Border Carbon Adjustments Revisited

Christoph Böhringer, Carolyn Fischer, Thomas F. Rutherford

Abstract. Increasingly it is the case that countries with greenhouse gas mitigation policies are implementing border carbon adjustments (BCA) that is, charges on the carbon embodied in imports from regions without carbon pricing. Given divergent climate policy ambitions across jurisdictions, BCA to foster destination-based carbon pricing have emerged as a salient policy instrument. Competitiveness concerns for energy-intensive industries subjected to increasing CO_2 prices have sparked a willingness in climate-ambitious countries to adopt BCA which had been viewed too controversial because of their potential to create trade disputes. The quantitative estimates for BCA impacts differ substantially not only with respect to the magnitude of specific effects but even with respect to their direction. This paper investigates how the economic and environmental effects of BCA policies depend on (i) the input-output data characterizing initial heterogeneities of production, consumption and trade patterns across countries, (ii) the policy design of BCA, and, (iii) structural assumptions on economic responses, in particular with respect to international trade mechanisms.

Keywords: border carbon adjustments, computable general equilibrium analysis

1. Introduction

Cost-effective climate action calls for coordinated uniform carbon pricing across jurisdictions worldwide to reduce carbon emissions where abatement is cheapest (Pearce 1991; Weyant 1993). In reality, however, there is no supranational authority which could enforce global emissions pricing. Instead there is a myriad of fragmented sub-global climate policies with considerable asymmetries in emissions pricing across national and subnational jurisdictions (World Bank 2022). The landscape of divergent carbon prices with limited geographical scope offers a conduit for international trade to undermine their effectiveness through carbon leakage – the counterproductive relocation of emissions from regions with stringent regulations to others with more lenient restrictions (Hoel 1991; Bohm 1993; Felder and Rutherford 1993) .

Economists are worried that carbon leakage hampers global cost-effectiveness. Representatives of emissions-intensive and trade-exposed (EITE) industries in carbon pricing jurisdictions point out that leakage results from an undue disadvantage compared to less-regulated competitors abroad. Environmentalists view leakage as an avoidance mechanism—a loophole where consumers in industrialized countries substitute higher-priced domestic products of lower carbon content with cheaper but more carbon-intensive imports.

To address those concerns, countries with a domestic carbon price could implement border carbon adjustments (BCA)—that is, levy a charge on the carbon embodied in imports from regions without carbon pricing and rebate embodied carbon payments on exports to these regions. Combining a domestic carbon price with BCA is similar to the treatment of value-added taxes, which apply only to goods consumed domestically, in that imports are charged with the domestic value-added tax rate while exports are exempt. In both cases, the adjustment has the effect of taxing consumption rather than production.

Given heightened climate ambitions in various jurisdictions, BCA to foster destination-based carbon pricing have emerged as a salient policy instrument. In particular, competitiveness concerns for EITE industries subjected to increasing CO_2 prices have sparked the willingness in climate-ambitious countries to adopt BCA which had been viewed too controversial until recently because of their potential to create trade disputes (Mehling et al. 2022). For example, Canada started in 2020 exploring the feasibility of border adjustment measures.[1] The USA is considering a border adjustment tax on carbon-intensive imports from countries that do not meet their climate obligations.[2] Most advanced is the BCA initiative of the EU – the so-called Carbon Border Adjustment Mechanism (CBAM) – which has been adopted by the European Parliament in 2022.[3] CBAM will require importers into the EU to purchase allowances for carbon emissions embodied in imported products such as cement, aluminum, fertilizer, or iron and steel. The regulation targets direct emissions from the production process (scope1) and indirect emissions from electricity (scope2), while this could be extended to imported indirect emissions for other intermediate inputs (scope3). According to EU legislation, CBAM will enter into force in 2027, following a transitional phase (2023-2026) characterized by data collection only.

While BCA appeal with respect to leakage and competitiveness concerns, it remains highly disputed even if it passes muster with international trade law. BCA provide scope for back-door trade policies since they can work as a substitute for strategic tariffs, shifting economic burden to countries that are subjected to BCA. Such countries might will face a loss in export revenues joint with a loss in the terms of trade to the extent that export prices (net of BCA levies) decrease. While the burden shifting potential of BCA may accommodate strategic leverage to trigger cooperation by non-abating countries, its coercive nature can also backfire and lead to detrimental trade conflicts.

BCA might even more become a political quagmire if their economic impacts burden low-income developing countries and emerging economies. In this case, BCA raise fundamental equity concerns rooted in the United Nation's principle of common but differentiated responsibilities (CBDR) as reflected in the UNFCCC articles 4.8/4.9 and re-affirmed in Article 4(3) of the Paris Agreement. The CBDR principle is at the core of the climate justice debate which recognizes that developing countries who are disproportionately impacted by climate change tend not to be those most responsible for causing it. Climate justice addresses the equitable distribution of responsibilities for the burdens of climate change and the fair sharing of the resources for mitigation and adaptation. Concerns of burden-shifting underpin the strong opposition against BCA on behalf of developing and emerging economies such as India, Brazil, or South Africa.

To date, there is no empirical evidence on the economic and environmental impacts of BCA – simply because BCA have not yet been applied in international policy practice.[4] The impact assessment of BCA hinges on ex-ante simulation analysis – primarily using computable general equilibrium (CGE) models that incorporate interindustry and international economic relations based on observed multi-region input-output data.

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[1] https://budget.gc.ca/fes-eea/2020/report-rapport/FES-EEA-eng.pdf

[2] https://joebiden.com/climate-plan/

[3] https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/file-carbon-border-adjustment-mechanism

[4] So far, California is the only jurisdiction where BCA are used. California's emissions trading system requires carbon border adjustments for imports of electricity from jurisdictions without a carbon trading framework.

The quantitative estimates for BCA impacts, however, differ substantially – not only with respect to the magnitude of specific effects but even with respect to their direction. The main reasoning behind is that different simulation studies adopt different assumption on key drivers of results such as (i) the input-output data characterizing initial heterogeneities of production, consumption and trade patterns across countries, (ii) the policy design of BCA, and, (iii) structural assumptions on economic responses, in particular with respect to international trade mechanisms.

To gain insights into the relative importance of these drivers, it is inevitable to have simultaneous control over data inputs, policy designs, and structural assumptions within a single coherent analytical framework. This paper presents a flexible CGE framework which is used for the systematic sensitivity analysis on key drivers of BCA impacts. Such analysis can inform decision makers about critical trade-offs between efficiency and equity objectives in the design of climate policies – particularly with respect to adverse redistributive effects of BCA for developing countries.

The remainder of the paper is organized as follows. Section 2 provides a literature review on international spillover effects from unilateral emissions pricing. Section 3 discusses multi-region input-output (MRIO) data as an input requirement for a CGE-based impact assessment of climate policies and presents descriptive MRIO analysis of carbon embodied in trade. Section 4 summarizes briefly the basic feature of the canonical CGE model for impact assessments. Section 5 provides an illustrative application of the CGE framework to the issue of unilateral emissions pricing and the imposition of BCA. Section 6 investigates the implications of unilateral emissions pricing in more detail via systematic sensitivity analysis. Section 7 concludes.

2. Review

The quantification of economy-wide impacts triggered by climate policy regulations calls for the use of numerical simulation techniques in order to assess systematically the interference of the many forces that interact in the economy. Compared to stylized analytical models, the numerical approach facilitates the analysis of complex non-linear interactions and the impact assessment of structural rather than marginal policy changes.

Due to the lack of historical experience the economic impact assessment of prospective policy initiatives such as BCA is based on ex-ante simulation analysis. The impacts of policy reforms are quantified with respect to a benchmark where the reform is not in place, the so-called business-as-usual. Comparative-static analysis provides a comparison of two different economic situations, before and after a change in exogenous settings such as the imposition of BCA.

Among numerical simulation methods, computable general equilibrium (CGE) models constitute an established scientific framework for ex-ante economic impact assessment of policy reforms based on rigorous economic theory as well as empirical data for the benchmark situation. CGE models are rooted in general equilibrium theory that combines assumptions regarding the optimizing behavior of economic agents with the analysis of equilibrium conditions (Shoven and Whalley 1992). Producers employ primary factors and intermediate inputs at a least cost subject to technological constraints; consumers maximize their well-being subject to budget constraints and preferences. Price-responsive supply and demand decisions by economic agents explain policy-induced changes in production, consumption and trade across households, sectors, and regions. Substitution and transformation possibilities in production and consumption are typically described in a top-down fashion by means of continuous functional forms where economic responses are driven by empirical estimates of elasticities and initial value shares derived from empirical economic accounts. The disaggregation of macroeconomic production, consumption, and trade activities at the level of multiple regions and sectors based on multi-region input-output data permits to track structural change in larger detail. The comprehensive coverage of market interactions and income-expenditure cycles accommodates the coherent quantitative trade-off analysis between gross economic performance (allocative efficiency), income distribution (incidence), and environmental quality (Böhringer and Löschel 2006). More specifically, the CGE framework keeps track of key determinants for economic adjustment to policy shocks including (i) technological options which prescribe how easy production can adjust to policy constraints such as higher prices for fossil fuels or energy efficiency mandates, (ii) consumer preferences which capture how much households will be affected by regulation in their expenditure patterns (incidence on the expenditure side), (iii) endowments with factors whose productivity and earnings will change (incidence on the income side), (iv) the pre-existence of initial regulations such as market-based taxes or subsidies but likewise command-and-control policies which will interfere with the prospective additional regulations (overlapping regulation), and (v) the structure of commodity and factor markets where assumptions on the market conduct – such as perfectly versus imperfectly competitive markets – are critical for supply and demand-side responses of economic agents.

Structural assumptions on international commodity markets are essential to capture the economic and environmental implications of climate policies whose principal objective is to reduce greenhouse gas emissions as a global externality in a cost-effective manner. As a first-round effect, unilateral emission constraints of single countries induce domestic adjustment while international markets and prices seemingly remain unaffected – the domestic adjustment cost are thereby primarily driven by the stringency of emissions reduction and the ease of carbon substitution in domestic production and consumption. The higher the emissions reduction target and the lower the substitution possibilities (elasticities) for carbon, the higher are the marginal and inframarginal cost of emissions reduction.

However, international spillovers play a critical role. Emissions abatement in open economies not only cause adjustment of domestic production and consumption patterns but also influence international prices via changes in exports and imports. Changes in international prices – the so-called terms of trade – imply a secondary benefit or burden which can significantly alter the economic implications of the primary domestic policy (Böhringer and Rutherford 2002). International market responses are at the core of concerns on competitiveness, carbon leakage (global environmental effectiveness) and burden shifting. Hence, single-country impact analysis which neglects policy-induced changes in international prices, can be quite misleading in quantifying the ultimate economic and environmental effects of emissions regulations.

For a comprehensive incidence analysis of carbon pricing, it is important to distinguish between price changes on international fuel markets and price changes on international market for energy-intensive and trade-exposed (EITE) goods (Böhringer and Rutherford 2002).

Regarding fuel markets, emissions regulations in open economies reduce demand for fossil fuels, causing global fossil fuel prices to fall and thus stimulating demand for fossil fuels in unregulated regions. As a consequence, countries which are net importers of fuels will gain via international fuel price adjustments while net exporting countries will be worse off. The extent to which international fuel prices will decrease depend on the supply responses of fossil fuel producers that are captured through fossil fuel supply elasticities. The lower these supply elasticities are, the higher will be the depression of international fuel prices. With respect to the global environmental effectiveness of unilateral emissions pricing, a decrease in fossil fuel prices will lead to carbon leakage through the so-called fossil fuel market channel (Burniaux and Oliveira-Martins 2012). Various CGE studies identify larger terms-of-trade effects via the fossil fuel market with the fossil market channel being the major source of carbon leakage (Bernard et al. 2007; Mattoo et al. 2009; Böhringer et al. 2010, 2011, 2012.; Fischer and Fox 2012). However, these studies assume competitive market structures with a rather inelastic supply side disregarding empirical evidence on non-competitive behavior of larger fuel producer such as OPEC (see e.g. Griffin 1985; Alhajji and Huettner, 2000a,b; Smith, 2005; Hansen and Lindholt 2008). When adopting alternative assumptions on the market conduct of fossil fuels such as oligopolistic behavior of OPEC, leakage through the oil market may drop drastically and even become negative while the incidence of carbon pricing will change markedly as dominant producers retain profits through supply-side rationing while fuel importers will not benefit as much from a depression of international fuel prices (Böhringer et al. 2014a). Structural assumptions on the market conduct of fossil fuels are therefore central to the incidence analysis of climate policies.

Regarding international trade in EITE goods, more stringent unilateral regulation imposes additional cost on domestic industries as compared to international rivals. This will incentivize the relocation of EITE production (including investment into future production facilities) to abroad. The changes in international competitiveness thereby amplifies adverse production and employment impacts for EITE industries in countries that advance with more stringent emission pricing. While the potential impacts of unilateral carbon pricing at the level of EITE production are relatively clear-cut – negative repercussions for regulated domestic industries and gains for unregulated foreign industries – the economy-wide incidence may critically hinge on assumptions about the market conduct of EITE industries. The bulk of CGE models used for climate policy analysis explains the pattern of international trade through relative cost differences aligned with perfect competition and regionally differentiated goods. The proposition to differentiate products by country of origin is referred to as the Armington assumption, after its seminal notion and application by Armington (1969). Imported and domestically produced goods of the same variety are demanded as imperfect substitutes in intermediate and final demand. Responses to relative price changes are then controlled through the assumed elasticity of substitution – the so-called Armington elasticities that govern the ease of substitution between domestic goods and imported (exported) goods of the same variety. The higher the Armington elasticities, the stronger are the repercussions for domestic EITE industries subject to stringent unilateral emissions pricing as other regions can more easily substitute new sources for EITE goods in response to the changes induced by the climate policy regime. With respect to global environmental effectiveness of unilateral action, relocation of EITE production from jurisdictions with stringent emissions pricing to jurisdictions with more lenient or no emissions pricing will cause leakage through the so-called competitiveness channel which increases in the level of assumed Armington elasticities (Burniaux and Oliveira-Martins 2012).

The Armington structure has several empirical advantages, as (i) it accommodates the empirical observation that a country imports and exports the same good (so called cross-hauling of data); (ii) it avoids over-specialization implicit to trade in homogeneous goods; and (iii) it is consistent with empirical evidence of trade in geographically differentiated products. While the Armington assumption provides a convenient lens to view trade data, it may lead to unrealistically strong terms-of-trade effects that dominate the welfare results of policy changes (Brown 1987; de Melo and Robinson 1989; Kehoe 2005). Even in the absence of market power by individual firms, the Armington assumption of product heterogeneity provides implicit market power in a perfectly competitive market conduct which is the higher the larger are the trade flows and the smaller are the demand elasticities for the traded goods by trading partners. The Armington structure misallocates market power over varieties away from firms and toward the discretion of the policy authority. This explains why countries through domestic emissions regulations are able to shift part of their domestic abatement costs to trading partners; it furthermore provides scope for countries to use carbon policies as a substitute for optimal tariffs to changing the terms of trade in their favor. Modern trade theory points to the importance of scale economies (imperfect competition) and variety effects to quantify the magnitude and distribution of economic impacts at the level of sectors and countries. The new trade theory based on Krugman adopts firm-level product differentiation in a monopolistic-competition framework to illustrate that there are gains from trade even in the absence of comparative advantage (Krugman 1980). The new new trade theory inspired by Melitz introduces the competitive selections of heterogeneous firms in a monopolistic competition model – in this framework, trade induces a reallocation of within-industry resources away from low-productivity firms toward high-productivity firms (Melitz 2003). From an empirical perspective, the commonly adopted Armington approach misses out on empirical evidence for imperfect competition and firm heterogeneity. Alternative trade assumptions incorporating modern trade theory on firm-level product differentiation and imperfect competition may have important implications for how unilateral emissions pricing affect carbon leakage, competitiveness of sectors, and the cross-country burden shifting (Balistreri and Rutherford 2013; Balistreri et al. 2018).

When reviewing the economic literature on the impacts of unilateral emissions pricing it is important to keep in mind how international spillovers are driven by structural market assumptions and their parametrization (i.e. the choice of elasticities) – aspects which are crucial but often not made very apparent in analysis.

Reflecting the growing policy salience of BCA, there are meanwhile several overview articles which resume findings from the economic literature on the potential impacts of BCA (Böhringer et al. 2021; Keen et al. 2021; Overland and Huda 2022; Fontagné and Schubert 2023).

Regarding the incidence at the level of EITE sectors – usually termed as competitiveness effects – a common finding across simulation analysis is that BCA are effective in leveling the playing field: EITE industries in carbon-regulated jurisdictions recover some of the initial output losses due to unilateral emissions pricing while competing unregulated industries abroad tend to lose output (Böhringer et al. 2012, 2017a; Fouré et al. 2016). An important caveat relates to the role of export rebates in restoring competitiveness in foreign markets. Import adjustments alone may exacerbate rather than mitigate the negative effects of unilateral emissions pricing for EITE industries that import a large share of border-adjusted embodied carbon and export a large share of their production (Burniaux et al. 2013; Böhringer et al. 2015). Economy-wide CGE studies, which are less detailed at the industry level, understate the spread of impacts across more refined sectoral resolutions which show much more heterogeneity than the industry average (Caron 2012). It is worth mentioning that – beyond the output metric – there are several over definitions of competitiveness outcomes in the unilateral climate policy literature (Böhringer and Alexeeva-Talebi 2013). However, many of these definitions are rather poor proxies for measures of the change in economic incidence (welfare) at the national level (Carbone and Rivers 2017).

At the country (region) level, the results of simulation studies indicate that import adjustments may have a strong burden-shifting effect. The basic mechanism is well known from the economic theory on optimal tariffs (Broda et al. 2008). To the extent that import prices decrease to absorb some of the incidence of carbon adjustments, exporting countries subject to BCA will suffer a loss in export revenues while importing countries benefit from an improvement in their terms of trade. Import adjustments on embodied carbon applied by richer industrialized countries are likely to shift some of the burden of emissions pricing to poorer developing countries (Böhringer et al. 2012; Lanzi et al. 2012; Larch and Wanner 2017; Böhringer et al. 2018; Balistreri et al. 2018; Böhringer et al. 2021). One way to address such equity concerns is to return the revenues of carbon import adjustments to paying countries or exempting developing regions from BCA which on the other hand could undermine the legitimacy of BCA (Cosbey et al. 2019; Mehling et al. 2019).

From a broader economic efficiency perspective, the incidence of BCA with its potentially adverse effects on poorer countries must be weighed against the potential global cost savings to reach a given reduction in global emissions by unilateral CO_2 pricing. The basic efficiency rationale for BCA have long been laid out in economic theory (Markusen 1975; Hoel 1996; Keen and Kotsogiannis 2014). BCA can improve global cost-effectiveness by partially transferring carbon pricing via trade flows to trading partners without emissions pricing policies. As BCA reduce carbon leakage, unilaterally acting regions can scale back the level of domestic emissions pricing required to achieve the same global emissions reduction as without BCA. Effectively, BCA reduce the carbon pricing differential between regions with and without emissions pricing, which reduces efficiency losses from non-uniform carbon pricing. Yet, when it comes to the quantitative assessment of global cost savings, the results are sobering (Böhringer et al. 2012; Böhringer et al. 2014b; Fouré et al. 2016). The global cost savings from BCA turn out to be very limited for several reasons. First, only a relatively small fraction of emissions abroad is targeted in practical proposals with limited sectoral coverage on EITE industries and also incomprehensive metrics such as scope1 and scope2 emissions for embodied carbon. Second, demand-side instruments such as BCA only address carbon leakage through the competitiveness channel which may account just for a smaller share of counterproductive emissions relocation as compared to leakage through the fossil fuel market channel. Third, BCA on imports applied to the industry-average of embodied carbon do not incentivize polluters in unregulated countries to adopt less emission-intensive production techniques. The only way for foreign firms to avoid import charges is to reduce exports to countries with BCA which makes BCA a very blunt instrument. If – on the other hand – import levies will be based on firm-level emissions intensities, there is a substantial risk of reshuffling which could even further limit the potential for global effectiveness gains from BCA as compared to using a single benchmark for import charges based on a default emissions rate. Analysis that does not consider reshuffling options may significantly overstate the yield of firm-specific import adjustments with respect to leakage reduction and global cost savings. Fourth, there is re-routing of trade flows, i.e., foreign EITE industries may redirect part of their exports to other non-regulated markets.

Regarding efficiency-equity trade-offs in the assessment of BCA, the common finding in the CGE literature is that very limited efficiency gains of BCA contrast with substantial shifts in the incidence of carbon pricing. The distributional impacts of BCA are likely to become a thorny issue in the climate policy debate if the BCA will burden poorer developing countries thereby violating CBDR principles.

Due to their burden shifting potential BCA have been appraised as a means to secure greater cooperation and thereby achieve substantial gains in global cost-effectiveness from unilateral climate action: International spillovers via changes in the terms of trade establish the economic rationale of BCA as a sanctioning instrument. To avoid tariffs, other nations could adopt equivalent emissions pricing (Helm et al. 2012; Al Khourdajie and Finus 2020). Some numerical simulation studies that incorporate strategic behavior of individual countries suggest that import adjustments could coerce broader international cooperation in emissions pricing (Lessmann et al. 2009; Irfanoglu et al. 2015; Böhringer et al. 2016). When casted more broadly as uniform percentage tariffs on the imports of outsiders, a carbon club may even induce a large stable coalition with high levels of abatement (Nordhaus 2015). In this vein, a climate club that combines emissions pricing with trade sanctions could be a game changer. However, such sanctions are more likely to conflict with WTO obligations than BCA and to induce trade disputes. Recent economic analyses show that the additional consideration of retaliation significantly reduces the appeal of import adjustments as a means of expanding climate coalitions and may even risk a detrimental trade war (Böhringer and Rutherford 2017; Hagen and Schneider 2021). In international climate negotiations, BCA could be viewed as protectionist and discriminatory policy measure leading countries to reduce their voluntary commitments under the Paris Agreement or even withdraw from it (Hübner 2021).

3. Data and MRIO analysis

Economic impacts of policy interference such as BCA are determined by the responsiveness of supply and demand. On the production side, responsiveness is determined by technologies, on the demand (consumption) side by preferences. In economic records, technologies and preferences show up in cost shares of industries (firms) and expenditure shares of households. Beyond these cost and expenditure shares, elasticities of supply and demand govern the effective response of economic agents to changes in relative prices. Hence, the minimum requirement for quantitative impact assessment of BCA is the availability of empirical multi-region input-output (MRIO) data which capture production, consumption and trade patterns across sectors and countries together with elasticities that govern price responsiveness.

A common source for such MRIO data is the collection of economic statistics from the Global Trade Analysis Project (GTAP). GTAP is a research consortium initiated in 1992 to provide the economic community with a global economic dataset for use in the quantitative analysis of economic issues. The GTAP data provides input-output and final demand transactions in a globally consistent set of social accounts. The latest GTAP release (GTAP11), dated April 2023, features detailed balanced accounts of production, consumption, and bilateral trade flows for the base-year 2017 across 141 individual countries and 19 aggregate regions—with individual countries accounting for 99.1% of world gross domestic product (GDP) and 96.4% of world population (Aguiar et al. 2022).[5] As compared to previous releases, GTAP11 features more country details on Middle East and Central Africa regions, extending thereby the coverage of developing countries.

The GTAP database also includes default estimates for key elasticities: Armington trade elasticities which control the international trade response of the model, income and price elasticities for final demand to parametrize final demand, as well as substitution elasticities in production between primary factors.

The MRIO data together with elasticities are used to parametrize multi-region CGE models in line with basic assumptions on market structure and the optimizing behavior of economic agents (Mansur and Whalley 1984, Shoven and Whalley 1992): The free parameters of functional forms that characterize production technologies (cost functions) and consumer preferences (expenditure functions) are calibrated using cost and expenditure shares from the MRIO data which provide a coherent observation of economic transactions for a particular base year.

[5] More generally, GTAP11 offers a time series of 5 reference years (2004,2007, 2011, 2014, and 2017) which could be used to do sensitivity analysis of policy interference over time. Böhringer et al. (2021) provide an elaborate application of how the impacts of a given BCA policy will change as a function of the underlying MRIO base-year using data from the World Input–Output Data-base for the period 2000–2014.

GTAP11 also includes CO_2 emissions from fossil fuel combustion based on the Tier1 method of the 2006 IPCC Guidelines (Chepeliev 2022). Accurate accounting of emissions across fuels, sectors, and regions is a prerequisite for climate policy analysis on greenhouse gas emissions reduction strategies. Furthermore, the energy data treatment has been updated towards a more consistent representation of bilateral energy trade flows between key energy exporters and importers. As CO_2 emissions constraints are likely to depress international fuel prices, it is important to track changes in the pattern of energy trade which go along with potential terms-of-trade gains (losses) for fossil fuel importers (exporters). Likewise, changes in energy trade induced by unilateral climate policies determine carbon leakage via the fossil fuel market channel.

The GTAP database can be flexibly aggregated to reflect key sectoral and regional dimensions of the policy issue at stake. Regarding the choice of sectors for the aggregate dataset, all primary and secondary energy carriers (coal, gas, crude oil, refined oil products, and electricity) are represented explicitly to capture differences in CO_2 intensity and the potential for inter-fuel substitutability. Reflecting the use of BCA for EITE goods the composite dataset distinguishes chemicals (including rubber and plastics), non-metallic minerals, iron and steel as well as non-ferrous metals. Transport activities from the different modes are subsumed in a composite transport sector. The remaining sectors are attributed to three larger categories, i.e. agriculture, manufacturing, and services.

While the current version of GTAP covers 65 sectors, it may still lack sectoral detail to reflect specific policy proposals. Industries such as cement or fertilizers which are specifically addressed in current BCA proposals (e.g. EU-CBAM) are not explicitly represented but subsumed in composite sectors such as chemical products or mineral products. In order to refine sectoral coverage, one has to draw upon more disaggregate satellite data on the input-output structure of sub-sectors. Sector disaggregation can be done using e.g. public domain information by EXIOBASE, a multi-region multi-sector database funded by the European Commission (*cite*). Beyond the inclusion of additional economic data, the appropriate assessment of BCA proposals might call for the explicit accounting of process-based CO_2 emissions (in addition to emissions from the combustion of fossil fuels) as the former can represent the bulk of carbon emissions in specific industries such as cement.

At the regional level, the analysis of climate policies should cover all major geopolitical players that account for the bulk of global CO_2 emissions. In this vein, the aggregate dataset includes explicitly the top-3 emitting countries – China, USA, and India – as well as EU-27 which together account for around 60% of global GDP and CO_2 emissions (as of GTAP11 in 2017). Regarding pro-active unilateral climate policies, the composite region RG7 includes the remaining three G7 countries (United Kingdom, Japan, Canada) which might consider BCA together with the EU-27 and the USA as a protective demand-side policy. The composite region OEC contains all remaining OECD countries (Australia, New Zealand, Korea, Turkey, Israel, Chile, Colombia, Costa Rica, Norway, Switzerland) which as "developed countries Parties should take the lead in combating climate change." (United Nations 1992). Brazil, Indonesia, Argentina and South Africa form the composite of remaining G20 countries. As CO_2 emissions constraints are likely to have adverse effects on major fuel exporting countries, the composite region OEX covers OPEC+10 countries, i.e., all member countries of the OPEC cartel together with 10 associated countries.

All other countries and regions in GTAP11 dataset are grouped into four income categories according to the World Bank classification to track distributional consequences of climate policies at an aggregate level.[6] Given the special emphasis on the implications of BCA on developing and emerging countries the quantitative analysis is performed for the central case parametrization with all 17 individual low-income economies of the LOI composite and with all 33 individual lower-middle-income economies of the LMI composite.

Tables 1 and 2 summarize the current aggregation of sectors and regions underlying the subsequent BCA impact assessment. For the sake of brevity, we use GTAP sector and country acronyms to denote the composition of aggregate sectors and regions (the comprehensive list of countries and sectors associated with the acronyms is provided in Appendix A). The labels as of Tables 1 and 2 are employed subsequently in the exposition of data and simulation results.

Beyond MRIO data GTAP also provides estimates for key elasticities, in particular for trade elasticities – so-called Armington elasticities – that govern the ease of substitution across goods of the same variety originating in different countries. These Armington elasticities determine the scope for re-routing of trade flows as a consequence of BCA: Exporters in unregulated countries can to some extent re-route their products from countries that levy carbon tariffs to unregulated markets.

BCA is specified as import adjustments and export adjustments based on emission intensities of EITE goods. Its differential (price) and cost impacts are thus driven by differences in the emissions intensities of EITE production across sectors and regions as well as the prevailing pattern of international trade. The larger the differences in emissions intensities and the higher the volume of embodied carbon in the trade in EITE goods, the more potent BCA will be in leveling the playing field and redirecting EITE trade flows.

Table 1: Sector aggregation in quantitative analysis

Label	**Description**	**Composition**
	Primary and secondary energy carriers	
COL	Coal mining	COL
GAS	Natural gas extraction and distribution	GAS
CRU	Crude oil	CRU
OIL	Refined oil products	OIL
ELE	Electricity and heat	ELE
	Energy-intensive and trade-exposed goods (subjected to BCA)	
I_S	Ferrous metals	I_S
NFM	Metals	NFM
NMM	Mineral products	NMM
CHM	Chemical products, rubber and plastics	CHM, RPP
	Other composite macroeconomic sectors	
TRN	Transport	WTP, ATP, OTP
AGR	Agriculture	PDR, WHT, GRO, V_F, OSD, C_B, PFB, OCR, CTL, OAP, RMK, WOL, FRS, FSH

[6] https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

MAN	Manufacturing	TEX, LUM, FMP, MVH, OTN, OME, EEQ, CEO, OMF, CMT, OMT, VOL, MIL, PCR, SGR, OFD, B_T, WAP, LEA, CNS, PPP, OXT, BPH
SER	Services	AFS, CMN, OFI, OBS, RSA, ROS, WHS, OSG, EDU, HHT, WTR, DWE

Table 2: Region aggregation in quantitative analysis

Label	Description	Composition
EUR	EU-27	DEU, AUT, BEL, BGR, CYP, HRV, CZE, DNK, ESP, EST, FIN, FRA, GRC, HUN, IRL, ITA, LTU, LUX, LVA, MLT, NLD, POL, PRT, ROU, SVK, SVN, SWE
USA	USA	USA
RG7	Rest of G7	GBR, JPN, CAN
OEC	Other OECD	AUS, NZL, KOR, TUR, ISR, CHL, COL, CRI, NOR, CHE
CHN	China	CHN, HKG
IND	India	IND
RGT	Rest of G20	BRA, IDN, ARG, ZAF
OEX	OPEC+10	AU, VEN, KWT, QAT, ARE, IRN, NGA, DZA, COG, IRQ, GAB, GNQ, XNF, RUS, MEX, SDN, BHR, OMN, KAZ, AZE, MYS, BRN
HII	Remaining WB high-income economies ($13,205 OR MORE)	TWN, XEA, SGP, XNA, URY, PAN, XCA, PRI, TTO, XEF, XSU, PSE, XTW
UMI	Remaining WB upper-middle-income economies ($4,256 TO $13,205)	ALB, ARM, BLR, BWA, DOM, ECU, GEO, JAM, JOR, MUS, NAM, PRY, PER, SRB, THA, GTM, XEE, XER, XCB, XSM
LMI	Remaining WB lower-middle income economies ($1,086 TO $4,255)	BGD, BEN, BOL, KHM, CMR, COM, CIV, EGY, SLV, GHA, HTI, HND, KEN, KGZ, LAO, LBN, MNG, MAR, NPL, PAK, PHL, SEN, LKA, TZA, TJK, TUN, UKR, UZB, VNM, ZWE, SWZ, XSC, NIC, XAC, XSA, XSE, XOC
LOI	'Remaining WB low-income economies ($1,085 OR LESS)'	AFG, BFA, CAF, TCD, COD, ETH, GIN, MDG, MWI, MLI, MOZ, NER, RWA, SYR, TGO, UGA, ZMB, XWS, XEC, XWF

The emissions intensity of EITE goods, i.e., the carbon content per unit of production to which an import levy or likewise an export rebate applies can be based on different metrics. The total carbon content includes direct emissions (those due to the combustion of fossil fuel inputs in the production of the good) as well as indirect emissions (such as emissions created by the generation of electricity used for the production of the good). To calculate the region- and sector-specific carbon content of goods one can use MRIO accounting identities (see Appendix B for the algebraic summary of the carbon-accounting MRIO routine based on GTAP notations). The MRIO framework thereby facilitates a decomposition of the total embodied carbon into direct emissions from fossil fuel use in the production process and indirect emissions embodied in domestic or imported intermediate inputs. In BCA policy initiatives such as EU CBAM the product-specific carbon content is divided into three additive categories (i) direct emissions from fossil fuel combustion (scope1), (ii) indirect emissions from heat and electricity used as intermediate inputs (scope2), and (iii) indirect emissions from all other intermediate inputs (scope3).

Figure 1 provides a cross-region comparison of the carbon content — measured in kilograms of CO_2 emitted in the production of a given good per dollar of value — for the average EITE product as well as for the four specific EITE commodities considered for BCA in the EU CBAM proposal. The total carbon content is parsed into direct emissions (scope 1), indirect emissions from electricity inputs (scope 2), and indirect emissions embodied in all other intermediates used in production (scope 3).

In general, indirect emissions - associated with electricity use (scope 2) but even more so the indirect emissions embodied in all other non-electric intermediate inputs (scope3) – account for a large share of embodied emissions and for larger differences in emissions intensities across regions. Import adjustments based only on direct embodied emissions would therefore significantly underestimate the full emissions embodied in EITE goods. It can be seen, that G7 countries range at the very end of the emissions intensities for the composite of EITE goods. The numbers suggest that the composite of LOI countries may even gain comparative advantage across regions outside a potential G7 climate club – particularly with respect to China and India which stand out for the highest emissions intensities followed by the composite of OPEC+10 (OEX) and the lower-middle-income economies.

When split down to individual EITE sectors – iron and steel (I_S), chemical products (CHM), non-ferrous metals (NFM) and non-metallic minerals (NMM) – the data shows that average emissions intensities for iron and steel tend to be highest, followed by non-metallic minerals, non-ferrous metals, and chemical products. There is also some variation in regional ranking by individual EITE products (e.g. LOI has the lowest emissions intensity in NFM but ranks within the top-4 in CHM).

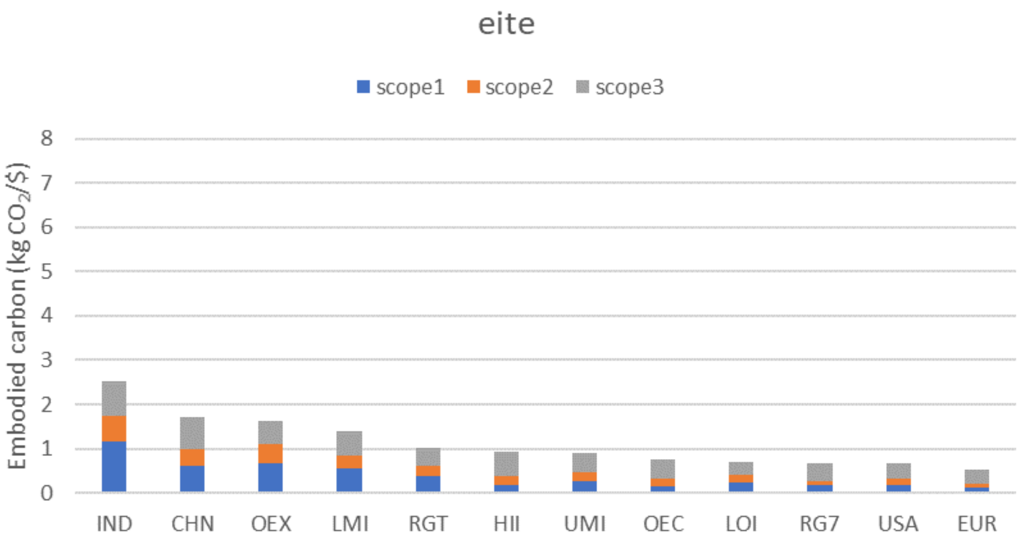
The average data for a composite region masks country heterogeneity which can be substantial and for that case might provide the main reasoning that the incidence of BCA across individual countries forming the composite region will not only differ in quantitative (relative) terms (e.g. as % output change) but also by sign. Figure 2 highlights such country heterogeneity for the composite region LOI established by 17 low-income countries with respect to emissions intensities. The average intensity of Figure 1 is marked as LOI. One can see that the heterogeneity within the LOI composite is more pronounced than the heterogeneity across the 12 regions establishing the core aggregation. Afghanistan and Syria stand out for the highest emission intensities while the composition in terms of scope1 and socpe2 emission shares is very different. At the lower end of emissions intensities are Rwanda and the Democratic Republic of the Congo where the latter more or less only shows up with scope3 emissions and therefore would not be directly affected from the current EU CBAM proposal at all as the latter only covers socpe1 and scope2 emissions.

Ceteris paribus, the impacts of BCA on domestic EITE production will be mirror-inverted pending on the position of the country as BCA sender or BCA recipient and their respective important and export shares for EITE products. From the perspective of the BCA sender, an import adjustment will be the more protective for domestic production the higher is the share of imports from BCA recipients in the domestic market demand of the BCA sender; likewise, export rebates are the more effective the higher is the value of exports of the BCA sender to

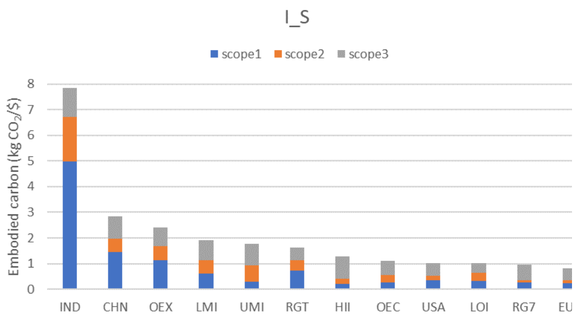
BCA recipients as a share of domestic production in the BCA sender country. From the perspective of the BCA recipient, BCA is the more harmful to domestic production the higher is the share of goods in domestic production which is exported to BCA senders; likewise, the higher is the share of exported goods from the BCA sender in domestic market demand of the recipient country, the more the BCA recipient will suffer from export rebates

Figure 1: Emission intensities of EITE products across regions

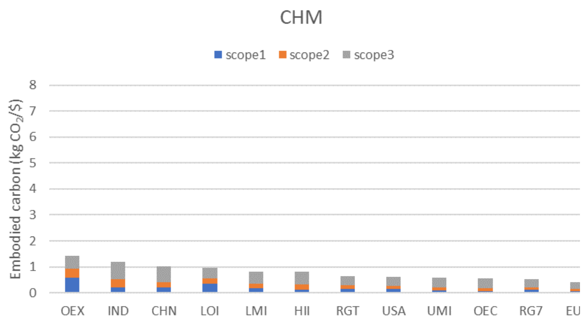
a. Average EITE product (eite)



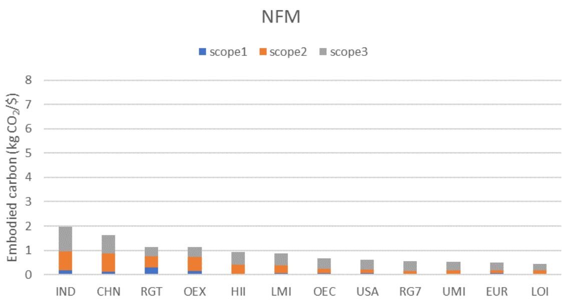
b. Iron and steel (I_S)



c. Chemical products (CHM)



d. Non-ferrous metals (NFM)



e. Non-metallic minerals (NMM)

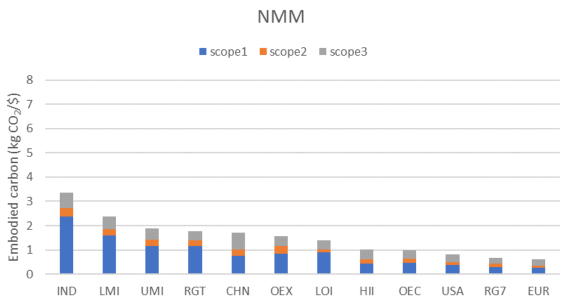


Figure 2: Emission intensities of the average EITE product across individual countries of LOI

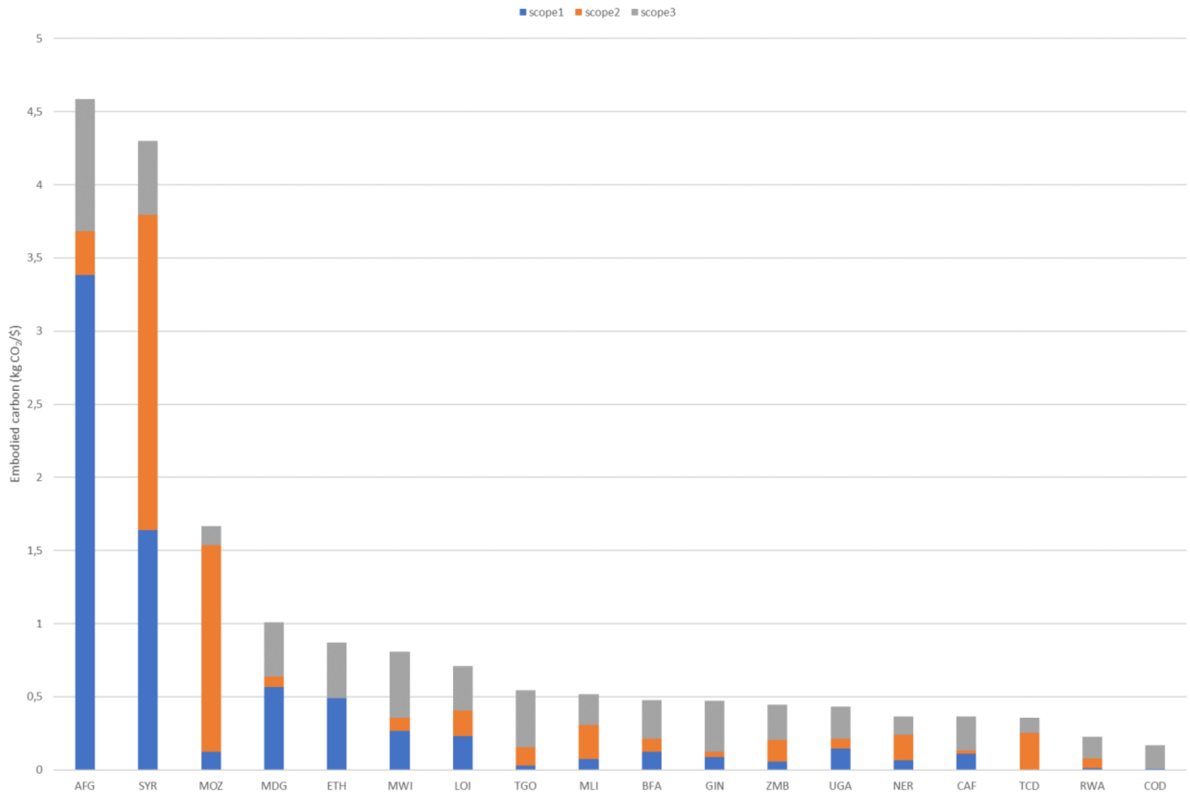
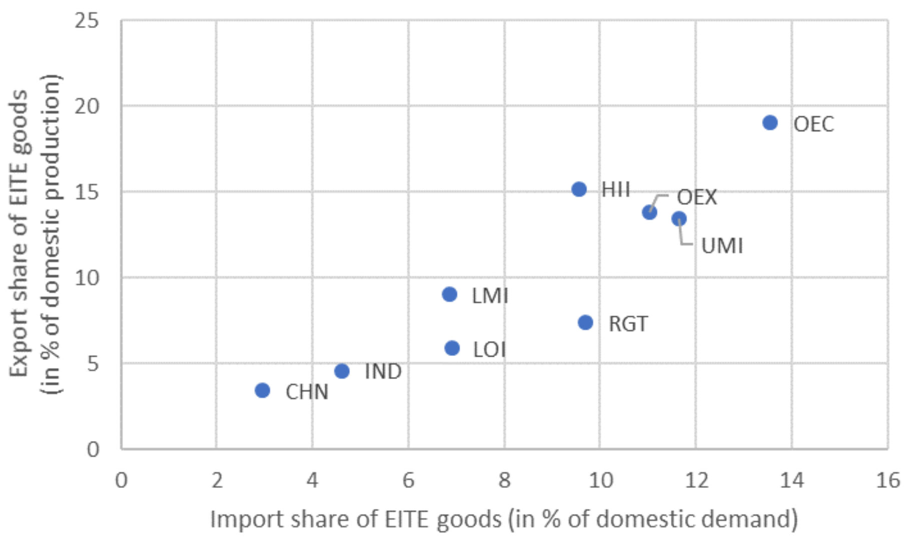


Figure 3 considers the protective nature of BCA for recipient regions regarding export competition in the sender's domestic market and import competition on the recipient's domestic market for the average EITE product.

Figure 3: EITE import and export shares of BCA recipients with respect to G7 as climate club



In the illustrative calculation, it is assumed that the G7 climate club of EU and other G7 countries (USA and RG7) considers import levies on embodied carbon as a demand-side policy towards the rest of the world. The figure depicts import and export shares of EITE products for the different regions outside the climate coalition. Import shares -- on the y-axis – are computed by dividing the value of the import from G7 to non-coalition countries by the value of domestic market demand in non-coalition countries. Export shares – on the X-axis - are computed by dividing the value of the export from non-coalition countries to G7 by the value of domestic production in non-coalition countries. The further to the right (top) an EITE industry is located, the more harmful an import adjustment (export rebate) will be for the domestic EITE industry in the recipient country subjected to BCA.

Not surprisingly, we see that the rest of other OECD countries (OEC) has the highest trade integration in EITE products with G7, whereas China and India show very low shares. The EITE trade links between developing regions LOI and LMI are also relatively weak.

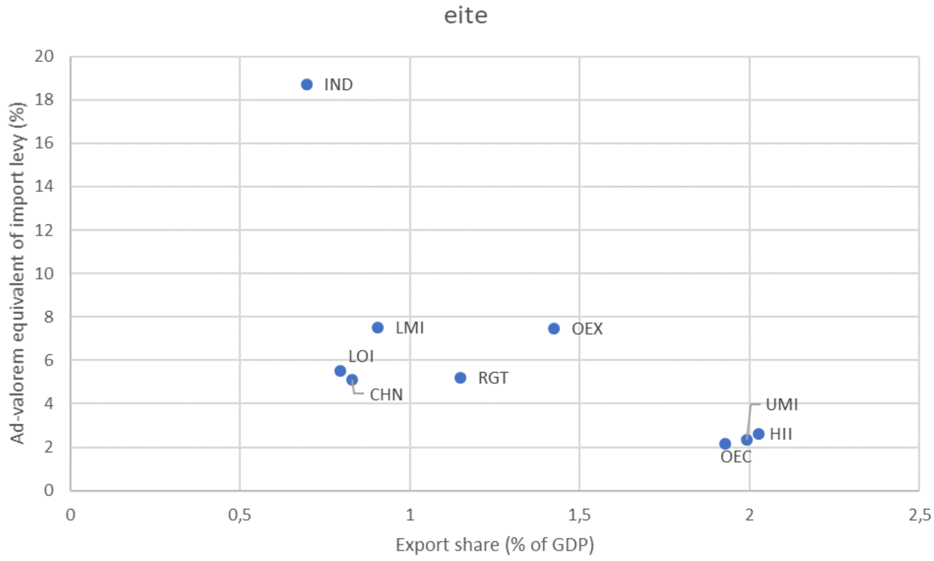
Figure 4 translates import adjustments as the most likely legal form of BCA into vulnerability indicators for recipient countries. The Y-axis indicate the ad-valorem equivalent of the BCA import levy on EITE goods. The X-axis depicts the value of EITE exports over GDP. For illustrative purposes it is assumed that the G7 climate coalition prices domestic CO2 at a price of 75$/t$CO_2$ and then levies this price on scope1+scope2 emissions embodied in imported EITE products of other countries. The higher the ad-valorem equivalent and the higher the export share – i.e. the further to the top right a recipient country is -- the stronger are prima facie the adverse implications of import adjustments.

The picture at the average EITE product level is quite mixed. While India stand out by far with the highest ad-valorem equivalent (ca. 18%), its exports to G7 as a share of domestic GDP is smallest (around 0.7%). On the other hand, we have regions OEC, UMI, and HII whose export shares are considerable higher (around 2%) while the ad-valorem equivalents are just around 2%. The composite of low-income economies (LOI) faces an ad-valorem equivalent of close to 6% on its average EITE exports but its export share is well below 1%. Figures 4b.-e. again highlight considerable heterogeneity of potential incidence at the more disaggregate sector level which carries over to heterogeneity across different countries within composite regions (not shown here for the sake of brevity).

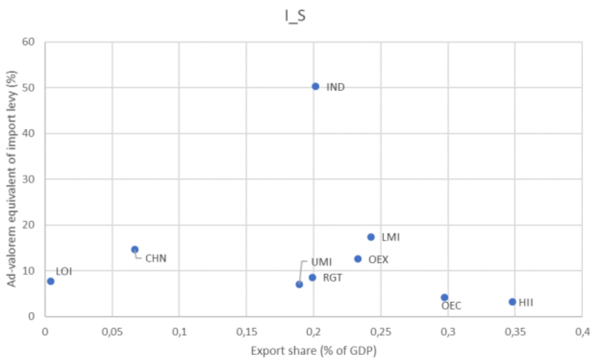
The potential of BCA to extend the coverage of unilateral emissions pricing beyond domestic borders and thereby improve global cost-effectiveness of sub-global emissions pricing obviously depends on the share of emissions embodied in trade which can be targeted. Figure 5 illustrate the trade patterns of carbon embodied in EITE goods between the composite of non-G7 regions and the potential G7 climate club. The trade in embodied carbon is calculated as the product of export flows and total emissions intensities. Figure 5 reports embodied carbon trade as gross exports of embodied carbon (in Mt CO_2), i.e., embodied emissions in exports. Each data point in Figure 5 represents the exports between a Non-G7 region and its G7 (x-axis) or its Non-G7 (y-axis) trading partners. In absolute terms, China and OPEC+10 are by far the most important target for import adjustments while the composite of low-income countries is negligible.

Figure 4: Ad-valorem equivalent of ETIE import levies and export shares for BCA recipients

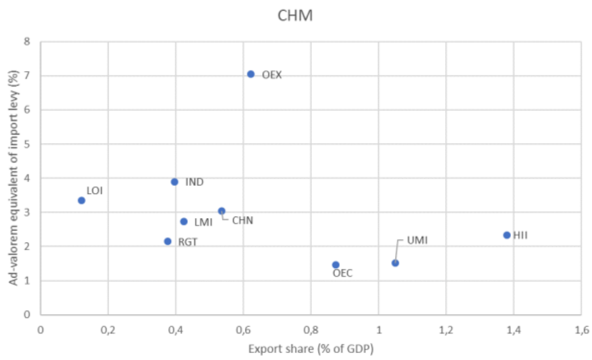
a. Average EITE product (eite)



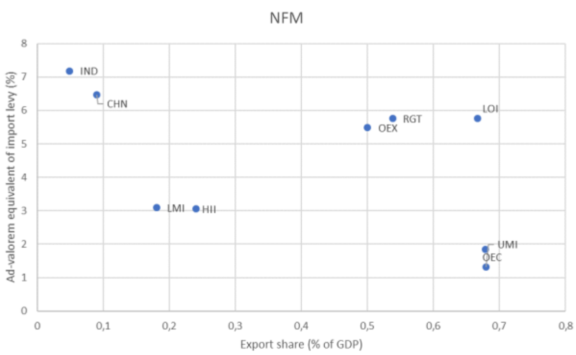
b. Iron and steel (I_S)



c. Chemical products (CHM)



d. Non-ferrous metals (NFM)



e. Non-metallic minerals (NMM)

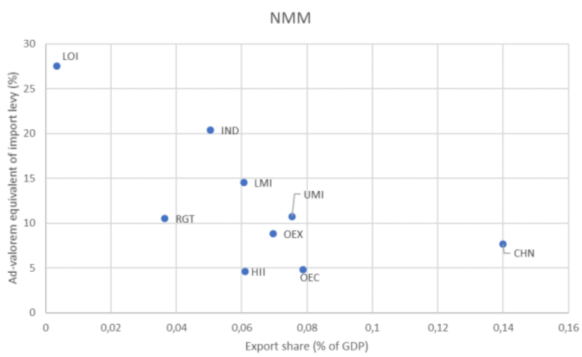


Figure 5: Exports of embodied carbon in EITE goods from non-G7 regions to G7 and non-G7

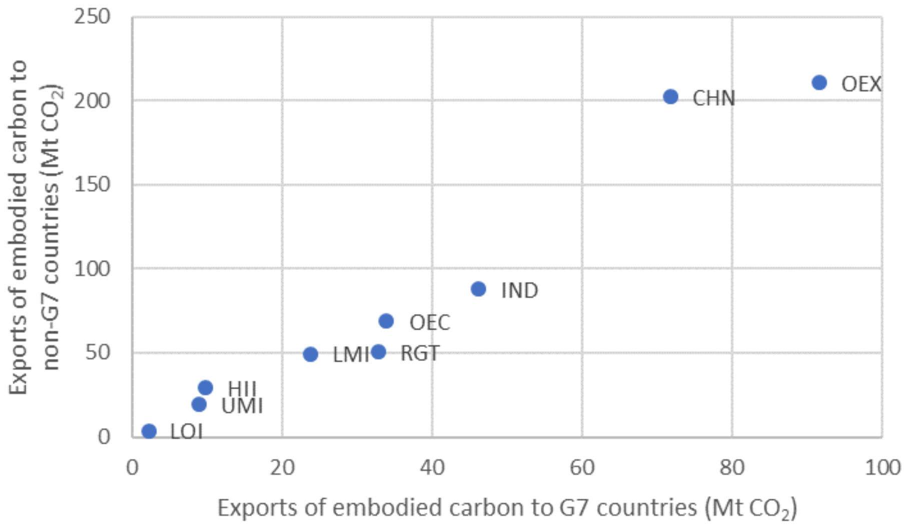
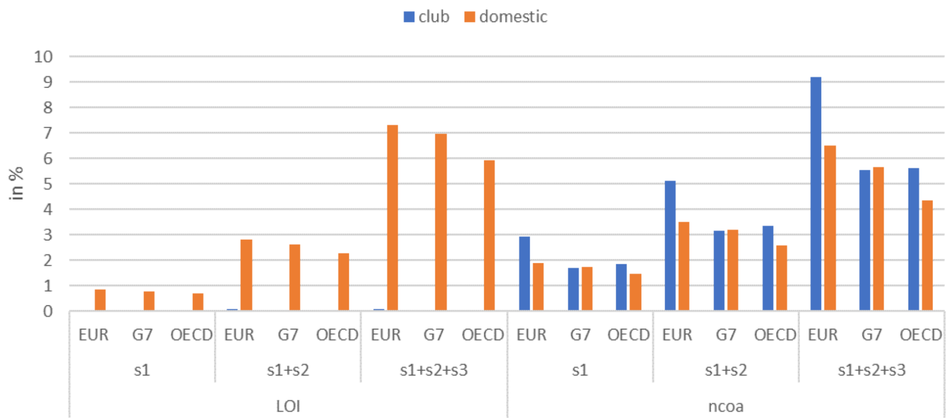


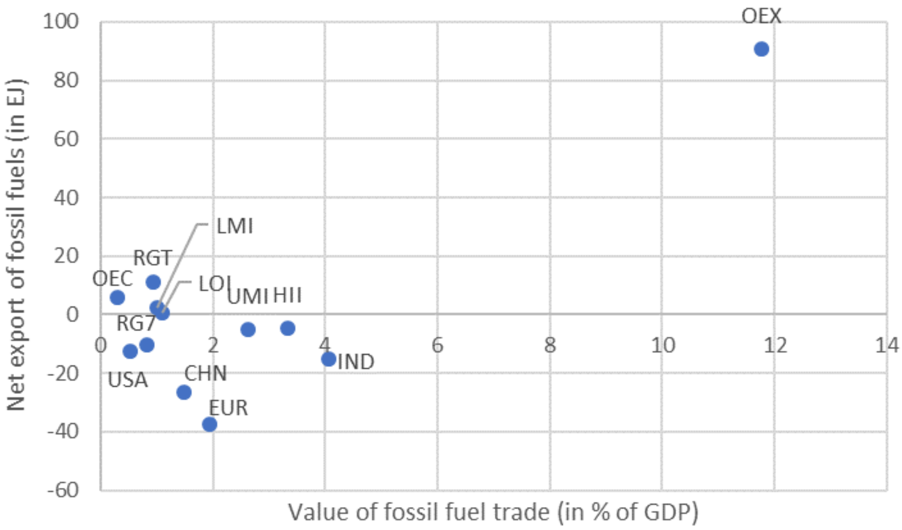
Figure 6 provides an overview of the emissions embodied in exports from LOI countries and the composite of all non-club countries (labeled ncoa) without carbon pricing as a function of the size of a potential climate club and the carbon metric applied to imports. The size of the climate club increases from the EU (labeled EUR) to G7 (labeled G7) and all OECD countries (labeled OECD). The carbon metric increases in coverage from scope1 (labeled s1) to scope 2 (labeled s1+s2) to scope3 (labeled s1+s2+s3) emissions. The respective emissions covered in imports from non-club countries to the climate club are stated as a share of domestic emissions in the non-club region (labeled domestic) and as a share of the emissions in the climate club (labeled club). Not surprisingly, one can see that the embodied emissions of LOI EITE trade is negligible as a fraction of production-based emissions in the different climate club and also amounts to less than 7% of LOI domestic emissions in the maximum across all combinations. For the total of countries outside the climate club the share of EITE emissions exports to the climate club as a share of the club's production-based emission is much higher but still does not exceed 9% in the maximum while the share of non-club (i.e., non-coalition, labeled ncoa in Figure 6) EITE emissions exports to the climate club over production-based emissions in the non-club countries is less than 6% in the maximum.

Figure 6: Share of emissions embodied in EITE exports by different metrics (s1, s1+s2, s1+s2+s3) from non-club regions (LOI and ncoa) to climate clubs (EUR, G7, OECD) over production-based emissions in non-club regions (domestic) and over production-based emissions in the climate club (club)



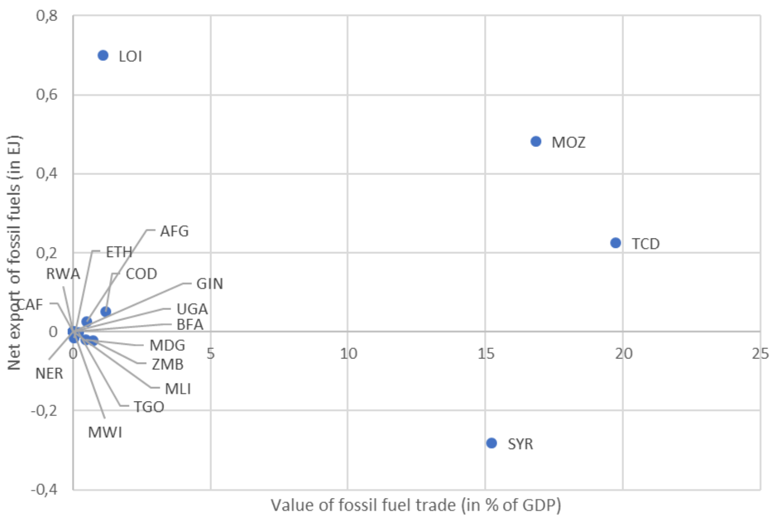
Beyond trade in EITE goods, another important statistical indicator for the potential incidence of carbon pricing is the trade position on fossil fuel markets. With a decrease in international fuel prices triggered by emission constraints, net fuel exporters are likely to face losses in revenues while net fuel importers can expect cost savings. Figure 7 provides a scatter plot across the 12 regions of the core aggregation with the value of net energy trade as a share of domestic GDP on the X-axis and the value of energy exports in EJ on the Y-axis. As expected, OPEC+10 (OEX) stands out as the major net exporters of fossil fuels with a value of fossil export around 12% of its gross domestic product. India (IND) and the EU (EUR) together with the composite regions of upper-middle-income (UMI) and higher-income economies (HII) are major fuel importers in terms of the value share in domestic GDP. The composite of low-income economies (LOI) is in aggregate an exporter of fossil fuels given the GTAP11 data for 2017 but the value share in GDP is less than 1%.

Figure 7: Net energy trade by 12 regions of the core aggregation



Again, the region composite masks substantial heterogeneity across individual countries as is evident from Figure 8 for the individual low-income countries. For Mozambique (MOZ) and Chad (TCD) the export value of fossil fuels amounts to ca. 17% and 20% respectively, while Syria (SYR) is a substantial net importer of fossil fuels at 15% value of its GDP.

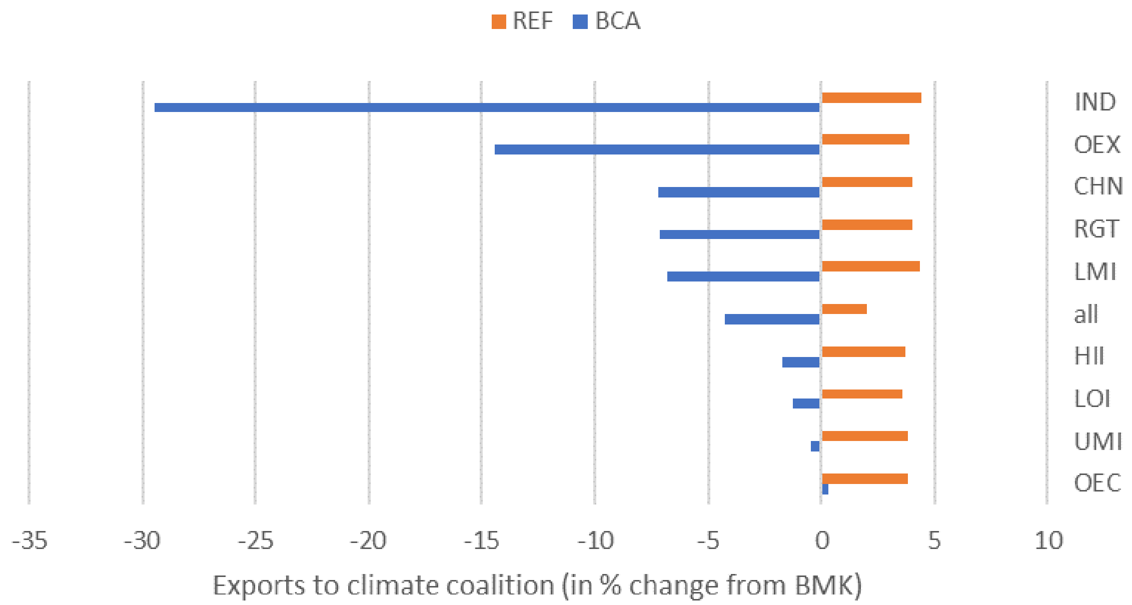
Figure 8: Net energy trade by 17 countries of the LOI composite.



The MRIO analysis can provide some guidance for potential impacts of carbon pricing based on differences in emissions intensities as well as in (value) shares of benchmark economic patterns in regional production and consumption as well as bilateral trade flows (trade integration) on different commodity markets. However, it is just static accounting without any behavioral responses which are driven by elasticities in supply and demand applied to benchmark value shares.

As a prelude to the CGE calculations which capture a broad range of substitution and income effects triggered by policy intervention, one can do a simple partial equilibrium calculation using isoelastic demand functions for EITE exports based on GTAP11 benchmark cost shares. Export demands emerge from cost-minimizing behavior of the importing region which trades off EITE goods of the same variety from other regions with its home-produced domestic variety at a constant Armington elasticity of substitution. Figure 9 reports the impacts for export demands of any non-club region to the climate club of G7 which puts a price of 75$/t$CO_2$ on emissions. The figure captures a reference situation (labeled REF) where the G7 climate club goes ahead with unilateral pricing of domestic emissions only. This provides a cost advantage to imports from outside the climate club which shows in an increase of export demands from non-G7 regions between 3-4%. As G7 levies the domestic CO2 price on the carbon embodied in scope1 plus scope2 emissions of imports, exports of non-G7 countries that have very high EITE emission intensities decrease substantially while other non-G7 countries with relatively low EITE emission intensities such as the composite of low-income countries (LOI) can still maintain some of their REF export gains. The partial equilibrium calculation is not meant to provide a closer alignment to the subsequent general equilibrium calculations but serves as a stylized example how the notion of price responsiveness may play out already in simplified terms.

Figure 9: Impacts of G7 emissions pricing on export demands from non-G7 regions



4. Computable general equilibrium framework

The standard CGE framework for the impact assessment of CO_2 reduction strategies entails a static multi-sector multi-region setting which describes regional economies through production and consumption patterns and their linkages via bilateral trade flows. The choice of a static time treatment is justified by the primary interest in the medium-run equilibrium impacts of policy interventions rather than the transitional effects. The multi-sector (multi-commodity) framework is essential to capture policy-induced structural change across heterogeneous industries and final consumption demands that differ in cost shares (emission intensities) and the ease of substituting away from emission-intensive inputs such as fossil fuels. The multi-region setting with bilateral trade flows is essential to reflect international spillover and feedback effects of emissions reduction strategies via endogenous changes in international prices, i.e., the terms of trade.

In this vein, the CGE model used for the impact assessment of BCA builds on a generic static multi-sector multi-region CGE model which has been routinely used for many years in peer-reviewed economic analyses of climate policy regulations (for early applications see Böhringer and Rutherford 2002, 2004; for more recent applications see e.g. Böhringer et al. 2018, 2021). The generic model can be refined and extended in a flexible manner to reflect a broader range of price and quantity instruments entailed by policy reforms such as alternative BCA proposals. The systematic control of policy settings facilitates insights into the cause-effect chains of alternative policy designs – both with respect to their economic (allocative) efficiency as well as with respect to their incidence across sectors and regions. The core model logic is rooted in the standard assumption of competitive markets with constant returns to scale which can be adjusted to reflect industrial organization features on imperfectly competitive markets with increasing returns to scale. Switches in structural assumptions facilitate the analysis how different perceptions of the market conduct will affect the outcome of one and the same policy measure.

The key features of the generic model framework are briefly summarized below in non-technical manner. Appendix C provides an algebraic exposition of the core model logic.

Production of goods other than fossil fuels is described by three-level nested constant-elasticity-of-substitution (CES) functions. At the top level, a material composite substitutes with a composite of value-added and energy. The second level describes the trade-off between value-added and energy. At the third level, labor and capital enter the value-added composite. At the same level, the energy goods—electricity, gas, oil, and coal —trade off in the energy aggregate. In the production of fossil fuels, the fuel-specific resources trade off with a Leontief composite of all other inputs. The top-level elasticity is calibrated to match exogenous supply elasticities for fossil fuels.

Primary factors in the model are labor, capital, and fossil fuel resources. Labor is fully mobile across sectors. The mobility of capital across sectors is limited by a constant elasticity of transformation. Fossil fuel resources are specific to the respective fossil fuel production sectors (coal, natural gas, and crude oil) in each region.

Final consumption demand stems from a representative agent (household) in each region, who receives income from primary factor earnings and transfers. Government and investment demand are fixed in real terms at base-year levels. Savings of the representative agent pay for investment while taxes pay for the provision of public goods. The representative agent maximizes consumption utility subject to a budget constraint where the consumption composite is a CES aggregate of a non-energy composite and an energy composite (both of which are formed as CES aggregates of different non-energy goods and energy goods, respectively).

CO_2 emissions are linked in fixed proportions to the use of fuels, with CO_2 coefficients differentiated by the specific carbon content of fuels (coal, gas, and refined oil). Economy-wide restrictions to the use of CO_2 emissions in production and consumption are implemented through explicit emission pricing of the carbon associated with fuel combustion either via CO2 taxes or the auctioning of CO_2 emission rights. CO2 emission abatement takes place by fuel switching (inter-fuel substitution) or energy savings (either by fuel-non-fuel substitution or by a scale reduction of production and final demand activities).

An important feature of the model is its multiregional structure which links national economies through bilateral trade flows. In this multiregional framework, international prices are endogenous and policy shocks will affect a country's terms-of-trade (measured as the ratio of a country's exports to its imports in value terms). In the core model version, countries are assumed to produce regionally differentiated goods under perfect competition with constant returns to scale (Armington 1969). The Armington composite for a traded good is a CES function of the good varieties imported from different regions and the domestically produced good variety. A balance of payment constraint satisfies the base-year trade deficit or surplus for each region.

5. Policy scenarios and simulation results

The general purpose of the quantitative simulation analysis is to demonstrate the versatility of the CGE framework for assessing the impacts of climate policies – pending both on the policy design as well as on structural assumptions for economic responses. The more specific objective is to gain insights into the incidence and efficiency implications of BCA as a complementary policy measure to unilateral emissions pricing.

5.1. Policy scenarios

Addressing the issue of BCA requires in first place a reference climate policy scenario without BCA against which one can quantify the changes once BCA are put in place.

One limitation of the GTAP11 database is that it does not include explicit CO_2 prices which may prevail in various countries already in the base-year 2017. Given that CO_2 prices in 2017 had been very low or even zero in most countries, the GTAP setting can be defended as a reasonable, yet critical assumption.[7] More rigorously, however – for reflecting the stringency of initial climate regulations – which interact with prospective policy measure, one would have to re-specify the GTAP data in a manner which does not only incorporate pre-existing CO_2 prices but also prevailing command-and-control policies such as efficiency standards.

For the present analysis the reference scenario – referred to as *REF* – is constructed as fictitious emissions pricing applied to the GTAP benchmark situation in the absence of other explicit climate policy regulations. For the sake of generality, the reference scenario depicts a generic setting where a coalition of countries undertakes domestic CO_2 pricing at a uniform price level which can be scaled to reflect alternative degrees of climate ambition.[8] The scenario *BCA*

[7] For an overview of carbon pricing initiatives over time see the World Bank Carbon Pricing Dashboard: https:/carbonpricingdashboard.worldbank.org/map_data

[8] Note that the MRIO analysis performed in section 3 is likewise based on the original GTAP data without explicit initial emissions regulations so it aligns as a descriptive starting point for the CGE analysis informing on GTAP cost and expenditure shares for 2017 which – together with elasticities – are key drivers for the simulated impacts of emissions pricing.

introduces border carbon adjustments by the coalition countries. Reflecting real-world legal constraints, BCA in the central case simulations are limited to import adjustments only.[9]

The implementation of BCA will affect emissions both by BCA sender countries, i.e. the climate coalition, as well as by all other countries outside the coalition who abstain from CO_2 emissions pricing. One key argument for BCA rooted in basic welfare economics is that BCA can help to improve the global cost-effectiveness of unilateral climate, i.e., to reduce the global economic adjustment cost for achieving a given reduction in global emissions. To investigate this proposition rigorously in a setting where the economic benefits of emissions reduction are not valued, one must keep global emissions at the level of the reference scenario. This can be implemented by an endogenous adjustment of the initial emissions prices in the coalition countries. The leakage-adjusted BCA scenario is referred to as *BCA+*.

In the counterfactual analysis, the three hypothetical climate policy scenarios contrast with a benchmark situation (*BMK*) which is provided by the GTAP11 dataset for the base-year 2017.

Table 3 summarizes the basic features of the three generic climate policies that are investigated in the central case simulations – more specific assumptions on the policy implementation which enter the sensitivity analysis for alternative policy designs are laid out in Table 4.

Table 3: Overview of generic policy scenarios

Scenario label	**Description**
BMK	Benchmark situation as reflected by the GTAP11 dataset for the base-year 2017
REF	A coalition of climate-ambitious countries undertakes unilateral (and uniform) CO_2 emissions pricing
BCA	Same as scenario *REF* but the climate coalition applies BCA to other countries
BCA+	Same as scenario *BCA* with endogenous adjustments of the CO_2 prices in coalition countries to achieve an identical global emissions reduction as in scenario *REF* (being a pre-requisite for the global cost-effectiveness analysis of border carbon adjustments)

The central case simulation adopts a stylized policy setting where the climate coalition consists of G7 countries and applies a uniform CO_2 price of 75\$/tCO_2 on emissions in domestic production and consumption (scenario *REF*). The level of the CO_2 price thereby roughly reflects the magnitude of CO_2 prices that prevailed in the EU emissions trading system as the world-largest emissions market over the last few years. In the BCA scenarios this emissions price is applied to the carbon embodied in scope1 and scope2 emissions of imports of EITE goods, i.e., iron and steel, chemical products, non-ferrous metals, and non-metallic minerals. The choices of the central case settings broadly reflect the characteristics of EU CBAM as the most advanced BCA design to be implemented in the next years.

5.2. Results of central case simulations

[9] Import adjustments are more likely to pass muster than rebates to exports (Pauwelyn 2013; Holzer 2014; Pauwelyn and Kleimann 2020). BCA on embodied carbon in imports could be justified under Article XX of the General Agreement on Tariffs and Trade (GATT), demonstrating that import levies reducing carbon leakage. Exempting exports from domestic carbon pricing prima facie increases carbon emissions which would make rebates most likely be disqualified as illegal subsidies under WTO law.

By default, all counterfactual policy effects are stated in percentage change with respect to the benchmark (*BMK*). In the exposition of regional incidence emphasis is put on low-income countries (LOI) which are placed at the top of bar charts followed by the group of lower-middle-income countries (LMI). The chart label "all" provides the world-wide average for all countries, followed by chart labels "coa" for the composite of climate coalition countries and "ncoa" for all remaining countries and regions outside the climate coalition which are potential recipients of BCA as they are not pricing CO_2. Next are the regions that form the G7 climate club which are assumed to go ahead with unilateral emissions pricing in our central case simulations: The EU (EUR) together with USA and the composite of remaining G7 countries (RG7). The rest of OECD countries (OEC) may join the climate coalition at some point given their more stringent obligations under the CBDR of the UNFCC (see sensitivity analysis on coalition sizes below). China (CHN) and India (IND) which stay outside the climate coalition are listed explicitly since they are under the TOP-3 CO_2 emitters and key G20 representatives with a substantial global trade integration and larger amounts of carbon embodied in their trade flows – rendering making them to important targets for BCA. The composite region RGT covers all remaining G20 countries (Brazil, Indonesia, Argentina, and South Africa). Regions UMI and HII refer to the World Bank categories of upper-and-middle-income countries and high-income countries, respectively. At the end of the chart list is the composite region OEX with OPEC and its 10 associated countries – the reason to put this regional composite at the more visible end of the chart is that fossil fuel exporting countries are likely to bear the highest burden of climate policies because the reduction in fossil fuel demands will have negative repercussions on international fuel prices. As pointed out in the literature review, the responses of fossil fuel markets to unilateral cuts in fuel demands are important both with respect to the incidence of unilateral regulation through international spillovers, i.e. terms-of-trade effects., as well as with respect to the global cost-effectiveness of sub-global emissions reduction strategies.

The discussion of the central case simulations results starts with the economic incidence at the regional level, followed by competitiveness implications for EITE industries, and completed by findings on global cost-effectiveness.

5.2.1. Incidence

The incidence of alternative climate policy designs are measures as Hicksian equivalent variation in income which is the standard welfare metric in economics. The Hicksian equivalent variation (HEV) in income denotes the amount of money that is necessary to add to, or deduct, from the benchmark income of the regional agents so that they enjoy a consumption utility level equal to that in the counter-factual policy scenario, on the basis of ex-ante (benchmark) prices. In the current CGE implementation with fixed (inelastic) labor supply (i.e., no labor-leisure choice) and fixed savings (i.e., exogenous investment), HEV is equivalent to changes in real consumption of the representative agent as the sole source for private utility.

Figure 10 reports the regional incidence of CO_2 emissions pricing for the three climate policy scenarios. Before addressing the economic impacts of BCA as a complementary measure to unilateral emissions pricing, it makes sense to take stock of the economic adjustment cost in the *REF* scenario where G7 price domestic emissions at 75 $/t$CO_2$ while all other countries abstain from emissions pricing.

Figure 10: Regional incidence of emissions pricing (% HEV in income)

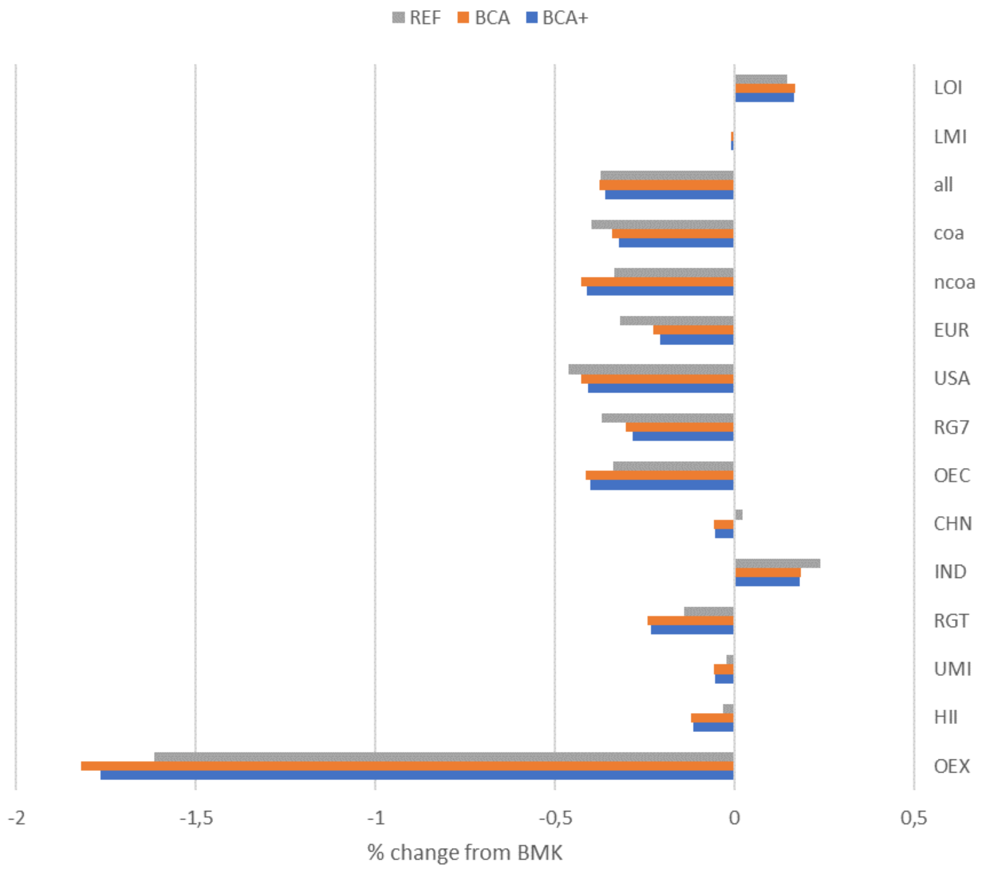
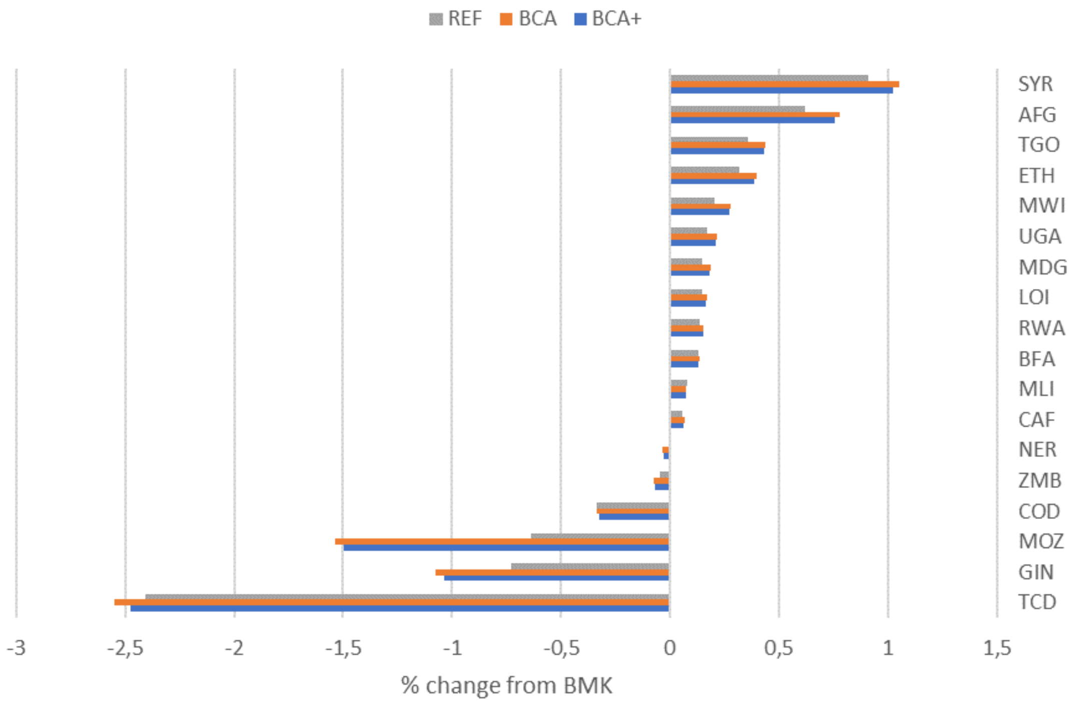


Figure 11: Incidence of emissions pricing for low-income countries (% HEV in income)



Whenever a country joins the climate club, one would expect first-round negative repercussions on its economy as domestic emissions pricing induces costly adjustment of domestic production and consumption patterns.

While adjustment cost for the climate coalition remain moderate at less than 0.5% of real income, one can observe substantial international spillover effects to other countries which are transmitted via changes in international prices for EITE products and changes in international fuel prices. On average there is a burden shifting via terms-of-trade changes from the climate coalition to the composite of non-coalition countries which in percent income losses bears comparable cost. Apart from higher export prices from the climate coalition, non-coalition countries might suffer from scale effect as economic activity and hence import demand by coalition countries decline. On the other hand, this effect can be offset by an opposite substitution effect. Non-coalition countries gain market shares in the domestic markets of coalition countries but also in domestic markets of non-coalition trading partners as their exports become more competitive. As can be seen, the incidence across non-coalition regions is quite disparate. The composite of low-income countries benefits – despite of being on average a slight net fuel exporter in the benchmark; this means that losses on fossil fuel export markets are more than offset by terms-of-trade gains in in other markets, most notable on EITE markets where LOI may gain most in comparative advantage as there EITE emissions intensities rank lowest among non-coalition countries. India also benefits from G7 emissions pricing – in particular via terms-of-trade gains as bigger fuel importer. Most pronounced are the income losses for oil-exporting countries which suffer from a depression of international fuel prices.

The imposition of a carbon levy on scope1+scope2 emissions embodied in imports from non-coalition countries has substantially smaller impacts on average as compared to the initial incidence triggered by unilateral G7 emissions pricing stand alone. The coalition countries are able to shift more of their domestic abatement burden towards the composite of non-coalition countries – carbon levies on imported carbon work could be viewed as strategic tariffs improving welfare of the climate coalition at the expense of countries outside the climate coalition; yet, the magnitude of burden shifting is rather small and unlikely to work as a credible sanction which could induce non-coalition countries to follow suit in applying similar domestic carbon prices for avoiding the cost of carbon-based tariffs. Rather striking is the observation that all countries outside the climate coalition will be burdened by import levies except for the composite of low-income countries who slightly gain as compared to the reference situation without carbon tariffs. The intuitive reasoning (to be consolidated by a more refined decomposition of substitution and income effects) is that LOI stands out for the lowest emission intensities across non-coalition countries and thereby gain most in comparative advantage with respect to EITE production.

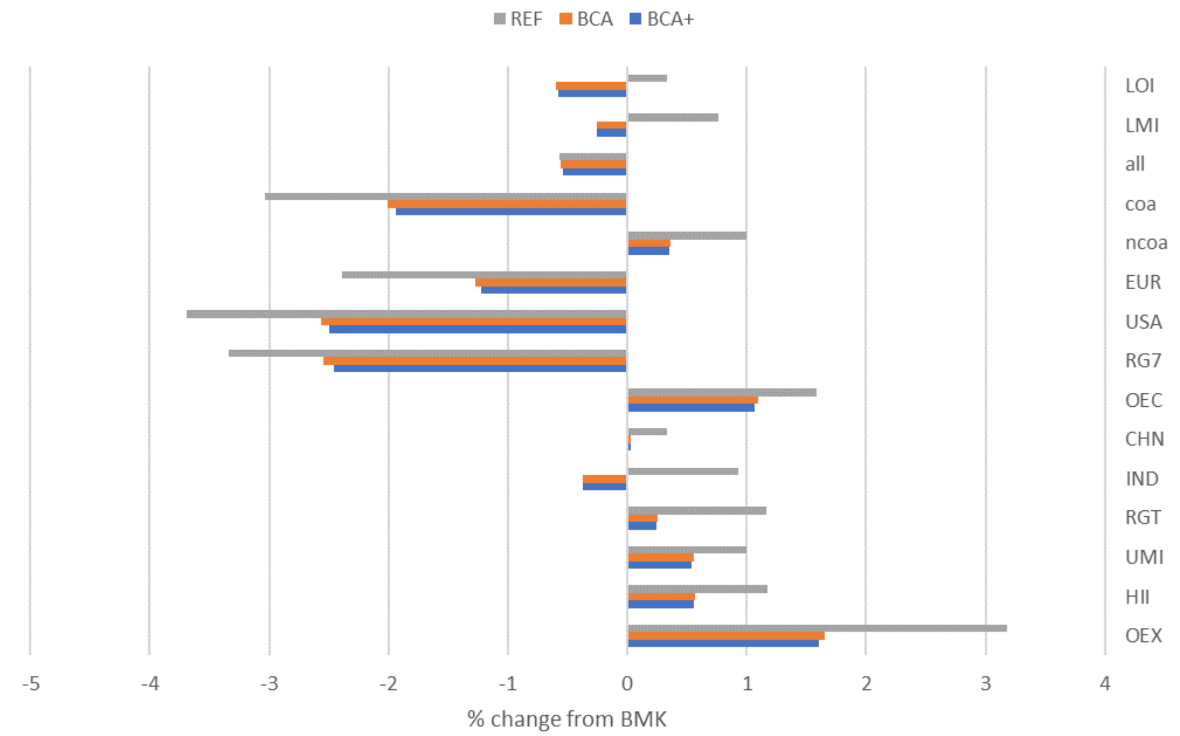
Imposition of additional carbon tariffs without accounting for environmental benefits of additional emissions reduction at the global level slightly increases global economic losses since carbon tariffs on top of unilateral emissions pricing further reduces gains from trade and specialization. However, scenario *BCA+* confirms the efficiency rationale for BCA in the context of a coherent cost-effectiveness setting, where domestic emissions pricing in G7 get re-adjusted to achieve an identical global emission level as in scenario REF. One can then see slight global cost savings from *BCA+* as compared to *REF*.

Figure 11 resolves the aggregate incidence for the composite LOI region into the incidence for its constituent low-income countries. As can be see there is a strong heterogeneity in impacts to both sides of the average impact captured by the chart label LOI. The differences are to a larger extent driven by the position of the individual country in fuel trading (see Figure 8). Syria as the biggest importer of fuels among LOI countries (in terms of the value of fossil fuel trade in % of GDP) experiences the largest welfare gains from unilateral emissions pricing stand-alone whereas Chad as the biggest fuel exporter in GDP-percentage terms is quite adversely affected. BCA as and additional regulatory measure on CO_2 induces further global emission reductions and thereby slightly amplifies the opposite terms-of-trade effects for fuel importers and fuel exporters while the differences in emissions intensities and trade integration of the individual countries drive the country-specific terms-of-trade changes on EITE markets.

5.2.2. Competitiveness of EITE industries

At the level of EITE industries the protective effect of carbon import adjustments is apparent from Figures 12 which display the changes in average EITE production across regions.

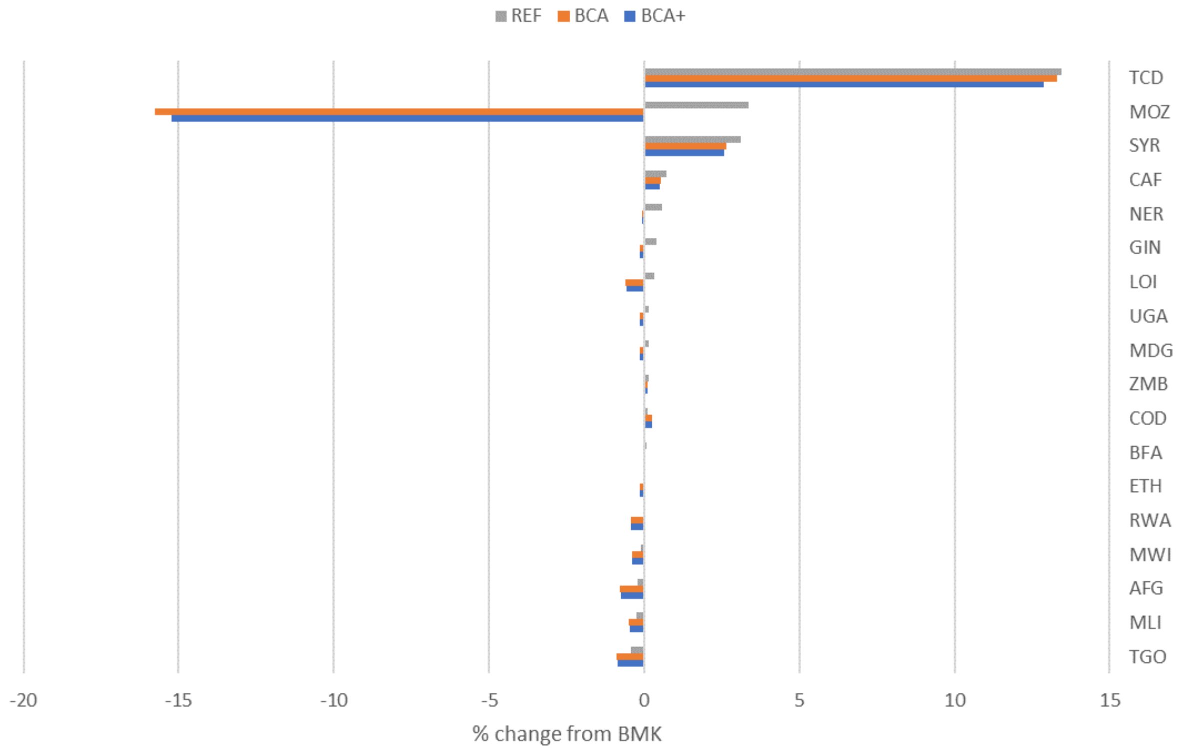
Figure 12: Changes of EITE production (% from BMK) across regions



Carbon tariffs level the playing field on the domestic market of the G7 regions as the climate coalition which prices imported goods and domestically produced goods at the same rate per ton of CO_2. Output repercussions for domestic G7 EITE industries can be significantly attenuated while the initial gains in comparative advantage for non-coalition countries get significantly curbed. Nonetheless, non-coalition countries keep on average a higher output level as compared to the benchmark situation. This reflects the limitation of BCA applied toe EITE imports only – without export rebates to G7 exports the non-coalition countries remain more "competitive" on foreign EITE markets outside the coalition

Figure 13 disentangles the composite EITE output effect for the LOI composite as a whole into specific output changes for EITE industries in the individual low-income economies. A striking insight from this decomposition is that output performance on EITE markets is a bad indicator for the welfare implications at the economy-wide level which becomes quite evident for the case of Chad where the dominant driver of incidence are changes in the terms-of-trade for fossil fuels.

Figure 13: Changes of EITE production (% from BMK) across low-income countries



5.2.3. Global cost effectiveness

The mainstream economic argument in favor of BCA is based on global cost effectiveness considerations as BCA are destined to reduce counterproductive leakage through the competitiveness channel. Figures 14 and 15 report emissions reductions and carbon leakage rates for the central case setting. As usual, leakage is reported in terms of leakage rates, which quantify the change in foreign emissions relative to domestic emission reduction as a direct consequence of unilateral emissions pricing. For example, a leakage rate of 50% would indicate that half of the domestic emissions reduction is offset by an increase in emissions abroad.

Uniform emission pricing in G7 countries at 75$/t$CO_2$ leads to emissions reduction across coalition countries of more than 20% which however boils down to just 6% of global emissions reduction reflecting counterproductive carbon leakage but much more the mere fact that G7 countries are just responsible for less than a third of global emissions in the benchmark. All countries outside the CO_2 pricing coalition increase their domestic emissions as compared to the benchmark situation without any CO_2 pricing (so there is no instance of negative carbon leakage in the central case setting). Overall leakage for the case of unilateral G7 emissions pricing only (scenario *REF*) amounts to ca. 11% with China being the major source of leakage and low-income countries as the minor source. Carbon levies on imports reduce leakage to ca. 8.5% that is by around 20%.

From an efficiency perspective the results confirm findings from the literature on the rather limited potential of BCA to improve global cost-effectiveness of unilateral emissions pricing. The reasons are clear: First, a larger part of leakage emerges from the fossil fuel market channel (see sensitivity analysis below) which cannot be targeted by demand-side measures such as BCA. Second, the coverage of foreign emissions through BCA is limited by the choice of the carbon metric and the sectors (commodities) which are subject border adjustments -- in the central case setting the emissions embodied in scope1+scope2 EITE imports from non-coalition countries to the G7 climate club amounts to just 3.1 % of emissions in G7 and 1.4% of emissions in non-coalition countries (see Figure 6). Third, recipient countries re-route part of their exports from coalition countries to non-coalition countries. Fourth, carbon levies that work at the average of EITE industries do not provide incentives for individual firms to reduce emissions by adopting cleaner technologies – they simply work as a blunt bilateral tariff on exported EITE goods with an ad-valorem equivalent of just 5% in the central case setting.

Figure 14: Changes in CO_2 emissions (% from BMK)

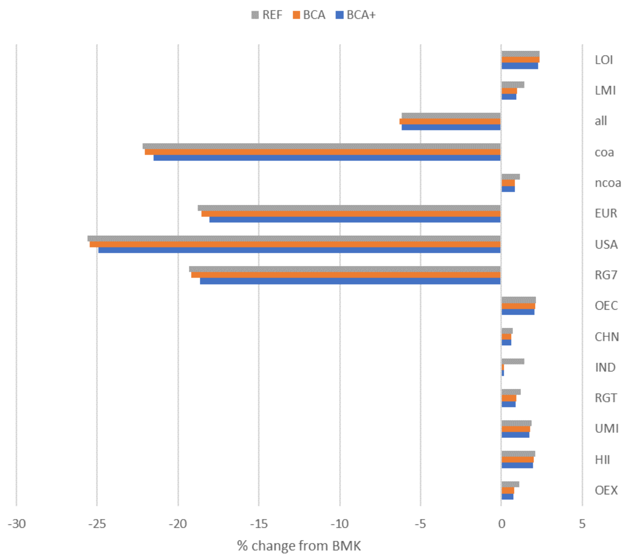
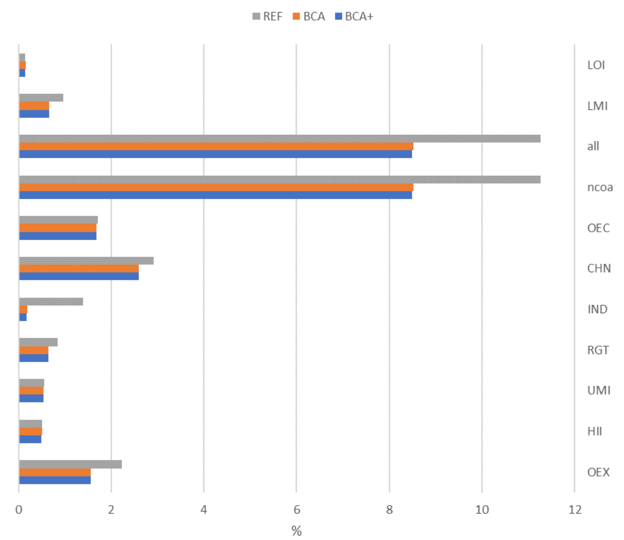


Figure 15: Leakage rates by non-coalition regions (in %)



6. Sensitivity analysis

For a given benchmark dataset – here: GTAP11 with the base-year 2017 – the flexible CGE framework allows to investigate how policy impacts depend on specific policy design features as well as on structural assumptions about market mechanisms.

The illustrative sensitivity analysis with respect to policy design covers (i) the stringency of unilateral emissions pricing, (ii) the coverage of regions undertaking unilateral CO_2 pricing,

(iii) the carbon metric for import levies (and potential export rebates), and (iv) alternative compensation options for BCA recipients such as the revenue recycling of carbon levies to BCA recipients or the exemption of specific country groups (here: low-income economies) from BCA.

The illustrative sensitivity analysis with respect to structural market assumptions covers (i) the responsiveness of trade in EITE goods , (ii) the responsiveness of fossil fuel supply, and (iii) productivity impacts across heterogeneous firms in EITE industries.

Table 4 summarizes the different variants for the designs of unilateral emissions pricing as well alternative structural assumptions with respect to EITE and fossil fuel markets. The central case simulation adopts the settings which are marked in bold.

Table 4: Parametrization of altermatic climate policy designs and structural assumptions

Dimension	**Description**	**Variants (labels and parametrization)**	
		Policy Design	
Size of climate coalition	Countries which undertake harmonized CO_2 emissions pricing and consider BCA ranging from *EUR* via *G7* to *OECD*	*EUR* ***G7*** *OECD*	EUR (EU-27) EUR, USA, RG7 EUR, USA, RG7
Stringency of CO_2 pricing	Level of domestic CO_2 price ranging from 50 to 75 to 100 $/t$CO_2$ in the climate coalition which may also apply to BCA	*50* ***75*** *100*	50$/t$CO_2$ 75$/t$CO_2$ 100$/t$CO_2$
Embodied carbon metric	CO_2 content to which BCA applies: either scope2 or scope1-2 or scope 1-3	*s1* ***s1+s2*** *s1+s2+s3*	scope1 scope1-2 scope1-3
Export rebates	BCA include export rebates (no/yes)	***no*** *yes*	no export rebates export rebates
Compensation	Revenues from carbon levies accrue to BCA sender (*no*) or BCA recipients (*verbta*); low-income economies (LOI) may get exempt from BCA (*exempt*)	***no*** *verbta* *exempt*	Revenues to BCA sender Revenues to BCA recipients BCA exemption for LOI
		Structural assumptions	
EITE trade responsiveness	Armington trade elasticities determine the substitution possibilities across ETIE goods from different regions	*lo* ***REF*** *hi*	0.5**REF* values *REF* values 2**REF* values
Fuel supply responsiveness	Fossil fuel supply elasticities determine how fuel supplies react to changes in fuel prices	*lo* ***REF*** *Hi*	0.5**REF* values *REF* values 2**REF* values
EITE market conduct	EITE markets can be treated as CRTS under perfect competition à la Armington (*arm*) or as IRTS on imperfectly competitive markets à la Melitz (*mel*)	***arm*** *mel*	CRTS IRTS

The piecemeal sensitivity analysis focuses on one-dimensional changes in the central case settings thereby focusing on the implications of isolated single variations in assumptions for policy design and market structure. More comprehensive sensitivity analysis – e.g. as the cross-combination of all variants in the different scenario dimensions (here: YYYY) – can be useful in assessing how the different dimensions interact and can be ranked in their relative importance. However, it should be noted that the economic relationships in the CGE model are fundamentally of non-linear nature such that the sequence of changes in assumptions matter for their respective relative contribution to the final overall outcome – in other words the decomposition of nonlinear impacts is path-dependent (see Böhringer and Rutherford 2004 for potential techniques to address this path dependency).

Results from the sensitivity analysis focus on regional incidence and global cost-effectiveness as the key indicators for identifying potential trade-offs between economic efficiency and equity. For the sake of transparency and compactness, region-specific results are selected for the composite of developing countries that constitute the low-income economies (LOI) and the cartel of oil-exporting regions OPEC+10 (OEX) as these two country groups may be particularly sensitive to spillover effects from unilateral emissions pricing in the industrialized world. China and India as the major G20 representatives that keep outside the climate coalition are listed as well – both because they are outspoken opponents of BCA and because they are central to future climate negotiations as major CO_2 emitters. Furthermore, the regional composites of coalition countries (coa) and non-coalition countries (ncoa) together with the global average (all) facilitate insights into burden-shifting and global cost-effectiveness of unilateral climate policies. The impacts of border carbon adjustments are reported through scenario *BCA+* as this scenario keeps global emissions exactly at *REF* emissions levels – the differences between BCA and BCA+ are rather small across all scenario variants such that there is no change in insights.

6.1. Policy design

6.1.1. Size of climate coalition (Figure 16)

Figure 16 reveals how changes in the coalition size affect the burden shifting potential of unilateral emissions pricing stand-alone as well as for BCA.

As the size of the climate coalition increases, the economic adjustment cost of unilateral emissions pricing (*REF*) increase for the climate coalition and the world economy as a whole. The cost increase reflects the more comprehensive nature of emissions constraints imposed on production, consumption and trade patterns. The burden shifting potential from the climate coalition to the composite of non-coalition countries increases in the size of the coalition as the bigger coalition has a broader coverage of international trade with associated spillovers effects to countries outside the coalition. This applies both to unilateral emissions pricing only as well as to the use of BCA on carbon embodied in imports from non-coalition countries – the scope for re-routing as an evasion channel to carbon levies shrinks with the coalition size .

At the single region level, the most notable results is that the composite of low-income economies (LOI) is adversely affected from unilateral emissions pricing for the EU acting as the climate coalition whereas it benefits from international spillover effects as the coalition expands to G7 or OECD – the reasoning behind are the changes in trade integration of LOI with respect to the different coalitions which play out in differential impacts via spillover effects on EITE and fossil fuel markets.

6.1.2. Stringency of CO_2 emissions pricing (Figure 17)

Figure 17 shows how changes in the level of CO_2 prices adopted by the G7 climate coalition translates into welfare changes across regions. Results of the central case simulation with a price of 75€/tCO_2 get monotonously scaled down (up) for lower (higher) carbon prices. India and the composite of low-income countries (LOI) benefit from an increase in G7 emissions prices due to stronger terms-of-trade effects on the fossil fuel market as the primary driver for India and the increase in competitiveness of EITE production as the primary driver for LOI. Among non-coalition countries, LOI is the single region that benefits from the imposition of BCA reflecting the low emission intensities in EITE production which amplifies competitiveness gains as compared to other non-coalition countries with substantially higher emission intensities.

6.1.3. *Embodied carbon metric (Figure 18)*

Figure 18 provides insights how an increase in the metric for carbon embodied in EITE imports from non-coalition countries affects changes the incidence of BCA across regions. By definition, the results from the *REF* scenario do not change as no BCA apply. As expected, one can see that the BCA incidence gets amplified as carbon levies are applied to a larger share of emissions embodied in imports.

6.1.4. *Export rebates (Figure 19)*

Figure 19 displays the differential impacts of BCA as domestic EITE industries in the G7 coalition get rebated their carbon payments for exports to non-coalition countries. Interestingly, this works on average in favor for non-coalition countries. The reasoning behind is that with leakage-adjusted BCA the effective CO_2 price in coalition countries declines which reduces burden shifting – global efficiency gains from BCA albeit very small accrue effectively rather to the composite of non-coalition countries than to the climate coalition.

6.1.5. *Compensation (Figure 20)*

Figure 20 shows how the incidence of BCA changes as carbon levies on EITE imports are not retained by G7 but handed back to the exporting non-coalition regions. Effectively, this setting is equivalent to voluntary restraints for EITE exports from non-coalition regions to the emissions pricing coalition. Obviously, such a "lump-sum" transfer reduces the burden of BCA for countries that suffered initially from adverse spillover effects and increases the benefits from BCA for countries that benefited from BCA. The welfare gains for the composite of non-coalition countries are substantial, making them better of as compared to the reference situation – however, a substantial part of burden shifting from unilateral emissions pricing in the G7 climate coalition still remains. Exempting EITE imports from low-income economies into the climate coalition from BCA is beneficial for the composite of these countries (LOI) while it has negligible implications for all other regions. Note that the global environmental effectiveness must be warranted for these exemptions as well but the share of exempted EITE emissions of LOI in global emissions is so small that adjustments for other countries via the endogenous scaling of emissions pricing in the coalition countries are hardly noticeable.

6.2. Structural assumptions

6.2.1. *Trade responsiveness (Figure 21)*

Responsiveness in EITE trade is governed by the choice of Armington elasticities for EITE goods. The higher these elasticities are, the easier countries outside the climate coalition can substitute costly EITE exports from coalition countries with domestic varieties or with varieties imported from other non-coalition countries. The burden shifting potential of emissions pricing via the competitiveness channel gets attenuated towards higher Armington elasticities which shows up in higher adjustment cost for the composite of coalition countries and lower cost for the composite of non-coalition countries in scenario

REF. BCA have more potency for higher Armington elasticities to redirect trade flows effect and thereby amplify the burden shifting potential to non-coalition countries on average.

6.2.2. *Fossil fuel market response*

Fossil fuel supply elasticities rule the price responsiveness of fossil fuel production. The lower these elasticities, the more pronounced is the price reaction to a fall in fuel demand in coalition countries. Consequently, spillover effects via the fossil fuel channel get amplified towards lower elasticities. Countries that are fuel importers will benefit from lower fuel supply elasticities, while countries that are fuel exporters will be worse off. As BCA above all affect the competitiveness channel, their implications are rather robust with respect to changes in fossil fuel supply elasticities.

6.3. Leakage and global cost-effectiveness

Table 5 provides a summary of how alternative assumptions on the design of BCA policies and structural assumption on the market conduct affect leakage and global cost-effectiveness of unilateral emissions pricing. A key determinant for leakage is the coalition size. The smaller the coalition is, the higher is the leakage rate as the scope for leakage increases (decreases) with the number of countries outside (inside) the climate coalition. Leakage rates in the reference scenario (REF) increase with the value of Armington elasticities via the competitiveness channel due to stronger relocation of EITE industries from regulated countries to non-regulated countries. Likewise, leakage rates increase towards less elastic fuel supplies via the fossil fuel market channel as a stronger depression of international fuel prices for a given reduction in fossil fuel demands of coalition countries spurs more fuel consumption in non-regulated countries. Leakage through the fossil fuel channel tends to be dominant as can be seen in the final row of Table 5 which reports results from an additional scenario (labeled 'constant prices') where fossil fuel producers ration their fossil fuel supplies to keep real fossil fuel prices at the benchmark level. In this case leakage even becomes negative. While BCA applied to emissions embodied in EITE imports are able to reduce leakage through the competitiveness channel by a substantial amount (see the fourth column of Table 5 which reports the reduction of leakage via BCA in relation to leakage in the *REF* situation), the global cost savings remain very limited (see the final column in Table 5 which reports global cost savings from BCA in relation to global adjustment cost for the reference scenario).

Figure 16: Regional incidence as a function of the climate coalition size

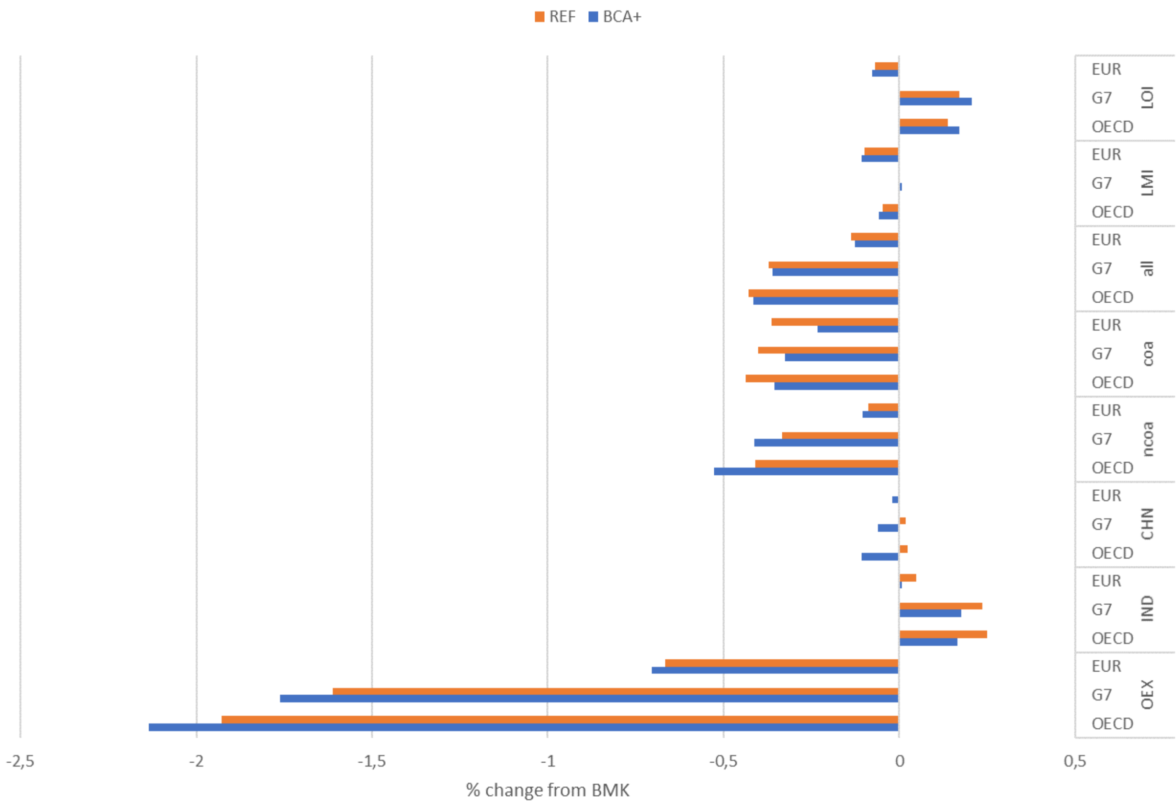


Figure 17: Regional incidence as function of the unilateral CO_2 emissions price

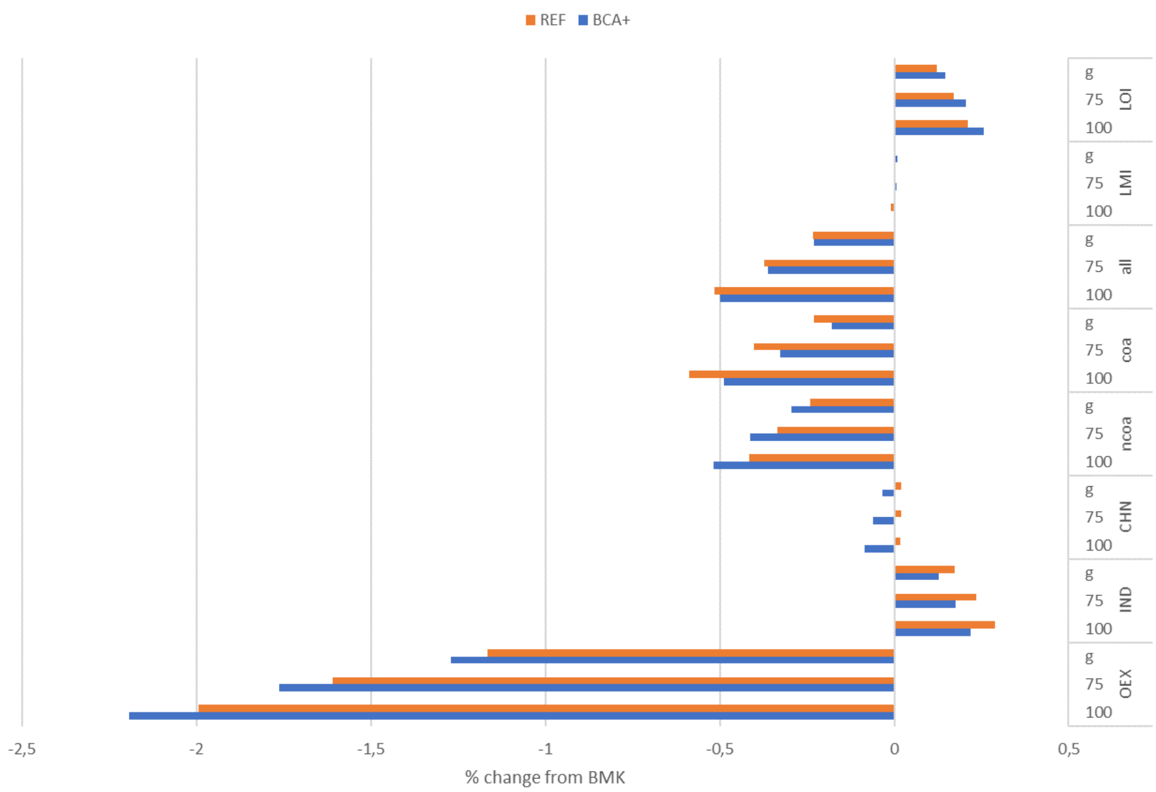


Figure 18: Regional incidence as function of the embodied carbon metric

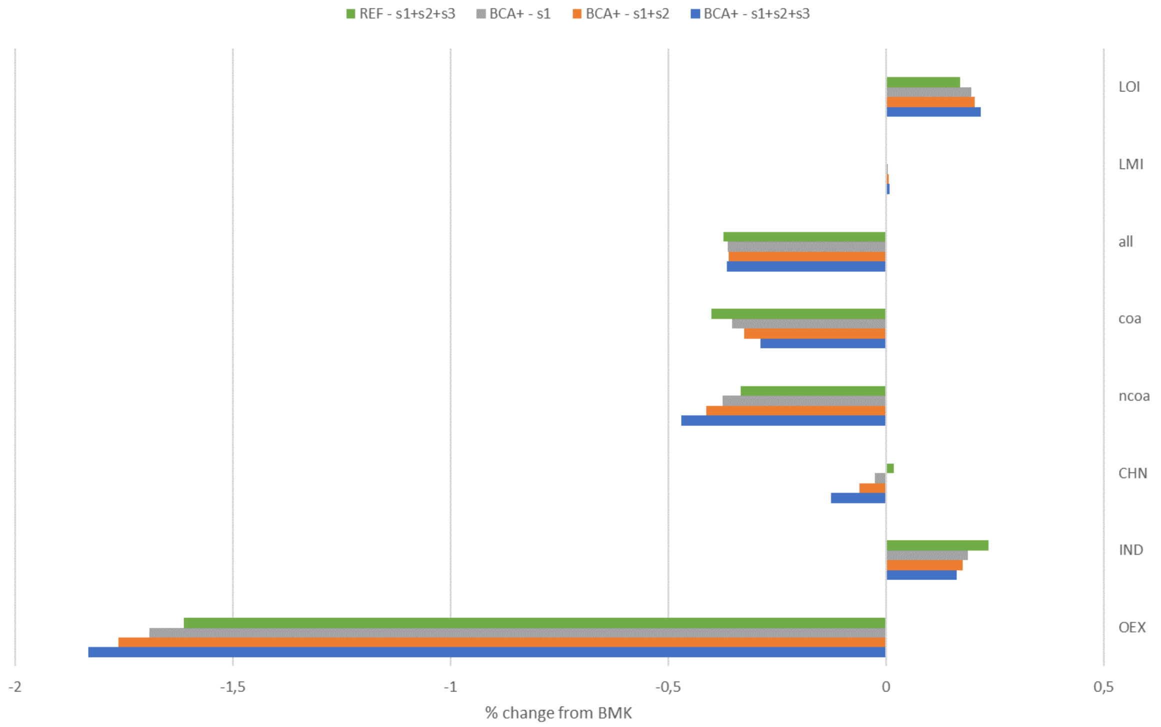


Figure 19: Regional incidence with and without export rebates

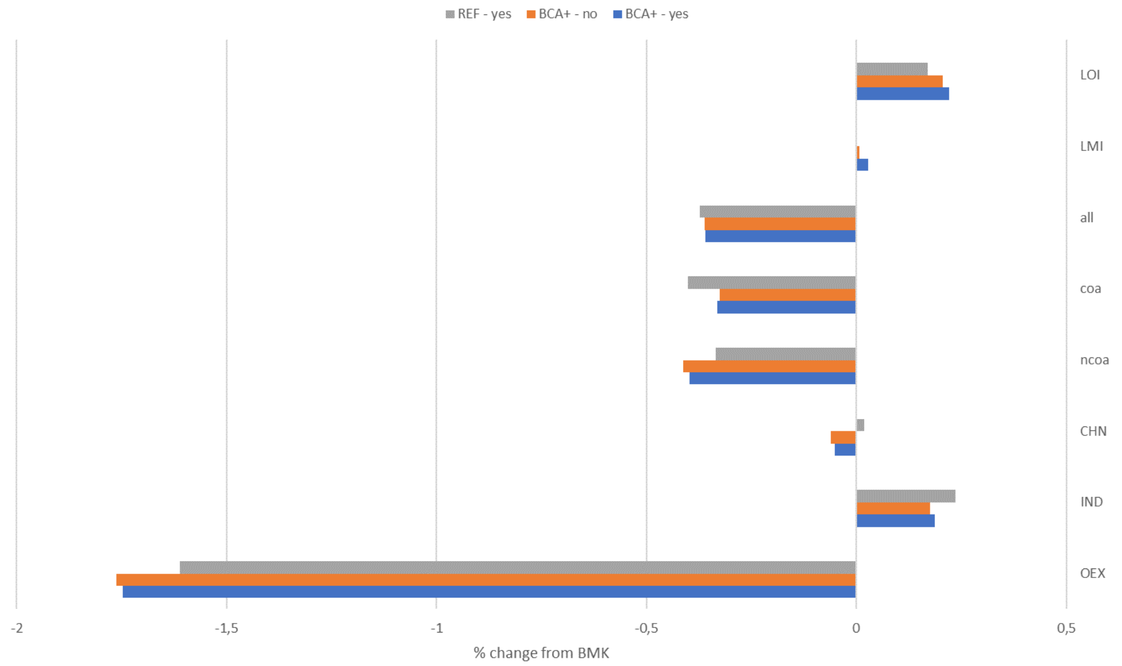


Figure 20: Regional incidence with tariff transfers (*verbta*) to BCA recipients or BCA exemptions for low-income economies (*exempt*)

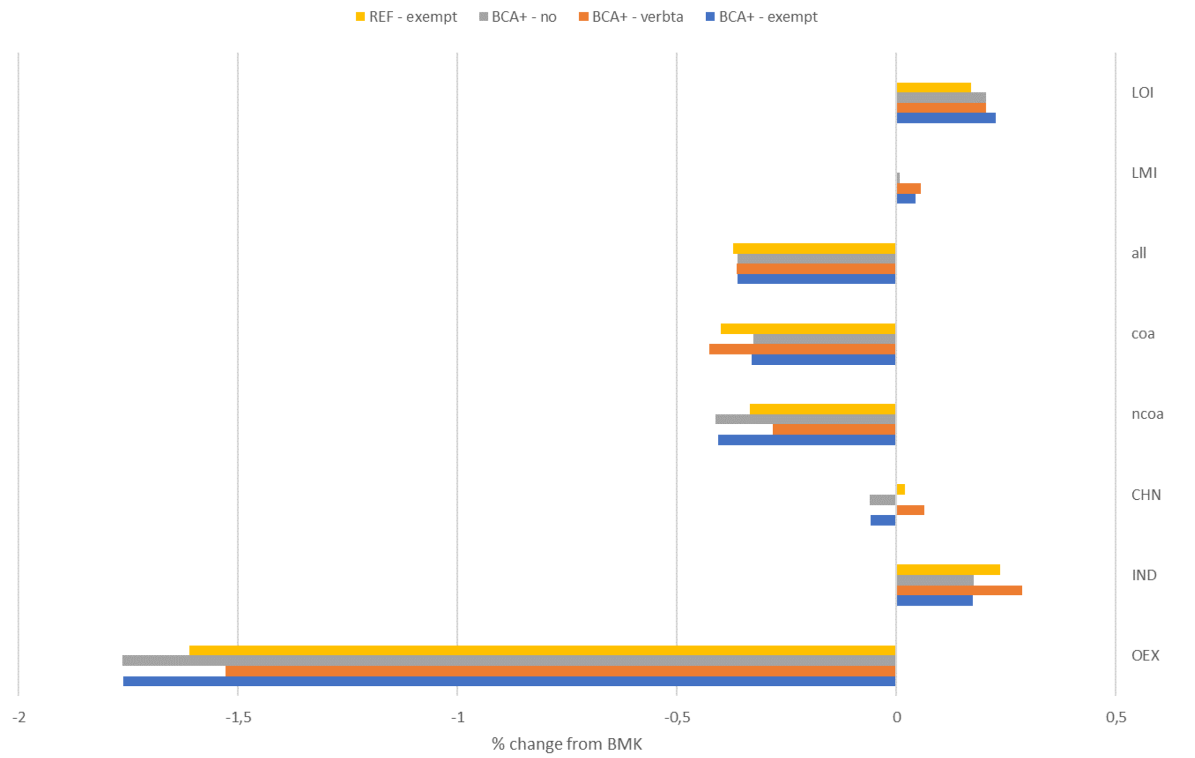


Figure 21: Regional incidence for changes in trade responsiveness (Armington elasticities)

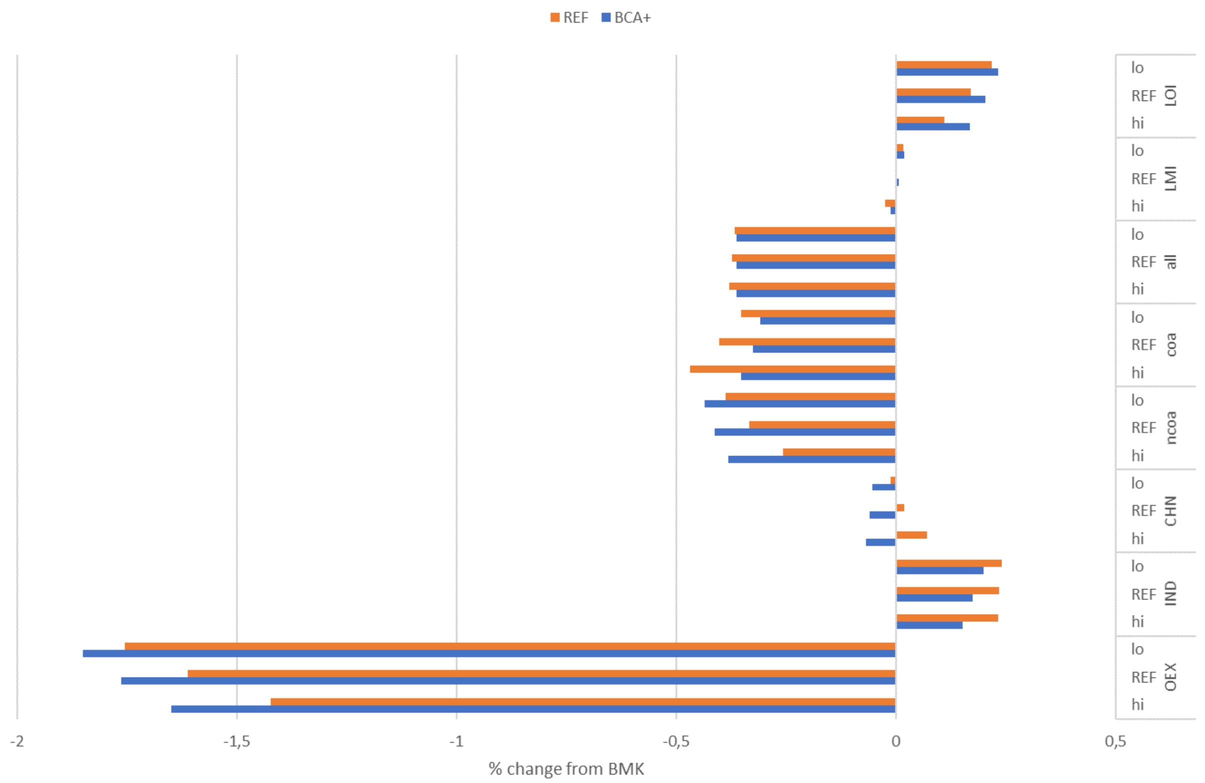


Figure 22: Regional incidence with changes in fossil fuel supply responsiveness

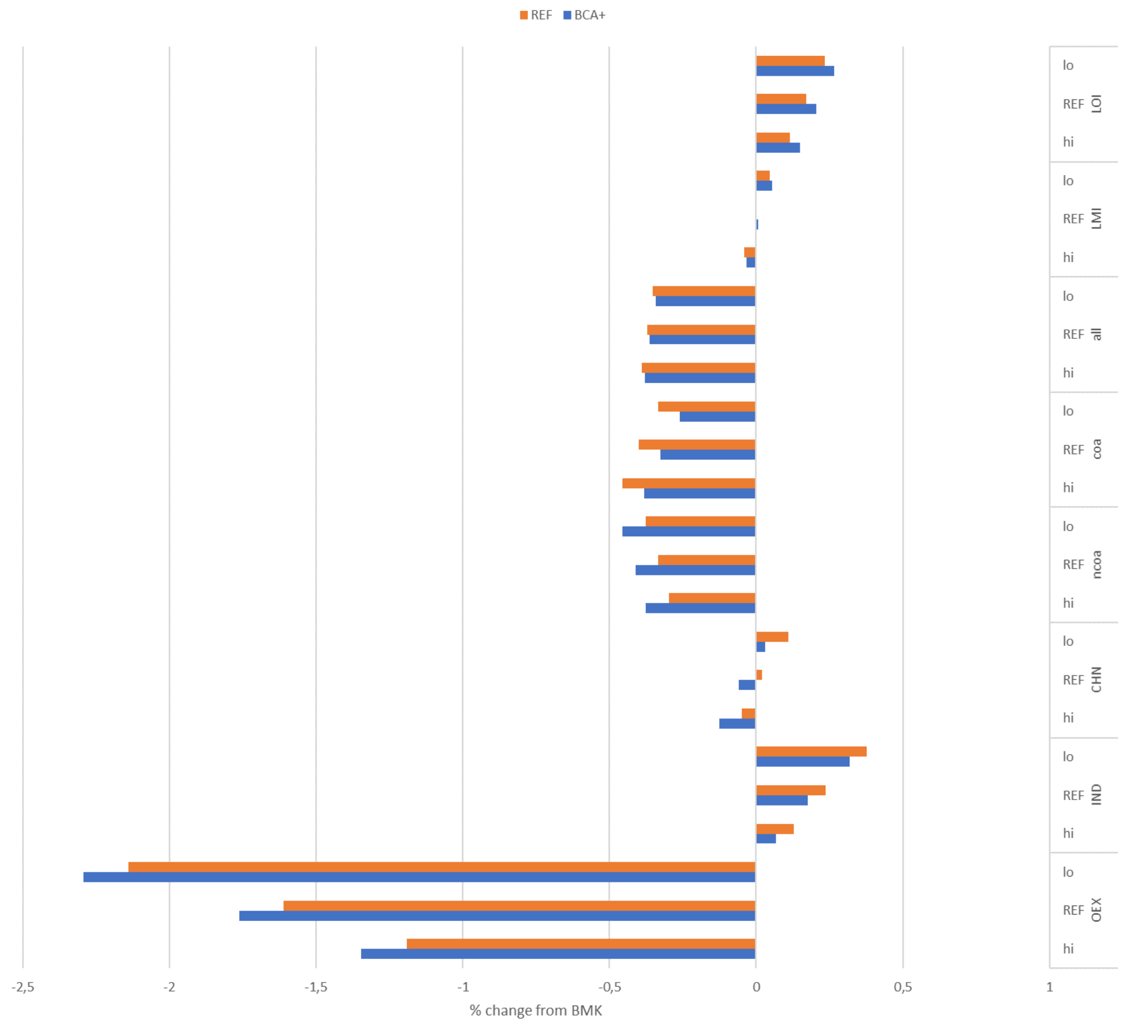


Table 5: Leakage reduction and global cost savings from BCA

		Leakage (%)	Leakage (%)	Leakage reduction	Global cost savings
		REF	*BCA+*	*BCA+* vs. *REF* – (in %)	*BCA+* vs. *REF* (in %)
Coalition size	*EUR*	21,1	16,5	-21,9	6,6
	G7	11,2	8,7	-22,8	2,7
	OECD	10,4	7,6	-27,1	2,8
CO_2 price	*50*	10,9	8,4	-22,5	2,1
	75	11,2	8,7	-22,8	2,7
	100	11,5	8,9	-23,1	2,9
Carbon metric	*s1*	11,2	9,4	-16,4	2,4
	s1+s2	11,2	8,7	-22,8	2,7
	s1+s2+s3	11,2	7,8	-30,7	1,9
Rebates	*no*	11,2	8,7	-22,8	2,7
Rebates	*yes*	11,2	8,4	-24,9	3,5
Compensation	*no*	11,2	8,7	-22,8	2,7
	exempt	11,2	8,8	-21,6	2,4
	verbta	11,2	8,8	-21,2	2,2
Trade response	*lo*	10,1	8,6	-15,0	1,4
	REF	11,2	8,7	-22,8	2,7
	hi	12,9	8,9	-30,7	4,0
Fuel supply response	*lo*	19,5	17,1	-12,3	2,6
	REF	11,2	8,7	-22,8	2,7
	hi	6,0	3,4	-43,5	2,6
	**constant prices*	*-2,1*	*-6,2*	*189,1*	*2,8*

7. Concluding remarks

BCA as an instrument to foster competitive neutrality and reduce carbon leakage has gained substantial policy momentum over the last years. Most notably, the European Union has passed a Carbon Border Adjustment Mechanism (CBAM) starting in 2027 with import charges to EITE goods regulated through its emissions trading system. Other countries such as Canada and the USA are equally considering border adjustment taxes on carbon-intensive imports from countries that lack climate policy action.

Despite its apparent appeal, BCA are heavily disputed both in the climate policy arena as well as in the scientific community. The reasoning behind is that BCA may not only increase the risk of international trade conflicts and undermine cooperation in international climate policy. The effectiveness of BCA to reduce leakage and foster global cost-effectiveness of unilateral action can be quite limited. At the same time, BCA may shift substantial parts of the economic burden of emissions reduction via changes in terms of trade from regulating (richer) countries to unregulated (poorer) regions, in particular to developing and emerging countries. Such redistributive effects would stand in stark contrast to the commonly accepted United Nations' principle of common but differentiated responsibilities.

To shed further light into the potential economic and environmental impacts of unilateral emissions pricing and the use of BCA as supplemental instrument, there is the need for quantitative ex-ante simulation analysis.

This paper has presented a canonical computable general equilibrium (CGE) model designed for the impact assessment of climate policies and calibrated to most recent multi-region input-output data as empirical foundation. The CGE model has been used for the systematic sensitivity analysis of key drivers for the magnitude and distribution of economic adjustment cost triggered by unilateral emissions pricing. These drivers include specific design features of BCA proposals for climate coalitions of different sizes and different emissions pricing levels as well as variations in structural assumptions on the conduct of EITE markets and fossil fuel markets which are essential to capture international spillover effects from unilateral climate action. A robust insight from the sensitivity analysis is that global cost savings from the use of BCA are rather small and contrast with larger redistributive effects which may work at the expensive of poorer countries outside the abatement coalition. At the same time, the results point to the importance of heterogeneity across sectors and regions to come up with robust conclusions on which countries should be afraid of BCA and which countries outside the abatement coalition might be even benefit from BCA. The current analysis indicates that the latter is the case for the composite region of low-income countries due to their rather low emissions intensities of EITE products. At the same time, the analysis points to the critical importance of capturing country heterogeneity as there is a big spread in incidence across individual low-income countries ranging from to pronounced winners to pronounced losers with the net-trade position on fossil fuel markets as an important determinant beyond the country's specific EITE emissions intensities and EITE trade integration.

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