Carbon Border Adjustment and Alternatives*

Cecilia Bellora (CEPII)†

Lionel Fontagné (Paris School of Economics – Université Paris I and CEPII)‡

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Abstract

Countries engaged in climate change mitigation combine different instruments ranging from environmental regulations to cap-and-trade systems. In the absence of international coordination, by reducing their emissions, these countries however displace some production of emitting industries (direct effect) and depress the price of fossil fuels leading indirectly to higher emissions by non-constrained countries. The direct effect can be addressed by free allowances of emission quotas to energy intensive industries, or tentatively through a carbon adjustment at the border. However, none of these strategies relaxes the problem of indirect leakages, while the legal consistency of Carbon Border Adjustments (CBA) with the WTO law is questionable. This paper investigates different policies aiming at *efficiently* curb *global* emissions in a context where not all countries adopt a cooperative behavior. Taking stock of the unconditional Nationally Determined Contributions of countries member of the Paris Agreement, we compare different modalities of a CBA at the border of the EU 27 with alternative approaches like the Nordhaus-type Club. We conclude that CBA is difficult to implement and hardly reduces the leakages induced by the Paris agreement, as opposed to an ambitious climate Club. Although optimal from the social planner perspective such Club would hardly attract large countries by applying moderate tariffs at its borders.

Key Words: Carbon Border Adjustment, Climate Change, International Trade, Tariffs.

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*We are grateful to xxxx

†CEPII, 20 avenue de Ségur 75007 Paris. Email: cecilia.bellora@cepii.fr.

‡Centre d'Economie de la Sorbonne, 106-112 Bd de l'Hôpital, F-75647 Paris Cedex 13. Email: lionel.fontagne@univ-paris1.fr.

Introduction

The tension between making ambitious commitments in terms of reduction of global emissions of Greenhouse Gases (GHGs) and keeping the multilateral trading system open is becoming a major political issue.[1] Climate is an international public good and the issue for governments is to make taxation of carbon acceptable to their constituencies in absence of international coordination. Alas, while containing global warming to the 1.5 degree temperature goal of the Paris Agreement would need to severely strengthen initial unconditional Nationally Determined Contributions (2019) (UNEP)[2], containing global GES emissions with minimal distortions would require imposing a common price for carbon worldwide, e.g. a cap-and-trade system applied to carbon-intensive industries in an integrated global carbon market, which is indeed not feasible.

The dividing line between rich and poor countries is a first obstacle to a cooperative action in favor of climate. Rich countries are overwhelmingly responsible for the stock of emissions accumulated over the past centuries and should support a stronger effort. In contrast, poor countries need to catch up in terms of income in order to reach the technical level they need to efficiently cap their emissions. The second obstacle is that except China and the USA (to a lesser extent EU 27, Russia or India), the contribution of an individual country (or economic union) to worldwide emissions is too limited to make a meaningful difference, hence limiting the incentive to individually reduce emissions.[3] The free riding problem is here reinforced by an incentive compatibility problem: countries waiting before action benefit from other's climate policy. This because non-participating countries attract highly emitting activities (direct leakage hypothesis) and benefit from the lowering of energy prices induced by reduced demand from acting countries (indirect leakage hypothesis). From a business perspective, non-participating countries become attractive locations (pollution haven hypothesis) which distorts competition (level playing-field argument). Recalling that the ultimate goal of the policy is acting for climate, a global good, not only will a local policy hardly fix a global issue, but the inaction of non-participating countries will render this policy ineffective.

There is here a dilemma: on the one hand the free-riding problem and the associated leakages necessarily increase the effort required of the acting countries to reach a given reduction in global emissions (the ultimate objective of the policy); but on the other hand the competitive distortion displace emissions internationally (direct leakage hypothesis), helping acting countries to reach their own targets of reduction of emissions (the intermediate objective of the policy). This partly explains the growing gap between the national inventories (based on actual production), on which Nationally Determined Contributions (NDCs) are based, and the carbon footprint (national actual emissions plus emissions due to the production of imported goods, minus emissions

[1]GHGs comprise carbon dioxide, methane, nitrous oxide and fluorinated gases.

[2]Nationally Determined Contributions are submissions by ratifying countries under the Paris Agreement. These commitments represent their national goals in terms of abatement of emissions to reach the long-term temperature goal of limiting global warming below 2 degrees. In the following, we will consider only unconditional pledges because these are the only credible commitments.

[3]Major emitters of CO_2 in 2016 are China (29%), USA (14%), EU 27 (9%), India (7%), Russia (5%) and Japan (4%).

caused by the production of exported goods) of advanced countries. Indeed, acting countries may achieve their (intermediate) objective and reach their NDCs, but this will come at a price which is a loss of competitiveness of their carbon intensive industries:[4] imports of goods from opting-out countries partly displace domestic production. Global emissions due to production do not decrease (unless production technologies abroad are less GHG-emission-intensive), while international transportation produces additional emissions. In absence of measures at the border, countries can choose to alleviate the burden of the cap-and-trade system by distributing free allowances to high emitting trade-exposed industries, either unconditional or output-based, which in both cases jeopardises the reduction of emissions (Böhringer, Carbone & Rutherford 2012). Under such circumstances, preserving an open access to the market is inconsistent with the ultimate goal of the policy (limiting emissions). As a consequence, acting countries will ultimately look for instruments compensating for carbon content at the border, which induces a potential clash with the multilateral trade system: the Most Favoured Nation principle (Art. I of the General Agreement on Tariffs and Trade – GATT), the National Treatment principle(Art. III)[5] and the commitments made in terms of Tariff Schedules (Art.II) would be violated, while the Special and Differential Treatment principle would be inconsistent with terms of trade effect detrimental to less advanced exporting countries. This potential clash can however be alleviated by resorting to a design of the measure consistent with the environmental exception of the GATT (Art. XX).

One may contemplate different schemes of compensation at the border in order to shield energy-intensive and trade-exposed industries (EITE) in acting countries from distorted competition. Tax or tariff are usually embraced in the generic wording of Carbon Border Adjustment (CBA), although being legally different instruments.[6] A tariff compensating for differences in carbon prices comprises limitations making it the ideal candidate to be challenged at the WTO: it is necessarily applied on a discriminatory basis (hence contradicting the MFN principle of the GATT); it leads to sizeable international redistribution of income (Böhringer, Bye, Fæhn & Rosendahl 2012, Böhringer, Carbone & Rutherford 2018) and has a strategic dimension leading to an extraction of rents detrimental to exporting countries (Balistreri, Kaffine & Yonezawa 2015). This optimal-tariff-type argument speaks against any CBA if acting countries are wealthier than opting-out countries, which is indeed not the case of the US. A tax may be more WTO-proof, although internal taxes are strictly restricted by the GATT, based on the exception present in the Article on the Schedules of Concessions.[7] On the export

[4]This is indeed the static argument. In a dynamic perspective, taxing emissions forces industries to innovate in low-emitting technologies and thus create a technological leadership for the green-economy.

[5]The legal question is whether products with similar characteristics can be considered as dissimilar because their production process differs: the jurisprudence of the GATT is ambiguous. The conservation of exhaustible natural resources can be invoked under Art. XX but then the defendant has to prove that "climate is exhaustible" which indeed is open to interpretation given that clean air has not been granted the status of exhaustible resource by the jurisprudence (Pauwelyn 2013). One argument in favour of using Art.XX is that climate change induces a depletion of a series of other natural resources (Böhringer, Carbone & Rutherford 2012). It has then to be demonstrated that the CBA is a necessary measure to attain the objective (the preservation of climate): e.g. Brazil could oppose that it stores carbon in the Amazonian forest, which is equivalent to abating emissions of carbon.

[6]The simple solution of capping domestic emissions with a tax and introducing a tariff at the border is known since (Markusen 1975).

[7]This exception to Art. II of the GATT reads: "Nothing (...) shall prevent any contracting party from imposing at any time on the importation of any product: *a charge equivalent to an internal tax* imposed consistently with the provisions of paragraph

side a tax rebate is usually contemplated in order to make sure that exporters compete on an equal foot with plants located in opting-out countries. The problem here is that a tax can hardly compensate a regulation under the WTO law. Accordingly, a tax compensating at the border for the cost of the allowances under the cap-and-trade system (a regulation) might not be WTO proof (as opposed to the VAT mechanism), and the more so for export rebates which would be considered as a subsidy (Pauwelyn 2007). Alternatively importers can be included in the cap-and-trade system in accordance with Article XX allowing for environmental exceptions (Brewer et al. 2010).

Depending of the reference emissions used to compensate the carbon content of imports and of the rate of taxation of this content (below, equal or above the domestic taxation of carbon), compensation will eventually reduce the direct leakage. Combined with an export rebate, the compensation will help levelling the playing field. However, two major loopholes remain. The first is the *indirect* leakage problem related to energy markets: by reducing their demand in fossil energy, regulating countries depress its price, which leads indirectly to higher emissions by non-constrained countries (Felder & Rutherford 1993, Bohringer, Voß & Rutherford 1998). This undesirable effect resists to the different designs of any adjustment at the border (tariff, tax, inclusion of imports in the cap-and-trade system). Worse, for countries engaged in the reduction of their emissions this induces a differential cost of energy over and above the cost of the allowances. The second problem is that the efficiency of the policy of reduction of emissions is ruined by the free-riding of opting-out countries.

Accordingly, even in presence of an adjustment at the border, the question remains how to incentivize non-participating countries to join the effort without clashing with WTO rules. International negotiations may help as evidenced by the Paris Agreement, because they put national policies under the spotlight of public opinions. But enforcement mechanisms are limited: nothing guarantees that countries will enforce domestic policies ensuring that their NDCs are within reach. Alternatively, tariffs can be a threat curbing the decisions of opting-out countries in such non-cooperative game (Böhringer, Carbone & Rutherford 2016), but this would hardly be acceptable under the GATT principles. Interestingly however, tariffs can alternatively play the role of *incentive* as is the Nordhaus-type Club proposal (Nordhaus 2015). The additional cost for countries outside the club make them indifferent between bearing the cost of implementing a policy of reduction of emissions as members of the Club, or pay the tariff and not investing in climate policies. The advantage of such an instrument is that it distorts less (no differences across exporters and sectors) than other solutions proposed. Being small and uniform, such a tariff is expected to trigger less retaliations than a more targeted CBA because it would less hit the emissive industries and their lobbies. Similar to enforcing the cap-and-trade system applied

2 of Article III [National Treatment on Internal Taxation and Regulation]". The related paragraph 2 states that "The products of the territory of any contracting party imported into the territory of any other contracting party shall *not* be subject, directly or indirectly, to internal taxes or other internal charges of any kind *in excess of those applied, directly or indirectly, to like domestic products.*". Italics are ours. Indeed, the corner stone of the applicability here is the concept of "like products" which easily pertains to homogenous goods but hardly fits differentiated products.

to imports, such a Club might also be WTO-proof according to Article XX,[8] and the more so to the Preamble of the GATT revised 1995 if designed properly with respect to developing countries,[9] although the devil is indeed in the details of the WTO jurisprudence (Pauwelyn 2013). Alternatively, one may contemplate a climate waiver (Holzer 2010, Bacchus 2017) of limited duration under which action could be taken in compliance with the Paris Agreement and the UNFCCC. This is not out of reach as three quarters of the countries have to step in: clearly the objective is here to embark low-income countries in the proposal, because they are potentially the first exposed to climate change consequences.

Based on applied modelling, we investigate in this paper different policies options aiming at efficiently curb global emissions in a context where not all countries adopt a cooperative behavior. We take stock of the implementation of cap-and-trade mechanisms in a series of countries and more generally take on board all the unconditional NDCs made under the Paris Agreement. Direct leakages are expected to be limited, as opposed to indirect ones, and the more so that large players' emissions (e.g. the US) are unconstrained. Thus, the question of international coordination is the corner stone of the success of an ambitious climate policy. Keeping in mind the ultimate goal of the policy (and constraining members of the Paris agreement to respect their unconditional NDCs), our research question is what is the best combination of instruments making it possible to achieve the goal of reducing global emissions in an efficient way minimizing the economic costs?

Our first policy experiment is to implement a CBA *at the border of the EU 27* which would exempt all countries already abating their emissions in line with their unconditional NDCs. The CBA is designed as a compensatory *tax* on imports; alternatively importers can be requested to purchase allowances on the EU ETS. This policy experiment is inspired by the ambitious policy, called *Green New Deal*, announced by the new European Commission in office since December 2019, aiming at drastically reducing GHG emissions and considering backing this policy by a CBA. Notice that from the modelling point of view, the two solutions (a tax on imports or the purchase of allowances by importers) are equivalent when the cap-and-trade system is modelled as a tax the level of which is endogenous, i.e. computed to cap emissions at a certain level, at each date in each country (under the assumption that countries stick to their unconditional NDCs in terms of abatement of emissions). In this scenario, the tax (or the purchase of allowances by importers) is not combined with a rebate (actually a complete refund) for domestic exporters (as for a VAT), thus departing from the so-called "complete CBA" (CCBA) solution: cap-and-trade & border tax & export rebate.

[8]Article XX states that: "Subject to the requirement that such measures are *not applied in a manner which would constitute a means of arbitrary or unjustifiable discrimination* between countries where the same conditions prevail, or a disguised restriction on international trade, nothing in this Agreement shall be construed to prevent the adoption or *enforcement by any contracting party of measures (...) relating to the conservation of exhaustible natural resources if such measures are made effective in conjunction with restrictions on domestic production or consumption*". Italics are ours.

[9]The statement about environment in the Preamble of the revised GATT, absent from the original one is as follows: "Recognizing that their relations in the field of trade and economic endeavour should be conducted with a view to raising standards of living, (...) while allowing for *the optimal use of the world's resources in accordance with the objective of sustainable development*, seeking both to protect and preserve the environment and to enhance the means for doing so in a manner consistent with their respective needs and concerns at different levels of economic development." Italics are ours.

The reference chosen in terms of emissions of opting-out countries is a key ingredient of the discussion: a simple policy inspired by the political economy (although challengeable from a theoretical point of view) is to charge a tax on importers (or an amount of allowances to be purchased) based on the actual carbon content of the imported good and at the tax rate (the price of allowances) of domestic producers. A first obstacle is that exporters from opting-out countries have no incentive to disclose their carbon content and will claim the same level of reference emissions as of competitors in the targeted market. The compensation can therefore alternatively be based on the average emission intensity of the EU27, or of a reference (group of) country(ies). We will model a pragmatic solution in terms of implementation of the policy, namely using as a reference the emission intensity of the *importer*. This is indeed also the least contentious approach from the WTO principles perspective.[10]

A second obstacle is that the carbon content of imports is notoriously difficult to measure, in particular in the case of complex value chains and if one wants a large coverage of imports, beyond high-emitting industries covered in Europe by the ETS system. In all the exercise, we consider the GHG content inclusive of all intermediate consumptions, and not only the one caused by the fuel consumed to produce the embodied energy. Lastly, in our scenario, the compensation at the border covers *all* GHG emissions from *all* economic sectors. Indeed, to be consistent with the level of ambition announced by the European commission in its *Green New Deal*, the effort to curb GHG emission can not plausibly be supported by some sectors only, be they those showing the highest emission intensity. We therefore consider that all sectors engage in GHG emission reduction. Importantly, in this first scenario there is no trading of carbon allowances beyond the borders of the country or group of countries abating their emissions, with the exception of EU 27 countries trading with the UK and EFTA countries in the ETS.

We then oppose in a second policy experiment the CCBA to a tariff at the borders of the EU 27, set to fully compensate differences in carbon prices at origin and destination of the trade flow.[11] The tariff rate is computed to be equivalent to the difference between the domestic and foreign prices of allowances, applied on the documented emissions of the importer. European exporters are not rebated their allowances. The assumptions about the tax base and the perimeter of the carbon trading system are the same as in the previous scenario.

In a third experiment, we model a Nordhaus-type Club comprising a subset of signatories of the Paris Agreement that would strongly tighten their initial NDCs. As an experiment, the perimeter of this Club would comprise the EU 27, the UK, Japan and China.[12] This experiment comprises two elements. First, members of the Club have a common market for emission allowances in order to minimize the leakages and to improve the efficiency of this market. We adopt the social planner approach which is to also mutualize emissions within

[10]n a further version of this paper we will benchmark this solution with the theoretical reference point of *exporters'* actual emissions provided by the model, although not revealed due to an incentive compatibility problem.

[11]Importantly, with respect to the World Trade Organization (WTO) definition, this is not a countervailing duty.

[12]To be able to compare this scenario with the others, sectors in EFTA countries that participate in the EU ETS under the Paris Agreement are also included in the design of the Club.

the group in order to allocate allowances to the sectors and countries where abatement costs are the smallest. Although not realistic from a political perspective, this approach confirms how a global problem should be tackled at the global level. Second members of the Club apply a penalty to imports from outside the Club in order to persuade non-members to join. A uniform and small tariff, i.e. 2 percentage points, as initially proposed by (Nordhaus 2015) on all goods imported from countries outside the Club is imposed by countries in the Club, in addition to the tariffs already in place. An important question here is the treatment of low-income countries. They neither have the technologies nor the financial resources to massively abate their emissions, and any WTO-compatible policy should consider exempting these countries thanks to the *Special and differentiated treatment* (SDT) principle. But exemption would wash-out the signal associated with the tariff. An alternative contemplated here is to redistribute the tariff income to countries under the umbrella of the SDT. The transfer would not be a "reimbursement" since the overall revenue (i.e. generated by the tax on the imports from *all* countries, not only from the beneficiaries of the redistribution) would be redistributed to low-income countries. This transfer could even be mobilised to purchase green technologies. Without entering into the details of the market for technologies, out of reach in a CGE, at this stage, we simply compute what would be the amount of tariff revenue to be redistributed to low income countries in order to alleviate the cost of reduction of their own emissions.

While the mechanisms underlying the impacts of an unilateral environmental policy are well known (Felder & Rutherford 1993), their relative magnitude and therefore the size of the resulting leakages remains an empirical question, depending on the characteristics of the policies in place, of the implementing countries and the affected sectors. A Computable General Equilibrium model (CGE) is therefore a good candidate to quantify these impacts. Based on our three experiments, we compare the efficiency of the different policy options in an unified framework.

We use the MIRAGE-VA model, developed at CEPII (Bellora & Fouré 2019). It is a global, dynamic, multi-sectoral and multi-regional model, featuring a detailed representation of energy use.[13] In particular, as it is standard in energy-oriented models, energy is not considered as an intermediate consumption but directly substitutes with capital in the production function. In addition, energy is subject to independent productivity improvements, specifically calibrated. GHG emissions due to both energy use (carbon dioxide) and production processes (carbon dioxide, methane, nitrous oxide and fluorinated gases) are explicitly reported. The model also accounts for trade policies, based on highly disaggregated databases of the *ad valorem* equivalents of tariff and non tariff protection, as well as climate policies, in particular cap-and-trade mechanisms. The CGE model additionally embeds an improved representation of value chains that, coupled to the results on emissions, and therefore allows to discuss in details the impacts on GHG leakage through international trade and on carbon

[13] We rely here on the assumption of perfect competition in all sectors.

footprints. We compare the outcome of the policies (CCBA, tariff, Nordhaus-Club) in terms of i.) reduction of global GHG emissions; ii.) GHG leakages from the constrained countries; iii.) impacts on sectoral value added in the constrained countries.

We are not the first to quantify the economic and environmental efficiency of a compensation at the border. Elliott, Foster, Kortum, Munson, Perez Cervantes & Weisbach (2010) perform a quantitative analysis of scenarios of compensating carbon taxes at the border of Annex B countries (before the US opt out) using a CGE.[14] (Babiker & Rutherford 2005) quantify with a CGE the effectiveness and consequences of various CBA schemes (Voluntary Export Restraints, compensating tariff, free allowances, export rebates) under the Kyoto protocol after the US opt-out. Böhringer, Bye, Fæhn & Rosendahl (2012) consider alternative designs for compensating *tariffs*, and analyze their effects on global welfare within a multi-region CGE model of the global economy. The carbon content for compensation at the border includes indirect emissions associated with intermediate non-fossil inputs corresponding to indirect carbon from electricity use and indirect carbon from non-electric and non-fossil intermediate inputs. The tax rate is either based on the average of the coalition or on the average of opting-out countries or alternatively on the actual emissions of the exporting country. The abatement of carbon emissions is obtained through exogenous emission constraints or CO_2-taxes. Compensation is applied alternatively on EITE sectors only or on all sectors. Weitzel, Hübler & Peterson (2012) and Antimiani, Costantini, Martini, Salvatici & Tommasino (2013) examine the consequences of a CCBA modelled as a tax compensating for internal carbon prices at the borders of a coalition comprising Europe, USA and other Annex I countries.[15] Manders & Veenendaal (2008) quantify with a CGE the outcomes of two scenarios (ETS imposed in Europe only versus coalition with other Annex I countries, plus Brazil, India and China) combined with different instruments: tax levied on the carbon content of EITE imports; export refund; redistribution of auctioning receipts to emitting sectors; Clean development Mechanisms with the EU investing in clean technologies in the developing world (as an alternative to more expensive emission reductions in their own countries). Kuik & Hofkes (2010) use a CGE to quantify the impact of two CBA-type policies in presence of the European ETS: obligation of purchasing allowances for importers of EITE products based on reference direct emissions in the EU versus in the exporting country. The model abstracts from any other cap-and-trade system. Böhringer, Carbone & Rutherford (2012) assess three proposals for leakage reduction with a CGE: CBA, industry exemptions, and output-based free allowances. The coalition comprises either Europe only, or Annex I countries, or the latter countries plus China. The CBA is implemented as tariffs levied on the carbon content (direct emissions plus indirect emission from electricity use) of imported EITE products. Böhringer, Garcia-Muros, Cazcarro & Arto (2017) performs the same type of analysis but focused on the US initial NDCs under the Paris agreement. McKibbin, Morris,

[14] We refer here to Annex B of the Kyoto protocol. This Annex sets binding emission reduction targets for 36 industrialized countries and the European Union, over the period 2008-2012. The countries *not* listed in the Annex B have no binding commitment, under the principle of the "common but differentiated responsibility and respective capabilities".

[15] We refer here to Countries that are listed in Annex I to the UN Framework Convention on Climate Change.

Wilcoxen & Liu (2018) rely on a CGE to quantify the economic and environmental impact of a taxation of carbon in the US in presence of a CBA. Böhringer et al. (2018) rely on a CGE to quantify the consequences of compensating carbon at the borders of OECD, with OECD applying a taxation of its emissions and possibly compensating non-OECD with lump-sum transfers.

We add to this literature in three ways. First, we integrate the Nordhaus Club policy option in a unified framework encapsulating different modalities of CBA and taking stock of equity issues. Second, we rely on a dynamic baseline of the world economy accounting for unconditional NDCs associated with the Paris agreement, including the withdrawal of the US. Third we combine a macroeconometric model of growth and a CGE model to produce this baseline.

As a final note, let us stress that the CCBA afore define – i.e. combining a cap-and-trade system with a tax at the border and a rebate on exports – very much resembles a consumption tax (Elliott et al. 2010). There is actually equivalence if and only if i.) the CCBA taxes carbon at the exact same price as the domestic tax; ii.) the carbon tax is fully passed onto the consumer by producers and iii.) there is full rebate for exporters. Then domestic producers and foreign producers pay the carbon tax when selling their products to domestic consumers, while no producer (domestic or foreign) pays the tax when serving foreign consumers.[16] There is however not full equivalence because taxation at the border is exerting a pressure on foreign exporters, hence strategically leading them to cut their export price.

The remaining of the paper is organized as follows. In a first section we survey the large literature addressing the economic and environmental impacts of the policies at stake. The CGE model, the data used and the hypotheses of our scenarios are presented in section 2. We compare the environmental and economic impact of the different policies in the third section. The last section concludes.

1 Related literature

Quantification of carbon compensation at the border has been repeatedly proposed since the Kyoto protocol, provided that leakages would have to be curbed in a situation where only a small number of countries committed to abate their emissions. To give a bird-eyes view of this abundant literature, we adopt the perspective of ex ante simulations of alternative policy instruments based on a structural model, in a situation where only a subset of countries have enforced their own abatement policies. Relying on a model clarifies the ultimate consequences of alternative policies and provides a metric of how leakages reduce the benefits of the decrease in emissions by ambitious countries. Calibrated model estimating the potential impact of a compensation at the border confirm

[16] A consumption tax could even be combined with free allowances (Böhringer, Rosendhal & Storrøsten 2019). This combination is equivalent to a tariff if the good is imported (Dixit 1985).

the existence of (moderate) leakages that care quite resilient to with CBAs.[17] We start by clarifying the term CBA used because the literature is loose when it comes to the exact content of this wording. We then reposition the results of previous papers in the institutional context of the abatement policies they refer to. Last, we recall how the impact of the exact design of the CBA has been addressed in the recent literature.

1.1 CBA versus CCBA

As afore mentioned, a central proposal in the policy debate is the CBA. We define here the "complete CBA" (CCBA) as a benchmark combination of a cap-and-trade system with a compensation at the border based on the carbon content of products; exporters are also rebated the tax they pay when mobilizing allowances to produce. This compensation is indeed limited in scope to products covered by the cap-and-trade system in the countries enforcing a CCBA. The tax at the border (or equivalently the export rebate) has two components. Firstly, the tax base is the considered carbon content of the product and different options can be contemplated: scope 1 emissions directly embodied in the product (under control of its producer); scope 2 emissions including indirect carbon content of off-site energy used; and scope 3 indirect emissions associated with the production or transport of intermediate inputs used in the production process of the considered plant.[18] Scope 1 and 2 correspond to the definition used under ETS-Phase 3 meaning that stricto sensu scope 3 emissions should not be compensated at the border of EU27.[19] On the other hand, from a theoretical point of view, an efficient instrument should be based on directly and indirectly emitted carbon along the whole value chain, deducted the indirect carbon already covered by allowances. This is the mechanism we will rely on here. Secondly, the tax rate is the daily price of the carbon content when the product crosses the border. So doing, the imported product will be charged the tax only on the fraction of its carbon content that is not covered by allowances on intermediate consumption.

For clarity, take the illustrative case of a washing machine imported in Germany from the US. Under our benchmark, a US washing machine made of Japanese steel would not bear the carbon tax on the incorporated Japanese steel, just because the US producer could claim that Japan has a (partial) system of cap-an-trade.[20] Conversely would the US washing machine be made of US steel, it would bear a compensation tax at the EU border. Notice finally that the consumer price of a washing machine produced in Spain with Polish steel and purchased in Germany would de facto include the cost of the allowance to produce steel within the ETS area,

[17]Considering emissions related to processes instead of emissions from fuel combustion only increases the leakage rate and the effectiveness of CBA to reduce the leakages (Bednar-Friedl, Schinko & Steininger 2012)

[18]These are the definitions from the GHG protocol – an international private standard for corporate GHG accounting and reporting. GHG Protocol " provides standards, guidance, tools and training for business and government to measure and manage climate-warming emissions" (`https://ghgprotocol.org/about-us` acceded April 9 2020.

[19]ETS-Phase 3 is covering heavy energy-using installations consisting of highly emitting power stations and combustion plants, oil refineries, coke ovens, iron and steel, cement clinker, glass, lime, bricks, ceramics, pulp, paper and board, aluminium, petrochemicals, ammonia, nitric, adipic and glyoxylic acid production, CO_2 capture, transport in pipelines and geological storage of CO_2.

[20]Japan has two locally (connected since 2010) emissions trading regimes: one in the Tokyo Metropolitan Government and one in Saitama Prefecture. The Kyoto Prefecture has a less stringent program, disconnected from the two others.

although the Spanish producer of electrical appliances does not need allowances to assemble washing machines under ETS-Phase 3: hence the need for a compensation at the border imposed on the US washing machine.[21]

Game theory provides a rationale for implementing such a compensation at the border of countries abating their emissions, given the uncooperative behavior of non-participating countries. Because opting-out countries do not put a price on carbon, they implicitly subsidize carbon-intensive industries. A BCA would change the pay-offs of this game and be an incentive for abating their emissions (Helm, Hepburn & Ruta 2012, Böhringer et al. 2016). There is also a rationale in terms of political economy because a border adjustment would reinforce the political acceptability of carbon taxation in regulating countries. Whether this rationale is consistent with the legal constraints at the WTO is an open question. The environmental exception of Article XX could be mobilized, although the devil is in the details. Coherence with the legal framework of the European union is also an issue, because for instance a tax would possibly enter in the perimeter of the decision at unanimity, as opposed to a tariff which resorts to competency of the Commission. We will disregard these debates and focus on the literature addressing economic rationale and efficiency of a compensation at the border. As the reader will notice, the exact definition of the instrument mobilized for compensation may vary across studies, and may not correspond necessarily to the ideal benchmark afore mentioned that will be modelled in the next section.

A meta-analysis of 25 studies and 310 estimates of carbon leakage shows a 14% leakage rate on average (within a 5% to 25% range) without CBA and 6% (respectively -'% to 15%) with a CBA (Branger & Quirion 2014). The leakage rate is decreasing in the simulated size of the coalition, while export rebate is the assumption minimizing the leakage (it acts as a subsidy to locate production in the most environmentally efficient countries). On the other hand the export rebate reduces the effectiveness of the abatement policy because the incentive for investing in clean technologies is lower.

By design, in this literature, the economic/environmental impact and efficiency of a border adjustment depends on the policy environment on which it is implemented. The perimeter of countries engaged in reduction of their emissions, the type of instrument mobilized and the international agreements backing these policies have changed repeatedly since the beginning of the 2000s. This complex landscape can be synthesized by considering three yardsticks: the Kyoto Protocol, the European cap-and-trade system and the Paris Agreement.[22] Economic studies aiming to balance the pros and cons of the CBA have followed this changing landscape and proposed

[21] In absence of CBA, this Spanish producer receives free allowances as it is considered as exposed to a significant risk of carbon leakage, for the period 2015 to 2019 (sector NACE 2751, Official Journal of the European Union, L 308/114: "To address this risk of carbon leakage, Directive 2003/87/EC provides that, subject to the outcome of the international negotiations, the Commission is to determine a list of sectors and subsectors deemed to be exposed to a significant risk of carbon leakage (...). Those sectors and subsectors should receive free allowances at 100% of the quantity determined on the basis of Directive 2003/87/EC and Decision 2011/278/EU, subject to the cross-sectoral correction factor". Under a CCBA free allowances should be frozen to make the system acceptable by third parties.

[22] The Kyoto Protocol, entered into force in 2005, sets emission reduction targets for 36 industrialized countries for the period 2008-2012. To comply with its objective of abatement of emissions, the EU put in place its cap-and-trade system, namely the European Trading Scheme (ETS) in 2005. The Doha amendment to the Kyoto Protocol that should cover a second commitment period, from 2013 to 2020, has been signed but not ratified yet. A separated instrument, the Paris Agreement, has been adopted in 2015. All the 195 parties that have signed the Paris Agreement contribute to climate change mitigation (contrary to what was set in the Kyoto Protocol), according to the Nationally Determined Contributions (NDCs) they report every five years.

evaluations valid with respect to a specific institutional environment. We now follow this line of reasoning and present the different attempts to model the CBA in general equilibrium. We disregard here another abundant strand of literature, based upon econometric estimations. Lastly, this literature has shown how details of the design of the CBA matter a lot for the efficiency of this instrument.

1.2 CBA under different institutional frameworks

Only 36 industrialized countries committed to reduce their emissions under the Kyoto Protocol, such that leakages were expected to be large. Early estimations of these leakages under the Kyoto protocol with a (static) CGE of the world economy however led to a wide range of estimated leakage rates from 10% (Paltsev 2001) to 28% (Böhringer & Löschel 2002). Dispersion in estimated leakages have different explanations, beyond the perimeter of participating countries (accounting or not for the withdrawal of the US from the Protocol). With the US opting-out larger leakages are systematically obtained (30%), concentrated on the US (one-third of the leakages) (Babiker & Rutherford 2005). The Armington elasticity used in the model, because it governs the substitutability between domestic products (submitted to carbon taxes in participating countries) and foreign products (not submitted to such taxes in countries with no abatement) is an obvious suspect, although its impact is ultimately limited (Böhringer & Löschel 2002). The substitution elasticity between energy and other inputs in production also plays a role. Another important issue is the perimeter of the market for trading emission allowances: do participating countries have separated markets for carbon or is there an integrated market where trading can take place? Leakage rates are higher in absence of carbon trading among participating countries. Lastly, the underlying economic growth in the baseline also plays a role. As of the low magnitude of the median leakage, the first explanation is indeed that initial ambition in terms of abatement was limited, leading to low tax rates (low price of carbon) and limited coverage (generalized exemptions of emitting industries sensitive to competitiveness losses). Imposing a compensating tariff at the border barely reduces the leakage (28% instead of 30% globally) and has virtually no impact on the US-induced leakages (10% instead of 11%) (Babiker & Rutherford 2005).

Later studies even enlarged the range of estimated leakage rates. Elliott et al. (2010) provide an estimation of leakages with the model CIM-EARTH. They present simulation results by aggregating the 16 regions of the simulation into three regions: USA, other annex B countries, and non-Annex B countries.[23] The simulation includes 16 sectors and shows results for different levels of carbon taxation, ranging from USD15 to USD175 per ton. Different policy options are examined. A carbon tax applied worldwide delivers a 40% reduction in global emissions in 2020 with the highest tax rate. Limiting the carbon tax to Annex B countries is much less efficient

[23] Annex B of the Kyoto Protocol sets binding emission reduction targets for 36 industrialized countries and the European Union, over the period 2008-2012. The countries not listed in the Annex B have no binding commitment, under the principle of the "common but differentiated responsibility and respective capabilities".

as it would achieve only one-third of the above reduction in emissions. There is a leakage here, in the range of 15% to 25% depending on the level of the tax (higher tax, higher leakage). A CCBA changes the results as follows: production (consumption) increases (decreases) in Annex B countries and decreases (increases) in non-Annex B countries, which is the purpose of the policy. With a 50 USD tax on the ton of emitted carbon, the leakage rate would be on average 7% but the sectoral variation in this rate would be huge, ranging from 2% to 57% depending on the sector, with the highest toll falling on manufacturing (Fischer & Fox 2012).

Taking stock of the different waves of estimations, Böhringer, Balistreri & Rutherford (2012) provide ranges for carbon leakages under the Kyoto Protocol ranging between 5% and 19%, with an average value of 12%, under unilateral policies. Implementing a CBA reduces this to a range of 2% to 12%, with a mean value of 8%. The CBA reallocates the abatement effort across regions and, in this respect, is cost-saving at the global level. It also helps to improve the competitiveness of regulated industries, at least in their domestic markets: the decrease in production of the regulated emissions-intensive and trade-exposed emitting industries located in regions that constrain their emissions falls from -2.8% to -1% in the scenario with a BCA.

Another institutional framework extensively studied in the literature is the European ETS. The ETS operates in the EU27, the UK, Norway, Iceland and Liechtenstein. It covers covering more than 11,000 heavy energy-intensive plants and, later on, intra-European airlines. This corresponds to a bit less than half of EU GHG emissions (beyond carbon). The general principle of a cap-and-trade scheme is to set a cap to GHG emissions that declines over time. In order to produce, plants need to get emission allowances. Firms receive, buy or sell allowances, which can also be received in exchange of emission-saving international projects. The price of these allowances is determined by market forces, hence the importance of the perimeter of the market. A larger market with more participants is more efficient. Setting a price for carbon provides an incentive for emitting industries to invest in green technologies. Till 2013 caps were defined at the country level. They are since then defined at the European level. Free allocation of allowances aims at levelling the playing field in absence of CBA. Free allocation can be output based (Australia, California, New Zealand) or based on an industry benchmark independent from the output as in the ETS (Meunier, Ponssard & Quirion 2014). Auctioning of allowances has progressively replaced free allocation in the ETS, from 80% of allowances allocated for free initially to 30% in 2020. If we abstract now from the policies by countries other than the EU, the size of leakages depend on the level of ambition of the European climate policy and of its main instrument, the ETS. In the first phase of implementation of the ETS, the target seemed to be quite low, and leakages were expected to be small. In such a context, a CBA proves to be quite inefficient, in particular as an incentive for other countries to implement climate policies. EU entered into the fourth phase in 2020.

Relying on the CGE model of the CPB (Worldscan) and an aggregation of the world economy in 25 sectors and 14 countries, Manders & Veenendaal (2009) obtain very low leakages (3%). A complete BCA would halve output and employment losses in the EU emitting sectors and reduce leakages to 0.5%. A reason for why leakages are so small is the limited impact of the ETS with low ambition on the carbon price within the EU, with in turn limited impact on competitiveness and thus limited leakages.

Kuik & Hofkes (2010) explore the implications of the EU ETS and possible border adjustment measures, using the GTAP-E model. Their scenario caps the emissions of three EU sectors (electricity, iron and steel, and metal products), while other countries do not constrain their emissions at all. Concerning the level playing field issue, they show that border adjustments (in absence of export rebates), by increasing the cost of imports, can stop the increase in imports, if they are set based on the average emission of the exporting country, but they do not prevent the decrease in European exports to third countries. Actually, they even exacerbate these losses: the European market becomes a less attractive destination for exporters, which divert their shipments to other regions, where competition become fiercer. Because of this increase in competition in third markets, EU exports of steel decrease by around 9% with an EU ETS with a CBA based on average foreign carbon content. In the case of an EU ETS without any border adjustment, they decrease by around 8%. However, protecting the European market more than compensates for the loss of competitiveness in third markets. EU production of the affected sectors decreases less thanks to the border adjustment (i.e. -1.3% vs - 2.5% in the steel sector, for instance). Next,Kuik & Hofkes (2010) explore the consequences of a CBA on sectoral and overall leakages in GHG emissions. In absence of a CBA, an increase in the non-European emissions associated with steel production abroad (direct leakage) offsets one-third of the reduction in emissions by the European steel sector. The CBA reduces this rate to 29% if based on average EU emissions but to 2% if based on average foreign emissions. In the mineral sectors, a border adjustment reduces the rate of leakage from 19% under the EU ETS to around 14% and 6% respectively. The take-home message is that a CBA reduces direct leakage significantly only if based on foreign emissions. In contrast, a CBA based on EU emissions is inefficient in curbing indirect leakages. Overall, a CBA reduce leakages from 10.8% to 8.2% in the best case, because half of the overall leakage (5.9 p.p.) comes from the indirect channel, especially from electricity generation taking benefit of reduced fuel and other primary energy prices.

Fouré, Guimbard & Monjon (2016) consider that the implementation of a BCA may trigger retaliation by the most affected trade partners (in particular the US and China). Exports of the main partners of the EU may decrease by -0.3% to -2.4% because of the CBA, with respect to a scenario in which only the ETS is in place. Retaliation mainly changes the distribution of gains across sectors in the economies involved (the EU as well as the countries that retaliate), while it does not affect aggregated impacts on macroeconomic indicators and on emissions. The overall picture remains the same, whatever the targeted goods, since the value of the trade affected by the CBA in each EU partner is small (between USD 17m and USD 1.4bn, for Brazil and the US respectively).

Finally, under the Paris Agreement, climate policies should be more widespread, which changes significantly the type of outcome of any simulated policy. However, the withdrawal of the United States from the Agreement raised the question of the role of a CBA in dealing with a large country and emitter becoming a free-rider. Fontagné & Fouré (2017) find that the implementation of the unconditional pledges taken by the signatories of the Paris Agreement leads to a decrease in global emissions of 27%. Leakages amount to 5% of the overall emission reductions (without any border adjustment). The withdrawal of the US from the Paris Agreement also offers interesting insights. In particular, Bellora & Fouré (2017), using the CGE model MIRAGE-e, examine the impacts of a tariff targeted on US exports and based on the carbon content of exported goods, in a world where the Paris Agreement is applied by all its signatories except the US, according to its NDCs. The kind of instrument considered here looks like a CBA but, since the tariff targets a specific exporter, it has a retaliatory dimension. If all the signatories of the Paris Agreement apply a carbon tariff on US exports, they would curb US exports by 3% but global emissions by only 1.7%, with respect to a world without retaliatory tariffs. The decrease in emissions mainly comes from the transportation sector. The US being a large country, where exports represent only a small share of domestic production, such policy is not effective in spurring it to rejoin the Paris Agreement (the impact on US GDP is trivial), to avoid its free-riding and to limit the impact on global GHG emissions.

1.3 Optimal design of a CBA

There is a trade-off between the complexity of the implementation and the efficiency of a BCA. Unfortunately, WTO-proof measures are the least efficient ones (Böhringer, Bye, Fæhn & Rosendahl 2012). This has led to excessively pessimistic statements, such as "*Designing a BCA regime that accomplishes economic objectives and is administratively feasible, WTO-legal, and politically acceptable may be impossible.*" (McLure (2014) p. 553). For instance, would the basis for taxation be the importation of the product, a CBA would necessarily be considered as a border tax adjustment by the WTO, in violation of Art. II of the GATT. But this could be bypassed if the CBA is not triggered by the importation as such, but rather by the internal sale of the product (Mehling, van Asselt, Das, Droege & Verkuijl 2019). To economists, this makes little difference, but this margin of interpretation is important from the point of view of international law. Let us sort out the different problems of policy design. What are the choices to be considered by the economic modeler?

The first choice to be made is to compensate the carbon content of all imported products or only of EITE industries. Even if one restricts the scheme to EITE industries subject to a cap-and-trade system in the importing country, complexity arises because the carbon intensity is, for the same good, different across exporters. This is the question of the base for compensation (and the question of discrimination clashing with the GATT principles). This difference in intensity is increasing in the ambition of the policy of abatement in participating countries, because a higher domestic tax rate on emissions will incentivize firms to adopt cleaner technologies, hence enlarging the gap with opting-out countries. Complexity is also increased by input-output relationships possibly involving a series of other countries with or without carbon policies: one may want to consider, or not, these indirect emissions. There are several methods for setting the reference for the carbon content to impose: the max/min/average emissivity of the domestic producers in the country abating its emissions, the max/min/average emissivity of foreign producers localized in opting-out countries, for each imported good.

As for the tax base, namely the reference carbon content for imports, more complex and detailed mechanisms have been shown more efficient, especially when the climate coalition is small (Böhringer, Bye, Fæhn & Rosendahl 2012). Using non-coalition technologies as the basis for carbon content calculations is key to success. However the actual carbon content of imports is hardly observable, at least because non-participating countries have no incentive to reveal information about their emissions. This said, one way of simplifying the administrative burden is using regional averages for carbon information, instead of country- and product-specific values. Alternatively, using domestic emissions as a benchmark is an easy way to proceed, also potentially WTO-proof (Ismer & Neuhoff 2007), but will compensate only partially and thus miss its environmental objective. Last levelling the playing field also requests a rebate on exports which should be WTO-consistent only if the compensation imposed on imports is a tax, not a tariff (as it is the case for the VAT).

The tax rate of the compensation imposed at the border is also difficult to choose, because the tax has a strategic dimension (Weitzel et al. 2012, Balistreri, Kaffine & Yonezawa 2019). The increase in the consumer price of the carbon-intensive goods is alleviated and the imposing country is extracting a rent from the exporting country. First this is leading to increased consumption which goes against the environmental objective: border adjustments inadvertently encourage consumption of emissions-intensive goods in unregulated regions. Second, countries imposing border adjustments at the domestic carbon price extract rents from unregulated regions which is not consistent with international trade law. This said, the environmental efficiency of the compensation scheme is increased with a CCBA (compared to a simple CBA), because the export subsidy helps concentrating the location of production in the most efficient countries (the ones abating their emissions and hence using more environmental-friendly technologies). Numerical simulations show that with a CCBA the optimal compensation rate is 80% of the optimal domestic tax on carbon. Bypassing the legal argument and setting a higher compensation rate would indeed curb leakages: the CBA is then used as a means of changing the pay-offs for non participating countries. The problem then is that the potential for decreasing leakage decreases at higher tax rates: a tax rate three times higher than the optimal domestic tax only marginally reduces the leakage rate, from 18.3% to 16.0% (Balistreri et al. 2019). This result suggests that overall leakages can hardly be curbed with a CBA even in a non-cooperative game.

The first take home of this literature is the trade-off between the complexity of the implementation and the efficiency of a carbon compensation. Determining the tax base is complex and contentious. Once the compensation base is set, the second trade off is between taxing imports consistent with GATT commitments or taking stock of the non-cooperative behavior of non participating countries and using the tax (or the tariff) to change the pay-offs. Taxation of imports (with a tax or a tariff indifferently) has a strategic dimension and the more so that the coalition is large. The tax rate for the border adjustment ought to be set below the internal taxation of carbon, independently from the base used for calculation. This would however jeopardize the objective of level playing-field and climate change mitigation. Alternatively, setting punitive tax rates (or tariffs) on imports of carbon-intensive goods from non-participating countries might incentivize these countries to opt-in, but would hardly fix the problem of leakages if the threat does not work, not to speak of retaliation. The withdrawal of the US from the Paris Agreement makes this issue systemic. These trade offs and the central issue of free-riding justify contemplating a different strategy based on a Club of countries abating their emissions which impose a small uniform tariff on all goods imported from non participating countries under the umbrella of the environmental exception of Article XX of the GATT. The tariff revenue would be redirected to developing countries with the purpose of acquiring green technologies. We will now discipline all these arguments in a common General Equilibrium framework in the next section.

2 Model, data and scenarios

Dynamic Computable General Equilibrium (CGE) modelling encompassing international trade and emissions is particularly adapted to address the economic impact of climate-change mitigation policies and the level of ambition required to reach the commitments. Calibrated multi-sectoral and global dynamic general equilibrium models properly address the impacts in terms of allocation of production, international trade and emissions of GHGs. Relying on a model taking explicitly into account Global Value Chains is also important when emissions related to intermediate consumptions have to be embarked. We rely here on the model MIRAGE-e that differentiates demand of goods according to their use, for final or intermediate consumption, thus explicitly representing GVCs. In addition MIRAGE-e tracks emissions at the country and sector level, for all GHGs. Last, MIRAGE-e is a dynamic model, consistent with the long term horizon to be considered for environmental studies. Our approach combines three tools: (i) a global and sectoral model featuring recursive dynamics and emissions of GHGs; (ii) a database of applied tariffs that can be shocked to impose tariffs at the product level on targeted goods and exporters; and (iii) a dynamic baseline of the world economy up to 2030. We present sequentially these three elements.

2.1 The General Equilibrium model

MIRAGE-e is the multi-sector and multi-region computable general equilibrium model developed at the CEPII to assess the impact of trade policies and the interactions between trade and climate change. We rely on version 2 of MIRAGE-e which innovates by featuring GVCs.[24] We rely here on the perfect competition version of the model by sake of computational constraints.

In this version of MIRAGE-e, a representative firm by sector and region charges the marginal cost. Production combines value-added plus energy and intermediate consumption, while demanding five primary factors (labor with two different skill levels, capital, land, natural resources), fully employed.

In each region, a representative consumer gathers households and the government. It maximizes its utility under its budget constraint. This representative agent saves a part of her income and spends the rest on commodities, according to a LES-CES functional form.

Trade is represented with two different Armington structures, one for final consumption and one for trade in intermediates. This double structure explicitly accounts for GVCs.[25] What the double Armington structure indeed captures is the difference in the preferences in the base year for a given sector (e.g. Vehicles) since, for instance, the share of imports coming from a given country is not the same whether they are of final (e.g. cars) or intermediate goods (e.g. components). Furthermore, it allows to apply policy shocks differentiated by the use of goods. Trade can be impacted by a wide range of measures, systematically differentiated according to the use of the affected goods. We explicitly consider tariffs and export taxes. Trade restrictiveness of non-tariff measures (NTMs), both on goods and on services, is also taken into account, under three possible different forms: tariff equivalents, export tax equivalents and iceberg costs. Section 2.3 provides details on data sources for each of this measures. International transportation is explicitly modelled: transportation demand is *ad volumen*, it can be satisfied through different transport modes, supplied by different countries.

Finally, MIRAGE-e is a recursive dynamic model: agents optimize their choices intra-temporally and the model is solved each year until the last year considered in the simulation. A putty-clay formulation captures the rigidity in capital reallocation across periods: the stock of capital is immobile, while investments are allocated each year across sectors according to relative return rates. In other words, structural adjustments result from the inertial reallocation of the stock of capital via depreciation and investment. The baseline required for dynamic simulations is calibrated in close relationship with the MaGE model and the resulting EconMap database (Fouré, Bénassy-Quéré & Fontagné 2013) to deal with world structural change at medium-run horizon (2030).

The model is calibrated using the ImpactECON database (Walmsley & Minor 2016) featuring a decomposi-

[24] Version 1 of the model is documented in Fontagné, Fouré & Ramos (2013). More information on the version used here is available on the MIRAGE wiki: `https://wiki.mirage-model.eu`. MIRAGE stands for Modelling International Relationships in Applied General Equilibrium.

[25] Elasticities of substitution across origins do not differ according to the use of goods, meaning that we actually assume that the behavior of an importer is the same whatever the kind of good (for final or intermediate use). These elasticities were estimated by Hertel, Hummels, Ivanic & Keeney (2007).

tion of trade in goods and services by final or intermediate use that is consistent with GTAP 9.[26] This release of the GTAP database features 2011 as the last reference year. The geographic decomposition is 140 regions of the world economy for 57 sectors. We aggregate this data into 27 sectors and 21 regions or countries (see Appendix **??** for the detailed aggregation).

2.2 Emission data

To account for GHGs emissions, MIRAGE-e explictly considers the consumption of five energy goods (electricity, coal, oil, gas, refined petroleum). In firms'consumption, the bundle of these five goods substitutes with capital, in the value added structure, instead of substituting with intermediate consumptions, with a constant elasticity of value 0.5, as in the model GTAP-E.[27] Within the energy bundle, oil, gas and refined petroleum are more substituable than coal or electricity. However, to avoid unrealistic results, energy production sectors other than electricity deserve a special structure: a constant Leontief technology is assumed, to avoid, for instance, to produce refined petroleum from gas and electricity. Nonetheless, productivity improvements are possible, at the level of the capital-energy bundle, they are calibrated based on the energy productivity projected by the Mage Model (see below, section 2.4).Carbon dioxyde emissions are then proportionnal to the consumption of the energy goods corresponding to fossil energy (coal, oil, gas, refined petroleum), based on fixed parameters determined in the intial year.

GHGs other than carbon dioxyde, namely nitrous oxyde, methane and fluorinated gases are considered as emitted during the production process. More precisely, these three GHGs are treated as production factors within the production functions. Their position in the production function, i.e. their relative substituability with respect to other factors and intermediate consumptions, varies across sectors, following Hyman, Reilly, Babiker, De Masin & Jacoby (2003). Their substitution elasticity is calibrated to match marginal abatement curves.

Unless otherwise specified, emission data are taken from the GTAP-E database and the satellite data on non-CO_2 emissions provided by GTAP.

[26]The "ImpactECON Global Supply Chain package" allows converting the GTAP 9.0 data into a global supply chain database. Since the goods traded in GTAP are aggregated within sectors over numerous HS-6 products categories, a given resulting sector can provide the same category of good to final consumer and to other sectors that use it as an intermediate product. Tariffs differ by HS6 category and thus by main use of the output of the sectors, as well as by the source and destination of the good. Combining COMTRADE and the Broad Economic Categories of the UN, ImpactECON fixes this problem: each bilateral flow in a GTAP sector is split into final and intermediate use. The GTAP 9.0 database is thus converted into a "Global Supply Chain Database", a database of value of imports of commodities purchased by sectors (intermediate), households (final), government and investment (final), by source and destination country/region, at market, agent and world prices. Notice that although the database also provides the tariffs aggregated along the same dimensions, we do not rely on the latter as we proceed with our own aggregation of the MAcMap HS6 database.

[27]Refer to Fontagné et al. (2013) for a detailed discussion on substitution between capital and energy and the value of the related elasticity.

2.3 Protection data

Market Access Map (MAcMap) provides a disaggregated, exhaustive and bilateral measurement of applied tariff duties at the product or tariff line level. It takes regional agreements and trade preferences exhaustively into account. The raw source data is from ITC (UNCTAD-WTO). The HS6 data set used here was constructed by the CEPII (Guimbard, Jean, Mimouni & Pichot 2012) for analytical purposes and provides an *ad valorem* equivalent (percentage) of applied protection for each triplet importer-exporter-product. To minimize endogeneity problems (when computing unit values or when aggregating data), it relies on "reference groups" of countries: bilateral unit values and bilateral trade are replaced by those of the reference group of countries in the weighting scheme (Bouet, Decreux, Fontagné, Jean & Laborde 2008). MAcMap-HS6 treats specific duties (per unit) as well as TRQs and offers MFN for all WTO members. The last two years reported in MAcMap are 2011 and 2013, both considered in the following exercise. *Ad valorem* equivalents of NTMs affecting goods are taken from Kee, Nicita & Olarreaga (2008), they are split across import taxes, export taxes and iceberg costs in an equally proportional way. *Ad valorem* equivalents of NTMs applying to services are from Fontagné, Mitaritonna & Signoret (2016) and are taken into account in the form of iceberg trade costs.

2.4 The dynamic baseline

The effects of the trade war are measured in terms of deviation from a dynamic baseline, using a ten years horizon in order to fully capture the dynamic adjustments of the economies. The baseline is build in two steps. First, it relies on a macroeconomic model of the world economy, used in projection up to 2030 (Fouré et al. 2013). For each country, the GDP, the savings rate, the current account, and the energy efficiency are consistently projected. They are then used as an exogenous trajectory of MIRAGE-e, the consistency of the assumptions between the two models being ensured by endogenizing the Total Factor Productivity. This is the first step of the construction of our baseline.

In a second step, we update the tariff protection to its level of 2013 (the most recent available in the MAcMap-HS6 database)[28] and represent – in a stylized way – the most recently signed or negotiated trade agreements: the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP), the EU-Japan Economic Partnership Agreement, the Comprehensive Economic and Trade Agreement between the EU and Canada and a soft Brexit.[29] For all the new trade agreements, we remove all the tariffs but leave the NTMs unchanged.

To sum up, the general equilibrium model is first run to calibrate the TFPs; a second run, updating trade protection, then constitutes what we consider our baseline. We then build policy scenarios, in which we imple-

[28] We do not consider changes in the MFN rates following 2013. In particular, the decreases in MFN tariffs implemented by China in 2018 and 2019 are neither taken into account in the baseline nor in the policy scenarios.

[29] We represent a soft Brexit by leaving the tariffs applied by the UK and the EU unchanged, while increasing their bilateral NTMs to halve the preferential access of the UK to the EU market, and reciprocally.

ment the trade policies we are interested in. The only element that differs between the baseline and a policy scenario is the policy of interest. Then, comparing the economic outcomes of the policy scenario to those of the baseline allows to assess the impact of the trade policy implemented in the scenario.

3 Comparison of outcomes of the different policies

We propose here a quantification of the environmental and economic impacts of CBA *versus* Climate Club, starting from a benchmark corresponding to the current (unconditional) commitments under the Paris agreement. We report in this section the results of *ex ante* simulations of alternative policy instruments based on MIRAGE-e. The time horizon considered is the year 2035. Importantly for the interpretation of the results, we observe deviations in the value of variables of interest with respect to the situation in 2035 in presence of the Paris agreement. This means that abatement of emissions is already effective in the benchmark situation (i.e. in the Reference scenario), already large for certain (group of) countries and consequently already costly. Last, recall that only a subset of countries have enforced their own abatement policies, while one of the major players – the US – has not.

We do not report results of a world without the Paris agreement, as this scenario would be irrelevant. But it is worth keeping in mind what a world in 2035 is thanks to an agreement of the Paris type. Countries having committed to reduce their emissions in absolute terms keep this cap till 2035 despite the growth of their GDP. The only source of extra emissions for signatories of the Paris agreement is commitments in relative terms, whereby emissions are proportioned to the GDP. At the global level, extra emissions from countries outside Paris are also present, especially from the US. In the absence of the Paris Agreement, worldwide emissions would be 36% higher in 2035. Emissions would be more than twice as large in the EU27, the UK and Japan, or more than 80% higher in China. US emissions would be 4% *lower*, because they benefit from the indirect leakage of a lower price of energy worldwide under Paris.

The starting year of the simulations is 2011, the model follows a dynamic path in the baseline, conditional on Paris commitments. At this stage, for sake of numerical resolution, we implement the different scenarios from the onset, not in 2020, in order to avoid a change of policy regime in the middle of the dynamic path. Thus the interpretation of the results is " where would be the world in 2035 if a CBA of a given type had been combined with the Paris agreement from the onset?".

One important motivation for carbon compensation is the magnitude of leakages induced by non-cooperative policies such as the Paris agreement. The latter are quantified in the first row of Table 1: in 2035, the leakages generated by the Paris Agreement, from which the US exited, amount to 1.7 Gt of CO_2eq. We then compare the reduction in this leakage associated with the different policies here contemplated. The Club (with or even without tax) is clearly the most efficient policy from this point of view with a reduction of 600 to 700 Mt CO_2eq of leakages worldwide. Scenario 2 (a simple tariff at the border of the EU compensating for differences in carbon taxation) delivers half of the benefits of the Club but implies huge swings in tariffs in certain sectors. The CBA (scenario 1) misses this target. This comparison leads us to comment the scenarios in reverse order, from the least plausible but theoretically appealing Climate Club, to the CBA often envisaged by policy makers. We examine the outcome of a practical solution whereby the carbon content of product is not revealed by the exporter and thus mirrors the emission performance of the import substitute (but what about a situation where this substitute is absent?). All goods are concerned by the compensation, not only ETS ones, which raises practical implementation issues beyond the question addressed in this paper. We will in the following refrain from commenting on the welfare results based on the usual calculation excluding the benefits of reduced pollution and cushioned globate warming.

3.1 A climate Club

We firstly examine the economic and climatic consequences of a climate club. Members of the Club keep globally their emissions targets unchanged but these emissions are mutualized in order to favour the producers most efficient in abating their GHG emissions and thus minimize the economic cost of a given reduction of emissions. This economic reasoning is indeed highly implausible politically but is a good benchmark to start from: this is how the social planner would address a global problem.

Emissions of the Club reported in Table 3 are basically unchanged, by construction. The other face of the coin is to have a massive redistribution of emissions, to the detriment of China. Japan, the UK and EU27 benefit from this approach. At the world level emissions drop by 0.85% which proves that this policy is superior to the Paris agreement.

China is bearing the cost of this redistribution, with a toll of 0.9% on the GDP (Table 2). On the other hand, other members of the Club benefit a lot, and Japan especially. The GDP of the Club increases by 1.6% overall. Interestingly, this solution also reduces the burden of the Paris agreement for the EU27, with a 3.5% increase in the GDP. These impacts on GDP show the infeasibility of this solution, at least in terms of political economy, unless gains are redistributed among the members of the Club.

The next step for this Club is to tentatively address the free-riding issue. As said, this suggests enforcing a small tariff at the border of the Club, on all goods exported by non-members. Inspired from Nordhaus' proposal, we contemplate here a modest 2 p.p. increase in tariffs at the border of the Club. Impact on emissions is shown in Table 3. The reference point is still the Paris agreement in absence of a Club, and one can notice that the tax has barely no effect on emissions. Even for members outside the Club, like the US, the reduction of emissions is only mild. This does not come as a surprise as a big chunk of emissions are associated with the domestic activity in such a large country. In terms of impact on GDP, conclusions are similar: the tax is just cancelling the gains of Paris for the US, while inside the Club the impact is slightly negative, as expected. Detailed results in Appendix (Table 7) confirms a mild impact on US exports (-0.9%) and a mild deterioration of US terms of trade (-0.2%). All in all, at moderate tariffs rate, the incentive to join the club would not be effective for large players outside the Club.[30] In this scenario, action is only on the tariff revenue side when compared to the previous scenario. For members of the Club, tariff revenues increase by 43% (China) to 125% (Japan). These 152 USD bn of additional tariff revenue (Club and 2 pp tariff compared to Paris agreement without Club) could be used to alleviate the cost of transition to a de-carbonized economy for low-income economies. This is equivalent to 2.1 % of their GDP under the benchmark of the Paris agreement and would be more tenfold larger in absolute terms than the -0.2% drop in their GDP induced by the 2 pp tariff they would have to pay.

The political economy of the solution envisaged by the social planner makes it difficult – to say the least – to implement. What about a Club keeping members' carbon markets and commitments isolated but simply imposing the 2% tariff at its borders? In economic terms the answer in column "Paris Ag. & tax" of Table 2 is clear-cut: such policy has a negligible impact on the Club itself but also on the target country, the US, with a -0.06% variation in the GDP compared to the Paris agreement in both cases. Exports of the Club decrease by 2%, due to a loss of competitiveness spreading along the GVCs, while US exports record a modest -1.3% drop (Table 4). This mirrors a negligible impact on GHG emissions even for the US (Table 3). The only region negatively affected is the developing world having not made commitments in the paris agreement, which is indeed not a desirable outcome of the policy.

The take home of these three first simulations is that the climate Club is definitely not fixing the free riding issue if tariffs are set at a low level. It only generates the resources that could be mobilized to help low income countries in their transition to a decarbonized economy. This also compares to the Official Development Assistance (ODA) from the 30 members of the OECD's Development Assistance Committee amounting to USD 153.0 bn in 2018. While some traction can be gained with low income countries, here is the puzzle: how to incentivize a large, rich and highly emitting country to join the Club? The next scenario to be commented is a compensatory tariff at the border.

3.2 A compensating tariff

The next simulation adopts a different perspective. EU policy makers internalize that cooperation on mutualizing emissions is out of reach and have to respond to their constituencies claiming for a simple tax at the border to compensate for unequal market conditions between domestic producers (who purchase allowances) and non-EU exporters, who may or not pay for allowances, but quite systematically at a lower price. Such policy would clearly target the US (out of Paris) and China (within Paris but at a lower carbon price due to

[30] To fully illustrate this point, one additional simulation is planned, to show the cost for the US of implementing the Paris Agreement and of joining the Club.

less ambitious commitments). The tariff is based on the differential price of allowances (which will be simply equal the ETS price for the US by construction) multiplied by the carbon content of the product evaluated at the average EU27 level (the exporter does not reveal its actual carbon content). We will address the latter issue in the next section.

As shown in Table 2 this policy has basically no economic impact on the EU27 (-0.09% GDP compared to Paris): the repatriation of activity is counterbalanced by the loss in competitiveness on export markets. Indeed, more expensive imports of intermediates translate in higher production costs and lower exports (-1.78%, see Table 4). Impact on emissions is negligible, with the exception of reallocation of emissions within the ETS to the benefit of the UK. GDP is increasing in China and in the US which shows that this policy does not fix the incentive compatibility problem either.

3.3 The CBA scheme

The last scenario to be considered is also, as said, the least efficient in terms of reduction of leakages induced by the incomplete country-coverage of unconditional commitments in the Paris agreement. Recall that this CBA is enforced only at the borders of the EU27 in our scenario. Alas, the impact on the GDP of the imposing region is negative (-0.23%) and this region is the only one for which a sizeable impact on the GDP is recorded. Interestingly, the US economy is not affected by this policy, whereas the cost of non-cooperative policies should be beard by this country. For the EU27 this is by far the most economically damaging policy. The impact on emissions is also very mild: US emissions record a -0.3% drop, and world emissions half of this. EU exports are more damaged than US ones.

All in all, this policy hardly reduces leakages, is economically detrimental to the implementing country and has no traction on free-riding countries. Reasons are understandable. In this scenario we adopt the pragmatic approach of exporters non revealing their emissions, which leads the imposing country to use its own emissions (already contained by the carbon pricing) as a benchmark. Second, the imposing country increases the price of its imports. Intermediate imports prices hamper the competitiveness of EU exporters (in absence of rebate), while the final consumer real income is negatively affected as shown in the three last rows of table 10. Indeed an export rebate could alleviate the cost for EU exporters, but would also increase the production of the most emitting industries hence jeopardizing the climate benefits of the CBA.

Conclusion

Climate is a global good necessitating global policies. In presence of free-riding of countries, any attempt to adopt ambitious policies is endangered by leakages and competitiveness distortions. Against this background, the social planner best solution – a Club – is clearly the most efficient: it minimizes the leakages and provides resources that can be mobilized to facilitate the energetic transition in the poorest countries. This policy has two main drawbacks: it fails to attract the US in the Club, and it imposes a redistribution of the economic gains within the Club, in our scenario towards China. The alternative solution of imposing a tariff at the EU27 border compensating for carbon pricing is simpler, quite efficient in terms of reducing leakages without too big damages to the imposing countries. But it would hardly be WTO compatible. Last, the appeal of CBA to policy makers is somehow misguiding. The cost of it is beard by the imposing country and the benefits for climate are the lowest among all our simulations.

4 Tables and graphs

Table 1: GHG Leakage

Scenario	Leakage (Mt CO_2eq)
Paris Agreement	1719
Club & tax	−701
Club w/o tax	−603
Scenario 2	−358
Scenario 1	−113

Notes: The first line provides the GHG leakage caused by the Paris Agreement. The following rows give the reduction in this leakage that occurs in the various scenarios.

Table 2: Long term changes in GDP, selected countries

	Paris Ag.	Scen. 3			Scen. 2	Scen. 1
		Club w/o tax	Paris Ag. & tax	Club & tax		
	(USD bn)	(%)	(%)	(%)	(%)	(%)
Club	64365	1.63	−0.06	1.56		
EU27	22324	3.50	−0.04	3.43	−0.09	−0.23
China	29838	−0.90	−0.04	−0.92	−0.00	0.01
Japan	7994	5.50	−0.14	5.35	0.03	0.01
UK	4209	2.23	−0.11	2.06	0.12	−0.05
USA	25135	0.07	−0.06	0.01	0.00	−0.01
Dev. No commit.	7141	0.25	−0.43	−0.19	0.01	−0.05

Notes: Variations, in volume, with respect to the reference scenario (i.e. Paris Agreement without club), based on a Fisher index.

Table 3: Impact on GHG emissions

	Paris Ag.	Scen. 3			Scen. 2	Scen. 1
		Club w/o tax	Paris Ag. & tax	Club & tax		
	(Mt CO_2eq)	(%)	(%)	(%)	(%)	(%)
Club	24041	0.04	−0.16	0.01		
EU27	3097	64.17	−0.10	63.35	−0.86	0.01
China	19709	−14.17	−0.17	−14.04	−0.01	0.01
Japan	809	67.71	−0.11	67.09	−0.01	−0.00
UK	426	62.94	−0.30	62.14	4.25	−0.44
USA	10452	−1.49	−0.16	−1.62	−0.71	−0.30
Dev. No commit.	7567	−2.32	−0.54	−2.80	−0.77	−0.25
World	72923	−0.85	−0.25	−1.03	−0.50	−0.14

Notes: Variations, in volume, with respect to the reference scenario (i.e. Paris Agreement without club), in 2035.

Table 4: Long term changes in exports, selected countries

	Paris Ag.	Scen. 3			Scen. 2	Scen. 1
		Club w/o tax	Paris Ag. & tax	Club & tax		
	(USD bn)	(%)	(%)	(%)	(%)	(%)
Club	14239	5.84	−2.01	3.70		
EU27	7278	9.09	−1.13	7.72	−1.78	−0.83
China	4689	0.32	−3.18	−2.83	−0.24	−0.01
Japan	1323	7.39	−2.77	4.57	0.09	−0.06
UK	949	5.98	−1.90	3.94	0.53	−0.09
USA	3344	0.38	−1.31	−0.92	−1.00	−0.39
Dev. No commit.	2403	0.78	−1.54	−0.77	−0.49	−0.33

Notes: Variations, in volume, with respect to the reference scenario (i.e. Paris Agreement without club), based on a Fisher index.

Table 5: Long term changes in imports, selected countries

	Paris Ag.	Scen. 3			Scen. 2	Scen. 1
		Club w/o tax	Paris Ag. & tax	Club & tax		
	(USD bn)	(%)	(%)	(%)	(%)	(%)
Club	15300	4.87	−1.48	3.31		
EU27	8276	6.64	−0.84	5.66	−1.28	−0.67
China	4424	1.18	−2.50	−1.33	−0.27	0.01
Japan	1307	6.70	−2.34	4.36	0.16	−0.05
UK	1293	4.39	−1.25	3.06	0.44	−0.09
USA	4354	0.66	−1.39	−0.72	−0.94	−0.41
Dev. No commit.	2543	1.11	−1.95	−0.87	−0.64	−0.41

Notes: Variations, in volume, with respect to the reference scenario (i.e. Paris Agreement without club), based on a Fisher index.

Table 6: Scenario 3, without tax – Main aggregate results for selected countries

	France	Germany	UK	China	Japan	USA
GDP	2.63	3.28	2.23	−0.90	5.50	0.07
Exports	7.84	6.16	5.98	0.32	7.39	0.38
T. of trade	−0.98	−0.02	−0.06	1.21	−1.64	0.31
Tariff rev.	−16.12	−13.12	−23.28	3.38	−2.58	0.41
Capital real return	8.08	9.12	7.76	−1.76	12.52	−0.41
Skilled real wages	7.09	8.99	7.44	−1.77	13.22	0.36
Unskilled real wages	6.37	7.26	5.88	−1.32	9.51	0.10

Notes: Percentage deviation from the baseline (Paris Agreement) in 2035, in volume. Volumes are based on a Fisher index.
Source: MIRAGE-VA, authors' calculation.

Table 7: Scenario 3, with tax – Main aggregate results for selected countries

	France	Germany	UK	China	Japan	USA
GDP	2.55	3.24	2.06	−0.92	5.35	0.01
Exports	6.23	4.81	3.94	−2.83	4.57	−0.92
T. of trade	−0.63	0.34	0.36	1.81	−0.85	−0.20
Tariff rev.	74.64	82.61	67.67	42.85	125.72	−2.01
Capital real return	7.88	8.82	7.85	−2.18	12.32	−0.39
Skilled real wages	6.95	8.89	7.04	−1.70	13.00	0.24
Unskilled real wages	6.24	7.08	5.60	−1.39	9.31	0.06

Notes: Percentage deviation from the baseline (Paris Agreement) in 2035, in volume. Volumes are based on a Fisher index.
Source: MIRAGE-VA, authors' calculation.

Table 8: Paris Agreement & 2 p.p. import tax imposed by a coalition w/o a common GHG reduction target – Main aggregate results for selected countries

	France	Germany	UK	China	Japan	USA
GDP	−0.06	−0.01	−0.11	−0.04	−0.14	−0.06
Exports	−1.42	−1.21	−1.90	−3.18	−2.77	−1.31
T. of trade	0.32	0.34	0.42	0.60	0.81	−0.49
Tariff rev.	88.62	93.08	92.78	39.74	115.39	−2.47
Capital real return	−0.12	−0.22	0.16	−0.47	−0.14	0.00
Skilled real wages	−0.09	−0.03	−0.28	0.03	−0.18	−0.11
Unskilled real wages	−0.08	−0.12	−0.20	−0.09	−0.16	−0.04

Notes: Percentage deviation from the baseline (Paris Agreement) in 2035, in volume. Volumes are based on a Fisher index.
Source: MIRAGE-VA, authors' calculation.

Table 9: Scenario 2 – Main aggregate results for selected countries

	France	Germany	UK	China	Japan	USA
GDP	−0.05	−0.20	0.12	−0.00	0.03	0.00
Exports	−2.18	−2.01	0.53	−0.24	0.09	−1.00
T. of trade	0.54	0.34	0.23	−0.03	0.12	−0.26
Tariff rev.	145.39	126.41	2.63	−0.45	0.68	−0.99
Capital real return	−0.41	−0.32	−0.17	0.02	0.03	−0.14
Skilled real wages	−0.32	−0.37	−0.19	−0.01	0.07	0.05
Unskilled real wages	−0.20	−0.52	−0.13	−0.01	0.02	0.03

Notes: Percentage deviation from the baseline (Paris Agreement) in 2035, in volume. Volumes are based on a Fisher index.
Source: MIRAGE-VA, authors' calculation.

Table 10: Scenario 1 – Main aggregate results for selected countries

	France	Germany	UK	China	Japan	USA
GDP	−0.05	−0.34	−0.05	0.01	0.01	−0.01
Exports	−0.72	−0.86	−0.09	−0.01	−0.06	−0.39
T. of trade	0.23	0.14	0.01	0.01	0.02	−0.15
Tariff rev.	32.33	36.15	0.90	0.00	0.34	−0.52
Capital real return	−0.22	−0.35	−0.13	−0.01	−0.01	−0.02
Skilled real wages	−0.23	−0.52	−0.21	0.02	0.02	−0.01
Unskilled real wages	−0.14	−0.41	−0.14	0.01	0.01	0.00

Notes: Percentage deviation from the baseline (Paris Agreement) in 2035, in volume. Volumes are based on a Fisher index.
Source: MIRAGE-VA, authors' calculation.

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