emissions are taxed without discriminating between the

[6] Following Mc Dougall and Golub (2007) and Ludena (2007) we converted emissions data from Ggcos'è? of CO2, as they were expressed in Lee (2008), into million tons of carbon.

source of the energy products. In these sectors, domestic and imported goods are treated alike and there are no grounds for fearing either carbon leakage or competitive disadvantage of national firms. As a consequence, all the CBTs described in Section 3.3 only apply to the sectors where fossil energy sources are burnt producing direct emissions (i.e. emissions deriving from the use of energy commodities as intermediate inputs). Indirect emissions, linked to the use of non energy intermediate inputs, whose production implied burning fossil energy sources and CO_2 emissions, are not taken into account.

3.2 *Model setting and baseline*

In order to simulate different scenarios in the context of an international agreement for the reduction of CO_2 emission we decided to hypothesize the implementation of the abatement targets of the Kyoto Protocol. To this purpose, an aggregation of 21 sectors and 21 regions was chosen (Table 1).

Table 1- Regional and Sector aggregation

Regions	Sectors
Bloc Annex I	
EU	Agriculture
USA	Chem., Rubb., Plast.
Australia	Coal
Canada	Crude oil
Japan	Gas
New Zealand	Oil products
Norway	Electricity
Swiss	Metal products
Croatia	Mineral products
Belarus	Paper products
FSU	Electrical equipement
Bloc non-Annex I	Food industry
Brazil	Machinery equipment
China	Motorvehicles
India	Textile and Leather
Mexico	Transport equipement
South Africa	Other Manufacturing
Energy Exporters	Transport
Rest of Africa	Sea Transport
Rest of America	Air Transport
Rest of Asia	Services
Rest of Europe	

With regard to regional aggregation, we consider a "Post-Kyoto" environment, with 11 Annex I countries/regions featuring country-specific CO_2 reduction commitments. Moreover, in our disaggregation we single out the major emerging economies, including Brazil, China and India, since they may be the source of alleged carbon leakage. According to Babiker and Jacoby (1999), for instance, China, India, Brazil plus South Korea and Mexico, account for 60% of global leakage. As far as sectoral aggregation is concerned, in addition to the energy sectors such as coal, crude oil, gas,[7] refined oil products and electricity, we singled out energy intensive sectors (e.g., cement, paper, steel and aluminium) that are expected to be the main sources of carbon leakage.

A 2012 baseline was created based on the GTAP 7.1 database and using 2004 data. To this end, we build a business as a usual scenario for emissions data assuming a slow adoption of clean technologies and economic projections to 2012 based on IMF and World Bank data on actual growth rates after the financial and economic crisis. Several steps were necessary to obtain a convincing 2012 baseline. We first updated the database to 2008, assuming population and gross domestic product as reported by the World Bank and IMF data[8] and calibrating the emissions to the most recent IEA CO_2 data (IEA, 2010). The same procedure was adopted to bring the model to 2012. In both cases, while the emissions level in aggregate was correct, its distribution in terms of emissions quota among regions was not satisfactory. As a consequence, in the 2008 baseline, we corrected CO_2 emissions to fit the IEA data while in the 2012 baseline, we calibrated the CO_2 emissions to the IEA projections (IEA, 2010b).[9]

The carbon emissions in the baseline from 2004 to 2008 computed in our version of the GTAP-E model, which includes the changes in emission intensity factors and substitution elasticities, are much more consistent with those provided by international IEA. The improvement obtained is quite substantial since the standard GTAP-E model provides aggregate results that in some cases are at odds with current data. As a consequence, we are confident that our specification is able to provide a more accurate assessment of the potential extent of carbon leakage.[10]

As a final remark, we would like to mention that CO_2 emissions in the GTAP-E model, as well as the IEA data, refer to fossil fuels emissions only, excluding all other possible CO_2 equivalent emission sources. As a consequence, we recomputed the 1990 emission levels in order to get consistent CO_2 emission targets in the implementation of Kyoto Protocol commitments.[11] Even if our ultimate goal is not to provide realistic CO_2 projections but to

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[7] The gas sector in the present aggregation includes the sector of natural gas extraction and gas manufacture and distribution.

[8] In order to treat regional GDP as an exogenous variable and to shock it, regional technological progress was taken as an endogenous variable.

[9] Emissions have been swapped with technical progress using a specific closure (Altertax) that allows some data to be changed preserving the overall consistency of the model.

[10] Robustness checks for model results to different parameters have been addressed by a sensitivity analysis where standard deviation from results in our version is rather small. More importantly, we have also found that relying on original GTAP 7.1 substitution elasticities, carbon leakage would result into overestimated values, especially due to substitution elasticity between capital and energy in the first nest under the production function.

[11] In order to make emission levels in GTAP-E model as consistent as possible with those considered for the Kyoto targets by official IPCC documents, we first calculated the deviation between GTAP-E and IPCC

compare the economic effects of alternative policy scenarios, it is worth emphasizing that Annex I emissions in our baseline are almost identical to those proposed by IEA (2010b) and reported in the most recent European Environmental Agency Report (EEA, 2010).

3.3 Scenario Setting

The rate of carbon leakage is defined as the increase in CO_2 emissions in the rest of the world induced by the domestic reduction measures as a percentage share of the absolute value of the volume of CO_2 reduction obtained by compliant countries (Kuik and Ofkes, 2009). Then, we first check the existence of carbon leakage in a pure Kyoto Protocol scenario, where we impose reduction targets on all Annex I countries with respect to their 1990 emission levels, as if also the United States ratified the Protocol.

We assess the existence of carbon leakage both allowing for the possibility of emission trading among Annex I countries (KT scenario) and only implementing domestic measures (KNT scenario).[12] Since results show that emission trading is going to be a more efficient policy instrument in terms of compliance costs for abating countries and consequently more convenient in welfare terms at the global level (as explained in details in the results), all the following simulations assume that the Kyoto Protocol is implemented by allowing for emission trading (Figure 1).

When simulating emission targets, some corrective measures should be adopted since the emission permits potentially supplied by transition economies (the FSU and Belarus in our model) to the carbon market are substantially higher than permits demanded by the other Annex I countries, resulting in a close-to-zero carbon price. Such uncertainties may be included in the so-called 'hot air' debate which also addresses the role of the other flexible mechanisms required by the Protocol (World Bank, 2010). In order to avoid these extreme outcomes, we adjusted, albeit partially, the emission targets for Belarus and the FSU. For these countries, the emission levels in 2012 represent the reference to which the 0% target scheduled in the Protocol should be applied, rather than the usual 1990 period, substantially reducing the permits supply.

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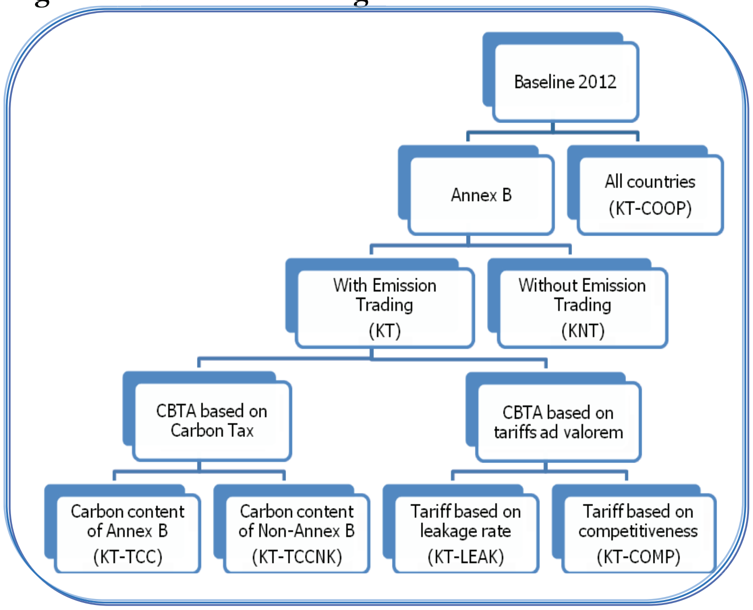
emissions data in 2004 and then we proportionally changed the 1990 IPCC emissions data in order to calculate the effective abatement efforts required by the achievement of the Kyoto Protocol targets.

[12] In this paper, we follow a standard assumption in the literature using applied general equilibrium models, namely that all abating policies may be expressed in monetary values by computing a domestic carbon tax applied to fossil fuels consumption. When we assume the existence of an emission trading system, the carbon tax at equilibrium equals the permits price. We are aware of the existence of more complex policy schemes adopted in many countries, but for the aim of this paper we are only concerned with the relative incidence of the compliance costs with respect to different countries and not to different environmental policies.

Figure 1 – Simulation design



The fact that only some countries, namely the ones in Annex I, contribute to a global common goal such as the avoidance of climate change is already quite controversial. The very fact that the efforts made by a group of countries may be undermined, even partially, by the behaviour of other countries cast serious doubts on the political feasibility of international negotiations inspired by the Kyoto Protocol agreement. Since domestic firms, especially in the energy intensive sectors, are going to be hurt by carbon taxes introduced to meet the abatement targets, several governments are considering introducing taxes on imports from countries that have not introduced climate change policies so far.

Border tax adjustments could be 'two-way' if they were also applied to products exported to Non-Annex countries as is customary in differences in indirect taxes (e.g., the value added tax) between trading partners. However, such an export rebate would provide obvious incentives to keep 'dirty' plants operating for export purposes and this would make it even more difficult for other firms to meet the abatement commitments (Fisher and Fox, 2009). Consequently, our scenarios are based on 'one-way' CBTs, applied to all imported goods that did not pay for the emissions implied by their production.[13]

The alternative strategies envisaged in order to cope with carbon leakage usually assume that carbon tax is extended to imported goods from Non-Annex countries either on the basis of the carbon intensity of domestic production or on the basis of the emission intensity in the exporting country. In order to assess the impacts of these implementation choices, we

[13] Since in the GTAP-E structure carbon tax is levied on all energy commodities, produced domestically or abroad, carbon tariff is not applied to imported energy commodities, otherwise a double counting problem will arise.

simulate additional counterfactual scenarios not related to the current political debate. In these scenarios, carbon tariffs are endogenously determined in order to achieve some predetermined goals such as the elimination of carbon leakage or the preservation of domestic firms' competitiveness.

Since we allow for emission trading, CBT scenarios extending the carbon tax to imports (KT-TCCNK and KT-TCC) are based on a single price for carbon emission, but border taxes are going to differ by sector according to the carbon contents (Bordoff, 2008). In the KT-TCCNK scenario, border taxes are based on the carbon content of imported goods whereas in the KT-TCC scenario, they are based on the carbon content of the corresponding domestic production in the importing country according to a BTA approach. In the latter case, all Non-Annex countries face the same (specific) border taxes on their exports to each Annex I country whereas in the former case, all Annex I countries adopt the same policy implying different (specific) taxes for the same good according to the country of origin.

The KT-TCCNK scenario is likely to be deemed inconsistent with WTO provisions since it discriminates between Non-Annex countries as well as between domestic and imported products that are going to face different carbon taxes. The KT-TCC scenario avoids these discriminations and it is certainly much more realistic in terms of information requirements, but it should be noted that the *ad valorem* equivalent of the tax differs according to the bilateral flows unit values so that we may well expect exporters of low quality goods to be worse off. CBTs, as a matter of fact, are established in specific terms (i.e., price per ton of emissions associated with the production of each good), and it is well-known that specific tariffs translates into higher *ad valorem* equivalents for goods featuring lower prices.

These scenarios are close to the current political debate, especially in the EU, where a non-distorting trade measure which can be designed as the difference between production costs before and after the imposition of a carbon tax is the same, in absolute terms, in both Annex I countries and elsewhere. All imports by Annex I countries then face the same price difference when they enter the foreign markets.

By comparing the performance of these two approaches for CBT implementation in terms of efficiency and effectiveness in reducing carbon leakage, we join a large and quickly growing literature. The most innovative part of the paper adds to these somewhat standard scenarios, where the carbon tariff is exogenously set according to the tax resulting from the implementation of the abatement targets, other simulations where carbon tariffs are endogenous. To this end, we start from a given goal, either in terms of carbon leakage or competitiveness, and use the model to compute the sector-specific *ad valorem* tariffs that would allow these goals to be reached. The counterfactual sector-specific tariffs are then imposed by Annex I countries on all imports from the Non-Annex countries. Accordingly, these tariff surcharges (since they are levied on top of the existing tariff structure) are uniform across (Annex I) importers and (Non-Annex) exporters.

The first counterfactual scenario (KT-LEAK) targets carbon leakage, and one may think that an obvious goal would be to keep the overall sectoral emissions in the exporting countries constant. It turns out that such a goal is not feasible. In the model, as well as in reality, emissions result from the choices of different agents – governments and households, for instance – whereas exports only concern firms: even if we introduce prohibitive tariffs, we cannot claim to influence overall emissions by only affecting a tiny share of production such as exports. As a consequence, in our simulation, we adopt a closure by swapping the tariff with the emissions by the exporting countries' firms. Such a set-up is already quite insightful: a carbon tariff that completely eliminates carbon leakage simply can not be implemented, since no tariff can intervene on the energy price fall caused by the decrease on Annex I countries, and then avoid the corresponding increase in Non-Annex domestic demand.

As far as the competitiveness scenario is concerned (KT-COMP), we first need to define what is meant by this elusive term. Given that much of the public debate is supposedly about unfair competition, we assume that Annex I countries introduce *ad valorem* tariffs so that the share of imports from Non-Annex I in total production in each sector remains constant.

All the above simulations have been conceived in a non-cooperative setting where Annex I countries adopt unilateral policies in order to cope with the fact that other countries do not act to keep their emissions under control. The final scenario (KT-COOP) simulates the effects of a cooperative solution where Non-Annex countries do not allow their emissions to increase with respect to the 2012 baseline. This would eliminate the leakage problem by definition, since all Non-Annex countries accept to keep their overall emission levels unchanged. Moreover, the introduction of emission trading at world level would represent the most efficient way of reaching the emission reduction objectives. Consequently, even if we do not necessarily consider this scenario a realistic one, we use it as a benchmark in order to assess the relative benefits and costs of the other non-cooperative scenarios.

4. Empirical Results

We first compare the implementation of the abatement targets with and without an emission trading scheme (KT and KNT scenarios). Results reported in Table 2 reveal that, when emission trading is allowed, there is a substantial reallocation in emission reductions. In particular, the United States (US) reduce less with respect to their emissions quota whereas the EU reduces more. This result is consistent with the expected higher allocative efficiency of market-based instruments since larger abatement efforts are associated with countries with lower marginal abatement costs. As a consequence the average domestic carbon tax level in the KNT scenario (39.16 \$ per tCO2) turns out to be much higher than the equilibrium price for emission permits in the KT scenario (22.92 \$ per tCO2). This result is hardly surprising if we consider that the EU includes 12 new member states which are characterized by substantially lower marginal abatement costs and less stringent abatement constraints. The combination of these two elements explains why for the EU as a whole it is more convenient to reduce emissions below the target, selling emission permits in the international market. As expected, the other potential seller is FSU, given its production structure as well as the abundance of fossil fuels endowment (Zhang, 2000, 2001).[14]

Both simulations generate carbon leakage, but in the KT scenario, the leakage rate is higher than in the no trade scenario. We can explain this result by considering that, despite the reduction in energy demand is the same in the KNT and KT scenarios fro Annex I as a group – since the same overall emission reduction objective should be reached – it is allocated in a different way. This implies that some large economies with demanding abatement targets should implement less structural adjustments and undergo a smaller contraction, showing higher imports from those non-compliant countries than in the KNT scenario.

At country level, the Non-Annex countries most responsible for carbon leakage in absolute terms are represented by South Africa, Rest of Europe and Energy exporters countries,[15] and – to a lesser extent – Brazil, India and China.

It is worth mentioning that our results are broadly consistent with previous findings, such as, for instance, in Elliot *et al.* (2010b), where the percentage change in emissions associated to a carbon tax of around 23 US\$ per ton of CO2 is in the range of 5-6%, which corresponds to our 5.66% world emission reduction in the KT scenario.

[14] It is worth noticing that in the KNT scenario Belarus and FSU have a zero change constraint to emissions level, in order to reduce the potential dimension of a hot air event. As a check, when simulating a KNT scenario with no constraints for Belarus and FSU, these two countries behave more consistently with a zero constraint rather than with their potential percentage change in a pure Kyoto setting, corresponding to emissions increase by +0.95% and +1.85% with respect to emissions targets of +73% and +48% for Belarus and FSU, respectively.

[15] The Energy exporter group represents countries in which energy resources represent the major asset in export flows, as defined by IEA Energy Balances. When Annex I countries apply some abatement strategies, the fossil fuels demand at world level decreases, thus inducing Energy exporters to shift their production structure towards energy intensive industries and explaining their role in producing carbon leakage.

Table 2 - Emissions, welfare and price effects with and without emission trading

	KNT			KT		
	CO2 change (%)	Welfare change (million US$)	Carbon tax (US$/ ton CO2)	CO2 change (%)	Welfare change (million US$)	Price of permits (US$/ton CO2)
EU	-3.79	5,114	10.09	-9.38	-683	22.87
USA	-22.69	-27,226	38.30	-15.10	-25,089	22.88
Australia	-31.14	-5,182	48.44	-19.21	-4,151	23.11
Canada	-27.98	-7,737	58.04	-13.55	-5,391	22.96
Japan	-12.22	-1,184	33.51	-8.66	-387	22.89
New Zealand	-30.43	-355	84.64	-10.77	-205	22.95
Norway	-35.62	-2,916	159.36	-7.98	-2,876	23.18
Swiss	-11.29	-278	22.74	-11.09	-203	22.83
Croatia	-7.70	-48	26.36	-6.15	-23	22.80
Belarus	0.00	233	1.13	-9.62	1,085	22.43
FSU	0.00	-4,257	1.08	-20.43	1,806	23.22
ANNEX I	**-13.69**	**-43,836**	**39.16**[a]	**-13.69**	**-36,118**	**22.92**[b]
Brazil	1.8	229		1.77	344	
China	0.89	-701		0.96	-14	
India	1.58	1,851		1.54	1,854	
Mexico	1.13	-3,888		1.17	-2,496	
SouthAfrica	3.1	42		5.38	78	
Energy Exporters	2.12	-23,890		2.46	-21,969	
Rest of Africa	1.62	-293		2.03	-171	
Rest of America	1.95	-119		2.46	359	
Rest of Asia	2.13	3,428		2.19	3,851	
Rest of Europe	1.52	752		2.62	829	
NON-ANNEX	**1.47**	**-22,589**		**1.68**	**-17,334**	
World	**-5.77**	**-66,425**		**-5.66**	**-53,452**	
Leakage rate (%)	**11.79**			**13.44**		

Source: elaborations on model results

Notes: a Average Carbon Tax for Annex I is computed as a weighted average of national carbon tax rates

b The price of permits related to the aggregate Annex I corresponds to the equilibrium international market price

Turning to the welfare effects (Table 3), it is worth noticing that there are large discrepancies in single welfare components when comparing the domestic carbon tax scenario (KNT) with the existence of an emission trading scheme (KT), since two prevailing effects may be detected.[16]

For countries which are net buyers of carbon permits, there is a substantial improvement in the allocative efficiency loss since energy intensive goods may continue to be produced. In other words, the domestic efforts to reduce fossil fuels consumption in a pure domestic policy scenario would force the economic system to make heavy structural adjustments in the production specialization pattern by relocating production factors across sectors. Net buyers pay the permits price for having the possibility to reduce the adjustments required by the implementation of the domestic targets whereas the opposite is true for net sellers that are compensated, at least partially, for the larger adjustments through the emission trading revenue.

[16] Welfare equivalent variation (EV) in GTAP can be decomposed (Hanslow, 2000; Huff and Hertel, 2000) into several aspects, mainly related to investment allocation, allocative efficiency (when allocation of resources changes relative to pre-existing distortions), and terms of trade effects (related to changes in export relative to import prices).

Table 3 – Welfare decomposition for Annex I countries with or without emission trading (US $)

	KNT			KT			
	Allocative efficiency effect	Terms of trade effect	Investment-saving effect	ETS permits revenue	Allocative efficiency effect	Terms of trade effect	Investment-saving effect
EU	-2,170	7,261	23	5,197	-17,243	11,639	-277
USA	-40,811	12,228	1,356	-10,521	-20,937	6,545	-176
Australia	-4,402	-599	-181	-1,147	-1,834	-1,026	-144
Canada	-7,418	-297	-21	-1,873	-2,487	-984	-47
Japan	-7,118	6,530	-597	-985	-4,159	5,322	-565
New Zealand	-589	236	-2	-155	-115	72	-8
Norway	-2,541	-1,159	784	-289	-289	-2,707	409
Swiss	-439	305	-144	-3	-422	399	-178
Croatia	-133	76	9	-8	-75	49	11
Belarus	125	96	12	152	528	373	31
FSU	-1,243	-3,179	166	9,755	-7,735	-3,036	2,821
ANNEX I	**-66,738**	**21,498**	**1,405**	**124**	**-54,769**	**16,650**	**1,878**

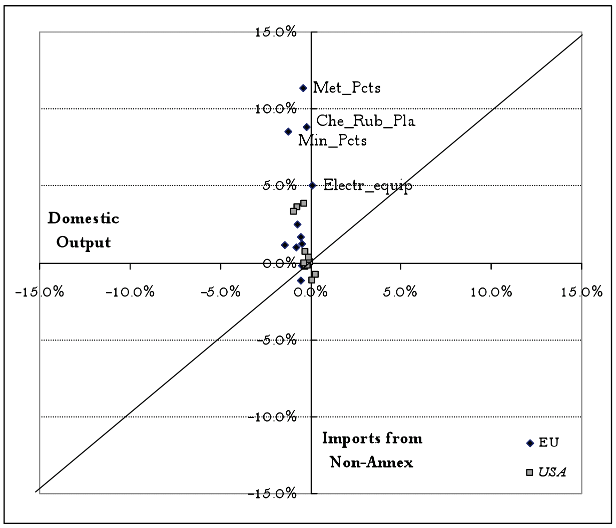
Source: elaborations on model results

Babiker *et al.* (2004) find that direct gains from trading permits may be outweighed by "indirect costs" due to pre-existing distortions and market imperfections. In particular, two channels can be traced: an efficiency cost effect of IET (namely an allocative efficiency effect) due to the interaction between carbon taxation and pre-existing taxes, and a terms of trade effect if the policy affects international prices, even in the absence of other distortions. According to our results, the allocative efficiency effect seems to have the upper hand.

Since carbon leakage is larger in the KT scenario, from here on, we assume that Annex I countries can trade carbon dioxide emission permits as established in the Kyoto Protocol even if such a mechanism has not been implemented yet. In Figure 2 we elaborate on some results of the KT scenario for the EU and the US by combining changes in the domestic output and changes in imports coming from the Non-Annex group at sector level with respect to the 2012 baseline. The fact that most observations are in the left-hand upper quadrant confirms that the reductions in domestic production are often compensated for by a surge in imports from non-abating countries. Since these sectors are also chiefly responsible for carbon leakage (metal products, chemicals, mineral products), this figure clearly shows the relocation of production from Annex I to Non-Annex countries, highlighting the link between environmental and competitiveness concerns.

Let us now turn to the "non-cooperative" scenarios where Non-Annex countries do not keep their emissions under control and Annex I countries react by adopting unilateral policies. We first compare the results of the two scenarios in which carbon tariffs are based on permits equilibrium price for carbon emissions aiming at (re-) establishing a level playing field. In the KT-TCCNK scenario, border taxes are based on the carbon content of imported goods whereas in the KT-TCC scenario, they are based on the carbon content of the corresponding domestic production in the importing country. Table 4 summarizes the results in terms of carbon dioxide emissions and welfare changes for these two scenarios. As a first result, according to Babiker and Rutherford (2005), the introduction of a CBT is welfare improving for compliant countries with respect to the no tariff case.

Figure 2 – Changes in domestic output and imports from Non-Annex countries in KT scenario



Source: elaborations on model results

It is worth noting that the distribution of emission reductions across Annex I countries hardly changes by applying an exogenous CBT. Conversely, the introduction of tariffs strongly affects the geographical distribution of carbon leakage. In particular, the KT-TCCNK scenario, where the carbon content is related to the exporting countries, reveals a larger impact in terms of leakage reduction, especially for Energy exporters, South Africa, China and India. In any case, the environmental effectiveness of such unilateral policies seems to be rather small since, although carbon leakage is uniformly reduced across all Non-Annex countries, the overall change is trivial (especially in the KT-TCC scenario).

This result is hardly surprising if we look at the share of emissions related to exports by Non-Annex towards Annex I countries (Table 5). The first column includes the amount of emissions associated with exports for each Non-Annex countries to the Annex-I group in the KT scenario. If we compare these figures with the total amount of emissions produced by firms in non-compliant countries (the second column), the share of emissions influenced by the CBT is rather low (fourth column), and it is even lower if we compare it with total Non-Annex emissions (third and last columns). In terms of welfare effects, CBTs improve the terms of trade for Annex I countries while Non-Annex countries register a corresponding loss, resulting in a pure redistribution of unilateral climate change policies costs, without substantial gains in environmental terms.

Table 4 – Emissions, welfare and permits price effects in KT-TCC and KT-TCCNK

	KT-TCC			KT-TCCNK		
	CO2 change (%)	Welfare change (million US$)	Price of permits (US$/ton CO2)	CO2 change (%)	Welfare change (million US$)	Price of permits (US$/ton CO2)
EU	-9.37	696	22.91	-9.34	4,162	23.04
USA	-15.12	-23,915	22.92	-15.12	-21,861	23.05
Australia	-19.19	-4,104	23.15	-19.23	-4,056	23.28
Canada	-13.52	-5,175	22.99	-13.46	-4,930	23.11
Japan	-8.65	-111	22.94	-8.70	461	23.08
New Zealand	-10.79	-197	22.99	-10.73	-194	23.13
Norway	-7.95	-2,884	23.23	-7.89	-2,960	23.36
Swiss	-11.10	-195	22.87	-11.08	-149	23.00
Croatia	-6.13	-22	22.84	-6.08	-20	22.98
Belarus	-9.46	1,098	22.45	-9.49	1,097	22.59
FSU	-20.42	1,815	23.25	-20.45	1,748	23.40
ANNEX I	**-13.69**	**-32,993**	**23.15**	**-13.69**	**-26,702**	**23.31**
Brazil	1.72	129		1.60	-125	
China	0.91	-838		0.74	-3,315	
India	1.50	1,630		1.30	1,137	
Mexico	1.05	-2,834		0.98	-2,987	
South Africa	5.20	-7		4.08	-322	
Energy Exporters	2.37	-22,879		1.93	-26,376	
Rest of Africa	2.00	-380		2.07	-168	
Rest of America	2.43	110		2.38	105	
Rest of Asia	2.11	3,250		2.08	3,095	
Rest of Europe	2.48	577		2.32	223	
NON-ANNEX	**1.62**	**-21,242**		**1.39**	**-28,733**	
World	**-5.70**	**-54,235**		**-5.82**	**-55,435**	
Leakage rate (%)	**12.91**			**11.09**		

Source: elaborations on model results

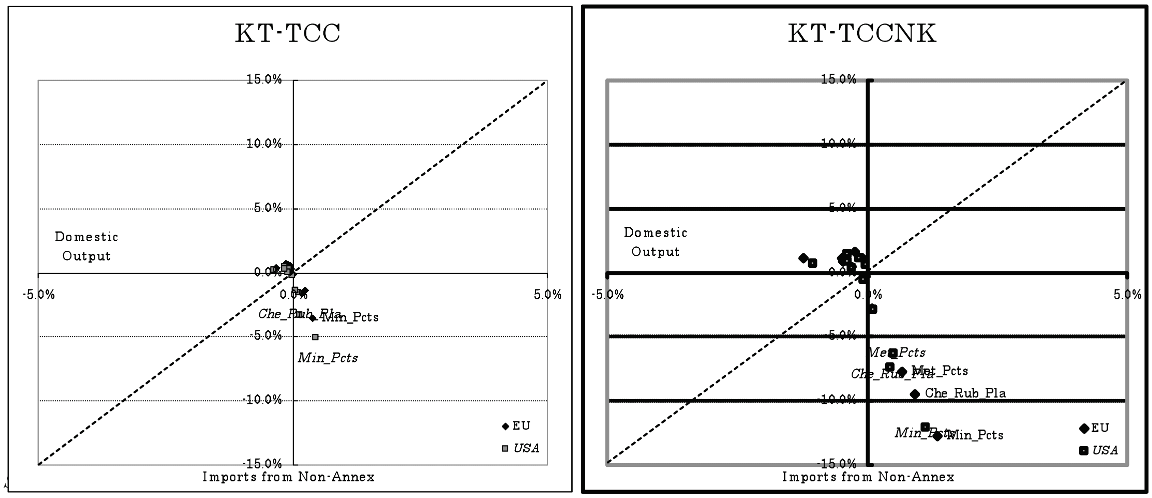
Table 5 – Share of emissions associated with leakage in the KT scenario (Mt of CO2)

	CO2 firms for exports (tCO2)	CO2 firms total (tCO2)	CO2 total (tCO2)	Share leakage/ total firms	Share leakage/total emissions
Brazil	29	322	409	8.94%	7.04%
China	227	6554	7269	3.46%	3.12%
India	24	1359	1647	1.74%	1.43%
Mexico	26	368	484	7.13%	5.42%
South Africa	29	412	471	6.98%	6.10%
Energy Exporters	241	2308	3237	10.42%	7.43%
Rest of Africa	13	135	190	9.58%	6.84%
Rest of America	31	226	322	13.55%	9.52%
Rest of Asia	104	1502	1797	6.91%	5.78%
Rest of Europe	25	290	372	8.70%	6.78%

Source: elaborations on model results

When we develop a comparison of domestic output and imports from Non-Annex, considering now the results in the KT scenario as a baseline, Figure 3 shows that EU and US domestic production is hardly affected by the CBT when the domestic carbon content is considered (KT-TCC). On the other hand, both countries take advantage of the larger import reductions due to the higher tariffs justified by higher carbon content of Non-Annex countries (KT-TCCNK), especially in energy intensive sectors (see Table 7 for a comparison of tariffs in *ad valorem* terms).

Figure 3 – Changes in domestic output and imports from Non-Annex countries in KT-TCC and KT-TCCNK scenarios



In the second set of scenarios, carbon tariffs are endogenously determined in order to keep the overall production emissions in Non-Annex countries (scenario KT-LEAK) and the share of imports in total production in Annex I countries (scenario KT-COMP) unchanged. The KT-LEAK scenario guarantees the lowest rate of carbon leakage, although it should be noted that the problem is only halved since, for the reasons explained in Section 3.3, it cannot be eliminated. In particular, some countries, such as China, India, South Africa and Rest of Europe, substantially reduce their emissions, and the contraction of their industrial sector is associated with high welfare losses. In this respect, the higher tariffs of this scenario also lead to very large terms of trade gains for Annex I countries. On the other hand, the KT-COMP scenario, even if not explicitly focused on carbon leakage, still leads to a reduction which can be compared with those in the exogenous CBTs scenarios and the same is true for the welfare impacts (see Table 6 for a comparison of these two scenarios).

In line with previous contributions (Veenendaal and Manders, 2008), our findings confirm that for compliant countries, imposing a CBT is welfare improving with respect to a IET scenario with no carbon tariffs, but welfare gains are rather small, as acknowledged by McKibbin and Wilcoxen (2008), with the exception of the KT-LEAK scenario where terms of trade play a major role.

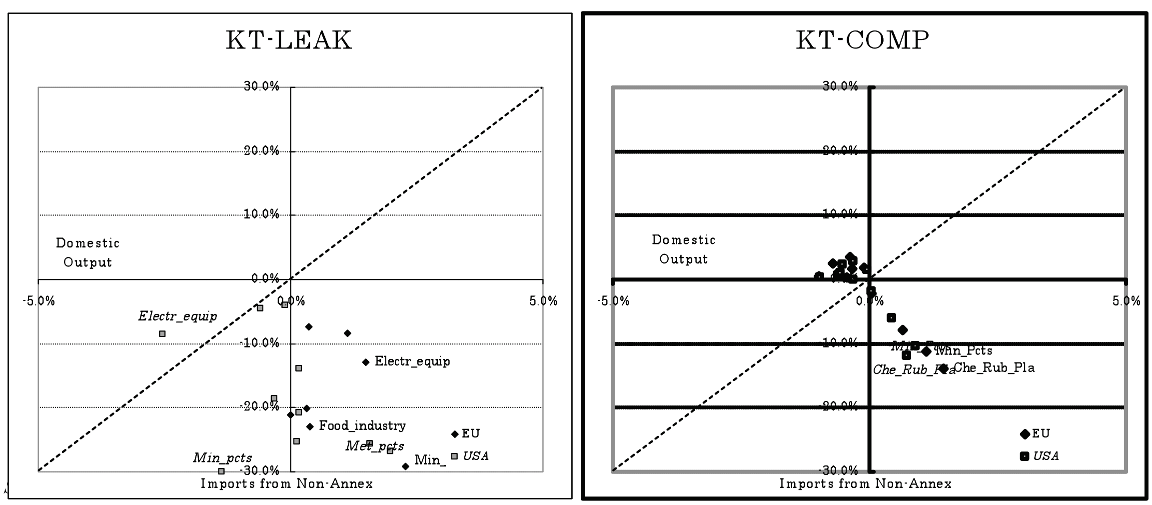
Looking at the relationship between output and import changes in the EU and the US, Figure 4 shows that the KT-LEAK scenario features larger reductions with respect to the KT scenario not only for imports, but also for domestic supply. It is also worth noting that in the KT-COMP scenario, imports decrease (still in comparison with the KT scenario) only for some energy-intensive sectors and even increase in other cases, especially in the EU market.

Table 6 – Emissions, welfare and permits price effects in KT-LEAK and KT-COMP

	KT-LEAK			KT-COMP		
	CO2 change (%)	Welfare change (million US$)	Price of permits (US$/ton CO2)	CO2 change (%)	Welfare change (million US$)	Price of permits (US$/ton CO2)
EU	-9.18	42,632	22.91	-9.36	4,902	23.04
USA	-15.08	16,603	22.92	-15.10	-21,077	23.05
Australia	-19.79	-4,315	23.15	-19.27	-4,054	23.28
Canada	-13.62	-1,950	22.99	-13.41	-4,847	23.11
Japan	-8.52	7,256	22.94	-8.90	509	23.08
New Zealand	-11.14	-121	22.99	-11.12	-197	23.13
Norway	-8.29	-3,873	23.23	-7.72	-2,882	23.36
Swiss	-11.28	-132	22.87	-11.07	-119	23.00
Croatia	-6.24	-5	22.84	-6.10	-21	22.98
Belarus	-9.43	1,200	22.45	-9.49	1,063	22.59
FSU	-20.79	-747	23.25	-20.36	1,893	23.40
ANNEX I	**-13.69**	**56,549**	**24.60**	**-13.69**	**-24,829**	**23.17**
Brazil	1.23	-5,686		1.61	-196	
China	0.41	-39,501		0.80	-3,340	
India	0.59	-4,098		1.37	937	
Mexico	-0.95	-17,640		0.77	-3,608	
South Africa	3.88	-2,176		4.73	-173	
Energy Exporters	1.47	-46,089		2.06	-25,420	
Rest of Africa	1.55	-5,657		1.89	-678	
Rest of America	2.33	-5,972		2.30	-350	
Rest of Asia	1.28	-24,030		1.92	1,485	
Rest of Europe	0.87	-6,318		2.15	98	
NON-ANNEX	**0.87**	**-157,165**		**1.43**	**-31,244**	
World	**-6.09**	**-100,617**		**-5.80**	**-56,074**	
Leakage rate (%)	**6.95**			**11.43**		

Source: elaborations on model results

Figure 4 – Changes in domestic output and imports from Non-Annex countries in KT-LEAK and KT-COMP scenario



If we look at the comparison between *ad valorem* carbon tariffs for alternative scenarios shown in Table 7, the most striking feature is that the carbon tariffs needed to significantly reduce the carbon leakage problem (scenario KT-LEAK) are much higher than those currently discussed in the political debate (KT-TCC and KT-TCCNK scenarios). It is interesting to note that tariffs aimed at keeping the share of imports from Non-Annex countries constant show some spikes among the energy-intensive sectors. In the KT-TCC and KT-TCCNK scenarios, tariffs are increasing in sectoral carbon contents. With regard to Non-Annex countries and the variance of the tariffs they face, KT-TCCNK and KT-LEAK scenarios are characterized by higher variances in all sectors, and this explains the larger costs arising for Non-Annex countries.

Table 7 – *Ad valorem* carbon tariffs for alternative scenarios[§]

	KT-TCC	KT-TCCNK	KT-LEAK	KT-COMP
Agriculture	1.11	1.15	21.42	0.36
Chem., Rubb., Plast.	0.71	2.15	14.47	3.32
Metal products	0.62	1.97	14.4	2.1
Mineral products	1.87	5.13	19.42	4.79
Oil products	1.03	2.9	8.12	8.78
Paper products	0.38	1.1	10.68	0.98
Average Energy intensive sectors	**0.92**	**2.65**	**13.42**	**3.99**
Electrical equipement	0.04	0.12	9.60	0.37
Food industry	0.23	0.33	14.30	0.16
Machinery equipment	0.07	0.29	12.54	0.52
Motorvehicles*	0.05	0.11	11.14	-
Other Manufacturing	0.08	0.69	8.27	0.33
Textile and Leather	0.14	0.41	8.81	0.33
Transport equipement	0.06	0.28	12.80	0.21
Average other sectors	**0.1**	**0.32**	**11.07**	**0.25**
Total average	**0.49**	**1.28**	**12.77**	**1.70**

*** In the KT-COMP no CBT are requested for this sector in order to comply with the conditions of the scenario**

§ Tariffs were all computed as weighted averages on the basis of bilateral import flows

Source: elaborations on model results

Finally, we simulate a cooperative scenario in order to obtain a benchmark for comparison with the other results (Table 8). The cooperative scenario solves (by definition) the carbon leakage problem since Non-Annex countries are committed to keeping their emissions constant in relation to the 2012 baseline. Moreover, in this scenario, we also register a much higher global emission reduction since all countries participate in emission trading and Non-Annex countries have lower abatement costs.

Table 8 – Comparing results with a Cooperative solution*

	KT-TCC	KT-TCCNK	KT-LEAK	KT-COMP	KT-COOP
CO2 reduction (%)	-5.70	-5.82	-6.09	-5.80	-6.54
Leakage rate (%)	12.91	11.09	6.95	11.43	0.00
CO2 Permits price (US$ per ton of CO2)	23.15	23.31	24.60	23.17	8.44
Welfare change (million US$)	-54,235	-55,435	-100,617	-56,074	-20,952

Source: elaborations on model results

*Note: * all figures for CO2 reduction and welfare effects refer to a global effect at the world level*

Looking at welfare changes for the world as a whole, our results clearly show that global welfare decreases when CBTs are introduced, as to be expected, due to the negative impacts on allocative efficiency (Table 9).

The cooperative scenario would constitute the best solution since welfare changes, although still negative, are more than halved with respect to the scenario with emission trading (KT) and almost five times smaller than the scenario designed to partially eliminate the carbon leakage through unilateral policies (KT-LEAK). Looking at the carbon emission permits price sheds some more light on CBT effects. As a matter of fact, all scenarios featuring CBTs lead to an increase, albeit rather small, in this price. CBTs protect the domestic production of carbon intensive sectors, and this leads to more stringent climate policies to obtain a given emission target, thus resulting in higher emission prices and larger welfare losses.

The distribution of welfare changes in the cooperative solution between Annex I and Non-Annex countries reveals that in relation to the KT scenario, Annex I countries significantly reduce their allocative efficiency losses: the price for that is the cost of the emission permits they need to buy on the market (Table 10). Non-Annex countries face opposite effects since they lose in terms of allocative efficiency but they gain as net sellers on the carbon market. More importantly, allocative efficiency gains (i.e., reduced losses) for Annex I countries are much larger than the allocative efficiency losses for Non-Annex countries.

Table 9 – Welfare decomposition for all countries for the COOP scenario

	Welfare change	ETS permits revenue	Allocative efficiency effect	Terms of trade effect	Investment-saving effect
EU	3,194	-228	-1,989	5,800	-389
USA	-9,527	-8,592	-5,193	3,627	631
Australia	-2,694	-822	-458	-1,313	-102
Canada	-2,193	-1,088	-612	-362	-131
Japan	2,475	-976	-305	4,489	-733
New Zealand	-90	-77	-24	26	-14
Norway	-1,574	-126	-72	-1,486	110
Swiss	-20	-40	-84	270	-166
Croatia	20	-12	0	21	11
Belarus	462	21	232	195	14
FSU	-2,097	1,377	-2,071	-2,544	1,141
ANNEX I	**-12,044**	**-10,563**	**-10,575**	**8,723**	**371**
Brazil	289	109	-254	558	-124
China	3,840	6,081	-2,994	1,446	-693
India	838	1,196	-1,413	1,242	-186
Mexico	-2,292	130	-1,703	-657	-62
South Africa	348	803	-488	36	-2
Energy Exporters	-16,299	1,461	-2,347	-16,763	1,350
Rest of Africa	-209	56	-126	-184	46
Rest of America	319	120	-253	519	-68
Rest of Asia	3,874	515	-564	4,621	-699
Rest of Europe	385	117	-211	403	76
NON-ANNEX	**-8,908**	**10,587**	**-10,354**	**-8,779**	**-362**
WORLD	**-20,952**	**24**	**-20,929**	**-56**	**9**

Source: elaborations on model results

5. Conclusions

In this paper we propose alternative border tax adjustments for dealing with carbon leakage.

We simulate different scenarios to gain a better understanding of to what extent a border tax is effective in reducing the leakage rate, and if major differences emerge when alternative CBTs are modelled. More specifically, we are interested in investigating the impact in terms of leakage reduction and to what extent such trade policies are also a valid instrument for protecting the economic competitiveness of compliant countries in the international market.

Our results confirm that the effectiveness of CBTs in reducing carbon leakage is limited and that they could even be damaging in terms of competitiveness. Moreover, border tariff adjustment compatibility with WTO-rules is still a moot point and justifying them by climate concerns could open the way to a proliferation of trade measures dealing with other areas where the competitive playing field is viewed as uneven.

We also provide a comparison with a global cooperative scenario where all countries contribute to reducing GHG emissions. In the cooperative scenario all major greenhouse gas emitting countries such as US, China and India participate in emission reduction efforts. Non-Annex countries pledge to maintain their current emission levels and they play a relevant role in the attainment of emission reduction target of Annex I countries, by participating in emission trading and offering cheap abatement opportunities. Our results suggest that the cooperative scenario would be preferable both in terms of welfare impacts and efficiency in emission reductions. We show that the cooperative solution is welfare improving with respect to all CBT forms, while gaining effectiveness in CO_2 reduction. This last point suggests that the bargaining power exerted by Annex I countries in the Post-Kyoto agreement should be directed towards a global solution rather than towards short-sighted solutions in which a domestically-oriented point of view prevails losing effectiveness as well as economic convenience.

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