Energy Economics 142 (2025) 108139

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneeco

Winners and losers of the EU carbon border adjustment mechanism. An intra-EU issue?

Marco Amendola

Department of Industrial and Information Engineering and Economics, L'Aquila University, L'Aquila, Italy

ARTICLE INFO

JEL classification:
C67
F18
Q58

Keywords:
EU CBAM
Carbon border adjustment mechanism
Burden shifting
Input–output
Carbon leakage

ABSTRACT

The paper develops a Multi-Regional Input–Output analytical framework to study the EU's recently adopted carbon border adjustment mechanism (CBAM). This policy introduces carbon tariffs to replace free allowances in several Emission Trading System (ETS) industries to reinforce and extend the EU carbon price signal while mitigating the risk of carbon leakage. Yet, the policy has prompted immediate international equity concerns, particularly regarding its potential burden-shifting effect, especially on low-income countries. In this context, the analysis provides a comprehensive examination of the distributional impacts of the EU CBAM, shedding light on the countries and industries most affected by the policy. Contrary to the apprehensions, the findings indicate limited evidence of burden shifting, with such a phenomenon being confined to a few specific geographical areas and industries. Instead, the results unveil more pronounced redistributive impacts within the EU, with certain Eastern EU countries facing particular losses from replacing free allowances with CBAM. Adverse competitiveness effects and carbon leakage in various downstream industries are also identified.

1. Introduction

In May 2023, the European Union formally embraced a carbon border adjustment mechanism (CBAM) to complement the more ambitious climate policies outlined in the "Fit-for-55" package and, more broadly, within the EU Green Deal (EU, 2023). The policy introduces carbon tariffs on specific imports, aiming to align the carbon prices of domestic products and imports and level the playing field between domestic and foreign firms in the European Union territory (EC, 2021). The CBAM is strategically crafted to strengthen the carbon price signal within the European economy and extending it to exporters to the EU, gradually replacing the free allocation of emission allowances in various sectors under the Emission Trading System (ETS). More generally, the policy is perceived as a unilateral step toward implementing more aggressive climate mitigation policies in the EU, even without global coordination on climate action.

A CBAM, in fact, purports to solve several problems associated with climate policies that fail to coordinate at a global level. Major issues of unilateral climate policies are the potential adverse competitive effects suffered by regulated domestic firms in international markets and the risk of carbon leakage (Hoel, 1991; Felder and Rutherford, 1993).

Carbon leakage occurs whenever implementing a climate policy in one jurisdiction increases emissions abroad, thus risking jeopardizing the environmental benefits of unilateral actions. Several carbon leakage channels have been identified in the literature (Dröge et al., 2009; Cosbey et al., 2019). A primary channel is associated with competitiveness, eventually arising from a shift in international trade patterns that favor producers in regions not adopting climate policies. Over the long term, some domestic firms may also relocate their production processes abroad to avoid domestic climate policy. A second relevant channel is through changes in fossil fuel prices. If successful climate policies reduce demand for fossil fuels in regulated markets, international fossil fuel prices may drop, encouraging fossil fuel consumption in non-regulated regions and markets.

Support for carbon leakage is typically found in ex ante numerical simulations. Analyses based on Computable General Equilibrium (CGE) models generally suggest a carbon leakage rate ranging from 5% to 30% (e.g., Böhringer et al., 2012a; Branger and Quirion, 2014; Carbone and Rivers, 2017). Higher leakage rates have been suggested by sector-specific models, as summarized by Böhringer et al. (2022). Empirical evidence is more scant and mixed, with several analyses failing to find clear evidence of carbon leakage (Branger et al., 2016; Naegele and Zaklan, 2019; Verde, 2020; Misch and Wingender, 2021). However, it is important to recognize that the historically low carbon prices and the generous free allocation of allowances likely explain the limited empirical evidence supporting carbon leakage, particularly in analyses of the early phases of the EU ETS (Joltreau and Sommerfeld, 2019; Verde, 2020; Böhringer et al., 2022).

E-mail address: marco.amendola2@univaq.it.

https://doi.org/10.1016/j.eneco.2024.108139
Received 12 February 2024; Received in revised form 4 November 2024; Accepted 10 December 2024
Available online 27 December 2024
0140-9883/

The CBAM has long been advocated as a means to prevent carbon leakage by safeguarding the competitiveness of domestic firms. Simulation models, particularly CGE models, generally demonstrate the effectiveness of the CBAM in reducing carbon leakage. For example, Böhringer et al. (2012a) found that the CBAM can reduce carbon leakage by about one-third, while according to Branger and Quirion (2014) the average reduction is about one-half. The literature also delves into various implementation details of the CBAM, such as the comparison between a comprehensive CBAM encompassing both import tariffs and export rebates and a CBAM relying solely on carbon tariffs (e.g., Elliott et al., 2010; Böhringer et al., 2012a; Branger and Quirion, 2014; Böhringer et al., 2018; Fontagné and Schubert, 2023). Despite a full CBAM has been frequently identified as more effective in reducing carbon leakage, several analyses have shown that for advanced countries, that typically are net carbon importers, carbon tariffs generally dominate export subsidy (e.g., Böhringer et al., 2012a). In addition, concerns have often been advanced regarding potential conflicts between export rebates and the World Trade Organization's Agreement on Subsidies and Countervailing Measures. More generally, the compatibility of the CBAM with international trade agreements has been deeply discussed in the literature (e.g., Demaret and Stewardson, 1994; Holzer, 2014). The benefits and costs of expanding the sectoral scope of the CBAM beyond the Emissions Intensive Trade Exposed (EITE) sectors have also been frequently investigated and discussed in the literature (e.g., Böhringer et al., 2012b, 2018; Parry et al., 2021). Analyses on the optimal carbon tariffs have also been developed, with several studies arguing for tariffs below internal carbon price (e.g., Böhringer et al., 2018; Balistreri et al., 2019).

Another strand of literature focused on the potential impact of a CBAM adopted by advanced countries on non-adopting countries. Numerous analyses indicate that such a policy shifts a significant share of the transition costs to developing countries. For instance, Böhringer et al. (2012a) assess the adoption of a carbon border adjustment mechanism to complement domestic climate policies in various industrialized countries. Results from diverse CGE models suggest a notable decline in GDP in non-adopting regions, primarily stemming from a deterioration in their terms of trade. Yet, there is considerable heterogeneity among non-adopting countries, with adverse effects concentrated in fuel-exporting regions, while some countries gain from the policy. Lanzi et al. (2012) utilize a CGE model to explore similar policy scenarios, finding that, overall, the percentage welfare losses (measured as Hicksian equivalent variation) induced by carbon pricing policies are more pronounced in non-adopting countries than in adopting ones. This discrepancy becomes more pronounced when a carbon border adjustment mechanism is introduced. Ghosh et al. (2012) employ a CGE model and demonstrate that the burden-shifting effect substantially depends on the size and the specific countries composing the adopting coalition. For instance, if the EU is the sole region adopting a carbon price and CBAM, the burden-shifting effect is modest, with most of the welfare losses experienced by the EU. Using a CGE model, Böhringer et al. (2018) find that the primary welfare effect of carbon tariffs applied by OECD countries is to transfer the burden to the developing world. The burden is entirely shifted to non-OECD countries when carbon tariffs are based on the full embodied carbon content. Böhringer et al. (2021) simulate a CGE model, assuming a uniform carbon price in the OECD countries, eventually combined with a carbon tariff on EITE sectors. Results indicate a significant burden shifting to non-OECD countries even without carbon border adjustment mechanisms. Supplementary carbon tariffs on EITE imports further amplify these dynamics, with non-OECD countries suffering a significantly larger share of the global cost.

In summary, this body of literature underscores potential concerns regarding a trade-off between environmental sustainability and international equity in implementing a CBAM in developed countries. Conflicts with the principle of common but differentiated responsibilities may also emerge (Davidson Ladly, 2012; Böhringer et al., 2022). Therefore, despite the underlying environmental motivations and the policy's conceptualization as a means to address competitive disadvantages arising from international divergences in carbon pricing policies rather than as a tool to create a competitive advantage for adopting countries (Keen et al., 2022), there is a risk that the CBAM could be perceived as a form of protectionism by other nations, potentially leading to retaliation and international trade conflicts (Lim et al., 2021; Böhringer et al., 2022).

Acknowledging these challenges, there is a risk of significant international opposition to the EU CBAM, especially from countries that stand to be significantly impacted by the policy (Overland and Sabyrbekov, 2022). Early reactions from international partners align with this concern, with several countries that have vehemently criticized the European decision (Smith et al., 2024). Specific exemptions from the EU CBAM for least developed countries have been required, among others, by Brandi (2021) and Lowe (2021). The European Commission itself has acknowledged the potential risks for the least developed countries, discussing the possibility of complementing the European policy with compensating mechanisms, such as technical assistance, technology transfer, extensive capacity building, and financial support (EC, 2021, 2024). Understanding the distributional effects of the EU CBAM is thus crucial, both in its inherent significance and for eventually devising more targeted compensation mechanisms and bolstering the overall acceptability of the policy in the international arena.

This paper contributes to this objective by examining the still relatively under-explored distributional effects of the EU CBAM across industries and countries, within a more general evaluation of the policy. A Multi-Regional Input–Output (MRIO) model based on the EXIOBASE 3 database is adopted for these purposes. A major appealing feature of this database is the high level of sectoral disaggregation of the data (Stadler et al., 2018), a characteristic that enables a realistic portrayal of the policy's sectoral coverage and allows an in-depth examination of the policy impact at the industry level. Concerning the model, I build upon recent Input–Output models adopted for similar purposes (Ward et al., 2019; Zhong and Pei, 2022), basically expanding the model of Zhong and Pei (2022). This expansion results in a more comprehensive framework to assess the effects of the CBAM policy within an Input–Output framework, notably by accommodating all second-order effects along the supply chains induced by the policy. Yet, the model is built on a series of strong and simplification assumptions. Consequently, the analyses do not assert the ability to produce pinpoint estimations of the expected policy impacts. Instead, the aim is to present a comprehensive overview of the possible distributional trends of the EU CBAM, shedding light on the countries and industries more likely to face important losses or gains due to the policy within and outside the EU.

The rest of the paper is organized as follows. Section 2 presents more in detail the EU CBAM and summarizes the existing literature on this policy. The model is presented in Section 3, while Section 4 presents scenario in details. The main results of the analysis are shown in Section 5. Section 6 concludes.

2. The EU CBAM

While extensively studied in the literature, the practical implementation of CBAM has mostly remained theoretical to date.[1] Indeed, before the European Union took the initiative, only California and Quebec embraced a limited carbon border adjustment mechanism in recent years. Factors such as potential adverse reactions from international partners, equity concerns, and compatibility issues with international trade agreements, coupled with historically not particularly aggressive carbon price policies, have certainly contributed to this trend. However,

[1] Recent excellent literature reviews on CBAM can be found, among others, in Böhringer et al. (2022) and Zhong and Pei (2024).

the European initiative could potentially be a significant game changer in this regard.

The EU CBAM was first announced in December 2019 as a core policy of the European Green Deal. It was developed to complement the EU ETS revision included in the "Fit-for-55" package. The reforms to the EU ETS involve an extension of the sectors covered, a faster reduction rate in the emission cap, and a progressive phasing-out of free allowances. Free allocation of emissions allowances was primarily motivated by concerns about carbon leakage and competitiveness issues, resulting, however, in an unsatisfactory carbon price signal within the European economy (EC, 2019). Although free allocations do not directly impact the marginal price signal of carbon, they can dampen the average price signal, discouraging low-carbon investment (Flues and Dender, 2017). Removing free allowances is thus expected to strengthen the carbon price signal within the EU. In addition, substituting free allowances with CBAM extends the carbon price signal to exporters to the EU, providing incentives to decarbonize their production processes, and is more consistent with the polluter-pays principle (EC, 2021).

A final version of the EU CBAM policy was approved in May 2023. According to the final agreement (EU, 2023), the CBAM will initially apply in the following EITE industries: (i) cement; (ii) iron and steel; (iii) aluminium; (iv) fertilizers; (v) electricity; and (vi) hydrogen. The carbon tariff will be calculated as the difference between the weekly average auction price of EU ETS allowances and the eventual carbon price in foreign countries, times the carbon content of the imported goods.[2] The latter will primarily reflect the actual direct emissions of the imported good, with indirect emissions considered only for the cement and fertilizers industries. The greenhouse gases considered include carbon dioxide (CO_2) across all the covered industries, nitrous oxide (N_2O) in the fertilizer industry, and perfluorocarbons ($PFCs$) in the aluminium industry.

Considering actual emissions incentives foreign producers to reduce their emissions content to lower their border charges. However, monitoring the carbon content of goods produced in foreign jurisdictions is challenging, costly, and subject to the risk of emission reshuffling, i.e., the relocation of the cleanest production for export to regulated regions (Böhringer et al., 2022). Default values have been then adopted by the EU whenever actual emissions cannot be adequately determined. In this case, default values for direct emissions can be set at the average emission intensity of each exporting country (plus a mark-up) or, if these values are not available, at the average emission intensity of the 10% worst-performing EU ETS installations.

The EU CBAM will enter into force on January 1, 2026, with a transitional phase based solely on emissions accounting starting in October 2023. The carbon border adjustment mechanism will gradually phase in, parallel with the phasing-out of free allowances. A complete replacement of free allowances with carbon tariffs is scheduled for 2034. The possibility of broadening the product scope to include other goods produced in sectors covered by the EU ETS, such as certain upstream input materials and downstream products at risk of carbon leakage, will be evaluated in the next years (EU, 2023).

This policy has attracted increasing attention among policymakers and scholars, prompting analyses to evaluate its potential effects along various dimensions. A summary of this emerging literature follows.

The initial impact assessment conducted by the European Commission involved the evaluation of various alternative CBAM scenarios through an extended version of the JRC-GEM-E3 model (EC, 2021). At the aggregate level, the results suggest a negligible effect on the EU GDP from eliminating free allowances (−0.002%) and implementing CBAM (−0.003%). However, more pronounced effects arise within the covered sectors: the transition to an auction-based mechanism consistently leads to reduced production levels (−4%), while CBAM proves particularly effective in mitigating these negative dynamics, especially in the fertilizer market. The complete removal of free allowances results in significant carbon leakage (42%), with CBAM able to reduce the leakage rate by less than one-half if carbon tariffs are based on average EU emissions intensities and to completely reverse it if calibrated on the emission intensities of exporting countries. Additional analyses using various CGE models include: (Chepeliev, 2021) who finds limited evidence of burden shifting from the EU CBAM for most countries, except Ukraine and the Rest of Europe region; Perdana and Vielle (2022), who estimate the impact of the EU CBAM under the "Fit for 55" package and find evidence of burden-shifting effect, especially in Africa, India, Russia, and the Rest of the World region. The policy positively affects the EU GDP (0.1%), while big players, such as China and the US, are substantially unaffected. Strong support in favor of revenue-redistribution targeted to promote clean and efficient use of energy in the least developed countries is also founded; Mörsdorf (2022) that estimates the impact of a carbon tax in EU of 50 USD/tCO_2eq coupled with alternative carbon border mechanisms on three energy-intensive industry ("metals", "minerals" and "chemicals"). Results indicate that the carbon tax generates a carbon leakage above 20%, reduced by about half if a carbon tariff covering Scope 1 and Scope 2 emissions is adopted. The leakage rate is further reduced if a full CBAM is adopted, i.e., if export rebates are considered; Clora et al. (2023) who find a sizable rebound effect induced by the EU Green Deal (around 46%) and modest effectiveness of the CBAM in reducing this leakage, even in the case of the most "aggressive" CBAM characterized by carbon tariffs based on Scope 1 and Scope 2 actual emissions embodied in imports (about six percentage points). No clear evidence of burden-shifting effect is found. Alternative reactions of non-adopting countries, ranging from retaliation to cooperation, have also been investigated; and Bellora and Fontagné (2023) who find that the CBAM is even more effective than free allowances in containing carbon leakage. However, substituting free allowances with CBAM substantially reduces the EU GDP (−1.2%). The drop in GDP is mainly driven by a reduction in the international competitiveness and exports of several downstream sectors not covered by the CBAM.

Schotten et al. (2021) adopt a MRIO model to assess the impact of a carbon tax and a CBAM on the EU ETS industries. Results indicate that, albeit competitiveness effects are relatively small for the entire EU economy, negative effects are more substantial in several Central and Eastern European countries. Moreover, findings suggest that the CBAM fully mitigates the negative impact of a carbon tax on domestic market competitiveness for most countries and sectors. This is not the case in a few EU countries, such as Bulgaria, Poland, and Estonia. Zhong and Pei (2022) develop a MRIO model to study the international impact of an EU CBAM and find that the most negative impacts on output are expected in several non-adopting countries, such as Russia, China, Turkey, India, and the Rest of the Word region. Using trade data and MRIO matrices, Magacho et al. (2024) evaluate the degree of exposure of exports of several countries, finding that East European economies and several African countries are the most exposed areas. Beaufils et al. (2023) exploit MRIO data to quantify how alternative EU CBAM affects extra-EU countries by channeling the European carbon price to other economies. Results indicate that the policy disproportionally impacts several middle- and low-income countries, especially those highly dependent on exports to the EU. An international revenue recycling scheme is then suggested to enhance the international acceptability of the EU CBAM and foster global climate cooperation. Eicke et al. (2021) assesses the risks for non-adopting countries of the EU CBAM using exposure and vulnerability indexes. Findings indicate that risks are unevenly distributed globally, concentrating mainly in Africa and South-Eastern European countries. Overland and Sabyrbekov (2022) constructs an "Opposition Index" to evaluate which countries are more likely to react to the EU CBAM. The index is constructed using data on

[2] Carbon tariffs are not applied to goods originating in the following extra-EU countries: Iceland, Liechtenstein, Norway, and Switzerland.

trade with the EU, carbon intensity, litigiousness in the World Trade Organization, domestic public opinion on climate change, and capacity for innovation. Results indicate that, besides several developing countries, crucial players such as the US and China are among the countries most likely to oppose the European policy. Finally, the World Bank assesses countries' exposure to EU CBAM based on a competitiveness index derived from carbon emissions intensity and exports of CBAM products to the EU (World Bank, 2023a). Results indicate potential strong negative impacts on Ukraine, India, and several African countries, while no adverse competitiveness effects are identified for the US and China.

3. Methods

An MRIO-based analysis framework is developed to study the impacts of the EU CBAM. Exploiting monetary and emissions flows included in EXIOBASE 3, I first account for emissions flows targeted by the CBAM policy, calculating the emissions per unit of output that fall under the policy's coverage. These values are then used to estimate the additional cost burden imposed by the policy within each industry and country and, by assuming a full pass-through, estimate production price shocks and CBAM tariffs. The (production and export) price shocks guide the simulation of new production levels in each country and industry through the following three-step procedure. First, I calculate the new final demand for each industry and country by integrating price shocks with Armington and own-price demand elasticities. Next, I construct a revised technical coefficients matrix, assuming no substitution between intermediate inputs belonging to different industries but allowing within-industry substitution among different suppliers (countries). Again, this substitution process is driven by price shocks and Armington elasticities. Finally, I compute new intermediate inputs by applying basic IO formulas to the new final demand vector and the new technical coefficients matrix to determine the updated production levels in each industry and country. Variations in monetary productions are coherently deflated to correctly identify "winners" and "losers" of the policy at different levels of aggregation.

The model includes 163 industries and 49 regions, comprising 44 countries and five Rest of the world regions.[3] All the 27 EU member states are considered in the analysis and included in the subset of the *adopting countries* (AC). I additionally include Norway and Switzerland in this subset of countries for two reasons. First, they have an emission trading system strictly connected to the EU ETS. Second, the European policy explicitly excludes carbon tariffs for imports from Norway and Switzerland EU (2023). Considering these two countries as adopting ones implies assuming that they also adopt a carbon border adjustment mechanism on imports from the extra EU. The remaining 20 countries are identified as *non-adopting countries* (NC). To avoid capturing any idiosyncratic dynamics associated with the Covid-19 shock, the data used refers to 2019.[4]

A detailed description of the model is provided in the rest of the section.

3.1. Emissions account

To quantify policy-covered emissions, I start by computing the covered direct emissions (Scope 1) per unit (euro) of output in each industry and country included in the model. By indexing industry with the subscript and country with the superscript, these emissions in industry i and country u are:

$$ed_i^u = \frac{CO_2 e_i^u}{X_i^u} \tag{1}$$

where $CO_2 e_i^u$ and X_i^u represent the country-sector-specific carbon dioxide equivalent emissions and the total output, respectively. EXIOBASE 3 accounts for all policy-covered greenhouse gases – CO_2, N_2O, and PFCs — by directly providing emissions for N_2O, and PFCs in carbon dioxide equivalents, adopting "standard" 100-year Global Warming Potential (GWP) values for the conversion (IPCC, 2013).

Indirect emissions (Scope 2) per unit of output, relevant for the cement and fertilizer industry, are calculated as follows:

$$ei_i^u = \begin{cases} \sum_{j\in E} \sum_{v\in NC} ed_j^v a_{j,i}^{u,v} & \text{if } i \in CF \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

where E and CF represent the subsets of the electricity industries and the cement and fertilizers industries, respectively, and $a_{j,i}^{u,v}$ is an element of the technical coefficients matrix A, indicating the monetary amount of intermediate input j produced in country v required to produce one euro of output in industry i in country u.[5]

The policy requires companies in adopting countries to account for greenhouse gas emissions incorporated within regulated intermediate inputs imported from non-adopting countries. These emissions, in per unit of output terms, are determined as follows:

$$ec_i^u = \sum_{j\in T} \sum_{v\in NC} (ed_j^v + ei_j^v) a_{j,i}^{u,v} \tag{3}$$

where T is the subset of regulated industries.

By jointly considering direct and embedded emissions, policy-covered emissions per unit of output for domestic firms operating in the industry i and country u are:

$$et_{i\,(u\in AC)}^u = \begin{cases} ed_i^u + ec_i^u & \text{if } i \in T \\ ec_i^u & \text{otherwise} \end{cases} \tag{4}$$

where the ed_i^u component directly derives from eliminating free allowances, while the ec_i^u component results from adopting a carbon border adjustment mechanism.

Emissions also need to be tracked for regulated final goods imported into European territory. In this case, emissions per output unit can be obtained considering Scope 1 or Scope 2 emissions, depending on the specific industry. So, by indexing with $ex_i^{v,u}$ the covered emissions in the case of industry i export to country v from country u, we have:

$$ex_{i\,(u\in NC)}^{v,u} = \begin{cases} ed_i^u + ei_i^u & \text{if } v \in AC,\ i \in T, \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

Eqs. (4) and (5) summarize all the policy-covered emissions. Notice, however, that previous calculations provide policy-relevant emissions flows under the assumption that firms in non-adopting countries collaborate with the EU jurisdiction by declaring their effective emission levels. This can be defined as the *collaborative scenario*. However, such cooperation cannot be guaranteed nor enforced by the EU. Indeed, default values have been adopted by the EU whenever foreign firms fail to provide reliable emission information. This requires also considering a *non-collaborative scenario*, where foreign industries behave opportunistically, reporting actual emissions only when they are lower than the default values and otherwise relying on these default values. This strategic behavior results in a reduction of the industry-specific emissions value for non-adopting countries in the model. However, quantifying this reduction is challenging due to the lack of detailed

[3] These regions are: (i) RoW Asia and Pacific (WA); (ii) RoW Europe (WE); (iii) RoW Africa (WF); (iv) RoW America (WL); and (v) RoW Middle East (WM).

[4] Data are from the version 3.8.2 of EXIOBASE. Link to the data: https://zenodo.org/records/5589597.

[5] Indirect emissions are thus computed considering only electricity produced by a non-adopting country, as free allowances in the EU electricity industry were largely phased out before 2019.

firm-level data in most countries. I naively approximate this reduction by assuming a uniform 10% decrease in the direct emission factors of industries in non-adopting countries.[6]

3.2. Price shocks

An immediate effect of the policy is to increase the production cost for domestic firms proportionally to the amount of policy-covered emissions per unit of output produced. More precisely, a percentage direct shock on production costs of domestic firms can be derived as:

$$\Delta c_i^u = \Delta p_i^u = et_i^u(\theta_i^0 - \theta_i^1)ct \tag{6}$$

where θ_i^0 and θ_i^1 respectively indicate the share of free allowances granted before and after the policy reforms, and ct is the EU ETS price.[7] In line with several preceding analyses (e.g., Ward et al., 2019; Zhong and Pei, 2022), I assume a full pass-trough on price, thus implying that cost shocks are totally translated into price shocks (Δp_i^u).

These price shocks are very short-term inflationary effects. Indeed, the input–output structure of the model naturally suggests considering secondary inflationary repercussions originating from sectoral interconnections. This may produce an inflationary cascade effect, spreading impacts across industries and countries via (global) value chains, with final effects on prices estimated by closing the model in the so-called cost-push form (Miller and Blair, 2009):

$$\Delta P = L' \Delta p \tag{7}$$

where ΔP and Δp are vectors representing the final and direct price shocks, respectively, while $L = (I - A)^{-1}$ denotes the Leontief inverse.

The EU CBAM affects international trade terms by introducing carbon tariffs for regulated goods imported in the EU. These tariffs reads as:

$$cbt_i^{v,u} = \begin{cases} ex_i^{v,u}(1-\theta_i^1)ct & \text{if } v \in AC, \text{if } u \in NC, \quad i \in T, \\ 0 & \text{otherwise} \end{cases} \tag{8}$$

in the case of exporting a product from industry i in the country u to the country v. The term $(1 - \theta_i^1)$ reflects the fact that, as prescribed by the EU policy, and in line with international trade rules, the same share of free allowances must be granted to domestic and imported goods. Export price shocks can be calculated by simply adding the CBAM tariff to the production price shocks of the exporting industry.

3.3. Macroeconomic effects

By building upon Ward et al. (2019) and Zhong and Pei (2022), price shocks are exploited to simulate new domestic production and import-export flows in each industry and country.

I begin by computing the real share of domestic expenditure on final goods fulfilled by domestic producers in industry i and country u, denoted as $d_i^{*,u}$, as follows (Zhong and Pei, 2022):

$$d_i^{*,u} = d_i^u(1 + \Delta P_i^u - \overline{\Delta P}_i^u)^{1-\theta_i^d} \tag{9}$$

where d_i^u is the before policy share of domestic expenditure satisfied by domestic producers, ΔP_i^u is the production price shock for domestic producers, $\overline{\Delta P}_i^u$ is the internal price shocks, a weighted average between price shocks for domestic production and imports from different countries, and θ_i^d is the industry-specific Armington elasticity between domestic products and imports.[8] In a nutshell, domestic producers gain (lose) real market shares within the domestic market when their price hikes are less (more) substantial than those of (a weighted average of) foreign competitors, with stronger effects the higher the difference between the two price shocks and the industry-specific import substitution elasticity. Industry-specific elasticities are derived from the GTAP 10 database (Aguiar et al., 2019; Hertel and van der Mensbrugghe, 2019), using the concordance table shown in to map this information onto the more disaggregated industry-level structure of the model.

The new market share for foreign producers ($m_i^{*,u}$) is derived residually, reading as:

$$m_i^{*,u} = 1 - d_i^{*,u} \tag{10}$$

while the new market share satisfied by each foreign producer ($m_i^{*,u,v}$) is derived as:

$$m_i^{*,u,v} = m_i^{u,v}(1 + \Delta PM_i^{u,v} - \overline{\Delta PM}_i^u)^{1-\theta_i^m} \frac{m_i^{*,u}}{m_i^u}\gamma_i^u \tag{11}$$

where $m_i^{u,v}$ is the before policy real share satisfied by foreign producers of country v, $\Delta PM_i^{u,v}$ is the price shock suffered by imports from country v, $\overline{\Delta PM}_i^u$ is a weighted average of import price shocks from different sources, and θ_i^m is the of industry-specific elasticity of substitution among imports from different sources, here assumed to follow the "rule of two", such that $\theta_i^m = 2\theta_i^d$ (Jomini et al., 1994; Zhong and Pei, 2022). $\gamma_i^u = \frac{m_i^{*,u}}{\sum_v m_i^{*,u,v}}$ is introduced to assure that the sum of import shares from different sources remains equal to the overall import share computed in Eq. (10) after the non-linear transformation implied by Eq. (11).

Final expenditure may respond to price shocks. Here, I assume a simple structure implying that changes in real expenditure in each industry are exclusively based on its own price shock, here defined as a weighted average between price shocks for domestic production and imports from different countries, assuming that the share adjustment has occurred. Accordingly, the percentage variation in real final expenditure in sector i and country u reads as:

$$\xi_i^u = -\rho_i^u \overline{\Delta Pe}_i^u \tag{12}$$

where ρ_i^u is the (eventually) country-industry-specific price elasticity, and $\overline{\Delta Pe}_i^u$ is the (share-adjusted) internal price shock.

New monetary flows are then easily derived as:

$$D_i^{*,u} = d_i^{*,u}(D_i^u + M_i^u)(1 + \Delta P_i^u)(1 - \xi_i^u) \tag{13}$$

$$M_i^{*,u,v} = m_i^{*,u,v}(D_i^u + M_i^u)(1 + \Delta PM_i^{u,v})(1 - \xi_i^u) \tag{14}$$

$$X_i^{*,u} = \sum_{v \neq u} M_i^{*,v,u} - CT_i^u \tag{15}$$

$$f_i^{*,u} = D_i^{*,u} + X_i^{*,u} \tag{16}$$

where D_i^u and M_i^u are the before policy expenditure on domestic final product and imports, $X_i^{*,u}$ is the new monetary final good exports — net of carbon tariffs charges (CT_i^u), and $f_i^{*,u}$ is the total final demand for industry i in country u.

Regarding intermediate inputs, I operate under the standard assumption in the IO framework of no substitution among different inputs. Nevertheless, I relax this assumption by allowing substitution between each specific intermediate input's suppliers (countries) (Zhong

[6] While this rule is for sure overly simplistic and not empirically based, the hypothesized magnitude of the reduction is consistent with a hypothetical scenario characterized by: (i) a uniform distribution of emission intensities at the firm level, with support equal to 0.5 and 1.5 times the average industry-country level; (ii) a mark-up on the default values equal to 10%; and (iii) an opportunistic behavior adopted by all firms.

[7] As a simplifying assumption, I am assuming no carbon price in the covered sectors in the non-adopting countries.

[8] In the following, final price shocks are used to assess competitiveness effects and macroeconomic impacts. However, a similar investigation can be conducted based on direct price shocks by simply substituting final price shocks with direct price shocks in the equations presented in the present section.

and Pei, 2022). To be more precise, I derive new real shares by replicating the previous calculations on intermediate input data. So, by respectively indexing with $zd^{*,u}_{i,j}$, $zm^{*,u}_{i,j}$, $zm^{*,u,v}_{i,j}$ and with $zd^{u}_{i,j}$, $zm^{u}_{i,j}$, $zm^{u,v}_{i,j}$ the new and before policy real share of domestic, overall imported, and imported from country v, intermediate inputs j in the production of the industry i in country u, we have:

$$zd^{*,u}_{i,j} = zd^{u}_{i,j}(1 + \Delta P^{u}_{j} - \overline{\Delta P}^{u,i}_{j})^{1-\theta^{d}_{i}} \tag{17}$$

$$zm^{*,u}_{i,j} = 1 - zd^{*,u}_{i,j} \tag{18}$$

$$zm^{*,u,v}_{i,j} = zm^{u,v}_{i,j}(1 + \Delta PM^{u,v}_{j} - \overline{\Delta PM}^{u,i}_{j})^{1-\theta^{m}_{i}} \frac{zm^{*,u}_{i,j}}{zm^{u}_{i,j}} \gamma^{u}_{i,j} \tag{19}$$

where $\overline{\Delta P}^{u,j}_{i}$ and $\overline{\Delta PM}^{u,j}_{i}$ are the internal and importing price shocks evaluated at the specific industry level, and $\gamma^{u}_{i,j} = \frac{zm^{*,u}_{i,j}}{\sum_v zm^{*,u,v}_{i,j}}$.

A new technical coefficient matrix (A^*), expressed in the new price levels, can then be easily derived by these new real shares. For instance, the new technical coefficient $a^{*,u,v}_{i,j}$ reads as:

$$a^{*,u,v}_{i,j} = zm^{*,u,v}_{i,j} \chi^{u}_{i,j} \frac{1 + \Delta PM^{u,v}_{j}}{1 + \Delta P^{u}_{i}} \tag{20}$$

where $\chi^{u}_{i,j}$ is the share of the intermediate input j in industry i and country u, expressed in the before policy prices, and computed as $\frac{\sum_v a^{u,v}_{i,j}}{X^{u}_{i}}$.

As a final step, knowing new final demand levels (f^*) and technical coefficient matrix (A^*), new output level (x^*) and intermediate inputs (Z^*) are easily derived as:

$$x^* = (I - A^*)^{-1} f^* \tag{21}$$

$$Z^* = A^* x^* \tag{22}$$

New final demand and intermediate inputs monetary flows are then converted into real flows, in the before policy price, by deflating each flow with its own correct deflator.

4. Scenarios

The sectoral coverage of the policy is here modeled by assuming the following subset T of regulated industries: (i) cement: “Manufacture of cement, lime and plaster”, “Re-processing of ash into clinker”; (ii) iron and steel: “Manufacture of basic iron and steel and of ferroalloys and first products thereof”, “Re-processing of secondary steel into new steel”; (iii) Aluminium: “Aluminium production”, “Re-processing of secondary aluminium into new aluminium”; (iv) fertilizer: “N-fertilizer”, “P- and other fertilizer”, and; (v) “Electricity” from all the sources. I do not include hydrogen, as it constitutes a tiny share of a more aggregated industry within EXIOBASE. I contend that this exclusion has minimal impact on the results, given the historically limited production and international trade of hydrogen, though this may change in the near future.

Regarding the treatment of free allowances, I assume the complete elimination of such allowances. Accordingly, I assign a value of zero to θ^{1}_{i} for all $i \in T$. This projection aligns with a medium-term outlook, anticipating the complete phasing out of free allowances by 2034. Coherently, with the situation prevailing in the year of the dataset - 2019, I presume that all regulated industries, except for electricity, received 100% of free allowances before the policy reform. For electricity, instead, I set the share of free allowances granted before the policy reform equal to zero, as an auction-based mechanism has prevailed in the EU electricity industry since before 2019.

I set the EU ETS price at €$100/tCO_2e$. This price can be seen as too high from a historical perspective, substantially reflecting the peak historical value for the EU ETS, reached in the first half of 2023. On the other hand, however, most available projections predict a significant upward trend in the EU ETS price over the coming years and decades (e.g., Pietzcker et al., 2021; Pahle et al., 2022; IETA, 2023). From this standpoint, thus, the carbon price adopted in the model can be even seen as too conservative.

Table 1
Alternative scenarios.

Scenario	Foreign firms behavior	Price elasticity
Scenario 1	Collaborative	0
Scenario 2	Collaborative	0.4
Scenario 3	Collaborative	Country-Industry-specific
Scenario 4	Non-collaborative	Country-Industry-specific

The analysis encompasses four distinct scenarios, each delineated by a combination of alternative behaviors by foreign firms (collaborative vs. non-collaborative) and price elasticity ρ (null vs. positive). While the behavior of foreign firms influences the carbon tariffs adopted, the price elasticity determines the final expenditure reaction to price shocks. The scenarios are as follows.

Scenario 1: Zero-sum game. A zero price elasticity is assumed, indicating a scenario where monetary flows adjust seamlessly to sectoral inflationary pressures. While this assumption might be extreme and short-term, by freezing real production at both global and industry levels, it isolates distributional effects driven solely by changes in international relative prices within a zero-sum game framework. A *collaborative* behavior of foreign firms is assumed.

Scenario 2: Uniform price elasticity. Relaxing the zero-sum game assumption, this scenario introduces a positive price elasticity, adding a layer of complexity to the analysis. This allows penalizing countries and industries particularly affected by inflationary pressure, and by extension, countries and industries closely linked in the supply chain to those facing inflation challenges. A rather conservative price elasticity of 0.4 is assumed across industries and countries. Foreign firms are again assumed to adopt *collaborative* behavior.

Scenario 3: Country-industry-specific price elasticities. Leveraging the GTAP 10 database (Hertel and van der Mensbrugghe, 2019), this scenario is run under empirically calibrated country-industry-specific price elasticity values (see , A.2). Elasticities vary between −0.01 and 1.05, depending on the industry and region analyzed (see Table A.3). Foreign firms continue to exhibit *collaborative* behaviors.

Scenario 4: Non-collaborative. The effects of a *non-collaborative* behavior of foreign firms, resulting in lower carbon tariffs due to the strategic use of default values (see Section 3.1), are tested in this last scenario. As in the previous scenario, empirically calibrated price elasticities are considered.

Table 1 briefly sketches these alternative scenarios.

5. Results and discussion

The current section provides a comprehensive overview of the results, starting from the most aggregate perspective and then progressively narrowing its focus.

5.1. Aggregate analysis: adopting vs. non-adopting regions

Table 2 sheds light on the macroeconomic effects observed in adopting and non-adopting regions. Some initial considerations follow. (1) Despite certain model assumptions that tend to overestimate the policy impacts on prices (e.g., full pass-through, limited factor substitution), the overall inflationary impacts of the policy remain relatively limited, primarily manifesting in the adopting region. This effect is predominantly ascribed to eliminating free allowances, with the contribution of the CBAM deemed largely negligible. (2) The policy, on the whole, leads to a modest reduction in the GDP of the adopting region, driven by decreases in both internal production and exports.

Table 2
Aggregate effects under alternative scenarios. Adopting vs. non-adopting regions.

	Adopting region			Non-adopting region		
	Free allowances	CBAM	Full policy	Free allowances	CBAM	Full policy
Scenario 1:						
Production prices (%)	0.208	0.037	0.245	0.007	0.001	0.008
Internal production (%)	−0.104	0.027	−0.077	0.028	0.002	0.03
Export (%)	−0.451	−0.043	−0.494	0.161	−0.037	0.124
GDP (%)	−0.163	0.015	−0.148	0.039	−0.001	0.037
Emissions (million tonnes)	−31.34	7.76	−23.58	47.34	−49.42	−2.08
Scenario 2:						
Internal production (%)	−0.148	0.017	−0.131	0.024	0.001	0.025
Export (%)	−0.482	−0.052	−0.534	0.147	−0.041	0.105
GDP (%)	−0.205	0.005	−0.2	0.034	−0.003	0.032
Emissions (million tons)	−33.49	7.31	−26.18	45.3	−49.75	−4.45
Scenario 3:						
Internal production (%)	−0.177	0.011	−0.166	0.023	0	0.023
Export (%)	−0.501	−0.058	−0.559	0.139	−0.043	0.096
GDP (%)	−0.232	−0.001	−0.233	0.032	−0.003	0.029
Emissions (million tonnes)	−34.66	7.07	−27.6	44.56	−49.84	−5.28
Scenario 4:						
Internal production (%)	−0.177	0.011	−0.166	0.023	0	0.023
Export (%)	−0.501	−0.048	−0.548	0.139	−0.042	0.098
GDP (%)	−0.232	0.001	−0.231	0.032	−0.003	0.029
Emissions (million tonnes)	−34.66	7.03	−27.63	44.56	−48.63	−4.07
Carbon coverage (% of 2019 global carbon emissions)	0.620	0.161	0.781			

This outcome primarily stems from an overall deterioration in international trade terms originating from the introduction of an auction-based mechanism in the EU covered sectors. Several downstream industries significantly contribute to this result, as discussed later. (3) While the CBAM provides limited protection to domestic producers in the adopting region, it simultaneously exacerbates losses in the export sector. Overall, the impact on the GDP of the adopting region is negligible. (4) Adopting an opportunistic behavior by foreign firms results in minimal macroeconomic and environmental impacts. Despite the somewhat oversimplified approach taken in the paper to model this behavior, this suggests that the strategic utilization of default values by the most polluting foreign companies may have a limited impact on the effectiveness of the European policy.

Concerning the burden-shifting induced by the EU CBAM, the findings reveal a negative yet extremely negligible effect on the GDP of the non-adopting region (−0.003% in the worst scenario). When considering the entire policy, no burden-shifting effect is retrieved, as evidenced by the small yet positive impact on the GDP of the non-adopting region. This reflects the benefits for the non-adopting region derived from removing free allowances in the regulated sectors in the EU. Upon initial examination and adopting a very aggregate perspective, the findings thus suggest that concerns regarding a potential international equity issue related to the EU CBAM may be overstated.

In terms of emissions, the findings illustrate that the CBAM effectively reduces emissions and addresses carbon leakage. It achieves annual savings of approximately 40 million tonnes of CO_2e, rendering the EU policy successful in curbing global emissions (estimated at −33 million tonnes in the best-case scenario). While these impacts remain modest on a global scale – amounting to roughly 0.1% of total global carbon emissions – the policy's relative effectiveness becomes more apparent when evaluated considering its limited carbon coverage. The emissions priced under the policy represent, in fact, only about 0.8% of global carbon emissions, with CBAM alone accounting for approximately 0.16% of global emissions.[9]

[9] Please note that, thanks to the detailed sectoral breakdown of the data, the analysis is based on a carbon coverage that is typically lower than that implied by several preceding analyses on the EU CBAM. For example, the emissions covered in the analysis amount to nearly half of those considered by Zhong and Pei (2022).

5.2. *Unveiling heterogeneity*

More intricate patterns emerge as we delve deeper into the disaggregation of results. Fig. 1 reveals that the prior level of aggregation significantly masks sizable heterogeneity among countries in the macroeconomic repercussions of the policy. Notably, variability is particularly pronounced within the EU, with several countries at risk of losing a share of GDP three to four times higher than the EU average from replacing free allowances with CBAM. This heightened risk is particularly evident in several Eastern European countries, as highlighted by Fig. 2. These are also the countries experiencing the most substantial inflationary pressure from the policy (see Fig. 3). Adverse effects are also particularly strong for Portugal, while they are more contained in several core European economies, such as Germany and the Netherlands, and absent in other EU countries like Denmark, France, and Finland. A clear intra-EU redistributive pattern is emerging from the results, with several Eastern EU countries significantly losing market shares to core EU countries due to intra-EU competitiveness differentials generated by the policy (see Fig. B.1). In summary, the macroeconomic costs of the EU policy are unevenly distributed within the Union, exacerbating intra-EU inequality. Moreover, CBAM seems largely ineffective in alleviating this regressive impact and, in certain instances, it may even substantially exacerbate the macroeconomic losses incurred by specific Eastern EU economies (e.g., Bulgaria, and Slovenia).

Broadening the analysis to non-adopting countries allows for a more nuanced examination of the burden-shifting effect. Although evidence is lacking for most of the countries investigated, including major economies like the US, China, and Japan, signs of burden shifting emerge in a few cases. Countries such as India, Russia, and Turkey display moderate burden shifting dynamics. Nevertheless, these effects are relatively minor and are largely offset when considering the overall impact of EU policy, that is, also accounting for the effects deriving from removing free allowances. The most compelling evidence of burden shifting is retrieved in the case of the Rest of the European Economies (WE), largely encompassing non-EU Eastern European countries. Here, the EU CBAM poses a significant risk, potentially leading to a consistent reduction in GDP (−0.4%) and exports (−1.4%) for this region. At the same time, only minor benefits derived from eliminating free allowances manifest in this case. This finding aligns logically with the strong ties of this region to the EU in terms of import-export flows.

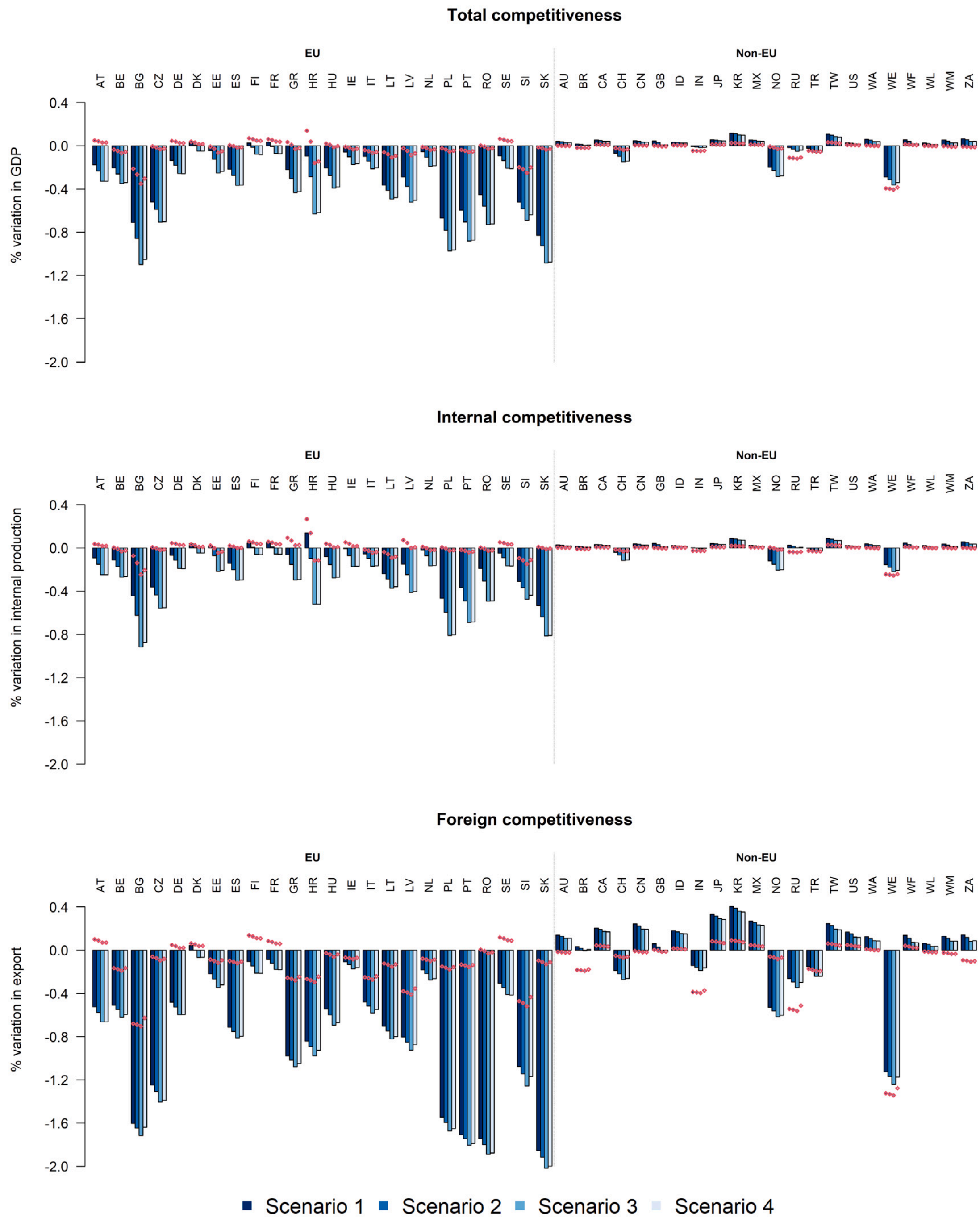
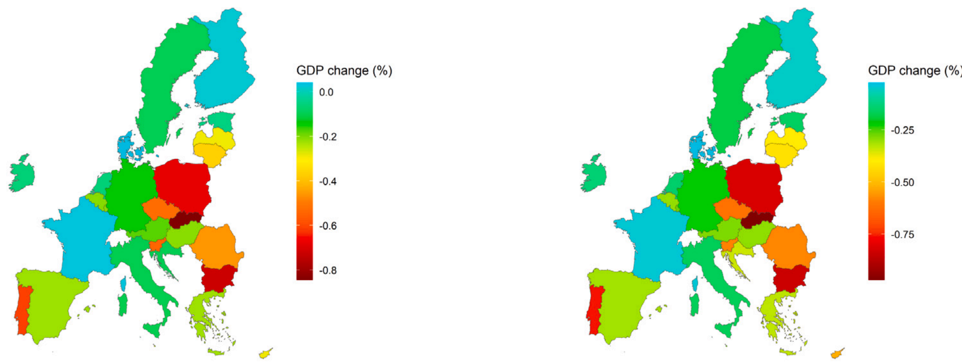


Fig. 1. Macroeconomic impacts at the country level. The bars represent the effects of substituting free allowances with a CBAM (full policy), while the red diamonds indicate the impacts of the CBAM alone. To isolate the effect of removing free allowances, compare the heights of the bars and diamonds. Small EU countries not included in the graphs. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Adopting a sectoral perspective, Table 3 highlights the most affected industries in both adopting and non-adopting regions. Percentage variations in sectoral production indicate that, in the adopting region, most regulated sectors are among the most adversely impacted. For instance, the "P- and other fertilizer" industry experiences the largest production decline, approximately −5.5%. Production losses in the range of −1.5% to −2.5% are observed in most remaining regulated industries. Despite CBAM providing robust protection in many of these industries, this positive impact is often overshadowed by the detrimental effects of eliminating free allowances. The "N-fertilizer" industry is an exception, with CBAM's protection outweighing the negative consequences of removing free allowances. Negative repercussions also extend along the value chain, affecting various related industries.

Evidence of burden shifting at the industry level becomes more evident as the EU CBAM reduces overall production in the non-adopting region across all regulated sectors. However, these negative effects are relatively modest, ranging from −0.1% to −1.8% depending on the industry. Moreover, they are largely reversed when considering the benefits of eliminating free allowances. In fact, several regulated industries in non-adopting regions emerge as primary beneficiaries of the comprehensive EU policy.

Examining industry-specific effects in absolute rather than percentage terms provides several additional insights. First, regulated sectors



(a) Scenario 1 (b) Scenario 4

Fig. 2. GDP changes in EU countries deriving from replacing free allowances with CBAM.

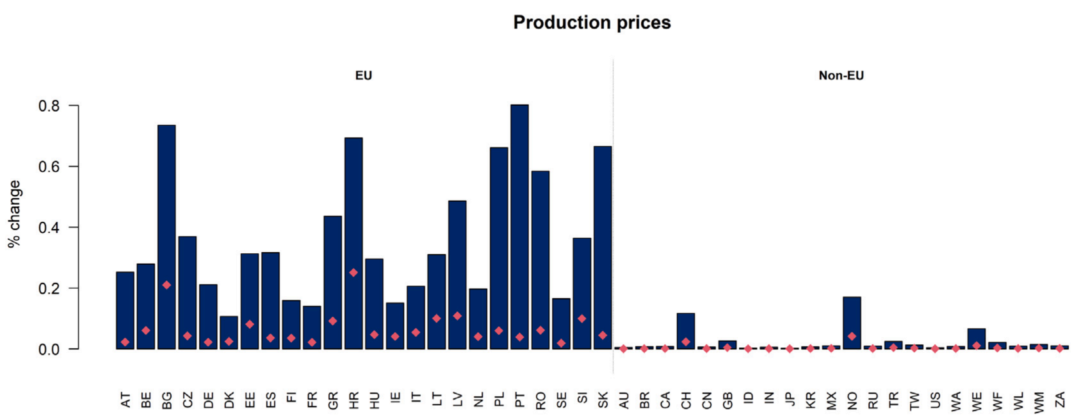


Fig. 3. Percentage changes in production prices. Country-level averages. Scenario 1. The bars represent the effects of substituting free allowances with a CBAM (full policy), while the red diamonds indicate the impacts of the CBAM alone. To isolate the effect of removing free allowances, compare the heights of the bars and diamonds. Small EU countries not included in the graphs. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

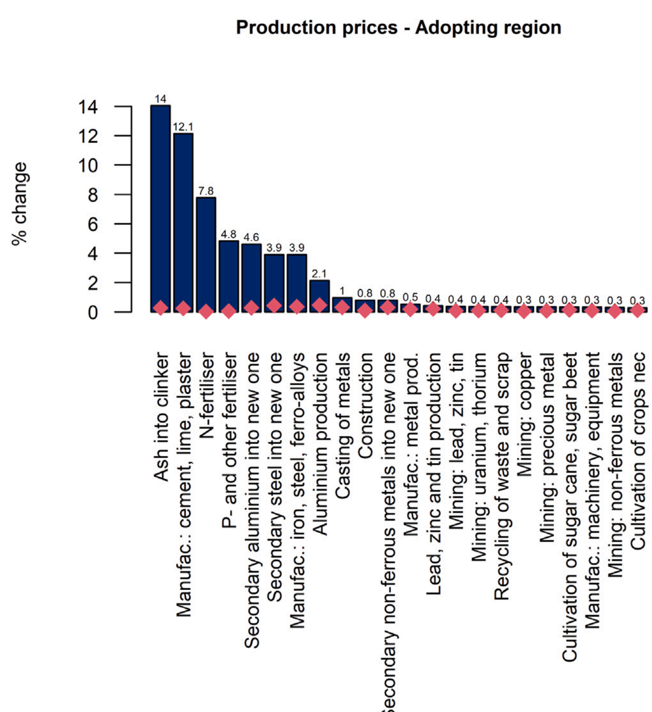


Fig. 4. Percentage changes in production prices. Industry-level averages within the adopting region. Scenario 1. The bars represent the effects of substituting free allowances with a CBAM (full policy), while the red diamonds indicate the impacts of the CBAM alone. To isolate the effect of removing free allowances, compare the heights of the bars and diamonds. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 3
Changes in sectoral production: most affected industries. Averages for the adopting and non-adopting regions. Means across scenarios.

Adopting region			Non-adopting region		
Industry	CBAM	Full Policy		CBAM	Full Policy
(a) Percentage effects					
Losing industries					
P- and other fertilizer	4.26	−5.42	N-fertilizer	−1.83	−0.61
Mining: iron ores	2.16	−3.05	Electricity: wind	−0.53	−0.47
Ash into clinker	0.33	−2.43	Electricity: biomass-waste	−0.26	−0.19
Secondary steel into new one	0.26	−2.41	Processing of nuclear fuel	0.05	−0.18
Manufac.: iron, steel, ferro-alloys	3.74	−2.20	Electricity: gas	−0.21	−0.14
Mining: copper	−0.08	−1.85	Electricity: solar photovoltaic	−0.16	−0.12
Secondary aluminium into new one	0.33	−1.80	Electricity: petroleum, oil deriv.	−0.15	−0.09
Manufac: coke oven products	0.82	−1.67	Electricity: coal	−0.10	−0.04
Lead, zinc and tin production	−0.62	−1.65	Mining: coal, lignite, peat	−0.16	−0.03
Mining: non-ferrous metal	0.51	−1.61	Wool, silk-worm cocoons	0.05	−0.01
Manufac.: cement, lime, plaster	1.79	−1.54			
Recycling of waste and scrap	0.89	−1.26			
Gaining industries					
N-fertilizer	10.04	2.95	Ash into clinker	−0.85	6.56
Mining: aluminium	1.53	0.88	Secondary aluminium into new one	−0.50	3.63
Electricity: petroleum, oil deriv.	0.94	0.56	Secondary steel into new one	−0.08	2.14
Electricity: gas	0.69	0.39	Secondary copper into new one	0.31	0.69
Mining: nickel	0.59	0.16	Recycling of bottles by direct reuse	0.14	0.40
Electricity: coal	0.59	0.08	P- and other fertilizer	−0.26	0.31
Electricity: tide, wave, ocean	0.06	0.06	Manufac.: cement, lime, plaster	−0.63	0.27
Electricity: biomass, waste	0.37	0.05	Secondary lead into new one	0.11	0.25
			Manufac.: iron, steel, ferro-alloys	0.20	0.25
			Manufac.: machinery, equipment	0.06	0.23
			Manufac.: metal prod.	0.07	0.22
			Mining: iron	−0.03	0.22
(b) Total effects (€ million)					
Losing industries					
Manufac.: machinery, equipment	−244	−862	Electricity: gas	−53	−36
Construction	−78	−749	Electricity: coal	−48	−20
Manufac.: metal prod.	−164	−650	Mining: coal, lignite, peat	−76	−16
Manufac: motor vehicles, trailers	−122	−518	Electricity: petroleum, oil deriv.	−12	−7
Manufact.: electrical machinery	−98	−401	N-fertilizer	−12	−4
Other business activities	6	−344	Electricity: wind	−3	−3
Manufac.: iron, steel, ferro-alloys	512	−301	Electricity: biomass, waste	−3	−2
Wholesale/commission trade	14	−239	Health and social work	−1	−2
Manufac.: other transport equip.	−66	−230	Processing of nuclear fuel	1	−2
Secondary steel into new one	22	−204			
Manufac: cement, lime, plaster	215	−184			
Manufac: rubber, plastic prod.	−35	−177			
Gaining industries					
Electricity: gas	52	29	Manufact: machinery, equipment	220	788
Electricity: petroleum, oil deriv.	11	7	Manufac: iron, steel, ferro-alloys	−465	587
Electricity: coal	46	7	Manufac.: metal prod.	142	437
N-fertilizer	11	3	Manufac: motor vehicles, trailers	96	376
Electricity: biomass, waste	4	0	Manufact.: electrical machinery	103	327
			Manufac: other transport equip.	65	223
			Other business activities	32	190
			Chemicals nec	60	178
			Wholesale/commission trade	−7	164
			Secondary steel into new one	−5	138
			Manufac: rubber, plastic prod.	38	135
			Manufac: radio, tv, communicat.	41	135

contribute a mere −0.02 percentage points to the overall GDP reduction in the adopting region. This is unsurprising given the small share of these sectors in the adopting region's value added. Second, the observed adverse macroeconomic effects in the adopting region primarily stem from a contraction in production in several non-regulated downstream industries. Eliminating free allowances adversely affects production in these industries, with the CBAM consistently exacerbating negative effects in several instances. Fig. 4 provides insights, revealing that several downstream industries display heightened responsiveness to inflationary dynamics originating from covered sectors. These industries absorb a portion of the inflationary pressure in their production processes due to sectoral interconnections, resulting in competitiveness losses in both foreign and internal markets. It also shows that, although inflation is not a significant challenge at the aggregate level, substantial inflationary pressures emerge within regulated sectors. These dynamics largely explains the particularly weak macroeconomic protection offered by the CBAM in most adopting countries. Third, clear carbon leakage patterns emerge for most of these downstream sectors, with emissions increasing in the non-adopting region's non-regulated sectors by 5 to 8 million tonnes, depending on the scenario. This shift contributes to a rise in sectoral global emissions when production moves to more polluting countries (see Fig. B.2) and helps explain the significant carbon leakage observed in the model (see Table 2). Overall, these results highlight the intricate nature of carbon leakage, emphasizing the substantial role played by competitiveness effects in various downstream industries (Bellora and Fontagné, 2023).[10]

[10] While these findings lend support for evaluating extending protection to specific downstream ETS industries, it is paramount to acknowledge that these identified leakage effects are still of secondary importance compared to the environmental risks posed by certain regulated sectors. A notable example is the cement industry, which, according to the results, could witness a global surge of approximately 16 million tonnes of CO_2e emissions if the EU cement

Fig. 5 delves deeper into the sectoral effects by showing the percentage changes in total production for regulated sectors (excluding electricity) in each country.[11] The results reveal a completely different order of magnitude at this level of granularity. Particularly severe repercussions are observed in Eastern-EU regulated industries, where production drops frequently exceed 10% and often fall within the 20–30% range. In some instances, the effects are even more drastic, with sectoral production losses in the range of 50%, as seen in the aluminium industry in Portugal, the iron industry in Slovakia, and the fertilizer industry in Hungary. The protection offered by CBAM proves to be inadequate in most of these cases, mitigating only a minimal fraction of the negative impacts, if at all.[12] On the flip side, the findings highlight the beneficial impacts of the policy in several adopting countries, with substantial production increases in various regulated industries. The CBAM is a major driver of these positive outcomes, though the elimination of free allowances also plays a contributing role in several cases. This trend once again highlights intra-EU redistributive dynamics, with production shifting from more polluting to less polluting EU countries. For a breakdown of these total effects into domestic and export components, refer to Figs. B.3–B.4.

At this level of analysis, the evidence of burden shifting becomes conspicuously apparent in specific contexts. The findings reveal that the CBAM carries the potential risk of significantly curtailing production in specific markets within non-adopting countries. To illustrate, the cement market in Turkey and the Rest of Europe region is particularly susceptible to the EU policy, facing potential losses amounting to approximately 10% of their business (−70% for exports). Similar risks are expected for the aluminium industry in the Rest of Europe region. The burden-shifting effect becomes even more pronounced, reaching 15% for the iron and steel industry in the Rest of Europe region and for the fertilizers market in Turkey (−23% for exports).

5.3. Robustness checks: WIOD data

Reconstructing input–output relationships and associated emissions flows is a notoriously complex task, with data reliability posing a potential issue, especially in analyses based on highly disaggregated data, such as the current study.

To further validate the previous results, a robustness check is conducted using an alternative and widely used Input–Output data source: the World Input–Output Database (WIOD) (2014 - Release 2016). The WIOD is less detailed than EXIOBASE 3, covering 44 regions and 56 sectors. This lower level of disaggregation complicates the isolation of regulated industries, as they are typically aggregated within broader sectors. The following larger sectors are thus considered to represent the regulated industries: (i) "Manufacture of other non-metallic mineral products": cement; (ii) "Manufacture of basic metals": iron, steel, and aluminium; (iii) "Manufacture of chemicals and chemical products": fertilizers; (iv) "Electricity, gas, steam, and air conditioning supply": electricity. The resulting carbon coverage is more than twice that of the previous analyses. Only CO_2 emissions are included, as data for N_2O and $PFCs$ are unavailable.

Although these scenarios differ from previous ones in terms of carbon coverage and reference year, the results remain qualitatively consistent with previous findings. Specifically, the following patterns continue to be observed. (1) Burden-shifting effects are generally absent or negligible, with the notable exceptions of Russia and Turkey. (2) Eastern EU countries experience the most substantial economic effects, with CBAM offering limited protection in most cases. (3) Although CBAM consistently protects covered sectors in the regulated region, this protection generally does not offset the impact of removing free allowances, resulting in considerable losses, especially in several Eastern EU countries. (4) Certain downstream industries in the regulated region suffer notable negative effects. (5) CBAM reduces global emissions, effectively preventing a significant carbon leakage dynamic. Please refer to Table B.1 and Figs. B.5, B.6, and B.7 for more details.

Overall, this robustness exercise further corroborates previous findings and conclusions, demonstrating their consistency across an alternative data source and a slightly modified scenario configuration.

6. Conclusions

The ongoing climate crisis represents an enormous emergency requiring immediate and ambitious global policies to enhance the probability of maintaining the climate system within acceptable boundaries (IPCC, 2023). However, various challenges, such as incentives to free-ride on emissions abatement policies, international tensions and disagreements on burden-sharing, absence of a supranational institution to enforce global treaties, short-term perspective, policy capture, climate change skepticism, and concerns about potential adverse effects of certain climate policies both among and within countries pose significant obstacles to translating this emergency into adequate global actions. As a result, climate policies are still lagging globally, marked by a fragmented scenario characterized by a myriad of uncoordinated, typically not ambitious enough, unilateral climate initiatives (OECD, 2023; World Bank, 2023b).

In the face of these challenges, the EU is taking action. Among the array of policies recently implemented, a notable decision involves the adoption of a carbon border adjustment mechanism to replace the free allocation of emission allowances in several ETS sectors. While this will strength and expand the EU carbon price signal and hopefully incentivize the diffusion of more sustainable technologies and consumption baskets, the CBAM is expected to reduce carbon leakage risks by protecting European firms' competitiveness on the domestic market. Yet, albeit the literature typically suggests that the CBAM can serve the purpose, at least partially (Böhringer et al., 2012b; Branger and Quirion, 2014; Böhringer et al., 2022; Zhong and Pei, 2024), several critical aspects of this policy have been emphasized, including possible tensions with international trade agreements, retaliation of non-adopting countries, equity issues connected to the risk of a significant burden shifting to non-adopting countries, especially the least developed ones, and skepticism about the policy's overall efficacy in achieving global goals for carbon emissions reduction (Böhringer et al., 2012a, 2018, 2022; Lanzi et al., 2012; Davidson Ladly, 2012; Brandi, 2021; Tarr et al., 2023). Thus, the EU CBAM risks encountering significant international opposition, as underscored by the initial skeptical and adverse reaction of several international partners (Lim et al., 2021; Overland and Sabyrbekov, 2022; Smith et al., 2024).

The paper leverages the first large-scale CBAM experiment to assess its impacts across different countries and industries. Developing an MRIO-based analytical framework, it identifies the countries and industries most susceptible to gains or losses under the policy, both within and outside the EU. While the approach lacks the complexity of CGE-based models, it offers distinct advantages. One key benefit is the higher granularity in sectoral and country disaggregation compared to many existing CGE analyses. As noted by Ward et al. (2019),

industry does not receive the CBAM protection. Furthermore, the impact on the overall emissions of these possible sectoral extensions cannot be taken for granted but must be carefully studied, resulting, for example, from the balance between opposing competitive effects in the new industries involved. Exploring the macroeconomic and environmental outcomes of an expanded sectoral scope could indeed be a valuable extension of the present study.

[11] Very small sectors – those with outputs below €10 million – were excluded from the graphs to avoid drawing attention to large impacts in minor, likely artifact sectors that may have emerged from efforts to maintain consistency during dataset construction. This specifically led to the exclusion of the small fertilizer sectors in Sweden and Slovakia.

[12] Aligned with (Burniaux et al., 2013) and Böhringer et al. (2015), it is noteworthy that the CBAM can occasionally have a perverse effect on the protected industry, albeit infrequently and typically with negligible consequences in terms of scale.

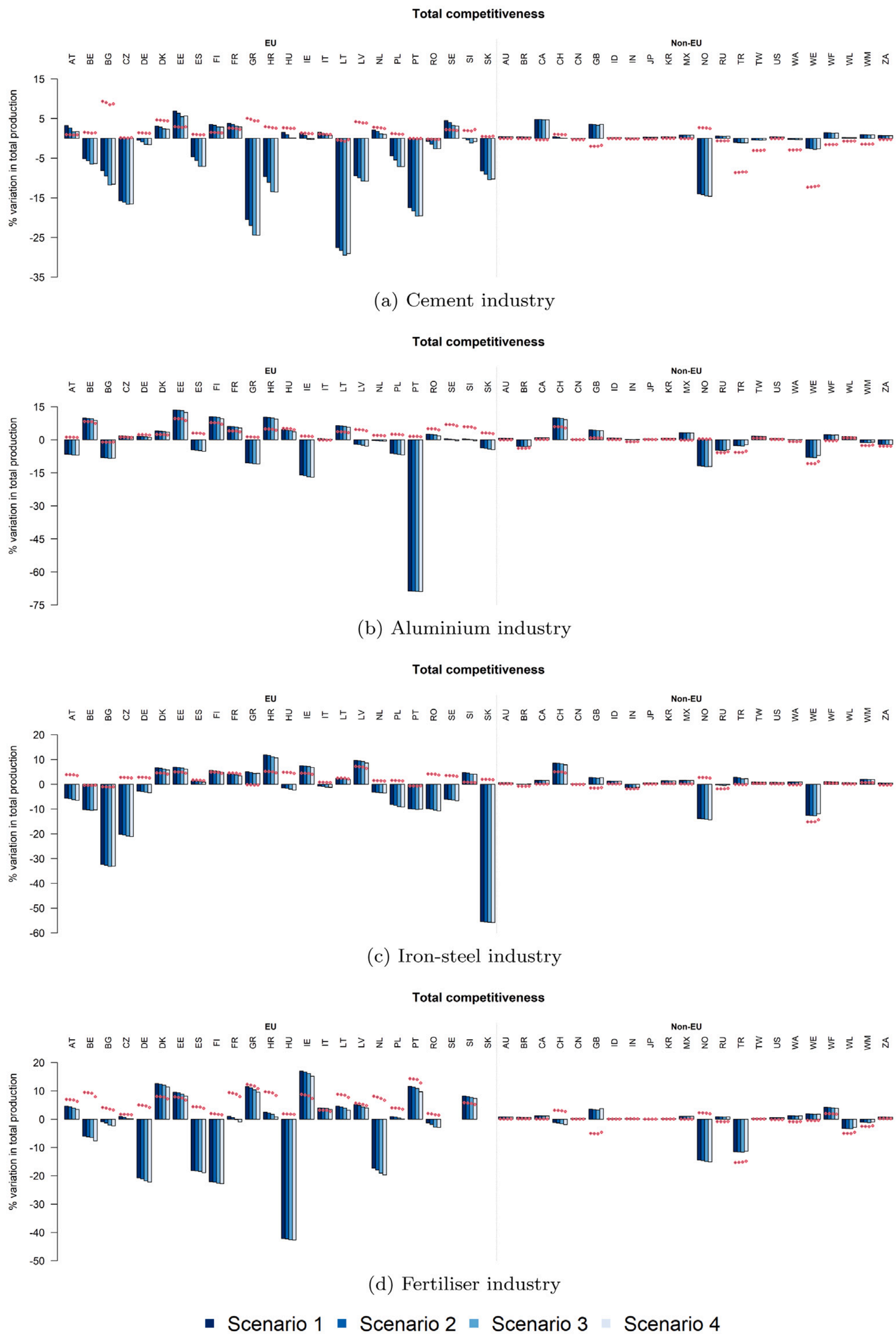


Fig. 5. Percentage production variation at the country-industry level: covered sectors. The bars represent the effects of substituting free allowances with a CBAM (full policy), while the red diamonds indicate the impacts of the CBAM alone. To isolate the effect of removing free allowances, compare the heights of the bars and diamonds. Small EU countries and sectors not included in the graphs. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

conventional CGE-based methods often struggle to accommodate the level of detail achievable with IO models. This granularity has proven crucial in the analysis, allowing the uncovering of substantial heterogeneity dynamics. Furthermore, although the model may omit various secondary feedbacks, it has the advantage of clearly spotlighting the first-round and short-term shocks faced by different countries and sectors. Simplicity and interpretability are, in fact, two main merits of Input–Output models (Zhong and Pei, 2022). Consequently, despite relying on stringent assumptions, particularly over the medium to long term, I believe my findings contribute valuable insights to the ongoing debate on the EU CBAM.

The results suggest that widespread concerns about substantial burden-shifting effects may be overstated. Findings indicate minimal negative effects of the CBAM on the GDP of most non-adopting countries, with these minor impacts often fully offset by the benefits gained from the removal of free allowances. Large economies such as China, the US, and Japan, in fact, experience slight net gains under the EU policy. While minor negative impacts are observed for India, Russia, and Turkey, these effects remain limited. Significant burden-shifting is evident only in the Rest of Europe region — mainly non-EU Eastern European countries.

At the industry level, burden-shifting is more pronounced, as the EU CBAM reduces the overall non-adopting region production in the regulated sectors. However, these effects are generally modest and largely counterbalanced by gains from the removal of free allowances, with several regulated industries in the non-adopting region even emerging as primary net beneficiaries. Although this trend holds at an aggregate level, more pronounced burden-shifting effects emerge in a few particular cases, such as the cement market in Turkey and the Rest of Europe region, the iron, steel, and aluminium industries in the Rest of Europe region, and the fertilizer market in Turkey.

In contrast, within the adopting region, the policy's impacts are more substantial. Certain Eastern EU countries may experience GDP reductions of approximately 1% due to the shift from free allowances to a CBAM. Production losses in regulated sectors can exceed 10%, and in some cases, even reach or exceed the 20 – 30% range. In these cases – primarily occurring in peripheral EU countries – the CBAM provides limited protection for competitiveness, as adverse effects are driven largely by intra-EU competitiveness imbalances. Production losses extend to several "inflation-absorbing" downstream sectors, particularly in manufacturing, which largely explains the negative macroeconomic outcomes observed in most adopting countries and reinforces carbon leakage dynamics.

These results suggest that, contrary to common belief, resistance to the EU policy may be most pronounced within the Union itself. Addressing these internal challenges may thus be essential to ensure sustained, long-term consensus and commitment to the policy, as well as to mitigate regressive redistributive effects within the Union. Critically, these policies should be carefully designed to preserve incentives for de-carbonizing production processes and consumption patterns. Targeted technology transfer, innovation programs, and subsidies focused on emission reductions in high-polluting sectors provide a valuable opportunity for the EU to green these industries while simultaneously reducing competitiveness imbalances. Revenues from CBAM duties and additional auctioned emissions allowances could serve as a stable funding source for these initiatives.

Acknowledgements

I am particularly grateful to Claudio Colacurcio, Giacomo Cotignano, Alessandra Lanza, and Marco Valente for their valuable comments and support. The work has also greatly benefited from the feedback of the editor, the three anonymous referees, and the participants at the Eleventh IAERE Annual Conference, held in Naples in February 2023, and the 64th SIE Conference, held in L'Aquila in September 2023, where an earlier version of this paper was presented.

Appendix A. Concordance tables: Armington and price elasticity

See Tables A.1–A.3.

Appendix B. Additional results

See Figs. B.1–B.7
See Table B.1

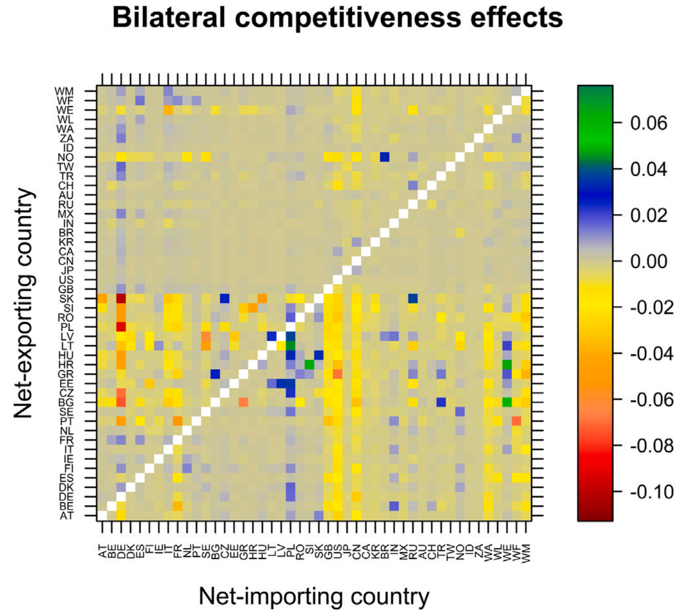


Fig. B.1. Bilateral competitiveness effects induced by the full EU policy, measured as percentage changes in bilateral net export flows relative to total output. Each colored square represents the change in net exports, in pre-shock prices, from the country on the y-axis to the country on the x-axis. These effects are evaluated in a zero-sum game scenario (scenario 1) to coherently isolate competitiveness effects from overall import-export flows. Small EU countries not included in the graphs. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

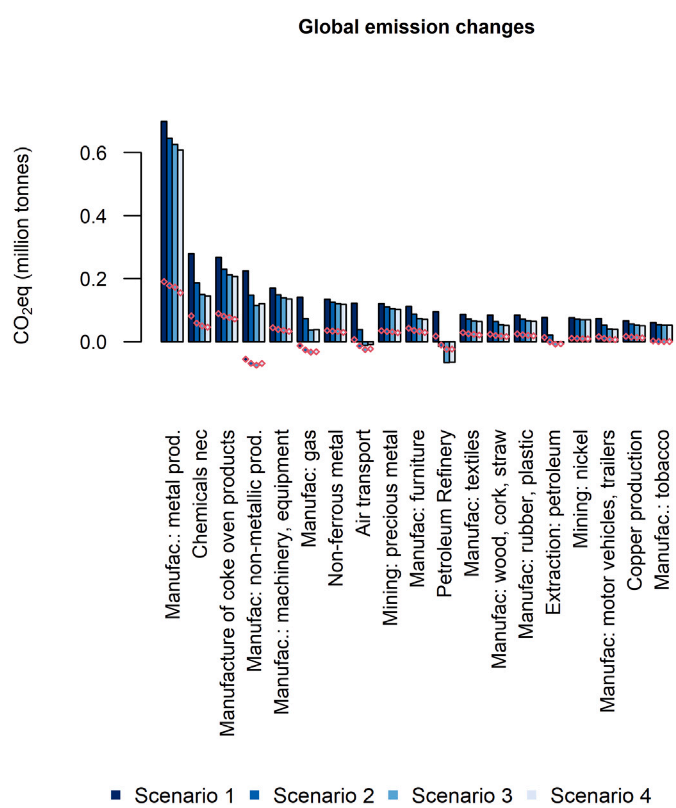
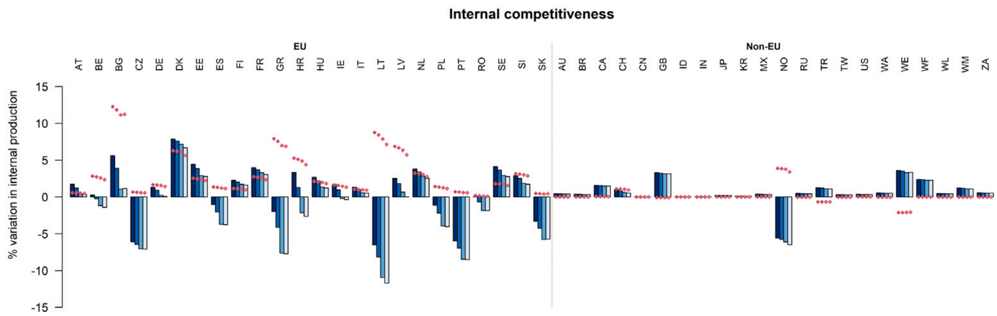
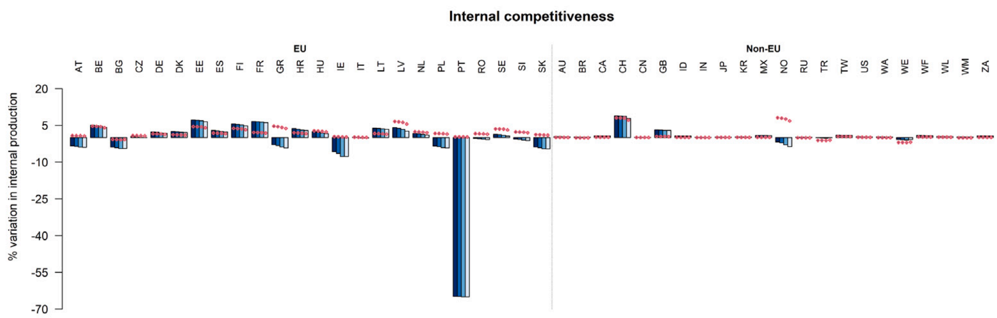


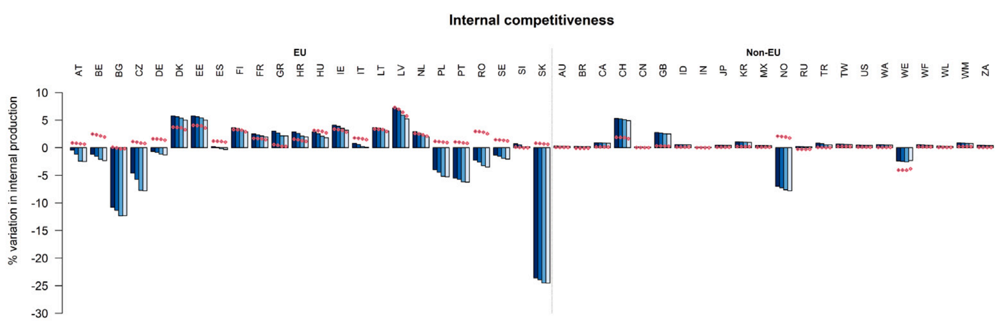
Fig. B.2. Global emission changes at the industry level: sectors experiencing the strongest increase in emissions due to the policy. The bars represent the effects of substituting free allowances with a CBAM (full policy), while the red diamonds indicate the impacts of the CBAM alone. To isolate the effect of removing free allowances, compare the heights of the bars and diamonds. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



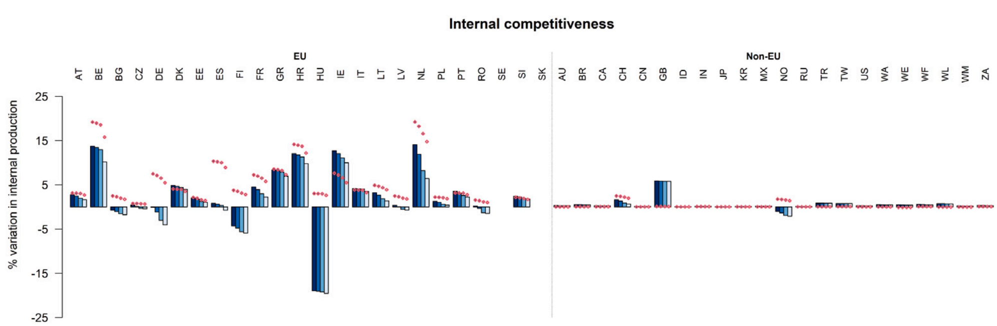
(a) Cement industry



(b) Aluminium industry



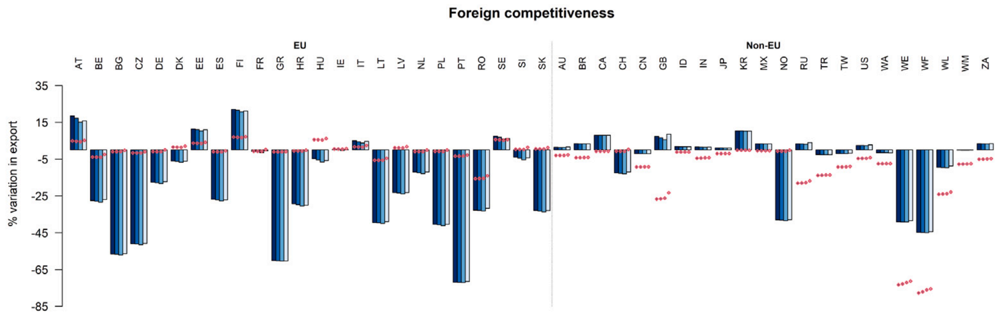
(c) Iron-steel industry



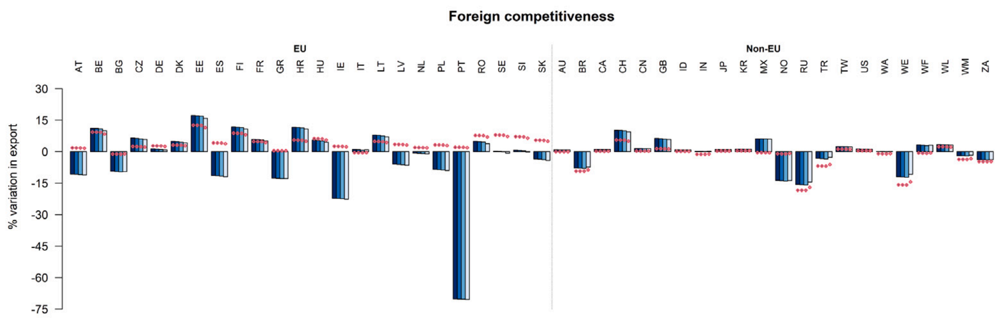
(d) Fertiliser industry

■ Scenario 1 ■ Scenario 2 ■ Scenario 3 ■ Scenario 4

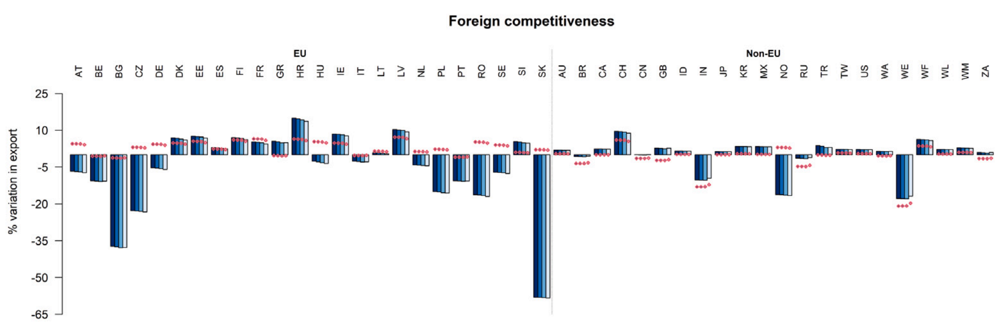
Fig. B.3. Percentage domestic production variation at the country-industry level: covered sectors. The bars represent the effects of substituting free allowances with a CBAM (full policy), while the red diamonds indicate the impacts of the CBAM alone. To isolate the effect of removing free allowances, compare the heights of the bars and diamonds. Small EU countries and sectors not included in the graphs. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



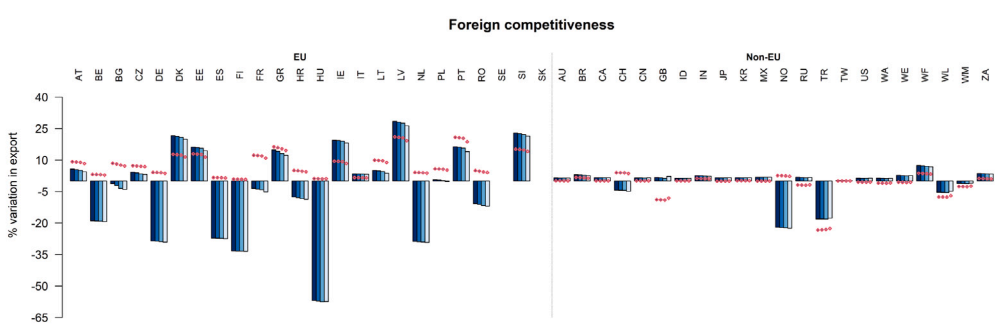
(a) Cement industry



(b) Aluminium industry



(c) Iron-steel industry



(d) Fertiliser industry

Scenario 1 Scenario 2 Scenario 3 Scenario 4

Fig. B.4. Percentage export variation at the country-industry level: covered sectors. The bars represent the effects of substituting free allowances with a CBAM (full policy), while the red diamonds indicate the impacts of the CBAM alone. To isolate the effect of removing free allowances, compare the heights of the bars and diamonds. Small EU countries and sectors not included in the graphs. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table A.1
Concordance table mapping Exiobase 3 industries to: (a) GTAP 10 industries and (b) aggregate commodity categories typically used in the GTAP framework for estimating country-specific own-price elasticities. Values for the domestic/imported Armington elasticity (θ^d) and the sourcing of imports Armington elasticity (θ^m), as well as commodity categorization, are from Hertel and van der Mensbrugghe (2019).

Exiobase industry	GTAP industry	θ^d	θ^m	Commodity category (ρ)
Cultivation of paddy rice	Paddy rice [pdr]	5.05	10.1	GrainCrops
Cultivation of wheat	Wheat [wht]	4.45	8.9	GrainCrops
Cultivation of cereal grains nec	Cereal grains nec [gro]	1.3	2.6	GrainCrops
Cultivation of vegetables, fruit, nuts	Vegetables, fruit, nuts [v_f]	1.85	3.7	GrainCrops
Cultivation of oil seeds	Oil seeds [osd]	2.45	4.9	GrainCrops
Cultivation of sugar cane, sugar beet	Sugar cane, sugar beet [c_b]	2.7	5.4	GrainCrops
Cultivation of plant-based fibers	Plant-based fibers [pfb]	2.5	5	TextAppar
Cultivation of crops nec	Crops nec [ocr]	3.25	6.5	GrainCrops
Cattle farming	Bovine cattle, sheep and goats, horses [ctl]	2	4	MeatDairy
Pigs farming	Bovine cattle, sheep and goats, horses [ctl]	2	4	MeatDairy
Poultry farming	Bovine cattle, sheep and goats, horses [ctl]	2	4	MeatDairy
Meat animals nec	Animal products nec [oap]	1.3	2.6	MeatDairy
Animal products nec	Animal products nec [oap]	1.3	2.6	MeatDairy
Raw milk	Raw milk [rmk]	3.65	7.3	MeatDairy
Wool, silk-worm cocoons	Wool, silk-worm cocoons [wol]	6.45	12.9	TextAppar
Manure treatment (conventional), storage and land application	Forestry [frs]	2.5	5	Mnfcs
Manure treatment (biogas), storage and land application	Forestry [frs]	2.5	5	Mnfcs
Forestry, logging and related service activities (02)	Forestry [frs]	2.5	5	Mnfcs
Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing (05)	Fishing [fsh]	1.25	2.5	MeatDairy
Mining of coal and lignite; extraction of peat (10)	Coal [coa]	3.05	6.1	HousUtils
Extraction of crude petroleum and services related to crude oil extraction, excluding surveying	Oil [oil]	5.2	10.4	GrainCrops
Extraction of natural gas and services related to natural gas extraction, excluding surveying	Gas [gas]	17.2	34.4	HousUtils
Extraction, liquefaction, and regasification of other petroleum and gaseous materials	Oil [oil]	5.2	10.4	GrainCrops
Mining of uranium and thorium ores (12)	Minerals nec [oxt]	0.9	1.8	Mnfcs
Mining of iron ores	Minerals nec [oxt]	0.9	1.8	Mnfcs
Mining of copper ores and concentrates	Minerals nec [oxt]	0.9	1.8	Mnfcs
Mining of nickel ores and concentrates	Minerals nec [oxt]	0.9	1.8	Mnfcs
Mining of aluminium ores and concentrates	Minerals nec [oxt]	0.9	1.8	Mnfcs
Mining of precious metal ores and concentrates	Minerals nec [oxt]	0.9	1.8	Mnfcs
Mining of lead, zinc and tin ores and concentrates	Minerals nec [oxt]	0.9	1.8	Mnfcs
Mining of other non-ferrous metal ores and concentrates	Minerals nec [oxt]	0.9	1.8	Mnfcs
Quarrying of stone	Minerals nec [oxt]	0.9	1.8	Mnfcs
Quarrying of sand and clay	Minerals nec [oxt]	0.9	1.8	Mnfcs
Mining of chemical and fertilizer minerals, production of salt, other mining and quarrying n.e.c.	Minerals nec [oxt]	0.9	1.8	Mnfcs
Processing of meat cattle	Bovine meat products [cmt]	3.85	7.7	MeatDairy
Processing of meat pigs	Bovine meat products [cmt]	3.85	7.7	MeatDairy
Processing of meat poultry	Bovine meat products [cmt]	3.85	7.7	MeatDairy
Production of meat products nec	Meat products nec [omt]	4.4	8.8	MeatDairy
Processing vegetable oils and fats	Vegetable oils and fats [vol]	3.3	6.6	OthFoodBev
Processing of dairy products	Dairy products [mil]	3.65	7.3	MeatDairy
Processed rice	Processed rice [pcr]	2.6	5.2	GrainCrops
Sugar refining	Sugar [sgr]	2.7	5.4	OthFoodBev
Processing of Food products nec	Food products nec [ofd]	2	4	OthFoodBev
Manufacture of beverages	Beverages and tobacco products [b_t]	1.15	2.3	OthFoodBev
Manufacture of fish products	Food products nec [ofd]	2	4	OthFoodBev
Manufacture of tobacco products (16)	Beverages and tobacco products [b_t]	1.15	2.3	OthFoodBev
Manufacture of textiles (17)	Textiles [tex]	3.75	7.5	TextAppar
Manufacture of wearing apparel; dressing and dyeing of fur (18)	Wearing apparel [wap]	3.7	7.4	TextAppar
Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear (19)	Leather products [lea]	4.05	8.1	TextAppar
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (20)	Wood products [lum]	3.4	6.8	Mnfcs
Re-processing of secondary wood material into new wood material	Wood products [lum]	3.4	6.8	Mnfcs
Pulp	Paper products, publishing [ppp]	2.95	5.9	Mnfcs
Re-processing of secondary paper into new pulp	Paper products, publishing [ppp]	2.95	5.9	Mnfcs
Paper	Paper products, publishing [ppp]	2.95	5.9	Mnfcs
Publishing, printing and reproduction of recorded media (22)	Paper products, publishing [ppp]	2.95	5.9	Mnfcs
Manufacture of coke oven products	Petroleum, coal products [p_c]	2.1	4.2	Mnfcs

(*continued on next page*)

Table A.1 (*continued*).

Exiobase industry	GTAP industry	θ^d	θ^m	Commodity category (ρ)
Petroleum Refinery	Petroleum, coal products [p_c]	2.1	4.2	Mnfcs
Processing of nuclear fuel	Petroleum, coal products [p_c]	2.1	4.2	Mnfcs
Plastics, basic	Rubber and plastic products [rpp]	3.3	6.6	Mnfcs
Re-processing of secondary plastic into new plastic	Rubber and plastic products [rpp]	3.3	6.6	Mnfcs
N-fertilizer	Chemical products [chm]	3.3	6.6	Mnfcs
P- and other fertilizer	Chemical products [chm]	3.3	6.6	Mnfcs
Chemicals nec	Chemical products [chm]	3.3	6.6	Mnfcs
Manufacture of rubber and plastic products (25)	Rubber and plastic products [rpp]	3.3	6.6	Mnfcs
Manufacture of glass and glass products	Mineral products nec [nmm]	2.9	5.8	Mnfcs
Re-processing of secondary glass into new glass	Mineral products nec [nmm]	2.9	5.8	Mnfcs
Manufacture of ceramic goods	Mineral products nec [nmm]	2.9	5.8	Mnfcs
Manufacture of bricks, tiles and construction products, in baked clay	Mineral products nec [nmm]	2.9	5.8	Mnfcs
Manufacture of cement, lime and plaster	Mineral products nec [nmm]	2.9	5.8	Mnfcs
Re-processing of ash into clinker	Mineral products nec [nmm]	2.9	5.8	Mnfcs
Manufacture of other non-metallic mineral products n.e.c.	Mineral products nec [nmm]	2.9	5.8	Mnfcs
Manufacture of basic iron and steel and of ferro-alloys and first products thereof	Ferrous metals [i_s]	2.95	5.9	Mnfcs
Re-processing of secondary steel into new steel	Ferrous metals [i_s]	2.95	5.9	Mnfcs
Precious metals production	Metals nec [nfm]	4.2	8.4	Mnfcs
Re-processing of secondary precious metals into new preciuos metals	Metals nec [nfm]	4.2	8.4	Mnfcs
Aluminium production	Metals nec [nfm]	4.2	8.4	Mnfcs
Re-processing of secondary aluminium into new aluminium	Metals nec [nfm]	4.2	8.4	Mnfcs
Lead, zinc and tin production	Metals nec [nfm]	4.2	8.4	Mnfcs
Re-processing of secondary lead into new lead, zinc and tin	Metals nec [nfm]	4.2	8.4	Mnfcs
Copper production	Metals nec [nfm]	4.2	8.4	Mnfcs
Re-processing of secondary copper into new copper	Metals nec [nfm]	4.2	8.4	Mnfcs
Other non-ferrous metal production	Metals nec [nfm]	4.2	8.4	Mnfcs
Re-processing of secondary other non-ferrous metals into new other non-ferrous metals	Metals nec [nfm]	4.2	8.4	Mnfcs
Casting of metals	Metals nec [nfm]	4.2	8.4	Mnfcs
Manufacture of fabricated metal products, except machinery and equipment (28)	Metal products [fmp]	3.75	7.5	Mnfcs
Manufacture of machinery and equipment n.e.c. (29)	Machinery and equipment nec [ome]	4.05	8.1	Mnfcs
Manufacture of office machinery and computers (30)	Computer, electronic and optical products [ele]	4.4	8.8	Mnfcs
Manufacture of electrical machinery and apparatus n.e.c. (31)	Electrical equipment [eeq]	4.4	8.8	Mnfcs
Manufacture of radio, television and communication equipment and apparatus (32)	Electrical equipment [eeq]	4.4	8.8	Mnfcs
Manufacture of medical, precision and optical instruments, watches and clocks (33)	Electrical equipment [eeq]	4.4	8.8	Mnfcs
Manufacture of motor vehicles, trailers and semi-trailers (34)	Motor vehicles and parts [mvh]	2.8	5.6	Mnfcs
Manufacture of other transport equipment (35)	Transport equipment nec [otn]	4.3	8.6	TransComm
Manufacture of furniture; manufacturing n.e.c. (36)	Manufactures nec [omf]	3.75	7.5	Mnfcs
Recycling of waste and scrap	Manufactures nec [omf]	3.75	7.5	Mnfcs
Recycling of bottles by direct reuse	Manufactures nec [omf]	3.75	7.5	Mnfcs
Production of electricity by coal	Electricity [ely]	2.8	5.6	HousUtils
Production of electricity by gas	Electricity [ely]	2.8	5.6	HousUtils
Production of electricity by nuclear	Electricity [ely]	2.8	5.6	HousUtils
Production of electricity by hydro	Electricity [ely]	2.8	5.6	HousUtils
Production of electricity by wind	Electricity [ely]	2.8	5.6	HousUtils
Production of electricity by petroleum and other oil derivatives	Electricity [ely]	2.8	5.6	HousUtils
Production of electricity by biomass and waste	Electricity [ely]	2.8	5.6	HousUtils
Production of electricity by solar photovoltaic	Electricity [ely]	2.8	5.6	HousUtils
Production of electricity by solar thermal	Electricity [ely]	2.8	5.6	HousUtils
Production of electricity by tide, wave, ocean	Electricity [ely]	2.8	5.6	HousUtils
Production of electricity by Geothermal	Electricity [ely]	2.8	5.6	HousUtils
Production of electricity nec	Electricity [ely]	2.8	5.6	HousUtils
Transmission of electricity	Electricity [ely]	2.8	5.6	HousUtils
Distribution and trade of electricity	Electricity [ely]	2.8	5.6	HousUtils
Manufacture of gas; distribution of gaseous fuels through mains	Gas manufacture, distribution [gdt]	2.8	5.6	HousUtils
Steam and hot water supply	Water [wtr]	2.8	5.6	HousUtils
Collection, purification and distribution of water (41)	Water [wtr]	2.8	5.6	HousUtils
Construction (45)	Construction [cns]	1.9	3.8	HousUtils
Re-processing of secondary construction material into aggregates	Construction [cns]	1.9	3.8	HousUtils

(*continued on next page*)

Table A.1 (*continued*).

Exiobase industry	GTAP industry	θ^d	θ^m	Commodity category (ρ)
Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessories	Trade [trd]	1.9	3.8	WRTrade
Retail sale of automotive fuel	Trade [trd]	1.9	3.8	WRTrade
Wholesale trade and commission trade, except of motor vehicles and motorcycles (51)	Trade [trd]	1.9	3.8	WRTrade
Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods (52)	Trade [trd]	1.9	3.8	WRTrade
Hotels and restaurants (55)	Accommodation, Food and service activities [afs]	1.9	3.8	WRTrade
Transport via railways	Transport nec [otp]	1.9	3.8	TransComm
Other land transport	Transport nec [otp]	1.9	3.8	TransComm
Transport via pipelines	Transport nec [otp]	1.9	3.8	TransComm
Sea and coastal water transport	Water transport [wtp]	1.9	3.8	TransComm
Inland water transport	Water transport [wtp]	1.9	3.8	TransComm
Air transport (62)	Air transport [atp]	1.9	3.8	TransComm
Supporting and auxiliary transport activities; activities of travel agencies (63)	Communication [cmn]	1.9	3.8	TransComm
Post and telecommunications (64)	Communication [cmn]	1.9	3.8	TransComm
Financial intermediation, except insurance and pension funding (65)	Financial services nec [ofi]	1.9	3.8	FinService
Insurance and pension funding, except compulsory social security (66)	Insurance [ins]	1.9	3.8	HousUtils
Activities auxiliary to financial intermediation (67)	Financial services nec [ofi]	1.9	3.8	FinService
Real estate activities (70)	Real estate activities [rsa]	1.9	3.8	FinService
Renting of machinery and equipment without operator and of personal and household goods (71)	Business services nec [obs]	1.9	3.8	FinService
Computer and related activities (72)	Business services nec [obs]	1.9	3.8	FinService
Research and development (73)	Business services nec [obs]	1.9	3.8	FinService
Other business activities (74)	Business services nec [obs]	1.9	3.8	FinService
Public administration and defense; compulsory social security (75)	Public Administration and defense [osg]	1.9	3.8	HousOthServ
Education (80)	Education [edu]	1.9	3.8	HousOthServ
Health and social work (85)	Human health and social work activities [hht]	1.9	3.8	HousOthServ
Incineration of waste: Food	Water [wtr]	2.8	5.6	HousUtils
Incineration of waste: Paper	Water [wtr]	2.8	5.6	HousUtils
Incineration of waste: Plastic	Water [wtr]	2.8	5.6	HousUtils
Incineration of waste: Metals and Inert materials	Water [wtr]	2.8	5.6	HousUtils
Incineration of waste: Textiles	Water [wtr]	2.8	5.6	HousUtils
Incineration of waste: Wood	Water [wtr]	2.8	5.6	HousUtils
Incineration of waste: Oil/Hazardous waste	Water [wtr]	2.8	5.6	HousUtils
Biogasification of food waste, incl. land application	Water [wtr]	2.8	5.6	HousUtils
Biogasification of paper, incl. land application	Water [wtr]	2.8	5.6	HousUtils
Biogasification of sewage slugde, incl. land application	Water [wtr]	2.8	5.6	HousUtils
Composting of food waste, incl. land application	Water [wtr]	2.8	5.6	HousUtils
Composting of paper and wood, incl. land application	Water [wtr]	2.8	5.6	HousUtils
Waste water treatment, food	Water [wtr]	2.8	5.6	HousUtils
Waste water treatment, other	Water [wtr]	2.8	5.6	HousUtils
Landfill of waste: Food	Water [wtr]	2.8	5.6	HousUtils
Landfill of waste: Paper	Water [wtr]	2.8	5.6	HousUtils
Landfill of waste: Plastic	Water [wtr]	2.8	5.6	HousUtils
Landfill of waste: Inert/metal/hazardous	Water [wtr]	2.8	5.6	HousUtils
Landfill of waste: Textiles	Water [wtr]	2.8	5.6	HousUtils
Landfill of waste: Wood	Water [wtr]	2.8	5.6	HousUtils
Activities of membership organization n.e.c. (91)	Public Administration and defense [osg]	1.9	3.8	HousOthServ
Recreational, cultural and sporting activities (92)	Recreational and other services [ros]	1.9	3.8	HousOthServ
Other service activities (93)	Recreational and other services [ros]	1.9	3.8	HousOthServ
Private households with employed persons (95)	Recreational and other services [ros]	1.9	3.8	HousOthServ
Extra-territorial organizations and bodies	Public Administration and defense [osg]	1.9	3.8	HousOthServ

Table A.2
Uncompensated own-price elasticities of demand by region. Source: Hertel and van der Mensbrugghe (2019). Elasticities for RoW regions are calculated as the average of available country-specific values within each region. To derive country-industry-specific price elasticities, combine these data with the commodity category shown in .

Region	Grain-Crops	Meat-Dairy	Oth-FoodBev	Text-Appar	Hous-Utils	WRT-Trade	Mnfcs	Trans-Comm	Fin-Service	Hous-OthServ
AU	−0.002	0.827	0.742	0.819	0.865	0.713	0.855	0.837	0.894	0.570
AT	0.001	0.752	0.679	0.733	0.775	0.624	0.769	0.752	0.862	0.697
BE	0.001	0.727	0.631	0.700	0.753	0.736	0.705	0.745	0.821	0.659
BG	0.083	0.305	0.245	0.307	0.425	0.447	0.406	0.376	0.539	0.420
BR	0.056	0.368	0.304	0.366	0.499	0.488	0.466	0.440	0.562	0.420
CA	0.000	0.752	0.678	0.746	0.777	0.687	0.760	0.755	0.816	0.622
CH	−0.006	0.934	0.900	0.942	0.907	0.851	0.947	0.930	0.991	0.634
CN	0.154	0.297	0.250	0.301	0.462	0.485	0.426	0.417	0.564	0.382
CY	0.015	0.499	0.428	0.497	0.587	0.481	0.581	0.536	0.641	0.471
CZ	0.046	0.458	0.376	0.460	0.488	0.576	0.571	0.492	0.650	0.627
DE	0.002	0.732	0.646	0.712	0.736	0.689	0.733	0.729	0.825	0.681
DK	−0.001	0.807	0.726	0.785	0.779	0.771	0.812	0.813	0.879	0.740
EE	0.030	0.467	0.384	0.468	0.571	0.531	0.587	0.559	0.657	0.545
ES	0.011	0.588	0.513	0.580	0.659	0.501	0.676	0.636	0.732	0.543
FI	0.002	0.733	0.665	0.735	0.761	0.677	0.768	0.753	0.848	0.633
FR	0.003	0.691	0.622	0.695	0.712	0.643	0.727	0.715	0.818	0.629
GB	−0.001	0.739	0.668	0.722	0.755	0.616	0.749	0.732	0.811	0.614
GR	0.013	0.516	0.444	0.516	0.557	0.499	0.604	0.500	0.645	0.583
HR	0.048	0.385	0.318	0.382	0.522	0.466	0.503	0.480	0.597	0.485
HU	0.066	0.388	0.318	0.392	0.517	0.490	0.513	0.497	0.610	0.458
ID	0.152	0.239	0.203	0.241	0.367	0.378	0.316	0.305	0.461	0.277
IE	0.009	0.753	0.663	0.734	0.773	0.639	0.820	0.709	0.855	0.808
IN	0.154	0.197	0.182	0.201	0.254	0.305	0.218	0.214	0.384	0.276
IT	0.006	0.634	0.573	0.629	0.694	0.549	0.696	0.670	0.765	0.574
JP	0.003	0.654	0.566	0.647	0.690	0.588	0.721	0.663	0.769	0.536
KR	0.002	0.557	0.480	0.551	0.620	0.605	0.652	0.612	0.723	0.512
LT	0.029	0.432	0.356	0.435	0.558	0.467	0.523	0.509	0.623	0.539
LU	−0.006	1.063	0.979	1.052	0.949	0.912	1.027	0.910	1.055	1.081
LV	0.031	0.430	0.343	0.427	0.533	0.487	0.518	0.523	0.619	0.480
MT	0.005	0.548	0.503	0.537	0.596	0.510	0.551	0.563	0.667	0.627
MX	0.058	0.350	0.281	0.353	0.509	0.479	0.451	0.406	0.562	0.365
NL	0.004	0.744	0.664	0.719	0.752	0.674	0.789	0.746	0.872	0.720
NO	−0.008	0.959	0.915	0.982	0.990	0.910	0.965	0.882	1.041	0.811
PL	0.044	0.398	0.335	0.404	0.487	0.498	0.494	0.484	0.589	0.522
PT	0.017	0.513	0.441	0.505	0.567	0.482	0.587	0.545	0.650	0.603
RO	0.070	0.334	0.270	0.338	0.453	0.477	0.456	0.439	0.567	0.430
RU	0.057	0.375	0.324	0.393	0.519	0.439	0.508	0.457	0.622	0.573
SE	0.002	0.780	0.707	0.776	0.785	0.731	0.826	0.777	0.892	0.719
SI	0.022	0.517	0.445	0.510	0.627	0.552	0.577	0.579	0.690	0.559
SK	0.036	0.453	0.377	0.447	0.514	0.556	0.538	0.508	0.627	0.594
TR	0.052	0.346	0.289	0.345	0.487	0.423	0.465	0.416	0.548	0.434
TW	0.047	0.489	0.409	0.486	0.630	0.533	0.628	0.586	0.688	0.454
US	−0.003	0.793	0.737	0.784	0.805	0.745	0.799	0.818	0.829	0.488
WA	0.104	0.308	0.274	0.306	0.399	0.418	0.371	0.362	0.508	0.402
WE	0.087	0.345	0.311	0.354	0.408	0.430	0.444	0.395	0.539	0.463
WF	0.128	0.207	0.177	0.209	0.283	0.374	0.232	0.261	0.393	0.318
WL	0.085	0.314	0.264	0.314	0.443	0.432	0.410	0.390	0.517	0.393
WM	0.064	0.487	0.422	0.480	0.594	0.620	0.516	0.530	0.646	0.563
ZA	0.111	0.281	0.227	0.276	0.383	0.501	0.387	0.377	0.514	0.367

Table A.3
Summary statistics for the uncompensated own-price elasticity of demand. This table presents the cross-country mean, standard deviation, minimum, and maximum values for each commodity category.

Commodity category	Mean	Sd	Min	Max
GrainCrops	0.038	0.046	−0.008	0.154
MeatDairy	0.540	0.214	0.197	1.063
OthFoodBev	0.475	0.206	0.177	0.979
TextAppar	0.537	0.210	0.201	1.052
HousUtils	0.608	0.169	0.254	0.990
WRTrade	0.565	0.137	0.305	0.912
Mnfcs	0.605	0.185	0.218	1.027
TransComm	0.578	0.176	0.214	0.930
FinService	0.693	0.159	0.384	1.055
HousOthServ	0.549	0.149	0.276	1.081

Table B.1
Aggregate effects in the WIOD-based analysis. Adopting vs. non-adopting regions. Averages across scenarios.

	Adopting region			Non-adopting region		
	Free allowances	CBAM	Full policy	Free allowances	CBAM	Full policy
Average across scenarios:						
Production prices (%)	0.409	0.122	0.531	0.026	0.007	0.033
Internal production (%)	−0.439	0.095	−0.344	0.124	−0.014	0.111
Export (%)	−1.724	0.111	−1.613	0.321	−0.134	0.187
GDP (%)	−0.655	0.097	−0.557	0.141	−0.024	0.117
Emissions (million tonnes)	−75.15	34.43	−40.72	130.65	−101.73	28.93
Carbon coverage (% of 2014 global carbon emissions)	1.333	0.527	1.860			

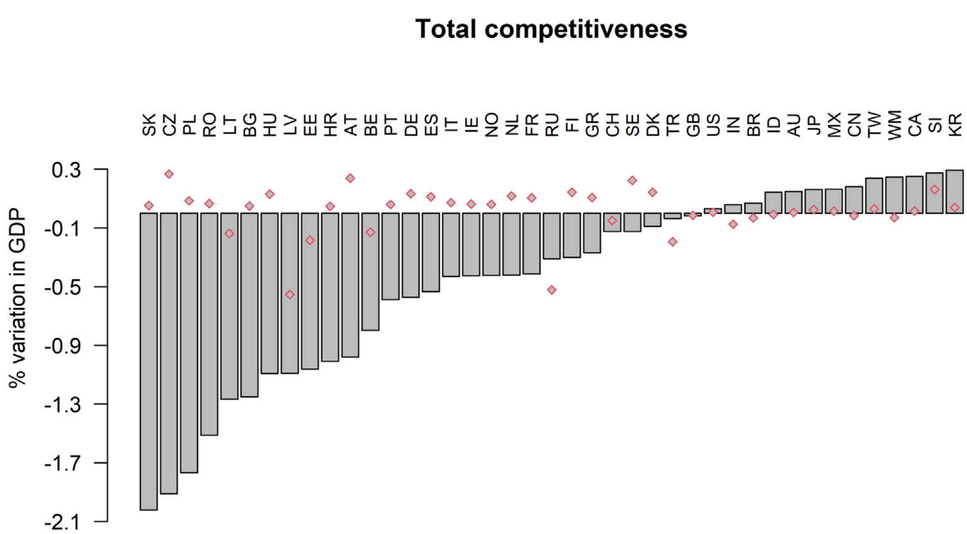
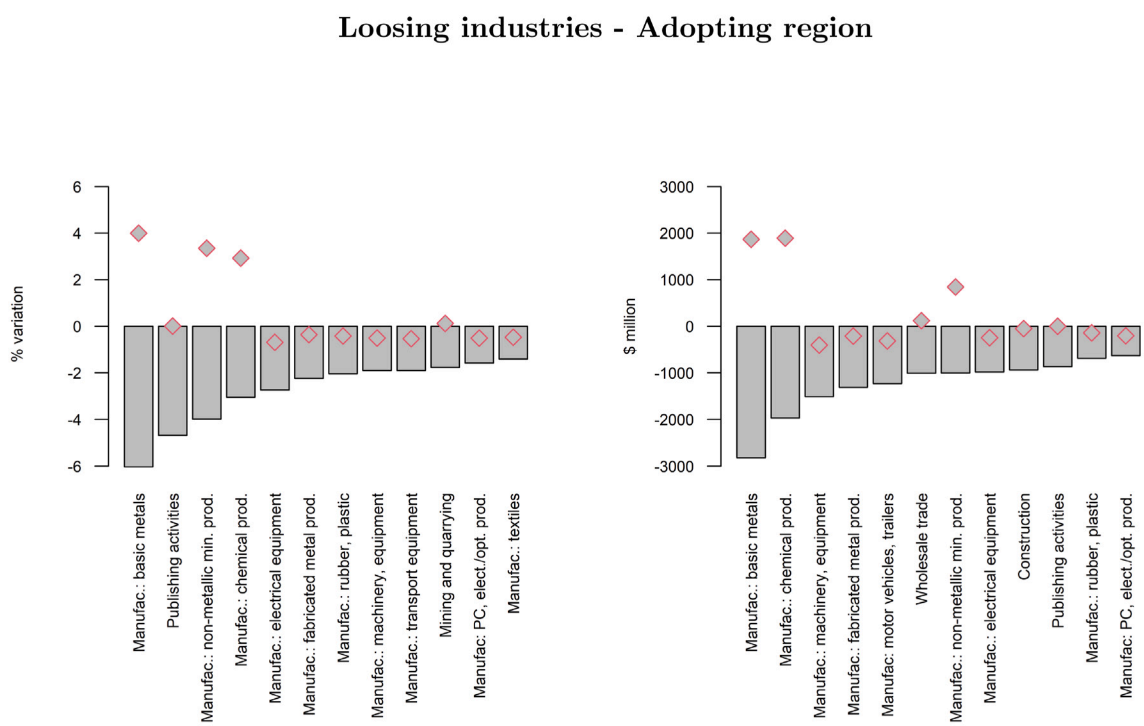
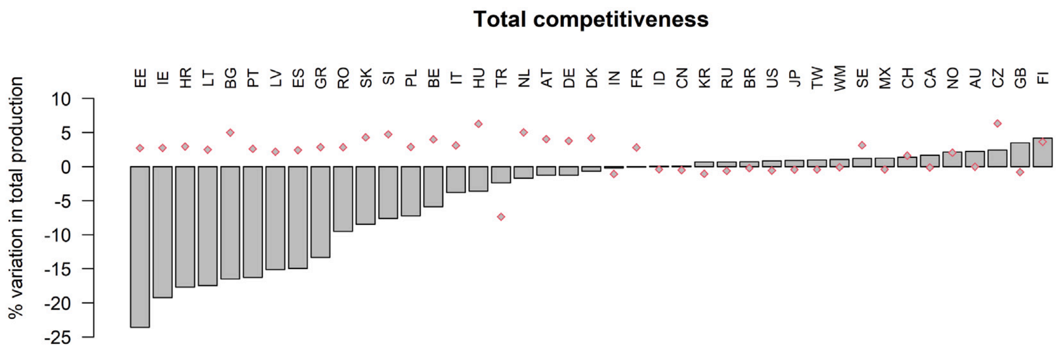


Fig. B.5. Macroeconomic impacts at the country level in the WIOD-based analysis. The bars represent the effects of substituting free allowances with a CBAM (full policy), while the red diamonds indicate the impacts of the CBAM alone. To isolate the effect of removing free allowances, compare the heights of the bars and diamonds. Small EU countries not included in the graphs. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

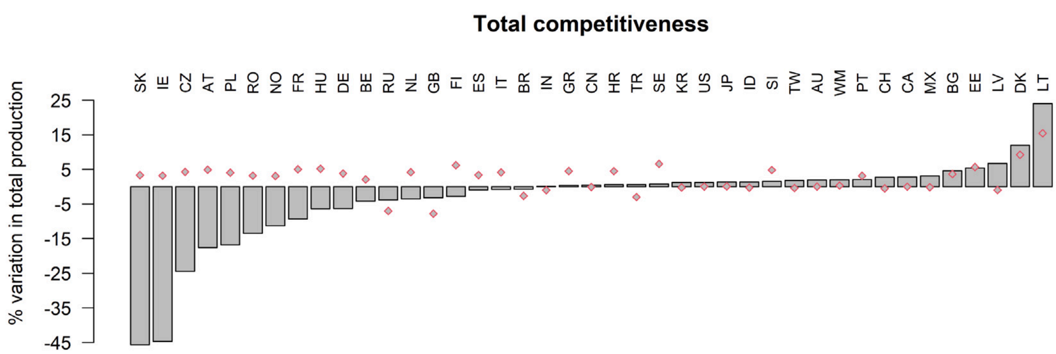


(a) Percentage effects (b) Total effects

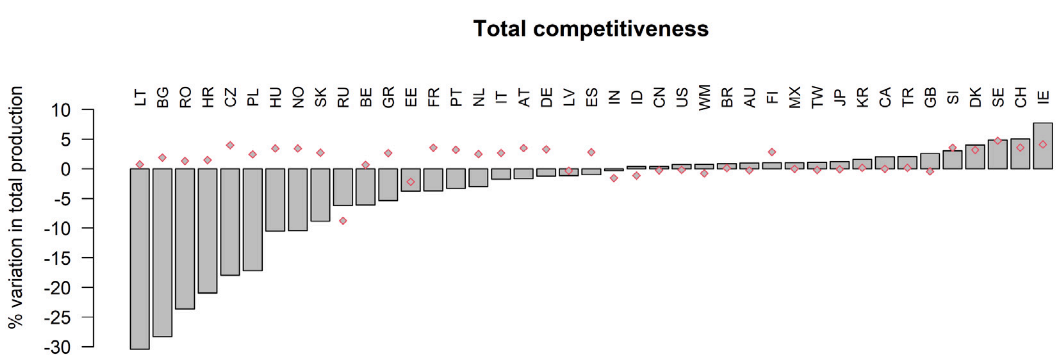
Fig. B.6. Loosing industries in the adopting region in the WIOD-based analysis. The bars represent the effects of substituting free allowances with a CBAM (full policy), while the red diamonds indicate the impacts of the CBAM alone. To isolate the effect of removing free allowances, compare the heights of the bars and diamonds. Small EU countries not included in the graphs. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



(a) Manufacture of other non-metallic mineral products



(b) Manufacture of basic metals



(c) Manufacture of chemicals and chemical products

Fig. B.7. Percentage production variation at the country-industry level: covered sectors. The bars represent the effects of substituting free allowances with a CBAM (full policy), while the red diamonds indicate the impacts of the CBAM alone. To isolate the effect of removing free allowances, compare the heights of the bars and diamonds. Small EU countries not included in the graphs. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

References

Aguiar, A., Chepeliev, M., Corong, E.L., McDougall, R., Van Der Mensbrugghe, D., 2019. The GTAP data base: version 10. J. Glob. Econ. Anal. 4 (1), 1–27.

Balistreri, E.J., Kaffine, D.T., Yonezawa, H., 2019. Optimal environmental border adjustments under the General Agreement on Tariffs and Trade. Environ. Resour. Econ. 74 (3), 1037–1075.

Beaufils, T., Ward, H., Jakob, M., Wenz, L., 2023. Assessing different european carbon border adjustment mechanism implementations and their impact on trade partners. Commun. Earth Environ. 4 (1), 131.

Bellora, C., Fontagné, L., 2023. EU in search of a carbon border adjustment mechanism. Energy Econ. 123 (10667).

Böhringer, C., Balistreri, E.J., Rutherford, T.F., 2012a. The role of border carbon adjustment in unilateral climate policy: Overview of an Energy Modeling Forum study (EMF 29). Energy Econ. 34 (S2), S97–S110.

Böhringer, C., Bye, B., Fæhn, T., Rosendahl, K.E., 2012b. Alternative designs for tariffs on embodied carbon: A global cost-effectiveness analysis. Energy Econ. 34 (S2), S143–S153.

Böhringer, C., Carbone, J.C., Rutherford, T.F., 2018. Embodied carbon tariffs. Scand. J. Econ. 120 (1), 183–210.

Böhringer, C., Fischer, C., Rosendahl, K.E., Rutherford, T.F., 2022. Potential impacts and challenges of border carbon adjustments. Nature Clim. Change 12 (1), 22–29.

Böhringer, C., Müller, A., Schneider, J., 2015. Carbon tariffs revisited. J. Assoc. Environ. Resour. Econ. 2 (4), 629–672.

Böhringer, C., Schneider, J., Asane-Otoo, E., 2021. Trade in carbon and carbon tariffs. Environ. Resour. Econ. 78, 669–708.

Brandi, C., 2021. Priorities for a Development-Friendly EU Carbon Border Adjustment (CBAM). Briefing Paper 20/2021, Deutsches Institut für Entwicklungspolitik (DIE), Bonn, https://hdl.handle.net/10419/242609. (Accessed 16 October 2023).

Branger, F., Quirion, P., 2014. Would border carbon adjustments prevent carbon leakage and heavy industry competitiveness losses? Insights from a meta-analysis of recent economic studies. Ecol. Econom. 99, 29–39.

Branger, F., Quirion, P., Chevallier, J., 2016. Carbon leakage and competitiveness of cement and steel industries under the EU ETS: much ado about nothing. Energy J. 37 (3), 109–136.

Burniaux, J.-M., Chateau, J., Duval, R., 2013. Is there a case for carbon-based border tax adjustment? An applied general equilibrium analysis. Appl. Econ. 45 (16), 2231–2240.

Carbone, J.C., Rivers, N., 2017. The impacts of unilateral climate policy on competitiveness: evidence from computable general equilibrium models. Rev. Environ. Econ. Policy 11 (1), 24–42.

Chepeliev, M., 2021. Possible implications of the european carbon border adjustment mechanism for ukraine and other eu trading partners. Energy Res. Lett. 2 (1).

Clora, F., Yu, W., Corong, E., 2023. Alternative carbon border adjustment mechanisms in the European Union and international responses: Aggregate and within-coalition results. Energy Policy 174, 113454.

Cosbey, A., Droege, S., Fischer, C., Munnings, C., 2019. Developing guidance for implementing border carbon adjustments: lessons, cautions, and research needs from the literature. Rev. Environ. Econ. Policy 13 (1), 3–22.

Davidson Ladly, S., 2012. Border carbon adjustments, WTO-law and the principle of common but differentiated responsibilities. Int. Environ. Agreem.: Polit. Law Econ. 12 (1), 63–84.

Demaret, P., Stewardson, R., 1994. Border tax adjustment under GATT and EC law and general implications for environmental taxes. J. World Trade 28 (4), 5–65.

Dröge, S., van Asselt, H., Brewer, T., Grubb, M., Ismer, R., Kameyama, Y., Mehling, M., Monjon, S., Neuhoff, K., Quirion, P., et al., 2009. Tackling leakage in a world of unequal carbon prices. Clim. Strateg.

EC, 2019. State of the union address by President von der Leyen. https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_20_1655. (Accessed 2 Febraury 2023).

EC, 2021. Proposal for a Regulation of the European Parliament and of the Council Establishing a Carbon Border Adjustment Mechanism. Impact Assessment Report, European Commission, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52021SC0643. (Accessed 12 April 2023).

EC, 2024. CBAM and Developing Countries/LDCs. Policy Note, European Commission, https://taxation-customs.ec.europa.eu/document/download/7abe56cc-4af0-490d-90e1-0a0825aabe37_en?filename=CBAM%20and%20developing%20countries.pdf. (Accessed 9 June 2024).

Eicke, L., Weko, S., Apergi, M., Marian, A., 2021. Pulling up the carbon ladder? Decarbonization, dependence, and third-country risks from the European carbon border adjustment mechanism. Energy Res. Soc. Sci. 80, 102240.

Elliott, J., Foster, I., Kortum, S., Munson, T., Cervantes, F.P., Weisbach, D., 2010. Trade and carbon taxes. Amer. Econ. Rev. 100 (2), 465–469.

EU, 2023. Regulation (EU) 2023/956 of the European Parliament and of the Council of 10 2023 establishing a carbon border adjustment mechanism. http://data.europa.eu/eli/reg/2023/956/oj. (Accessed 11 July 2023).

Felder, S., Rutherford, T.F., 1993. Unilateral CO2 reductions and carbon leakage: the consequences of international trade in oil and basic materials. J. Environ. Econ. Manage. 25 (2), 162–176.

Flues, F., Dender, K.Van., 2017. Permit Allocation Rules and Investment Incentives in Emissions Trading Systems. OECD Taxation Working Papers, No. 33, OECD Publishing, Paris.

Fontagné, Lionel, Schubert, Katheline, 2023. The economics of border carbon adjustment: rationale and impacts of compensating for carbon at the border. Annu. Rev. Econ. 15 (1), 389–424.

Ghosh, M., Luo, D., Siddiqui, M.S., Zhu, Y., 2012. Border tax adjustments in the climate policy context: CO2 versus broad-based GHG emission targeting. Energy Econ. 34 (S2), S154–S167.

Hertel, T., van der Mensbrugghe, D., 2019. Behavioral parameters. In: Aguiar, A. (Ed.), Global Trade, Assistance, and Production: The GTAP 10 Data Base. Center for Global Trade Analysis 14, Department of Agricultural Economics, Purdue University, West Lafayette, IN.

Hoel, M., 1991. Global environmental problems: the effects of unilateral actions taken by one country. J. Environ. Econ. Manage. 20 (1), 55–70.

Holzer, K., 2014. Carbon-Related Border Adjustment and WTO Law. Edward Elgar Publishing.

IETA, 2023. IETA GHG market sentiment survey 2023 18th edition. https://www.ieta.org/resources/ghg-sentiment-survey/2023-survey/. (Accessed 15 September 2023).

IPCC, 2013. Sections. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I To the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F. D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, a. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 1535.

IPCC, 2023. Sections. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III To the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland.

Joltreau, E., Sommerfeld, K., 2019. Why does emissions trading under the EU Emissions Trading System (ETS) not affect firms' competitiveness? Empirical findings from the literature. Clim. Policy 19 (4), 453–471.

Jomini, P., McDougall, R., Watts, G., Dee, P., 1994. The SALTER Model of the World Economy: Model Structure, Database and Parameters. Industry commission, Canberra.

Keen, M., Parry, I., Roaf, J., 2022. Border carbon adjustments: rationale, design and impact. Fiscal Stud. 43 (3), 209–234.

Lanzi, E., Chateau, J., Dellink, R., 2012. Alternative approaches for levelling carbon prices in a world with fragmented carbon markets. Energy Econ. 34 (S2), S240–S250.

Lim, B., Hong, K., Yoon, J., Chang, J.-I., Cheong, I., 2021. Pitfalls of the EU's carbon border adjustment mechanism. Energies 14 (21), 7303.

Lowe, S., 2021. The EU's Carbon Border Adjustment Mechanism: How To Make It Work for Developing Countries. Policy Brief, Centre for European Reform, https://www.cer.eu/publications/archive/policy-brief/2021/eus-carbon-border-adjustment-mechanism-how-make-it-work. (Accessed 10 October 2023).

Magacho, G., Espagne, E., Godin, A., 2024. Impacts of the CBAM on EU trade partners: consequences for developing countries. Clim. Policy 24 (2), 243–259.

Miller, R.E., Blair, P.D., 2009. Input–Output Analysis: Foundations and Extensions. Cambridge University Press.

Misch, F., Wingender, M.P., 2021. Revisiting Carbon Leakage. International Monetary Fund, WP/21/207, Washington, DC.

Mörsdorf, G., 2022. A simple fix for carbon leakage? Assessing the environmental effectiveness of the EU carbon border adjustment. Energy Policy 161, 112596.

Naegele, H., Zaklan, A., 2019. Does the EU ETS cause carbon leakage in European manufacturing? J. Environ. Econ. Manage. vol. 93, 125–147.

OECD, 2023. Environmental Policy: Effective Carbon Rates (Edition 2022). Dataset, OECD, https://Www.Oecd-Ilibrary.Org/Content/Data/8b73ecc7-En. (Accessed 8 October 2023).

Overland, I., Sabyrbekov, R., 2022. Know your opponent: Which countries might fight the European carbon border adjustment mechanism? Energy Policy vol. 169, 113175.

Pahle, M., Sitarz, J., Osorio, S., Görlach, B., 2022. The EU-ETS Price Through 2030 and beyond: A Closer Look At Drivers, Models and Assumptions. Input Material and Takeaways from a Workshop in Brussels. Documentation. https://www.ecologic.eu/19034. (Accessed 14 October 2023).

Parry, I.W., Dohlman, M.P., Hillier, M.C., Kaufman, M., Kaufman, M.M.D., Misch, F., Roaf, M.J., Waerzeggers, C., Waerzeggers, M.C.J., Kwak, M.K., 2021. Carbon pricing: What role for border carbon adjustments? In: IMF Staff Climate Note 2021/004. International Monetary Fund, Washington, DC.

Perdana, S., Vielle, M., 2022. Making the EU Carbon Border Adjustment Mechanism acceptable and climate friendly for least developed countries. Energy Policy 170, 113245.

Pietzcker, R.C., Osorio, S., Rodrigues, R., 2021. Tightening EU ETS targets in line with the European Green Deal: Impacts on the decarbonization of the EU power sector. Appl. Energy 293, 116914.

Schotten, G., Hemmerlé, H., Brouwer, G., Bun, M.J., Altaghlibi, M., 2021. The Impact of Carbon Pricing and a CBAM on EU Competitiveness. De Nederlandsche Bank, https://www.dnb.nl/en/publications/research-publications/analysis/the-impact-of-carbon-pricing-and-a-cbam-on-eu-competitiveness/. (Accessed 12 January 2023).

Smith, I.D., Overland, I., Szulecki, K., 2024. The EU's CBAM and its 'significant others': Three perspectives on the Political Fallout from Europe's unilateral climate policy initiative. JCMS: J. Common Market Stud. 62 (2), 603–618.

Stadler, K., Wood, R., Bulavskaya, T., Södersten, C.-J., Simas, M., Schmidt, S., Usubiaga, A., Acosta-Fernández, J., Kuenen, J., Bruckner, M., et al., 2018. EXIOBASE 3: Developing a time series of detailed environmentally extended multi-regional input–output tables. J. Ind. Ecol. 22 (3), 502–515.

Tarr, D.G., Kuznetsov, D.E., Overland, I., Vakulchuk, R., 2023. Why carbon border adjustment mechanisms will not save the planet but a climate club and subsidies for transformative green technologies may. Energy Econ. 122, 106695.

Verde, S.F., 2020. The impact of the EU emissions trading system on competitiveness and carbon leakage: the econometric evidence. J. Econ. Surv. 34 (2), 320–343.

Ward, H., Steckel, J.C., Jakob, M., 2019. How global climate policy could affect competitiveness. Energy Econ. 84, 104549.

World Bank, 2023a. Relative CBAM Exposure Index. Dataset, World Bank, https://www.worldbank.org/en/data/interactive/2023/06/15/relative-cbam-exposure-index#4. (Accessed 5 May 2024).

World Bank, 2023b. State and Trends of Carbon Pricing 2023. Technical Report, World Bank, http://hdl.handle.net/10986/39796. (Accessed 8 October 2023).

Zhong, J., Pei, J., 2022. Beggar thy neighbor? On the competitiveness and welfare impacts of the EU's proposed carbon border adjustment mechanism. Energy Policy 162, 112802.

Zhong, J., Pei, J., 2024. Carbon border adjustment mechanism: a systematic literature review of the latest developments. Clim. Policy 24 (2), 228–242.