HARVARD Kennedy School
JOHN F. KENNEDY SCHOOL OF GOVERNMENT

The Harvard Project on Climate Agreements

October 2012
Discussion Paper 12-54

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Insights from a Model-Comparison Study

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Prepared for

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The goal of the Harvard Project on Climate Agreements is to help identify and advance scientifically sound, economically rational, and politically pragmatic public policy options for addressing global climate change. Drawing upon leading thinkers in Australia, China, Europe, India, Japan, and the United States, the Project conducts research on policy architecture, key design elements, and institutional dimensions of domestic climate policy and a post-2012 international climate policy regime. The Project is directed by Robert N. Stavins, Albert Pratt Professor of Business and Government, Harvard Kennedy School. For more information, see the Project's website: http://belfercenter.ksg.harvard.edu/climate

Acknowledgments

The Harvard Project on Climate Agreements would like to thank the Harvard University Center for the Environment for its generous support of the current series of publications.

The Harvard Project also receives support from Christopher P. Kaneb (Harvard AB 1990); the James M. and Cathleen D. Stone Foundation; ClimateWorks Foundation; and the Qatar National Food Security Programme. The Project is very grateful to the Doris Duke Charitable Foundation, which provided major funding during the period July 2007–December 2010. The Project also receives ongoing support from the Belfer Center for Science and International Affairs at the Harvard Kennedy School.

The closely affiliated, University-wide Harvard Environmental Economics Program receives additional support from the Enel Endowment for Environmental Economics at Harvard University, the Alfred P. Sloan Foundation, the Mossavar-Rahmani Center for Business and Government at the Harvard Kennedy School, Chevron Services Company, Duke Energy Corporation, and Shell.

Citation Information

Böhringer, Christoph, Edward J. Balistreri, and Thomas F. Rutherford. "The Role of Border Carbon Adjustment in Unilateral Climate Policy: Insights from a Model-Comparison Study." Discussion Paper 2012-54, Cambridge, Mass.: Harvard Project on Climate Agreements, October 2012.

The Role of Border Carbon Adjustment in Unilateral Climate Policy

Insights from a Model-Comparison Study

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Abstract

Issues of emission leakage and competitiveness are at the fore of the climate policy debate in all the major economies implementing or proposing to implement substantial emissions cap-and-trade programs. Unilateral climate policy cannot directly impose emissions prices on foreign sources, but it can complement domestic emissions pricing with border carbon adjustment to reduce leakage and increase global cost-effectiveness. While border carbon adjustment has a theoretical efficiency rationale, its practical implementation is subject to serious caveats. This model-comparison study assesses the efficiency and distributional impacts of border carbon adjustment. We find that border carbon adjustment can effectively reduce leakage and ameliorate adverse impacts on energy-intensive and trade-exposed industries of unilaterally abating countries. However, the scope for global cost savings is small. The main effect of border carbon adjustment is to shift the economic burden of emission reduction to non-abating countries through implicit changes in international prices.

Note on the Energy Modeling Forum

The research project on which this Discussion Paper is based was carried out under the auspices of the Energy Modeling Forum (EMF), which is an international expert platform for the discussion of energy and environmental problems. The underlying project is identified as "EMF 29." The main objective of EMF studies is to develop robust insights into energy and environmental policy issues and thereby help to put decision makers on an informed basis. To achieve this objective, EMF studies build on the collective capabilities of experts who apply and compare analytical models to the policy issues in a systematic manner. Researchers involved with this study have jointly investigated a set of pre-defined policy scenarios with harmonized assumptions and a common dataset, as is typically the case with EMF projects.

1. Introduction

Given the bleak prospects for a global agreement on collective greenhouse gas reduction, individual industrialized countries are pushing for unilateral climate policy in the hope that other countries will follow suit. The fundamental drawback with unilateral action to combat the global greenhouse gas externality is that it forgoes large cost savings from "where-flexibility" (Weyant

1999): To minimize abatement cost, emissions should be reduced where it is cheapest world-wide. With unilateral emission constraints, marginal abatement cost in countries without emission control are zero, indicating a huge but unexploited potential for cost savings.

Beyond the lack of globally coordinated abatement action, unilateral climate policy faces additional challenges which can be traced back to international market responses. Emission constraints in an open economy not only cause structural adjustment of domestic production and consumption but also affect comparative advantage, which drives the pattern of international trade through relative cost differences between countries. As a consequence, the global cost-effectiveness of unilateral emission reduction can be hampered by so-called emission leakage, i.e., the relocation of emissions to parts of the world economy subject to no (or weaker) regulation. There are two major intertwined channels for leakage which capture international spillovers from fossil fuel markets, on the one hand, and from non-energy markets, on the other hand. Leakage through the fossil-fuel-price channel occurs as reduced energy demands of emission-constrained regions depress international fuel prices, which in turn triggers additional energy demand and emissions in unconstrained countries. Leakage through the competitiveness channel on non-energy markets occurs as energy-intensive and trade-exposed (EITE) industries of unilaterally abating countries face higher cost compared to international rivals, which incentivizes the relocation of these industries abroad. The competitiveness channel amplifies adverse production and employment impacts for EITE industries in unilaterally regulating countries.

Concerns about environmental effectiveness and the competitiveness of EITE industries are at the fore of the climate policy debate in all the major economies implementing or proposing to implement emissions reduction measures. In response to such concerns, border carbon adjustment (BCA) is appealing as a policy option for many countries that intend to move forward with unilateral climate policies. Unilateral policies cannot directly impose emission prices on foreign sources, but they can complement domestic emissions pricing with BCA to reduce leakage and increase global cost-effectiveness. On the import side, emissions embodied in imported goods and services from non-regulating countries should be taxed at the emission price of the regulating region. On the export side, emission charges paid by domestically regulated firms are rebated for exports to non-regulating countries. If comprehensively applied, BCA effectively works as destination-based carbon pricing which level the playing field in international trade while internalizing the cost of climate damage into prices of goods and services.

While BCA has theoretical appeal on global efficiency grounds (Markusen 1975, Hoel 1991), it may be rather controversial with respect to induced distributional impacts. BCA provides scope for back-door trade policy since it can work as a substitute for strategic tariffs, shifting the economic burden of emission reduction from abating countries to non-abating countries (Böhringer, Carbone and Rutherford 2011). The burden shifting potential of BCA may accommodate strategic leverage to trigger cooperation by non-abating countries, but the coercive nature can also backfire and lead to detrimental trade conflicts.

In this overview paper, we summarize results from a model-comparison study to assess the efficiency and distributional impacts of BCA, addressing the subsequent key policy questions:

- How effective is BCA in reducing carbon leakage?
- Is BCA an effective tool for the protection of EITE industries in unilaterally abating regions?
- How big are the global cost savings from BCA?
- What is the incidence of BCA across regions?

To answer these questions, the study builds on model-based analysis of twelve expert groups that jointly investigate a set of pre-defined policy scenarios with harmonized assumptions and a common dataset. Table 1 provides a summary of the groups involved in the model study and the respective models that they use.

Table 1. Expert teams participating in the model-comparison study

Model	Institution	People
BCR	Universities of Oldenburg, Calgary, and Wisconsin (Madison)	Böhringer, Carbone, Rutherford
CEPE	ETH Zürich	Caron
DART	Kiel Institute for the World Economy (IfW), Kiel	Weitzel, Hübler, Peterson
CVO	University of Oldenburg	Springmann
EC-MS-MR	Environment Canada, Ottawa	Ghosh, Luo, Siddiqui, Zhu
ENV-LINKAGES	OECD, Paris	Lanzi, Chateau, Dellink
FF	International Trade Commission (ITC), Resources for the Future (RFF), Washington	Fischer, Fox
MINES	Colorado School of Mines, Golden, University of Wisconsin, Madison	Balistreri, Rutherford
PACE	Centre for European Economic Research (ZEW), Mannheim	Alexeeva-Talebi, Böhringer, Löschel, Voigt
SNOW	Statistics Norway, Oslo	Böhringer, Bye, Faehn, Rosendahl
WEG_CENTER	University of Graz	Bednar-Friedl, Schinko, Steininger
WORLDSCAN	Netherlands Bureau for Economic Policy Analysis (CPB), Den Haag	Boeters, Bollen

All models included in the analysis are multi-sector, multi-region computable general equilibrium (CGE) models that constitute a wide-spread analytical framework for the impact assessment of climate policies. CGE models build upon general equilibrium theory that combines assumptions regarding the optimizing behavior of economic agents with the analysis of equilibrium conditions: Producers employ primary factors and intermediate inputs at least cost, subject to technological constraints; consumers maximize their well-being subject to budget constraints and preferences. CGE analysis provides counterfactual ex-ante comparisons, assessing the outcomes of policy reforms with what would have happened had they not been undertaken (the so-called business-as-usual scenario). The main virtue of the CGE approach is its comprehensive representation of market interactions through price- and income-responsive supply and demand reactions. Beyond price-induced structural change in production and consumption, CGE models can quantify efficiency implications and distributional impacts of policy measures.

As to the representation of international trade, which is central to our assessment of leakage and competitiveness impacts, all but one model in the comparison adopt the Armington assumption of product heterogeneity (Armington 1969) for all traded goods. Changes in trade are explained through relative cost changes between countries – in our case triggered by unilateral emission regulation. One model incorporates more recent findings in trade theory (Melitz 2003) to explain trade pattern through productivity differences across heterogeneous firms. The intra-industry reallocations of market shares and productive resources between heterogeneous firms add to effects associated with inter-industry reallocations that are driven by comparative advantage. As to data, all models make use of the GTAP (Global Trade, Assistance, and Production) 7.1 database, which includes detailed national input-output tables on production and consumption together with bilateral trade flows and CO_2 emissions for up to 112 regions and 57 sectors in the year 2004 (Narayanan and Walmsley 2008).

Our overview proceeds as follows. Sector 2 lays out the study design. Section 3 discusses the key findings of the twelve models included in the comparison. Section 4 concludes.

2. Study design

The primary objective of our model comparison is to investigate the economic impacts of BCA as a complementary instrument to domestic climate policy. The economic rationale for BCA is to counteract efficiency losses of unilateral abatement that emerge from international feedback effects.

Without international market responses, unilateral abatement would not be hampered on environmental grounds – domestic abatement would translate one-on-one to global emission reduction. In this case, efficient unilateral contribution to the global public good boils down to uniform emission pricing across all sources of the domestic economy (assuming that there are no other initial distortions), which can be implemented through a common emission tax or a cap-and-trade system. In our study, such uniform emission pricing constitutes the reference unilateral climate policy design (scenario label *ref*) against which we compare the imposition of additional BCA (scenario label *bca*). If unilateral reduction covers several sovereign countries within an abatement coalition, we assume identical emission reduction targets (relative to the respective business-as-usual emission levels) that can be traded across all members of the abatement coalition.

Accounting for international feedback effects, BCA qualifies in theory as a second-best instrument that complements uniform domestic emission pricing. Import tariffs should mimic the domestic emission price on the carbon content of all goods that are not regulated in the countries of origin. Likewise, payments for emissions embodied in exports to non-regulated countries should be rebated. In policy practice, however, such a comprehensive BCA system appears rather unrealistic – desirability and feasibility of BCA depend on legal, practical and political considerations that must be balanced against the theoretical potential for efficiency gains.

The policy-relevant design of BCA requires concretization along several dimensions, which apply as the default for the central case simulations of our model comparison:

- Sector coverage: We limit the application of BCA to EITE industries that are considered as most vulnerable to leakage through the competitiveness channel.
- Embodied carbon coverage: As to the accounting of emissions embodied in the production of imported goods, we only consider direct emissions from the combustion of fossil fuels and indirect emissions associated with the generation of electricity. Multi-region input-output calculations based on empirical data suggest that indirect emissions from electricity cover the bulk of total indirect emissions (Böhringer, Carbone and Rutherford 2011).[1]
- Tariff rate differentiation: We take carbon flow information provided by GTAP to determine country- and sector-specific carbon coefficients.
- Inclusion of export rebates: True destination-based carbon pricing calls for rebates, i.e., exports from regulating countries are relieved of the burden of the carbon payments associated with their production. Export rebates contribute to the cost-effectiveness of BCA since they avoid leakage from losing market shares in foreign markets. On the other hand, export rebates may constitute a subsidy under the WTO's Agreement on Subsidies and Countervailing Measures (Cosbey et al 2012). To assess the full efficiency potential of BCA, our central case simulations refer to full border adjustment, i.e., the combination of import tariffs and export rebates. In the sensitivity analysis, we investigate how important the inclusion of export rebates is as we compare full BCA with the case of import tariffs only.
- Use of revenues from import adjustments: By default, we assume that revenues from BCA tariffs are directed to the general revenues of the collecting (abating) country. Another policy-relevant option, which directly affects the distributional impacts of BCA, is to hand back import tariffs to the exporting country – we consider this variant in our sensitivity analysis.

[1] Note that the carbon metric in our central case simulations neither includes process-based CO_2 emissions nor other non-CO_2 greenhouse gases.

Emission leakage and thus the relative importance of BCA as a complementary anti-leakage measure hinges crucially on the size of the abatement coalition and the coalition's emission reduction target. All else being equal, leakage will be the more pronounced the smaller the coalition size and the higher the emission reduction target. For our central case simulations, we assume that industrialized countries as listed in Annex 1 of the Kyoto Protocol[2] –including the United States of America but without the Russian Federation[3] – take a lead in unilateral climate action. This abatement coalition (subsequently referred to as A1xR) agrees on a collective 20 % emission reduction from its historical emission level in 2004, which constitutes the base year of the GTAP7.1 dataset; the collective target is spread equally (in relative terms of 20 %) across all members of the abatement coalition.

The magnitude of the reduction target roughly reflects post-Kyoto reduction pledges of Annex 1 countries based on national communications following the 15th Conference of Parties (to the United Nations Framework Convention on Climate Change – UNFCCC) at Copenhagen in 2009. The reduction pledges are given for most Annex 1 countries with respect to historical emission levels in 1990 or 2005 but apply to 2020. As a consequence, the business-as-usual development for emissions will determine the effective emission reduction requirements. The higher the future business-as-usual emission levels, the more stringent are the effective reduction targets and thus the potential cost of climate policy. Given larger uncertainties in business-as-usual projections – not at least as a consequence of the global economic turmoil since 2008 – we decided to use the 2004 (data) base year also as the target year for emission abatement. While this assumption at first glance might lack policy appeal, it strengthens the coherence of the model comparison, since there is no need for model re-parameterization to controversial business-as-usual projections of macroeconomic growth and structural changes.

Using the same empirical data across all the models, we can focus on microeconomic cause-effect chains of emission regulation without overlapping "noise" from business-as-usual calibrations to future – rather hypothetical – data. The business-as-usual scenario (thereafter labeled *bau*) against which we measure the impacts of unilateral climate policies (*ref* and *bca*) in our central case simulations is therefore the historical economic situation in 2004. On the other hand, we acknowledge the policy interest in economic impact assessment of regulation that applies to future years and therefore investigate in the sensitivity analysis the implications of a shift in the target year to 2020.[4] Another dimension of our sensitivity analysis is to check the robustness of results with respect to changes in the coalition size.

[2] See http://unfccc.int/parties_and_observers/parties/annex_i/items/2774.php

[3] The reason to exclude Russia is that larger fuel exporting countries are rather opposed to climate policies since they fear substantial losses in their export revenues.

[4] The study provided information sources for official baseline projections such as the International Energy Outlook, but there had been no binding provisions on the business-as-usual in 2020.

In order to ensure a coherent comparison, all models in the study adopt a minimum level of sectoral and regional disaggregation which reflects the specific requirements of BCA assessment and the empirical data provided by the GTAP database. The harmonized composite dataset includes all major primary and secondary energy carriers: coal, crude oil, natural gas, refined oil products, and electricity. This disaggregation is essential in order to distinguish energy goods by CO_2 intensity and the degree of substitutability. In addition, all EITE sectors of the GTAP database are accounted for: chemical products, non-metallic minerals, iron and steel products, and non-ferrous metals. These four sectors, together with oil refineries, are most vulnerable to unilateral emission constraints and therefore are prime candidates for protective BCA; in the remainder of the study we refer to the composite of the five energy-intensive and trade-exposed sectors as EITE industries. Regarding regional coverage, the composite dataset includes all major industrialized and developing countries in order to adequately capture international market responses to unilateral emission regulation. Table 2 summarizes the minimum set of explicit sectors (commodities) and regions that are included across all models participating in the comparison.

Table 2. Sectors and regions explicitly included in the model comparison

Sectors and commodities	*Countries and regions*
Energy goods	*Annex 1 (industrialized) regions*
Coal	Europe – EU-27 plus EFTA**
Crude oil	USA – United States of America **
Natural gas	Russia
Refined oil products*	Remaining Annex 1 (RA1)**
Electricity	
	Non-Annex 1 regions
Non-energy goods	China
Chemical products*	India
Non-metallic minerals*	Energy exporting countries excl. Mexico (EEX)
Iron and steel industry*	Other middle income countries (MIC)
Non-ferrous metals*	Other low income countries (LIC)
Transport	
All other goods	

*Included in the composite of *energy-intensive and trade-exposed* (EITE) industries **Included in the composite region A1xR

Given the uncertainty of external cost estimates for carbon emissions, the consistent comparison of alternative unilateral climate policy designs implies a cost-effectiveness approach where we keep global emissions constant. In other words: Without quantification of emission damages, welfare comparisons only make sense between scenarios with identical global emission levels where the gross benefit of abatement across all regions is the same. For all policy simulations, the global emission constraint is set to achieve an effective emission reduction equal to the 20 % emission pledge of the abatement coalition. The global emission constraint requires that the initial emission cap of the abating coalition is scaled endogenously to compensate for emission leakage (note that the scaling already applies to the reference scenario without BCA). In this framework, leakage reduction through BCA implies that unilaterally-abating regions must cut back domestic emissions to a lesser extent than in the reference scenario in order to meet the global emission constraint.

Table 3 summarizes the key design elements for the central-case simulations of the model comparison.

Table 3. Basic features of unilateral climate policy design

Size of the abatement coalition	A1xR – all Annex 1 regions (including the USA but without Russia)
Unilateral emission reduction pledge	20 % from historical 2004 emission levels of the abatement coalition
Default unilateral climate policy (*ref*)	Each abating region adopts a uniform 20 % target that can be traded across abating regions.
Imposition of complementary BCA (*bca*)	- Import tariffs plus export rebates - Sector coverage: EITE industries - Embodied carbon coverage: direct emissions plus indirect emission from electricity - Import tariffs accrue to importing regions
Constant global emission constraint	*bau* emissions of non-coalition countries plus 80 % (= 100%-20%) of coalition countries' historical emissions in 2004

3. Results

Economic impacts of regulatory policies (*ref* and *bca*) are reported with respect to the business-as-usual where no explicit climate policy applies. Thus, we can not only quantify how complementary BCA changes the outcome of the reference climate policy but we also obtain policy-relevant information on the overall adjustment cost of emission regulation compared to the business-as-usual situation without climate policy (*bau*). As a matter of fact, the international policy debate is dominated by the issue of burden sharing, given the short-term nature of abatement cost and the long-term nature of (more uncertain) benefits from emission reduction.[5] Note that the business-as-usual benchmark helps to figure out how important the implications of additional BCA are with respect to overall economic adjustment triggered by emission constraints.

The multi-sector, multi-region structure of CGE models allows for detailed impact analysis at the level of individual sectors and regions. However, our primary interest is on how BCA affect global efficiency of unilateral climate policy: the incidence on the average abating region versus the average non-abating region, as well as the implications for the average EITE industry. We define two additional composite regions: "coa", the aggregate of coalition regions with unilateral emission

[5] Abstracting from benefits of emission abatement in our analysis, gross welfare changes from business-as-usual can serve at least as a lower bound estimate for the benefits of emission abatement that would justify abatement action from the perspective of a more comprehensive cost-benefit analysis.

regulation, and “ncoa”, the aggregate of non-coalition regions without emission regulation. These labels will show up in the graphical and tabular results presentations below. Beyond the explicit reference to model-specific results using the model acronyms as defined in Table 1, we provide mean results (labeled “mean”) across all models. As the default, we order simulation results by ascending order of the reference scenario’s (*ref*) impacts.

3.1. Leakage rates, CO_2 emissions, CO_2 prices, and EITE output effects

Fig. 1 shows the impacts of unilateral climate policy on leakage rates as a key environmental indicator of international feedback effects.

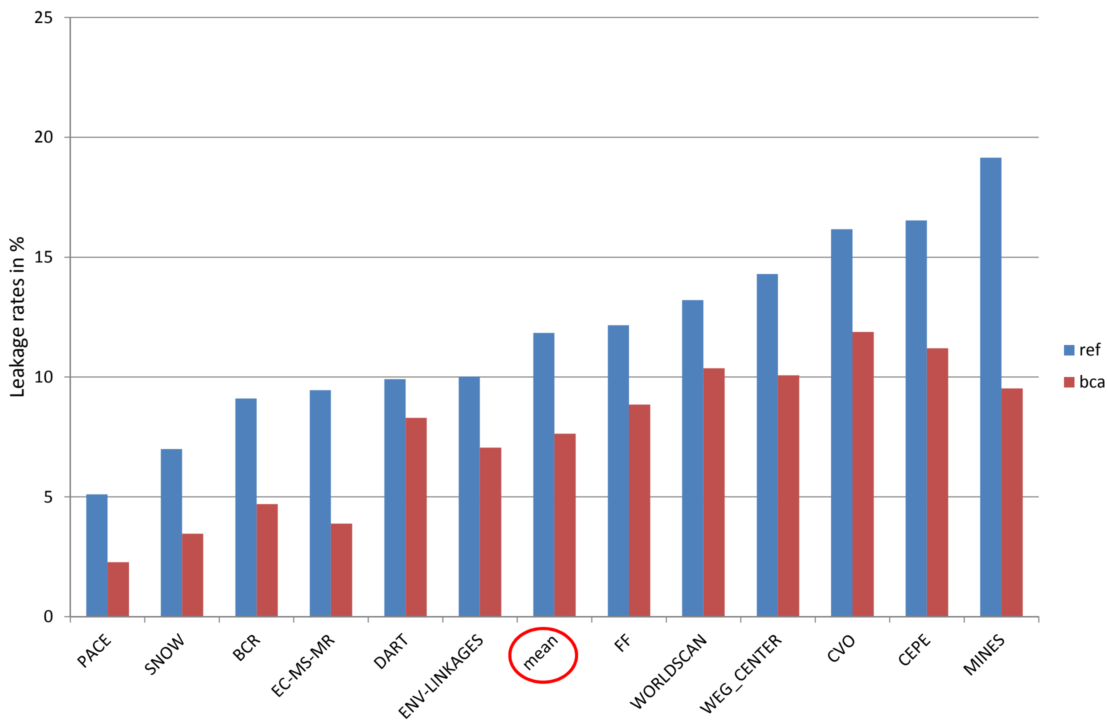

Fig. 1 Leakage rates (in %)

The leakage rate is defined as the change in foreign (non-coalition) emissions over domestic (coalition) emission reduction. A leakage rate of 50 %, for instance, means that half of the domestic emission reduction is offset by increases in emissions abroad. The higher the leakage rate in the reference scenario with uniform emission pricing only, the more important becomes complementary BCA to reduce leakage under global cost-effectiveness considerations.

In the reference scenario, leakage rates range between 5-19 % with a mean value across all models of 12 %. Given that the size of the abatement coalition and its reduction target have been harmonized across all models, differences in leakage rates can be primarily traced back to model-specific assumptions on the degree of fossil fuel supply responses and the heterogeneity in traded goods. Heterogeneity of traded goods is captured through the choice of Armington elasticities that determine the ease of substitution between domestic goods and imported (exported) goods of the same variety. The higher the Armington elasticities, the stronger is leakage through the competitiveness channel as regions can more easily substitute new sources for EITE goods in response to the changes induced by the climate policy regime. Supply responses of fossil fuel producers are captured through fossil fuel supply elasticities. The lower these supply elasticities are, the higher is leakage through the fossil fuel channel as the decreased demand for fossil fuels in abating regions produces larger reductions in the price of these goods on world markets.

BCA is effective in reducing leakage. Leakage rates under BCA range between 2 % and 12 % with a mean value of 8 %. Thus, the carbon-based import tariffs and export rebates to EITE products reduce the leakage rate on average by a third compared to the reference scenario with uniform emission pricing only.

The leakage-reduction effect of BCA directly shows up in the aggregate emission reduction requirements for the composite of abating and non-abating regions (cf. Fig.2). Under BCA the abatement coalition can scale down its domestic emission requirement to achieve the given global emission reduction target.[6] On global cost-effectiveness grounds, BCA helps to re-allocate emissions between the abating and non-abating countries in the “right” (cost-saving) direction. Yet, it should be clear that BCA is only a blunt second-best instrument as overall emissions in non-abating countries are still above the *bau* level and far off from a first-best outcome that would be achieved through a global cap-and-trade system.

[6] Drawing on the GTAP data for 2004, the 20 % emission reduction pledge of the A1xR abatement coalition corresponds to a 9.5 % reduction of global emissions, which equally applies to the *ref* and *bca* scenarios.

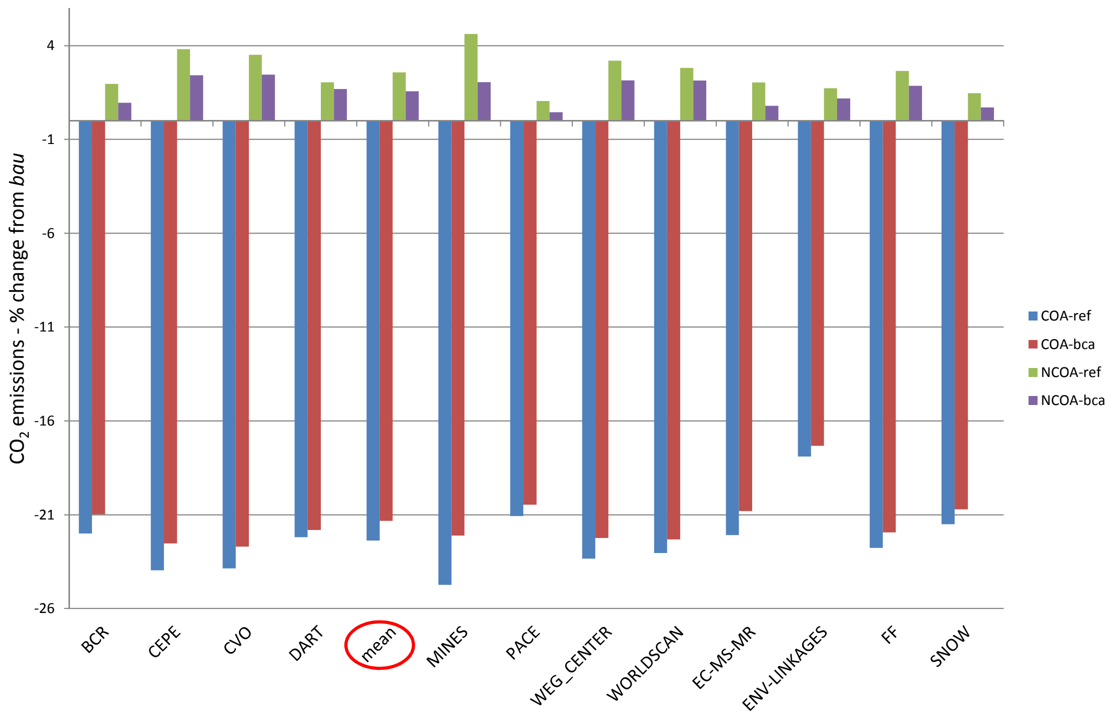

Fig. 2 CO_2 emissions in abating (COA) and non-abating regions (NCOA) – % change from *bau*

Marginal abatement cost in coalition countries for the reference scenario reveal a substantial spread across the different models ranging from 15 to 64 USD per ton of CO_2 with an average of around 42 USD per ton of CO_2 (cf. Fig.3). The variation is due to differences in the ease of carbon abatement across models. Effectively, there are three canonical options to reduce carbon in production and consumption: fuel switching (such as replacing coal-fired power plants through gas-fired power plants), energy efficiency improvements (such as substituting capital for energy in more energy-efficient air conditioning) or scale reduction in the production and consumption of energy-intensive goods. In an open economy, substitution can also take place through shifting to EITE products from unregulated countries (resulting in positive leakage if competing goods from abroad are more emission-intensive).

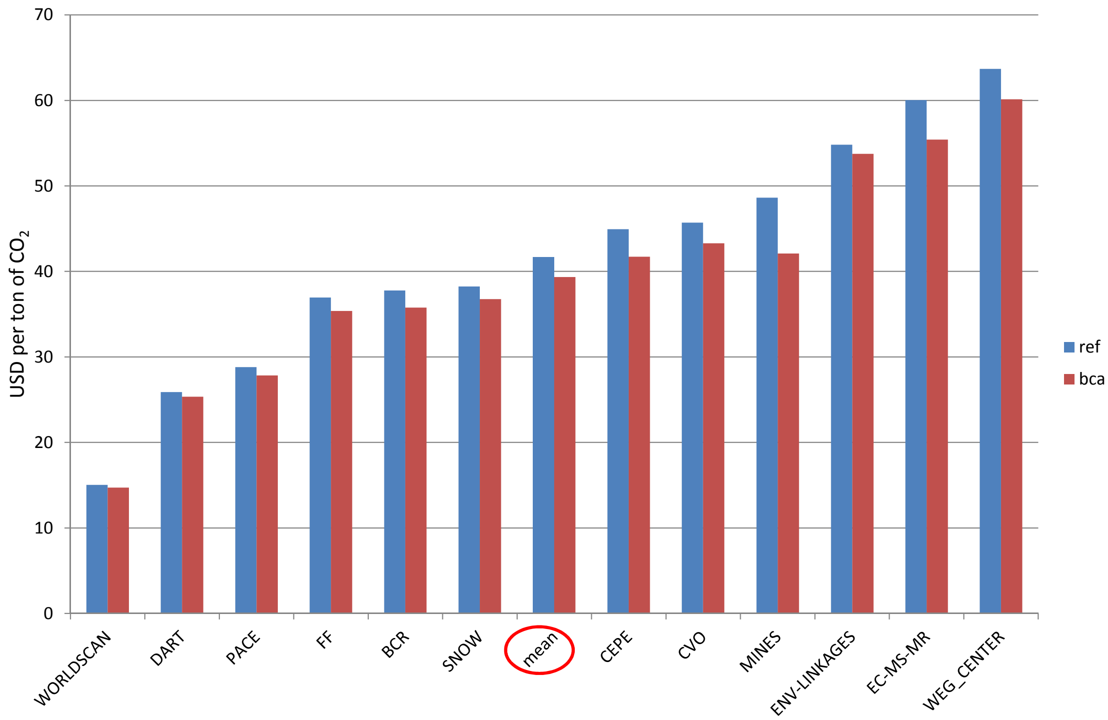

Fig. 3 CO_2 prices (USD per ton of CO_2)

All these abatement options are typically explicit in bottom-up representations of marginal abatement cost curves but implicit in top-down models based on continuous functional forms to characterize technologies on the production side and preferences on the consumption side through nested separable constant-elasticity-of-substitution (CES) cost and expenditure functions. The nesting of different inputs and the ease of cross-price substitution as captured through CES elasticities should reflect empirical evidence, but there is a broader range of sector- and region-specific empirical estimates that qualify for model parameterization. All else being equal, lower CO_2 prices in our comparative study indicate that the respective models postulate cheaper carbon abatement options, i.e., a flatter marginal abatement cost curve.

The implementation of BCA slightly reduces the marginal abatement cost compared to the *ref* scenario as the effective reduction requirement for abating countries is lower. Again, it becomes clear that BCA is only a weak instrument to improve on the global inefficiency of unilateral action. Marginal abatement cost in unregulated countries are still zero – tariffs applied to the sector-average of embodied carbon are far off from working as effective pricing of emission inputs in non-abating countries.

Competitiveness concerns of regulated EITE industries are central to the policy debate on unilateral climate policies. Unilateral emission pricing of industries where emission-intensive inputs represent a substantial share of direct and indirect cost puts these sectors at a disadvantage with international competitors. For the reference scenario, all models indicate output losses of EITE industries in the abating regions whereas EITE industries in non-abating countries increase production beyond *bau* levels (see Fig.4).[7] BCA levels the playing field in international trade of EITE commodities – the loss of EITE production in abating countries falls on average from 2.8 % to roughly 1 %; BCA thus constitutes an effective instrument for maintaining competitiveness of EITE industries.

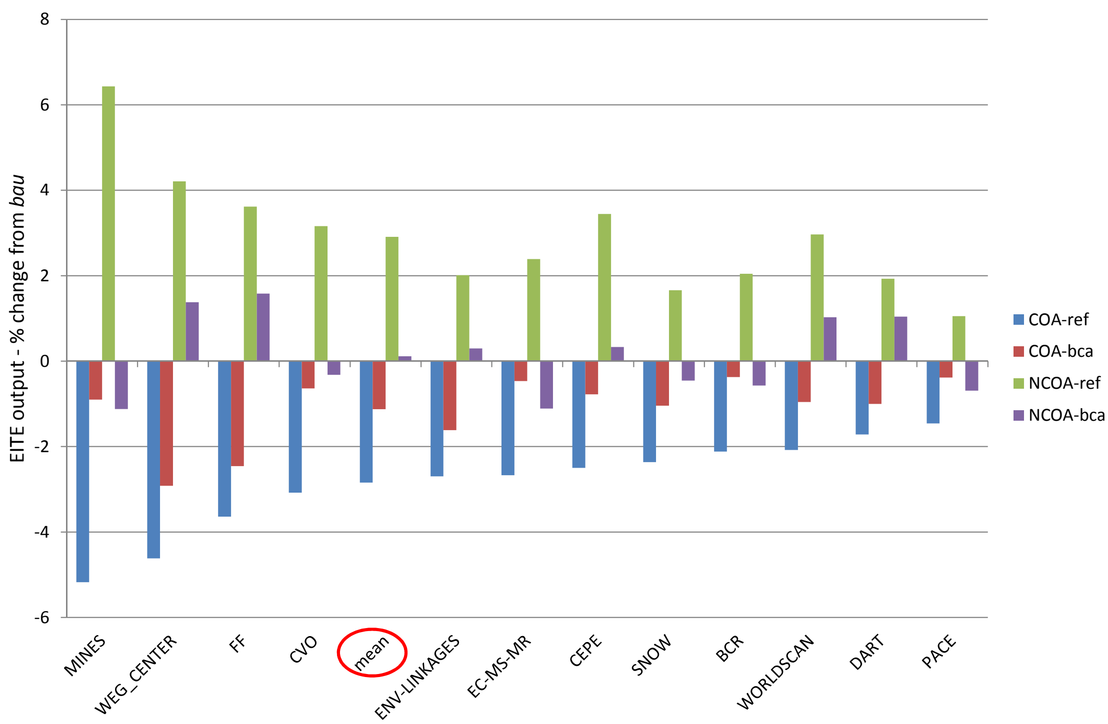

Fig. 4 Output of EITE industries in coalition and non-coalition countries (% change from *bau*)

3.2. GDP impacts – efficiency and incidence

Fig. 5 reports macroeconomic impacts in terms of global changes in the gross domestic product (GDP). The key message is that adjustment to achieve a global emission reduction by roughly 10 % through unilateral abatement action of A1xR countries cause relatively moderate GDP losses that range between 0.13 % - 0.63 % with a mean value of 0.35 %.

The second message is that BCA improves on global cost-effectiveness of unilateral action but the cost savings vis-à-vis the reference policy are quite small.[8]

[7] The competitiveness effects of unilateral action for EITE industries are most pronounced in the MINES model that accounts for firm heterogeneity and endogenous productivity shifts.

[8] A more precise metric for efficiency (welfare) losses would be the so-called Hicksian equivalent variation (HEV) in income denoting the amount of money that is necessary to add to or deduct from the benchmark income of consumers so that they enjoy a utility level equal to the one in the counterfactual policy scenario (on the basis of ex-ante relative prices). Provided at the global level, efficiency losses are then reported as changes in money-metric utility from a utilitarian welfare perspective, i.e., being agnostic on cost distribution. All model simulations reported adjustment cost also in terms of HEV, but we decided to stick to GDP as a more common,

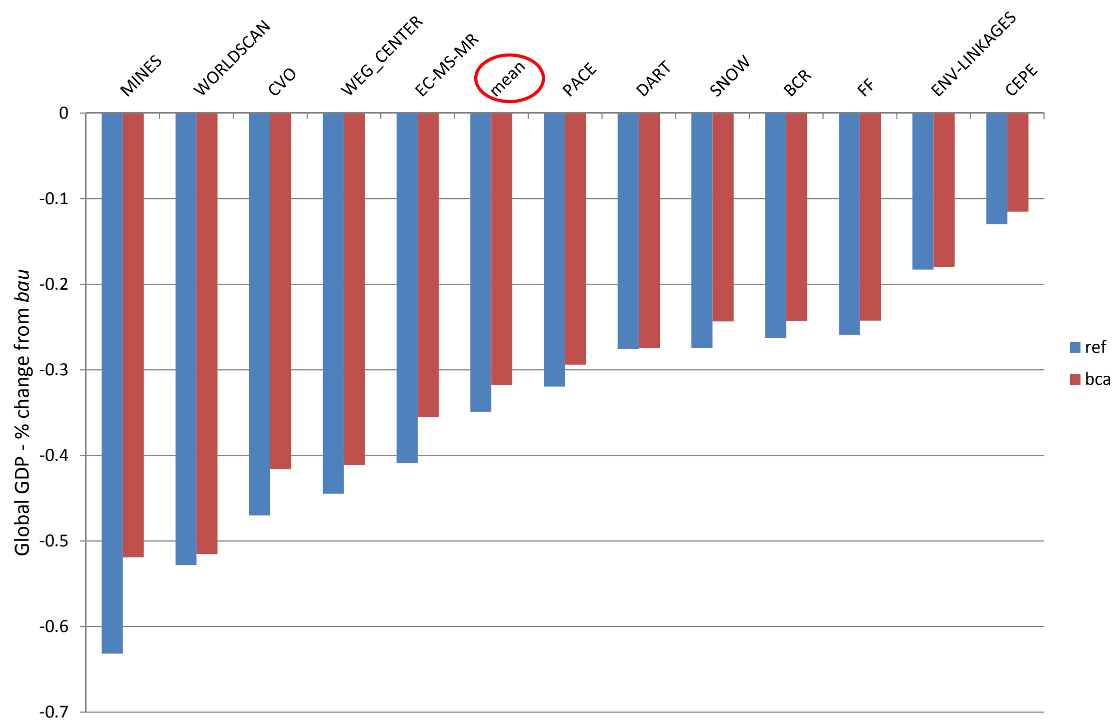

Fig. 5 Global GDP impacts (% change from *bau*)

Compared to the global GDP loss in the reference scenario the BCA cost savings range from close to zero to 18 % with a mean value of 7.7 %. The small potential for efficiency gains from BCA can be traced back to the fact that import tariffs applied to the industry-average of embodied carbon do not incentivize polluters in unregulated countries to adopt less emission-intensive production techniques.[9]

Figure 6 gives insights into potential distributional pitfalls of BCA. Starting from the reference scenario with uniform emission pricing only, we see that unilateral climate policy on average imposes a substantial burden to non-abating countries. The reasoning behind is that non-abating countries suffer from a deterioration of their terms of trade, i.e., the ratio of export prices to import prices. The terms-of-trade losses for the non-abating countries get more pronounced under BCA, while abating countries inversely enjoy terms-of-trade gains. Obviously, industrialized countries that are net importers of embodied carbon from the developing world can enact carbon-motivated EITE tariffs to exert market power and change the terms of trade to their favor. The re-distributive impacts of BCA are drastic: While the burden sharing ratio measured in percentage GDP loss for the coalition over the percentage GDP loss for the non-coalition amounts to about 3:1 in the reference scenario, it goes down

policy-relevant cost metric. Note that in our central case simulations, the economic impacts reported in terms of HEV are very close to those reported in terms of GDP.

[9] Exporters in unregulated countries can to some extent also re-route their products from countries that levy carbon tariffs to unregulated markets.

to 1:1 for the case of BCA. The model-specific results show substantial variation on the extent of the burden shifting impact of BCA but qualitatively all models are in line.

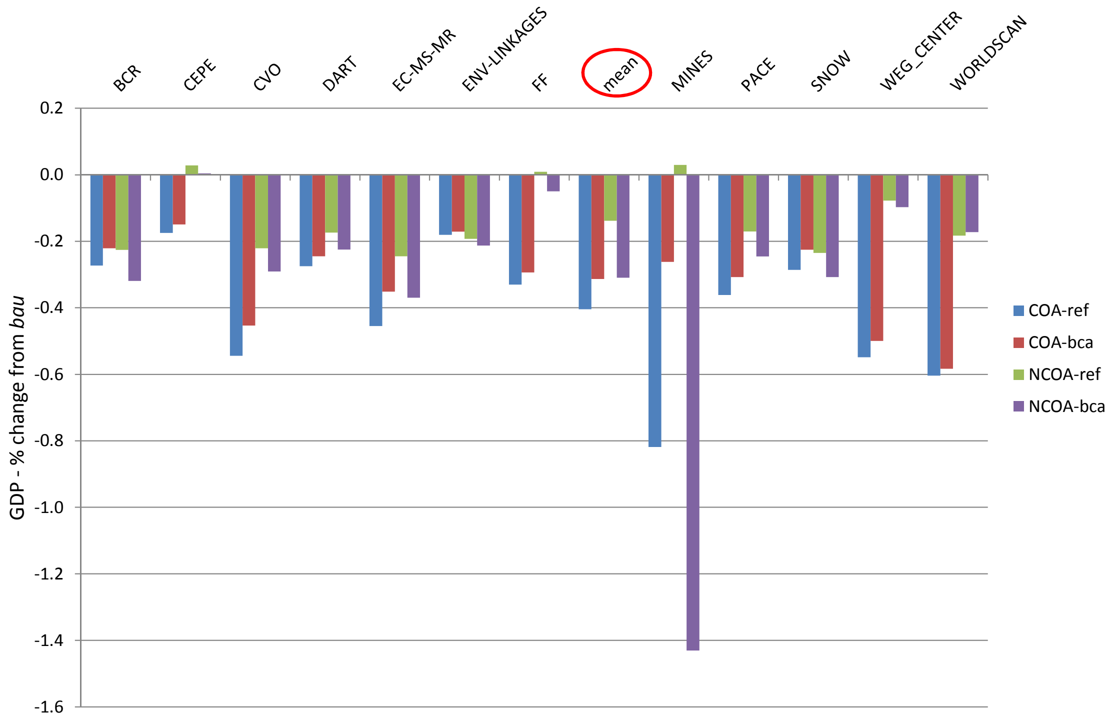

Fig. 6 Burden shifting – GDP impacts for coalition and non-coalition (in % change from *bau*)

Deviating from the mean result in qualitative terms, a few models indicate that non-abating regions on average could benefit from the reference scenario with uniform unilateral emission pricing only. This finding echoes conventional wisdom on shifts in comparative advantage (particularly in EITE industries) due to unilateral regulation – at the macroeconomic level, however, most models suggest that non-abating countries in the end will suffer from reduced economic activity in abating countries and terms-of-trade changes.

Fig. 7 provides more detailed insights into region-specific adjustment cost triggered by unilateral action. For the sake of transparency, we restrict our exposition of results to the mean value across models. It is well known in the CGE literature that domestic policies affect international prices (the terms of trade), which can substantially alter the economic implications of the primary domestic policy (Böhringer and Rutherford 2002). As with leakage, it is useful to distinguish spillovers from fossil fuel markets on the one hand and from non-energy markets on the other hand. Regarding spillovers on fossil fuel markets, cutbacks in international fuel demand of large open economies depress international fuel prices, which in turn reduces the energy bill of fuel importers and revenues for fuel exporters. As to spillovers on non-energy markets, abating countries may be able to pass on part of additional production cost to other countries due to product heterogeneity of traded goods.

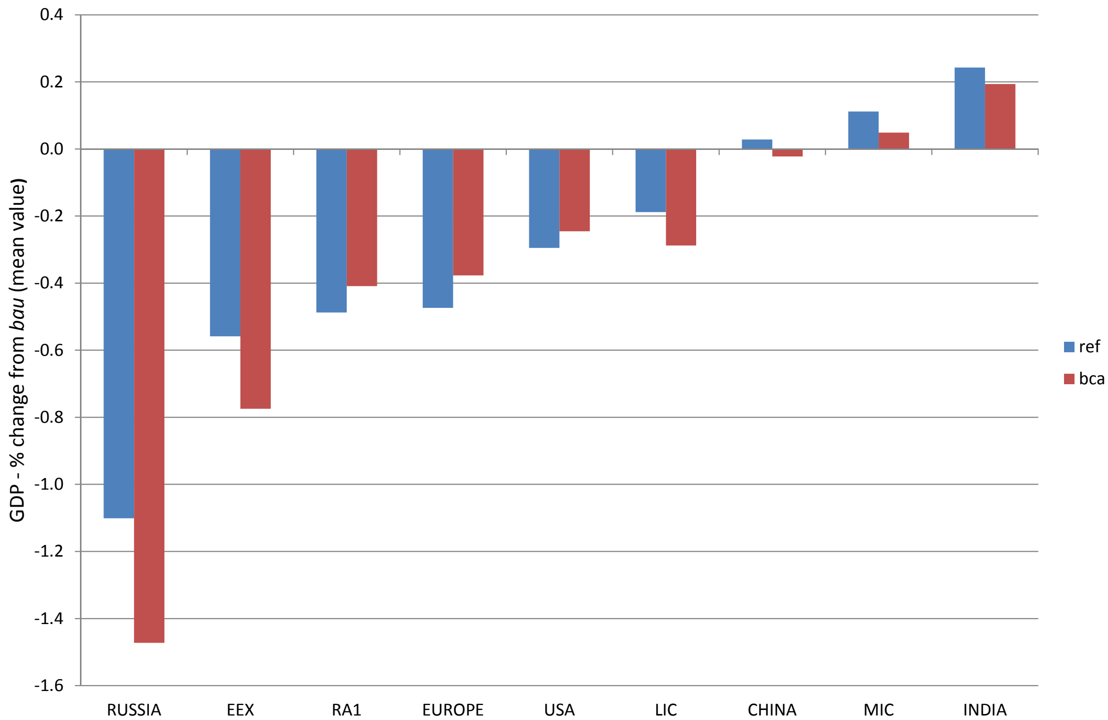

Fig. 7 GDP impacts at single-country level (% change from *bau*)
RA1 – rest of Annex I; EEX – energy exporting countries excl. Mexico; LIC/MIC – low/middle income countries

In our reference scenario, fuel exporting regions – here: Russia and other energy exporting countries (EEX) – are most adversely affected even if they abstain from domestic emission regulation themselves; the primary reason is the decline in fossil fuel prices. On the other hand, countries that are net importers of fossil fuels and do not commit themselves to stringent emission constraints can benefit from unilateral climate policy initiatives (here: India). Terms-of-trade effect on EITE markets are most evident for the case of BCA where all non-abating countries subjected to import tariffs are worse off than without BCA while all the abating countries do better.

3.3. Sensitivity analysis

The previous section discussed our central case simulation results which reflect a specific set of assumptions on unilateral climate policy settings: industrialized countries (including the USA but without Russia) go ahead with stringent coordinated emission regulation and consider the imposition of BCA as a means to deter leakage and preserve competitiveness of EITE industries; BCA includes EITE tariffs on embodied carbon (covering fuel-based direct emissions plus indirect emissions from electricity inputs) joint with rebates of carbon payments to EITE exports; revenues from import tariffs accrue to the importing (abating) country.

To test the robustness of our common findings, we perform sensitivity analysis with respect to important uncertainties in the design of unilateral climate policies: (i) the use of revenues from import tariffs, (ii) the omission of export rebates, (iii) the size of the abatement coalition, (iv) the target year to which emission reduction pledges apply (i.e. the effective reduction requirements), and (v) the supply responses of fossil fuel producers. In the result exposition below, we focus on the mean value across models' estimates.

Figure 8 shows how the incidence of BCA changes as import tariffs are not retained by importing countries but handed back to the exporting regions.[10] This setting would be equivalent to voluntary export restraints on behalf of exporting regions without emission regulation.

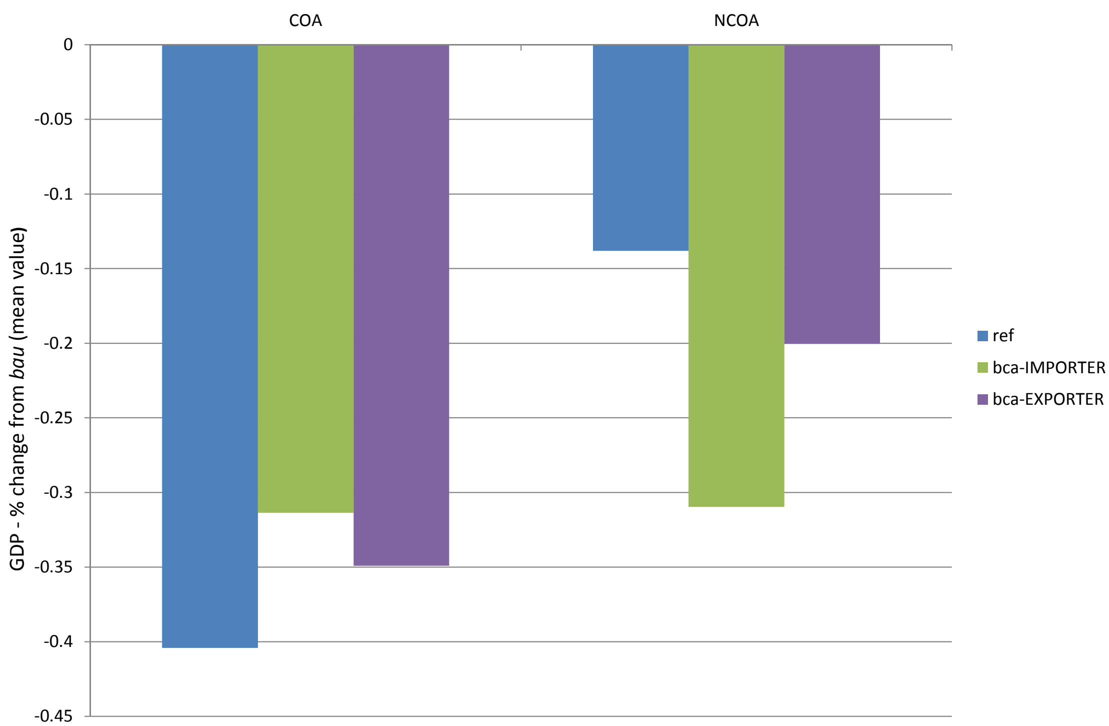

Fig. 8. Global economic impacts (in % GDP change from *bau*) for alternative uses of tariff revenues
IMPORTER: abating countries (COA) get tariff revenues; EXPORTER: non-abating countries (NCOA) get revenues

As tariff revenues are retained by exporters, the re-distributional effects of BCA vis-à-vis the reference scenario can be markedly reduced – however, the alternative use of revenues cannot fully offset the adverse terms-of-trade effects induced by BCA for the average developing country outside the abatement coalition.

Given the unclear legal status of export rebates, many policy proposals on BCA focus on import tariffs only. We find that border tariffs only have very similar efficiency and equity impacts as full BCA. The main reason is that the abatement coalitions under consideration are large net importers of embodied carbon, such that export rebates play a secondary role. The global efficiency gains of BCA are slightly lower, since leakage through the competitiveness channel is higher without rebates to EITE exports. On the other hand, the sole imposition of tariffs slightly enforces the distributional

[10] While direct money transfers may appear as unrealistic, there are at least proposals for the use of these revenues to subsidize clean technology transfer or to feed into (inter-)national funds for climate change mitigation and/or adaptation.

pitfalls of BCA, since additional rebates lower EITE export prices and thus ameliorate the adverse terms-of-trade effects for EITE-importing regions outside the coalition.

Table 4 summarizes how leakage in the reference scenario and global cost savings through BCA change as a function of the regional coverage of the abatement coalition. We consider three alternative sizes of the abatement coalition: EUR (EU plus EFTA), then our default coalition size A1xR (i.e., Annex 1 regions with USA but without Russia), and finally A1xR_CHN adds China. As the coalition size increases, leakage becomes less of a problem. The mean leakage rate drops from 23.9 % in the case of EUR to 11.8 % for A1xR, and to 6.7 % for the largest coalition size A1xR_CHN. In relative terms, the cost savings through BCA drop markedly from 14.7 % to 7.7 % and 3.1 %, respectively. It should be kept in mind, though, that the cost base to which the percentage numbers apply increase with the coalition size.

Table 4. Leakage in *ref* and *bca* cost savings as a function of the coalition size

Coalition size	EUR	A1xR	A1xR_CHN
Leakage in scenario *ref* (%)	23.9	11.8	6.7
Global cost savings in *bca* (% from *ref*)	14.7	7.7	3.1

For the central case simulations, the target year of compliance with unilateral emission reduction pledges is set to the base year of the models' parameterization (here: 2004 as provided by GTAP7.1). The upside of this choice is that our economic impact analysis applies to empirical data that is common across all models. The downside is a certain lack of policy appeal, since actual policy pledges of industrialized countries (as communicated in the Copenhagen Accords) mostly apply to the target year 2020 or even later. Impact analysis for a future target year, however, requires assumptions about how the global and regional economies will evolve, which will suffer from huge uncertainties not only at the macroeconomic level but in particular with respect to structural change (e.g., the role of EITE industries in a decade from now).

For the sensitivity analysis on the target year 2020, model teams were free to pick their preferred business-as-usual. This degree of freedom implies larger differences on the business-as-usual in 2020 across models, owing to alternative exogenous assumptions and alternative baseline calibration techniques for important trends such as the evolution of energy efficiency. At the aggregate level, the commonly shared assumption is that global economic growth goes along with a substantial increase in global carbon emissions. If this trend also applies to the countries of the abatement coalition, emission pledges that are stated with respect to 2004 emissions translate into higher effective targets when expressed as percentage reduction requirement with respect to the business-as-usual emission level in the target year 2020.[11]

Table 5 reports the implications of the change in the target year from 2004 to 2020 for the A1xR_CHN coalition, that is China plus all industrialized A1 countries (with the USA but without Russia). The 20 % reduction pledge with respect to 2004 implies a leakage-adjusted emission cut of 21.3 % for the A1xR_CHN abatement coalition in 2004, which goes up drastically to an emission cut of 41.2 % in 2020. The increase in the effective emission reduction target is mirrored in the sharp increase of CO_2 prices – as we move further out on the marginal abatement cost curves, cheaper abatement options are exhausted and the economy must revert to increasingly expensive adjustments in production and consumption. Likewise, the global economic adjustment cost rises substantially, and the leakage rate for the reference climate policy without BCA goes up. On the other hand, our sensitivity analysis indicates that the global cost savings from BCA remain small.

Table 5. Implications of alternative target years for compliance (coalition: A1xR_CHN)

Target year	2004	2020
CO_2 reduction in coalition COA (% from *bau*)	-21.3	-41.2
Global CO_2 reduction (% from *bau*)	-13.1	-23.1
CO_2 price in *ref* scenario (USD per ton of CO_2)	26.2	104.9
Leakage in *ref* scenario (%)	6.7	10.3
Global GDP in *ref* scenario (% from *bau*)	-0.3	-0.9
Global cost savings through *bca* (% from *ref*)	3.1	2.9

At the single country level, the combination of changes in the target year and coverage of the abatement coalition can have dramatic implications. Figure 9 provides an illustration for the case of China. As China enters the abatement coalition in 2004 it faces substantial economic adjustment cost, but the latter goes up dramatically if China's 2004 reduction pledge is applied to the target year 2020. The reason is the sharp projected increase of business-as-usual emissions in China.

[11] In this vein, the choice of a future target year is similar to the choice of a more stringent emission reduction, while keeping the target year at the base year. However, when using a future target year, there is an overlay of changes in the structural characteristics of the economy, since a more realistic forward-projection does not follow a steady-state growth path.

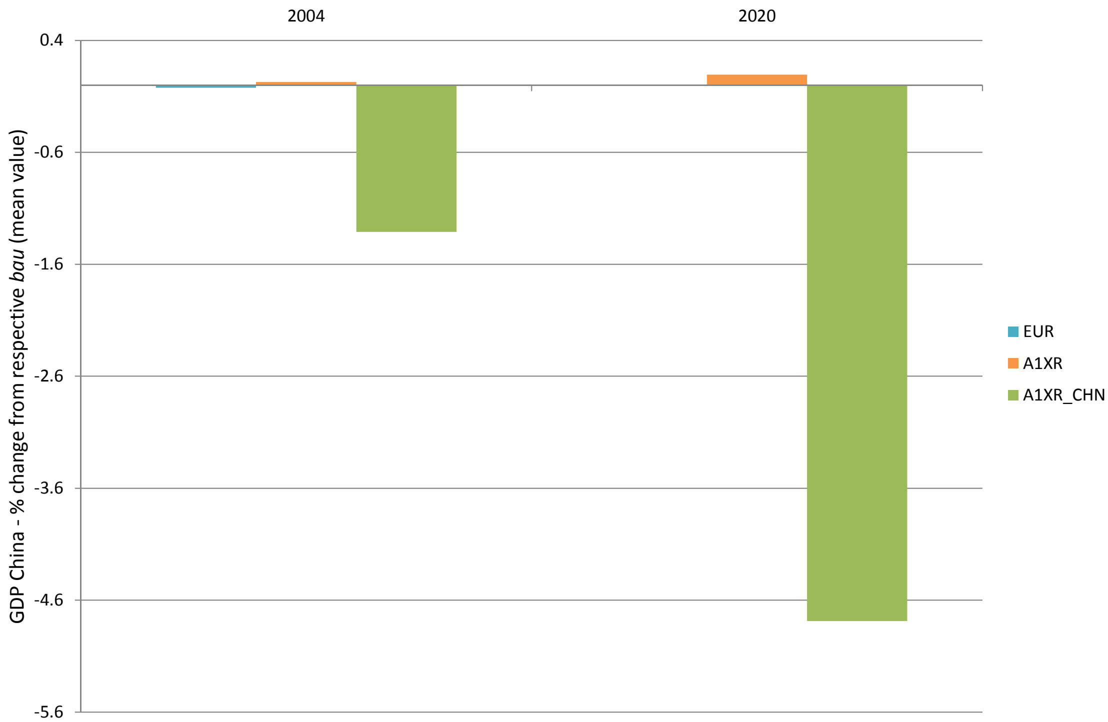

Fig. 9. Cost implications for China for alternative coalition sizes and target years

To investigate the role of fossil fuel market adjustments, the sensitivity analysis comprises additional simulations where fossil fuel producers ration their supply to keep fossil fuel prices at the *bau* level. Table 6 reveals that fossil fuel price changes are a central driver for leakage in our central case simulations.

The leakage rate for the reference scenario without BCA drops from 11.8 % to 2.5 % when fuel producers counteract the depression of fuel prices with supply-side rationing (scenario label *ref_ffp*). The imposition of BCA in the latter case (scenario label *bca_ffp*) can even lead to negative leakage. CO_2 prices in the abatement coalition are lower with fuel rationing, because leakage rates – and thus the domestic emission requirement to meet the exogenous global emission constraint – are smaller. The implications for global cost savings through BCA and the re-distributional impacts between average abating and non-abating regions remain robust. More specifically, fossil fuel price stabilization slightly reduces the cost of non-abating countries at the expense of abating countries, since major fuel exporters are outside the abatement coalition.

Table 6. Implications of fuel producers keeping fuel prices constant

Policy	*ref*	*ref_ffp*	*bca*	*bca_ffp*
Leakage (%)	11.8	2.5	7.6	-3.4
CO_2 price (USD per ton of CO_2)	41.7	33.4	39.4	30.6
Global GDP (% from *bau*)	-0.35	-0.35	-0.32	-0.33
GDP of coalition COA (% from *bau*)	-0.40	-0.38	-0.31	-0.31
GDP of non-coalition NCOA (% from *bau*)	-0.14	-0.23	-0.31	-0.38
Global cost savings through *bca* (% from *ref*)			7.7	5.7

4. Conclusions

Given the lack of globally concerted action, individual countries are moving forward with domestic climate policies, taking up responsibility in the battle against climate change. Overall cost-effectiveness of unilateral action to deal with the global emission externalities inherently suffers from the lack of comprehensive "where-flexibility": Emissions should be abated where it is cheapest world-wide, but unilateral action cannot reach out to sovereign jurisdictions without emission regulation in place. Global cost-effectiveness of unilateral emission abatement is further hampered by emission leakage, i.e., the relocation of emissions to parts of the world economy subject to weaker (or no) regulation. There are two main channels for leakage: the fuel price channel, where unregulated countries increase fuel demand as international prices get depressed from energy demand reductions of abating regions; and the competitiveness channel, through shift in comparative advantage of emission-intensive and trade-exposed (EITE) industries. It is in particular this competitiveness channel that justifies concerns in unilaterally abating regions about excessive (inefficient) structural change to the disadvantage of their domestic EITE industries.

In the debate on unilateral climate policy design, border carbon adjustment (BCA) figures prominently as a means to reduce leakage and improve the global cost-effectiveness of achieving global emission reductions through unilateral action. The appeal of BCA is intuitive: Tariffs on embodied carbon of goods imported from unregulated trading partners, joint with rebates of emission payments on exports from domestic sources, level the playing field in international trade while internalizing the cost of climate damage into domestic prices of goods and services.

BCA seems attractive under global efficiency and domestic political economy considerations, but its practical implementation deserves careful examination. Legal and administrative barriers may substantially constrain the scope for efficiency gains through BCA. Another very contentious issue, from a political perspective, is the burden-shifting potential of BCA. Tariffs on embodied carbon could be perceived as a means for back-door trade policy, where industrialized countries exploit international market power at the expense of trading partners in the developing world. Such burden-shifting through BCA is especially problematic in view of the UNFCCC principle of common but differentiated responsibility and respective capabilities.

This study provides quantitative evidence on the efficiency and distributional impacts of BCA. The robust insights that emerge from our model comparison can be summarized as follows:

- BCA can effectively reduce emission leakage through trade in emission-intensive and trade-exposed industries, thereby attenuating adverse impacts for these sectors in unilaterally regulating countries.
- The global cost savings of BCA are small. The main reason is that BCA – when pragmatically applied on the average emission content of industries – does not incentivize emission abatement in firms abroad.
- BCA can have substantial redistributive effects. Carbon tariffs levied by industrialized countries change the terms of trade against the developing world, thereby shifting the burden of emission abatement and exacerbating existing income inequalities.
- The inclusion of rebates in BCA is of secondary importance for efficiency and distributional effects, since industrialized countries are major net importers of embodied carbon.
- The attribution of tariff revenues to exporting countries can substantially reduce the adverse distributional impacts of BCA.

The ultimate objective of our model comparison is to put decision makers on an informed basis with respect to the benefits and costs of BCA as a complementary measure to domestic climate policy. While our quantitative analysis can strengthen or weaken qualitative arguments, the economic trade-offs inherent to BCA must be resolved in the end on the basis of domestic political considerations and international trade law.

References

Armington, P.S., 1969. A Theory of Demand for Producers Distinguished by Place of Production. IMF Staff Papers 16(1), 159–78.

Cosbey, A. et al., 2012. A Guide for the Concerned: Guidance on the elaboration and implementation of border carbon adjustment. International Institute for Sustainable Development. Draft version 13, August 2012.

Böhringer, C., Rutherford, T.F., 2002. Carbon Abatement and International Spillovers. *Environmental and Resource Economics*, 22 (3), 391–417; DOI: 10.1023/A:1016032424760.

Böhringer, C., Carbone, J., Rutherford, T.F., 2011. Embodied carbon tariffs. NBER working paper, 17376, Cambridge.

Hoel, M., 1991. Global Environmental Problems: The Effects of Unilateral Actions Taken by One Country. *Journal of Environmental Economics and Management*, 20, 55–70; DOI: 10.1016/0095-0696(91)90023-C.

Markusen, J.R., 1975. International Externalities and Optimal Tax Structures. *Journal of International Economics*, 5, 15–29; DOI: 10.1016/0022-1996(75)90025-2.

Melitz, M.J., 2003. The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity. *Econometrica*, 71(6), 1695-1725; http://www.jstor.org/stable/1555536.

Narayanan, B., Walmsley, T.L., 2008. Global Trade, Assistance, and Production: The GTAP 7 Data Base. In: Center for Global Trade Analysis, Purdue University.

Weyant, J.P. (Ed.), 1999. The Costs of the Kyoto Protocol: A Multi-model Evaluation. *The Energy Journal* (Special Issue), 1–390.