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EU carbon border tax:

General equilibrium effects on income and emissions

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Abstract

This paper employs a quantitative trade model to globally assess the implications of the EU carbon border adjustment mechanism (CBAM) on trade flows, welfare, real wages and CO_2 emissions. We quantify the general equilibrium effects on EU members and non-members under various carbon tax prices, including a sector-level composition, and also compare the results to a scenario including export rebates. For the EU, we find an increase in the terms of trade and, consequently, small positive welfare effects, although there are tiny negative effects on real wages. Non-EU countries face a decline in the terms of trade and a small welfare loss as well as marginally declining real wages. Global CO_2 emissions are marginally reduced, but they slightly increase in the EU due to specialisation effects.

Keywords: New quantitative trade model, carbon border adjustment mechanism (CBAM), trade policy welfare, CO_2 emissions

JEL classification: F11, F13, F14, F18, Q56

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1 Introduction

Since climate change represents the most pressing challenge for current and future generations, immediate and decisive action is required to mitigate any environmental damage caused by greenhouse gas (GHG) and other emissions. Overcoming the severe consequences associated with climate change will require a transition in industrial, trade and environmental policies with a strong emphasis on sustainability under the umbrella of an ideally strong global cooperation. The European Union (EU) has taken the lead in this effort by pioneering the European Green Deal (EGD), a climate measure aiming to reduce carbon emissions by 55% compared to 1990 levels by 2030, with the ultimate goal being to make Europe the first climate-neutral continent by 2050.[1]

The EU recently initiated a carbon border adjustment mechanism (CBAM). This climate measure aims to achieve two main objectives. The first objective is to improve the competitiveness of EU exporters (European Commission, 2020). In contrast to the European Emission Trading System (ETS), launched in 2005, the CBAM works as a 'carbon border tax' and does not include export rebates of CO_2 costs endured by EU exporters. Consequently, the CBAM aims to establish a level playing field for EU industries by imposing a carbon price on key sectors.

The second main objective of the CBAM is to address 'carbon leakage', which entails the relocation of carbon-intensive production to countries with less stringent environmental policies. However, ensuring World Trade Organization (WTO) compatibility still poses a major challenge for its completion (Bellora and Fontagné, 2022).

The full implementation of the CBAM, set for 2026, will require importers of specific carbon-intensive goods to pay for the emissions embedded in their products (Böning et al., 2023). The CBAM targets carbon-intensive goods (e.g. aluminium, cement, iron and steel, fertilizers and electricity) due to their significant GHG emission intensity and vulnerability to carbon leakage. This climate measure imposes a carbon price on these goods, which is expected to significantly affect their competitiveness within the EU market via prices while reducing carbon leakage at the same time.

[1] President Ursula von der Leyen announced the European Green Deal in September 2020. For further details, see: https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_20_1655.

However, as the CBAM so far only focuses on a narrow range of carbon-intensive products, its limited scope raises concerns about its overall efficacy in preventing carbon leakage. In addition, excluding downstream products and semi-finished goods introduces potential concerns that will need to be addressed. Therefore, some additional limitations include the increased risk of carbon leakage in such industries (Böning et al., 2023).

Furthermore, ensuring compatibility with international trade laws, particularly under the WTO framework, represents a major challenge (Böhringer et al., 2022). For example, research by Horn and Mavroidis (2011) suggests that border tax adjustments similar to those proposed under the CBAM must carefully navigate legal and trade complexities so as to avoid disputes that could weaken their effectiveness. Ultimately, the success of the CBAM will depend on its ability to adapt to these and future challenges while maintaining a balance between environmental goals and economic feasibility.[2]

With respect to the EGD, a significant portion of the revenues generated from the CBAM are marked as 'green own resources' for the EU. These resources support the EU's budget, particularly in financing climate-related initiatives and the post-COVID-19 economic recovery (Stöllinger, 2020). Similarly, the revenues from the ETS are directed towards the Next Generation EU recovery fund, with 37% allocated to EGD objectives. Additionally, funds from ETS auctions increasingly support the EU's Innovation Fund and its Modernisation Fund, which assist lower-income EU countries with the green transition (Böning et al., 2023). EU member states are required to channel these funds into climate- and energy-related projects. This strategic allocation of resources promotes green investments to advance the EU's environmental and economic agenda.

This paper examines the wider economic implications of the CBAM while recognising that the European Commission has already decided how these revenues will be allocated. Specifically, it looks at how the implementation of the CBAM affects trade flows, welfare and CO_2 emissions across countries and industries. By using a new quantitative trade model (NQTM) combined with novel data, this study provides new insights into the general

[2] In addition, there have been initiatives to examine the effects of the CBAM. For instance, the World Bank has prepared an interactive chart for the CBAM Exposure Index, which compares the carbon emission intensity of a country's CBAM-impacted products with the EU average. This tool helps to determine whether countries can enhance their competitiveness in EU markets by reducing the emission intensity of the affected products. For further information see https://blogs.worldbank.org/en/trade/trade-and-development-chart-cbams-impact-exports-eu.

equilibrium (GE) effects of the CBAM and highlights the mechanism's potential to reconcile the environmental and economic objectives in the EU.

The contributions of this paper are threefold. First, we quantify the effects that the CBAM's implementation has on trade flows, real wages, welfare and CO_2 emissions. Specifically, we follow the Caliendo and Parro (2015) framework type of model allowing for a multi-country multi-industry setting à la Eaton and Kortum (2002) to disentangle the GE effects of the CBAM. Second, the model allows for a sectoral decomposition of impacts, thereby providing a deeper understanding of how different industries within the EU and its trading partners are affected.[3] This sectoral analysis is invaluable for policy makers considering targeted interventions. Third, it explores the potential for refined policy adjustments and implications (e.g. the inclusion of export rebates) to mitigate any adverse effects on EU competitiveness while maintaining the environmental integrity of the CBAM. In addressing these issues, this paper contributes to the literature on trade policy and environmental economics.

The paper is structured as follows: Section 2 provides a literature review of previous studies related to the CBAM and the linkages between trade and environment. Section 3 explains the model applied, followed by Section 4, which describes the data and sources. Section 5 provides the main results and counterfactual scenarios. Lastly, Section 6 provides a conclusion.

2 Climate Challenge: Linking Trade and Emissions

2.1 EU goals and challenges

As the EU pursues its ambitious goal of achieving climate neutrality by 2050, it is becoming increasingly important to understand the geographical and sectoral distribution of carbon emissions. The EU's 'Fit for 55' package, which aims to reduce net GHG emissions by at least 55% by 2030, represents a significant milestone on the path of the green transition. However, the diverse levels of CO_2 emissions across EU member states pose significant challenges to

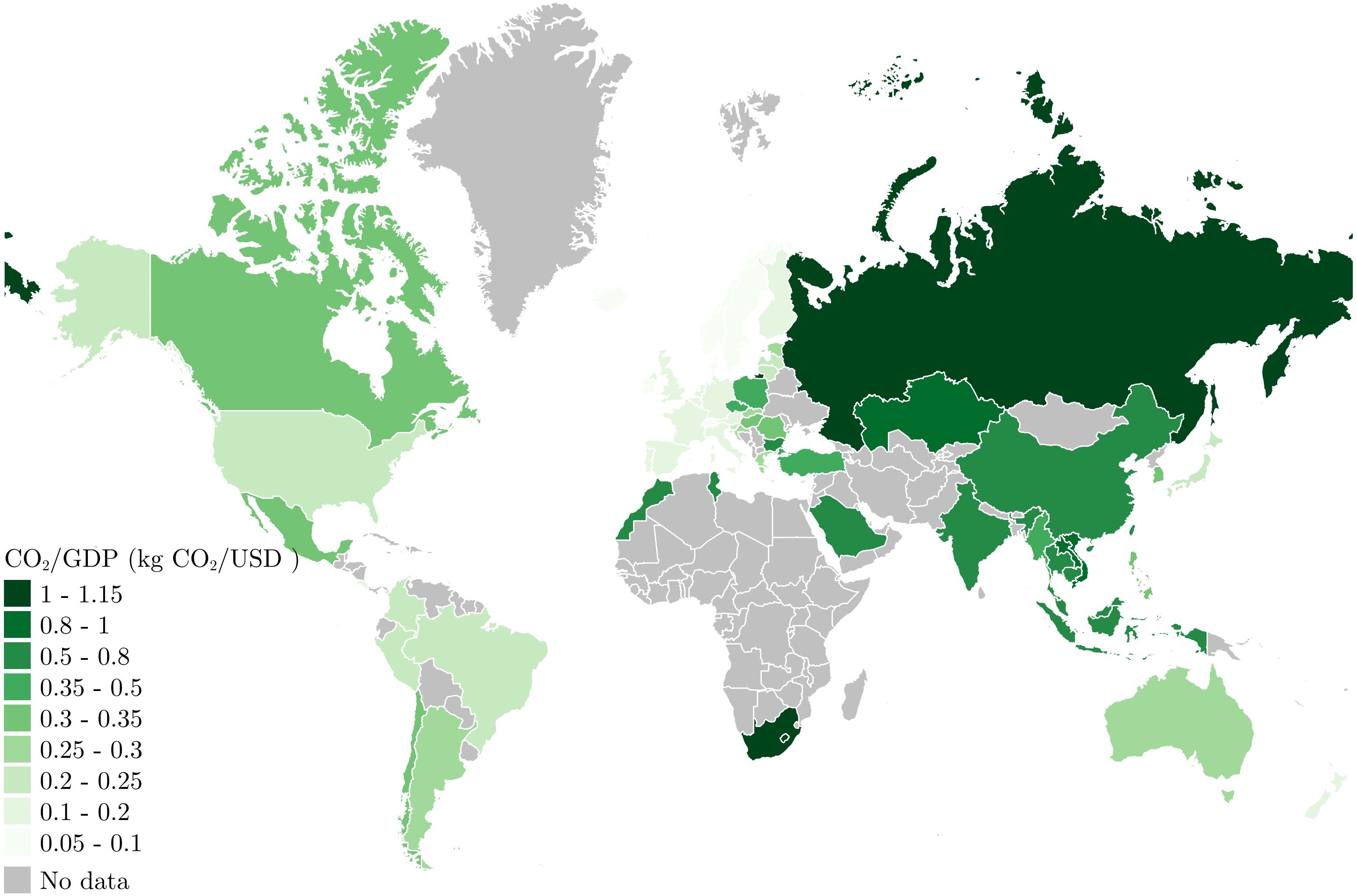
[3]This approach captures the complex input-output linkages between industries, allowing for a detailed examination of the impact of the CBAM across economies and sectors, thus providing novel insights that will contribute to the policy debate on trade and environment.

the implementation of harmonised policies like the CBAM. These challenges are particularly complex due to the inherent dilemma between promoting international trade and reducing CO_2 emissions. While the EU seeks to enhance economic integration by fostering trade flows with the proliferation of free trade agreements, these objectives often conflict with the need to maintain carbon emissions neutrality, especially given the diverse economic structures and energy dependencies among member states.

The heterogeneity across European regions entails an additional challenge to achieving a unified green transition. As recently highlighted by Maucorps et al. (2023), the degree of readiness for this transition varies widely, with some regions – particularly those dependent on carbon-intensive industries – struggling to cope with the necessary changes. This uneven preparedness underlines the complexity of implementing harmonised EU-wide policies to achieve climate neutrality, as regional disparities may hamper overall progress.

This issue is made even more complex by the challenges encountered in accurately tracking and reporting CO_2 emissions, which vary widely across different sectors and regions. Moreover, the global political landscape complicates efforts to achieve alignment and consensus on climate action. Although the Paris Agreement is a significant achievement, its reliance on a flexible framework through nationally determined contributions (NDCs) complicates the creation of a unified climate policy. As Larch and Wanner (2024) demonstrate, this flexibility can lead to risks (e.g. withdrawal or non-compliance), which may in turn weaken global efforts to mitigate climate change. Thus, the effectiveness of the Paris Agreement hinges not only on participation but also on the commitments of CO_2 emitters.

Figure 1: CO_2/GDP per 2015 USD (2020)



Source: Authors' elaboration with data from the International Energy Agency (IEA).

Figure 1 illustrates the significant disparities in global CO_2 emissions across countries in 2020.[4] Focusing on the EU, countries with a high ratio of CO_2 emissions relative to GDP are mostly Central and Eastern European countries. Conversely, Western European countries have much lower emission intensities. These intra-EU variations represent a complex challenge for developing climate policies that are both balanced and effective, as different EU member states face very different circumstances and have different capacities to reduce CO_2 emissions and, consequently, are affected differently by measures like the CBAM.

Expanding this analysis globally, Figure 1 shows further pronounced disparities in CO_2 emissions intensity. Countries with large intensities include Russia, South Africa, Ukraine, China, India, Turkey and, to a lesser extent, Canada, the United States and some countries in South America. These global discrepancies complicate the task of designing and implementing harmonised carbon pricing mechanisms like the CBAM.[5]

Thus, the key challenge is to design climate policies that consider different economic and environmental realities while achieving meaningful reductions in CO_2 emissions. As suggested by Larch and Wanner (2024), this requires an approach that combines carbon pricing with targeted incentives for adopting clean technologies as well as stronger enforcement of international commitments. Such a strategy would bolster the Paris Agreement, be consistent with the EU's ambitious climate goals, and ensure a fair and effective global effort. Moreover, integrating the climate club concept of Nordhaus (2015) could promote broader participation.[6]

In addition, there are wide disparities at the industry level. Figure 2 provides an overview of CO_2 emissions per gross output (i.e. CO_2 intensity) at the OECD inter-country input-output table (OECD-ICIO) industry level in the EU member states in 2020.[7] The most CO_2-intensive industries are energy, agriculture, air transport, minerals and mining

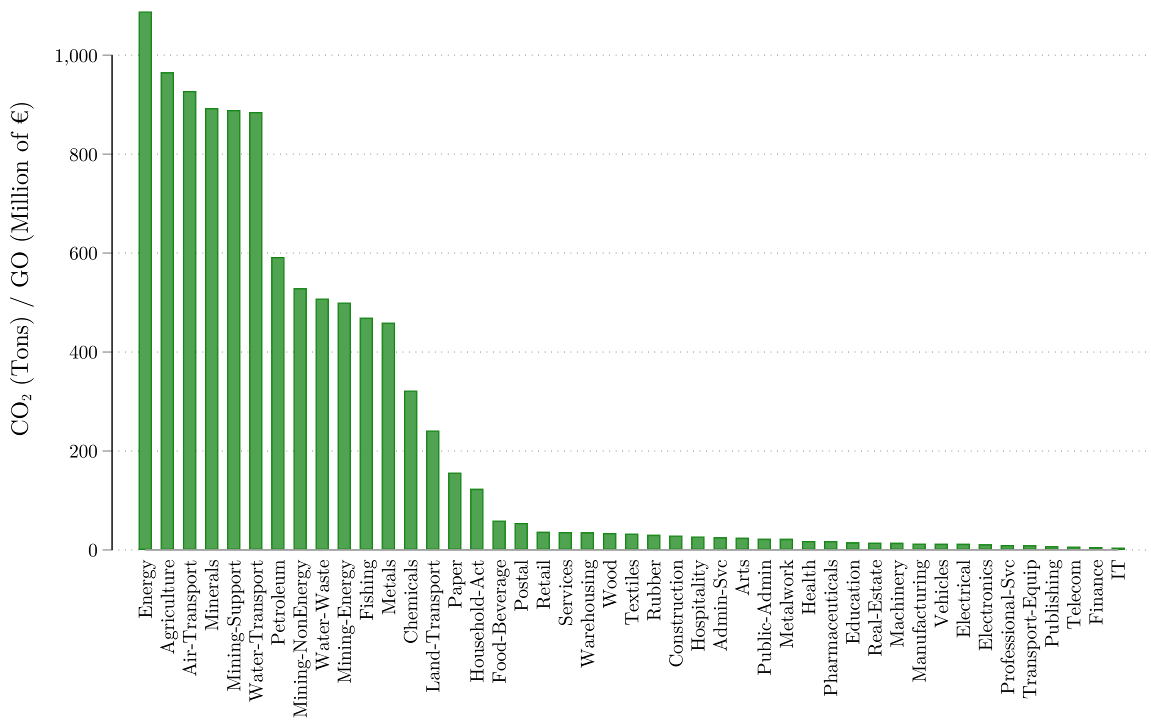
[4] Figure A.1 in Appendix A shows the overall CO_2 emissions, which of course also depend on country size. It is emphasised that these are not the CO_2 footprints (i.e. the emissions caused by a country's consumption).

[5] One should note that this figure indicates where the CO_2 emissions are produced but not necessarily who is responsible for them (i.e. the countries' CO_2 footprints).

[6] Nordhaus' climate club addresses the issue of 'free-riding' and encourages global cooperation.

[7] Total CO_2 emissions by industry for the EU are presented in Figure A.2 of Appendix A. Total CO_2 emissions are predominantly driven by industries like mining and quarrying, energy-producing products, agriculture, non-metallic minerals, chemicals products and metals.

Figure 2: CO_2 intensity of EU industries, 2020



Source: Authors' elaboration; GHG footprint indicators provided by Norihiko Yamano.

support.[8] This implies that carbon pricing or the CBAM will have strongly differentiated effects across industries.

2.2 The complex relations between trade and environmental impacts

The above-mentioned considerations indicate that the interactions among trade policies, economic impacts and environmental outcomes present significant challenges in the context of climate change. Issues that may be driven by free trade agreements (e.g. increased emissions from international trade and transportation as well as deforestation) highlight the complexity of aligning trade and environmental policies.[9] However, trade and trade policies could also help to mitigate these environmental concerns. Felbermayr et al. (2024) provide a comprehensive overview of the economic literature and recent developments on the linkages between trade policies and environmental outcomes. Their survey sheds light

[8]Table A.2 provides a complete description of the OECD-ICIO industry classifications.

[9]For a comprehensive review of the interaction between trade and environmental outcomes, see Copeland et al. (2021); Cherniwchan et al. (2017); Shapiro (2021); Shapiro and Walker (2018); Taylor (2011). Moreover, Harstad (2024) discusses how trade agreements can accelerate deforestation and examines the use of contingent tariffs to encourage conservation and the mitigation of adverse effects.

on the crucial role of input-output analysis and new quantitative trade models – such as computable general equilibrium (CGE) and structural gravity models – in exploring these linkages. These models serve as powerful tools for determining the environmental impacts embedded in trade and for assessing the effectiveness of various policy measures, thereby offering novel insights that can guide policy makers towards more sustainable practices.

Historically, the links between trade and environmental outcomes have been a subject of debate since the early 1970s. A seminal contribution by Markusen (1975) explored international externalities and optimal tax structures, providing the baseline for understanding the intertwining relationships of international trade and the environment. Following the passage of the North American Free Trade Agreement (NAFTA) in 1994, these topics gained even more momentum, with major contributions by Grossman and Krueger (1993) and Copeland and Taylor (1994) introducing key concepts. Notably, Grossman and Krueger (1993) identified three channels through which trade expansion can influence environmental quality: (i) mainly *scale* effects (increased production), (ii) *composition* effects (shifts in industry composition), and (iii) *technique* effects (improvements in production techniques). Subsequently, Copeland and Taylor (1994) explored the pollution haven hypothesis, according to which countries with less stringent environmental regulations may attract more pollution-intensive industries.

Further examining these dynamics, Davis and Kahn (2010) studied the impact of NAFTA on vehicle emissions, finding that while trade increased total lifetime emissions due to low vehicle retirement rates in Mexico, it also led to the trading of cleaner vehicles. This study unveils the complexity of the environmental impacts of trade agreements and their effects.[10]

Subsequent research has continued to expand the literature on the complex relationship between trade and trade policies and economic and environmental outcomes. For instance, Antweiler et al. (2001) and Frankel and Rose (2005) found that trade openness could lead to reductions in certain pollutants, such as sulphur dioxide (SO_2), due to technique effects. However, the overall impact of trade on emissions is likely positive. For example, a meta-analysis by Afesorgbor and Demena (2022) suggests that trade openness generally increases emissions, particularly those of carbon dioxide (CO_2), highlighting the importance

[10]Moreover, cross-border economic policies like NAFTA can indirectly exacerbate environmental damage, highlighting the critical need for accompanying climate policies that address these unintended externalities.

of incorporating environmental considerations into trade policy formulation.

Expanding on these findings, novel developments in NQTMs have facilitated a more sophisticated examination of the linkages between trade and environmental impacts. For example, the studies by Cherniwchan et al. (2017) and Forslid et al. (2018) reveal that trade liberalisation can reduce emissions through resource reallocation as more efficient and less polluting firms increase their market share. Empirical studies, such as Cui et al. (2016) and Holladay (2016), further support this conclusion, showing that exporting firms typically exhibit lower pollution levels due to greater investments in cleaner technologies.

2.3 Global climate policies: From Kyoto to Paris

This complex relationship also has impacts on global climate actions. The journey from the Kyoto Protocol to the Paris Agreement reflects a remarkable evolution in global climate policy, driven by the need to address the complex challenges of climate change. Established in 1997, the Kyoto Protocol was a pioneering effort to set legally binding emission-reduction targets for developed countries. However, its limitations – including its exclusion of major emerging economies and its reliance on rigid, top-down mandates – revealed the need for a more inclusive and flexible strategy (Böning et al., 2023). In response, the EU developed the ETS, a market-based mechanism designed to reduce emissions efficiently while encouraging innovation in green technologies (Löschel et al., 2019).[11]

This practice informed the creation of the Paris Agreement in 2015, which, unlike its predecessor, took a bottom-up approach by allowing countries to set their own targets through NDCs (Dechezleprêtre et al., 2023). This transition marked a new era in climate cooperation, recognising the different capabilities of nations and the importance of collective but flexible action. The ETS, as a cornerstone of the EU's climate strategy, consolidates leadership in climate efforts (Böning et al., 2023).

The concept of carbon leakage, whereby stringent environmental policies in one country lead to increased emissions in other countries, has attracted considerable research interest. Pioneering studies, such as Aichele and Felbermayr (2013), have used structural gravity

[11] Despite its shortcomings, the Kyoto Protocol did lay the foundations for future climate agreements (e.g. the ETS) by establishing a global framework for lower emissions (Böning et al., 2023).

models to assess the impact of the Kyoto Protocol on carbon flows, finding substantial evidence of leakage effects. Similarly, research by Naegele and Zaklan (2019) on the ETS shows comparable leakage effects within the EU, highlighting the complexity of implementing effective climate policies in a globally interconnected economy. Further analysis conducted by Aichele and Felbermayr (2015) confirmed that while the Kyoto Protocol did successfully reduce emissions within participating countries, it inadvertently led to increased emissions in non-participating countries, underscoring the ongoing challenge of carbon leakage in global climate governance.

To address these persistent challenges, including carbon leakage and the difficulty of achieving full global cooperation, recent studies have focused on the implementation of border carbon adjustments (BCAs). However, it is important to note that while BCAs can enhance the stability and effectiveness of global climate agreements by mitigating free-riding, they can also disproportionately affect low- and middle-income countries that rely heavily on exports to the EU, emphasising the need for careful implementation to avoid unintended economic consequences (Beaufils et al., 2023).

In response to these challenges, recent studies have explored the potential of carbon tariffs and other international mechanisms to mitigate leakage and enhance global cooperation. More recently, Larch and Wanner (2024) examined the consequences of non-participation in the Paris Agreement, underlining the economic and environmental costs for countries that remain outside the agreement due to trade isolation and a loss of access to cleaner technologies.[12] These findings reflect the ongoing evolution of global climate policy as the world moves beyond Kyoto's legacy to more integrated and adaptive frameworks, such as the Paris Agreement.

2.4 EU ETS unleashed: The backbone of the EU's green revolution

Launched in 2005, the EU ETS is the world's first and largest carbon market designed to reduce GHG emissions through a cap-and-trade system that imposes strict limits on total emissions from covered sectors. Initially focused on CO_2 emissions from power

[12]Larch and Wanner (2017) analysed the trade, welfare and emissions effects of carbon tariffs, finding that while tariffs can reduce leakage, they can also lead to welfare losses depending on their degree of stringency.

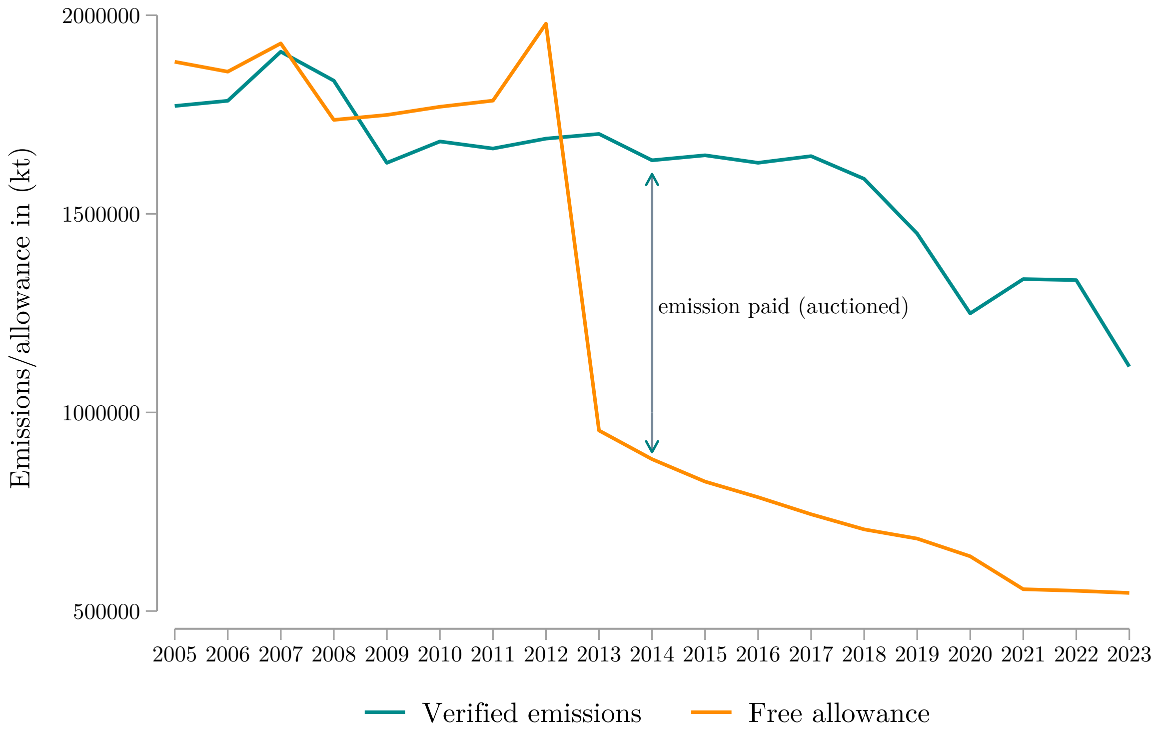
and heat generation as well as energy-intensive industries, the ETS has since expanded to cover a broader range of sectors and emission types. This expansion has reinforced its central role in EU climate policy, making it a cornerstone of efforts to achieve significant emissions reductions across the economy (Korpar et al., 2022). As the scheme has evolved, in addition to becoming more comprehensive, it has also set a global standard for market-based environmental regulation.

Despite its pioneering role in climate policy, the ETS faced significant challenges in its early phase, particularly due to carbon price volatility, which threatened its ability to create incentives for long-term investments in low-carbon technologies. To address these issues, the EU introduced the Market Stability Reserve (MSR) in 2019. This was a crucial reform, as highlighted by Löschel et al. (2019), because it was the key to stabilising the market, strengthening the carbon price signal, boosting investment in low-carbon technologies, and thereby improving the resilience of the ETS as a tool for long-term emissions reductions. Moreover, Dechezleprêtre et al. (2023) state that this instability initially undermined the scheme's effectiveness by making carbon prices unpredictable, a critical factor for sustained investment.

The evolution of the ETS exemplifies the EU's commitment to refining its climate policy framework, in particular through strategic reforms like the MSR. Böning et al. (2023) address the role of tightening the emissions cap and extending the ETS to more sectors to strengthen its impact and align it with the EU's 2050 net-zero target. The success of the ETS in stabilising carbon prices and reducing emissions has made it a global model for harmonised carbon pricing, reinforcing its prominent role in the EU's Green Deal strategy and influencing global climate policy.

Figure 3 depicts an extended version of a graph in Korpar et al. (2022), showing the evolution of total verified emissions and allocated allowances under the EU ETS from 2005 to 2023. This graph displays a significant decline in emissions, particularly after 2012, due to tighter emission caps and fewer free allowances. In the early years, the surplus of allowances led to price instability, which limited the effectiveness of the ETS. However, as the cap was tightened and allowances were reduced, emissions fell more sharply, especially in energy-intensive sectors. This trend confirms the role of strict caps in reducing emissions

Figure 3: Total verified emissions and free allowances under the EU ETS system 2005-2023



Source: Authors' elaboration, with data provided by the European Environment Agency (EEA) based on Figure A.1 in Appendix A.2 of Korpar et al. (2022).

and stabilising the carbon market.[13]

Continued reforms, including further cap tightening and increased auctioning, are essential for the ETS to meet the EU's 2050 net-zero target and to reinforce its roles both in the EGD and as a model for global carbon pricing. (Dechezleprêtre et al., 2023) underline the success of the ETS in delivering significant emissions reductions, particularly in energy-intensive sectors (e.g. power generation). As the EU sets more ambitious climate targets for 2030 and beyond, the ETS will need to adapt further, possibly by including additional sectors and introducing more dynamic mechanisms for allocating allowances. These adaptations will be essential for preserving the ETS's role as the backbone of EU climate policy, ensuring that it continues to deliver significant emissions reductions while fostering economic growth.

[13]Figure 3 also emphasises the impact of policy adjustments in aligning the ETS with the EU's climate change strategies. The decline in emissions after 2019 is consistent with strategic reductions in free allowances, particularly in sectors that are vulnerable to carbon leakage (e.g. steel and cement). These adjustments have reduced the allowance surplus and boosted the carbon price, making the ETS a more effective tool for encouraging low-carbon investment.

In 2023, the EU ETS achieved a record reduction in emissions, primarily driven by progress in renewable energy. In particular, the power sector reduced emissions by 15.5% compared to 2022, contributing to an overall reduction of 47% compared to 2005 levels. This progress is in line with the 2030 target of a 62% reduction. Growth in wind and solar energy largely replaced coal and gas, while energy-intensive industries reduced emissions by 7% through efficiency gains. Despite this, aviation emissions increased by 10%, reflecting a recovery from the COVID-19 pandemic.[14]

As the ETS enters its fourth phase, the focus will be on aligning the system with the EGD while supporting a smooth transition to a low-carbon economy. This phase will address concerns about carbon leakage and ensure that the benefits of emissions reductions are shared equitably across member states. Importantly, the ETS now includes non-EU countries (e.g. Iceland, Liechtenstein, Norway and Switzerland), which are integrated through the European Economic Area (EEA) and bilateral agreements (Borghesi and Flori, 2018). This expansion enhances the robustness of the system, promotes regional cooperation and makes the ETS a model for global carbon pricing.[15]

2.5 Studying the impacts of carbon pricing

The introduction of the EU CBAM has sparked a lot of debate and is the subject of many studies. For example, it has been examined by Korpar et al. (2022), who compare different scenarios for its implementation and employ a structural gravity model à la Larch and Wanner (2017) to quantify these effects. They find that while the CBAM can effectively reduce carbon emissions, it may also impact trade flows and foreign direct investment. The study evaluates several policy scenarios, including full and partial implementation of the CBAM in a general equilibrium framework. It finds that while the overall economic effects are relatively small, the mechanism can still serve as an effective tool for reducing emissions and mitigating carbon leakage. Additionally, they highlight the importance of using export rebates to maintain the competitiveness of domestic industries while lowering

[14] See: `https://climate.ec.europa.eu/news-your-voice/news/record-reduction-2023-ets`.

[15] Future developments are likely to emphasise further integration with other climate policies, both within and outside the EU, to strengthen the effectiveness of the ETS and ensure that it remains a key milestone on the path to achieving the EU's 2050 net-zero target.

the risk of carbon leakage. Their analysis emphasises the need for careful policy design to balance environmental objectives with economic competitiveness. Specifically, they stress that the implementation of the CBAM must account for the diversity of production processes and carbon intensities across sectors to avoid trade disruptions and protect vulnerable industries.

Further insights into the effectiveness of CBAs are provided by Clausing and Wolfram (2023), who explore the broader implications of CBAs within varying climate policies across countries. They emphasise that well-designed CBAMs not only mitigate carbon leakage but also create incentives for higher global climate ambitions by creating economic incentives for non-participating countries to adopt similar measures. Their analysis assesses the administrative complexities and the importance of accurate measurement of the carbon contents of imports to prevent so-called 'reshuffling' (i.e. when 'cleaner' products are sent to regions having introduced a CBAM while 'dirtier' products are directed elsewhere). Moreover, Böhringer et al. (2022) analyse potential impacts and challenges of BCAs,[16] underscoring that while BCAs are effective in reducing emissions, they must be implemented with consideration of global trade dynamics to avoid trade disputes and ensure WTO compliance.

In the context of the CBAM proposed by the European Commission, new quantitative trade models can shed light on better ways to understand the relocation of environmental impacts and to address the efficiency of BCAs. Previous studies, such as those by Böhringer et al. (2018), Wu et al. (2022), and Farrokhi and Lashkaripour (2021), have started to explore these critical issues, demonstrating how well-designed trade policies can effectively reduce global emissions without merely shifting pollution elsewhere. Additionally, recent work by Fadinger et al. (2024) provides insightful analysis using advanced quantitative trade models to offer reasonable estimates of policy impacts.

More recent studies further enhance our understanding of the EU CBAM and its implications by taking innovative approaches. For instance, Sogalla (2023) examines the CBAM using a Melitz (2003)-type model to incorporate firm heterogeneity, offering detailed insights into the potential for reducing carbon leakage by imposing tariffs on

[16] The acronyms CBAM, CBA and BCA can be used interchangeably to refer to a carbon border adjustment mechanism.

carbon-intensive imports. Additionally, this study highlights the administrative challenges resulting from the CBAM and underscores the need for international cooperation to ensure the mechanism's success. Similarly, Fadinger et al. (2024) introduce the Leakage Border Adjustment Mechanism (LBAM) alongside the CBAM, which requires less information on embedded emissions and instead applies tariffs and subsidies based on trade flow changes. Their model demonstrates that the LBAM can achieve significant global emissions reductions and enhance EU welfare more effectively than the CBAM on its own.

Likewise, Mahlkow and Wanner (2023) provide a comprehensive analysis of the carbon footprint of global trade imbalances using a sophisticated NQTM. Their model integrates sectoral input-output linkages, trade imbalances and carbon emissions from fossil fuel combustion while incorporating three types of sectors: primary-fossil-fuels, secondary-fossil-fuels and ordinary sectors. Their study highlights the key role of environmental specialisation patterns reinforced by global trade imbalances through a Ricardian trade structure with a Heckscher-Ohlin component. In addition, the model takes into account the fact that crude oil (a primary fossil fuel) is essential for producing petroleum (a secondary fossil fuel), illustrating the fixed input requirement in production, thus making the model more realistic. The study examines in depth the production, consumption and extraction footprints of carbon emissions, revealing that eliminating trade imbalances could reduce annual global emissions by 0.9%, or 295 million tonnes of CO_2. This approach underscores the critical impact of trade policies on global emissions using NQTMs, emphasising the need for strategies that take the complex interplay of trade and environmental outcomes into account. These studies emphasise the need for refined policy instruments to address carbon leakage and promote global climate cooperation.

In line with these findings, Felbermayr et al. (2024) provide an extensive review of the literature on the interactions between trade and environmental policies. Their study addresses the importance of advanced methodologies, such as computable general equilibrium (CGE) models, in capturing the direct and indirect links between trade and the environment. Additionally, they highlight the developments of employing NQTMs to provide more comprehensive policy recommendations that effectively integrate economic and environmental considerations.

Building on this overview, the main contribution of this paper is to evaluate the impact of the EU CBAM employing a Caliendo and Parro (2015) model, which provides robust estimates of the mechanism's effects. This paper distinguishes itself by incorporating the most recent data available from OECD (2023), by including CO_2 emissions data up to 2020 provided by Wiebe and Yamano (2016), and by focusing on sectoral composition.[17] This research thus aims to contribute empirically to the field of NQTMs and to provide valuable insights on the policy implications of the EU CBAM. The next section contains additional explanations regarding the model employed.

3 The Model

The analysis is conducted with the help of the CGE trade model proposed by Caliendo and Parro (2015), which provides a multi-sector version of the gravity model accounting for input-output linkages à la Eaton and Kortum (2002). In this section, we outline the model following the literature and discuss how the EU CBAM will be implemented.

3.1 Setup

There are N countries indexed i (origin) and n (destination) as well as J sectors indexed j and k. Production uses labour as the sole factor, which is mobile across sectors but not across countries $L_n = \sum_j^J L_n^j$ (L is fixed at the country level). Markets are perfectly competitive. Sectors are either wholly tradable or non-tradable. In each sector, there is a continuum of intermediate goods (materials) $\omega^j \in [0, 1]$ produced in each sector j. Households in n obtain utility from consumption C, and preferences are given by

$$u\left(C_n\right) = \prod_{j=1}^{J} C_n^{j\ \alpha_n^j}, \text{ where} \sum_{j=1}^{J} \alpha_n^j = 1 \qquad \text{(CP. 1)}$$

Here, α is the sectoral expenditure share. L_n denotes the representative household in country n, C_n^j is the consumption of final goods, I_n represents the households' income

[17] Nonetheless, a limitation of this study is that it does not consider the detailed production aspects of fossil fuels as discussed by Larch and Wanner (2017), nor does it cover the extraction footprints as incorporated by Mahlkow and Wanner (2023) due to data constraints.

derived from the supply of labour L_n at the wage w_n. Goods are produced using labour l and *composite* intermediate input bundles m from all sectors. Countries differ in their productivity for different goods from the continua, inversely captured by the input requirement z, and the input cost shares γ. The production technology of good ω^j is

$$q_n^j\left(\omega^j\right) = z_n^j\left(\omega^j\right)\left[l_n^j\left(\omega^j\right)\right]^{\gamma_n^j}\prod_{k=1}^{J}\left[m_n^{k,j}\left(\omega^j\right)\right]^{\gamma_n^{k,j}}$$

Here, $\omega^j \in [0,1]$ denotes a continuum of intermediate goods (materials) produced in each sector j. $z_n^j\left(\omega^j\right)$ is the efficiency of producing intermediate good ω^j in country n. Similarly, $l_n^j\left(\omega^j\right)$ is the labour for producing intermediate good ω^j in country n. The term $m_n^{k,j}\left(\omega^j\right)$ denotes the composite intermediate goods from sector k used for the production of intermediate good ω^j. $\gamma_n^{k,j}$ with $\sum_{k=1}^{J}\gamma_n^{k,j} = 1-\gamma_n^j$ is the share of materials from sector k used in the production of intermediate good ω^j. Both value-added shares and intermediate-goods shares vary across countries and sectors.

Since production of intermediate goods is at constant returns to scale and markets are perfectly competitive, firms price at a unit cost of $\frac{c_n^j}{z_n^j(\omega^j)}$, where c_n denotes the cost of an input bundle. Unit costs (which equal price due to perfect competition and constant returns to scale) are given by

$$c_n^j = \Upsilon_n^j w_n^{\gamma_n^j}\prod_{k=1}^{J} P_n^{k\gamma_n^{k,j}} \tag{CP. 2}$$

Here, P_n^k denotes the price of a composite intermediate good from sector k and the constant $\Upsilon_n^j \equiv \prod_{k=1}^{J}\left(\gamma_n^{k,j}\right)^{-\gamma_n^{k,j}}\left(\gamma_n^j\right)^{-\gamma_n^j}$. Thus, in Equation CP. 2, the cost of the input bundle depends on wages and the prices of *all* composite intermediate goods in the economy. Moreover, Equation CP. 2 captures a key difference compared to a one-sector model or the multi-sector model without interrelated sectors, as the cost of the input bundle depends on wages and on the prices of all composite intermediate goods in the economy, both tradable and non-tradable. A change in policy that affects the price in any single sector will indirectly affect all the sectors in the economy via the input bundle. Caliendo and Parro (2015) show that this interrelation plays a prominent role in evaluating the trade and welfare effects from trade openness.

Taking trade costs into consideration, the unit price of a tradable intermediate good ω^j produced in country i and available in country j can be calculated at unit prices $\frac{c_i^j k_{ni}^j}{z_i^j(\omega^j)}$. Thus, the price of intermediate good is given by ω^j in country n. A firm in country i can supply its output to country n, and producers of sectoral composites in country n search for the supplier with the lowest cost across all possible origin locations as follows:

$$p_n^j\left(\omega^j\right) = \min_i \left\{ \frac{c_i^j k_{ni}^j}{z_i^j\left(\omega^j\right)} \right\}$$

It is assumed that trade in goods is costly. Specifically, there are two type of trade costs: iceberg trade costs and ad valorem flat-rate tariffs. Iceberg trade cost are defined in physical units as shown in Samuelson (1952), where one unit of a tradable intermediate good in sector j shipped from country i to country n requires producing $d_{ni}^j \geq 1$ units in i, with $d_{nn}^j = 1$. Goods imported by country n from country i require the payment of an ad valorem flat-rate tariff τ_{in}^j applicable over unit prices. The combination of both trade costs is represented by

$$\kappa_{ni}^j = \tilde{\tau}_{ni}^j d_{ni}^j \quad \text{(CP. 3)}$$

Here, $\tilde{\tau}ni^j = \left(1 + \tau_{ni}^j\right)$. Also, triangular inequality holds: $\kappa_{nh}^j \kappa_{hi}^j \geq \kappa_{ni}^j$ for all n, h and i.

Caliendo and Parro (2015) model non-tradable sectors in the same way as tradable sectors but impose that $k_{in}^j = \infty$; hence, in some sectors, goods are not traded because it is always cheaper to buy goods from local suppliers. In non-tradable sectors, $p_n^j\left(\omega^j\right) = \frac{c_i^j k_{ni}^j}{z_i^j(\omega^j)}$ and the demand of intermediate goods is given by $r_n^j\left(\omega^j\right) = q_n^j\left(\omega^j\right)$.

The notion of Ricardian comparative advantage à la Eaton and Kortum (2002) through country-specific idiosyncratic productivity draws z^J implies a probabilistic depiction of technologies that accounts for variations in productivity across countries and sectors. Specifically, considering that the ability to produce a specific good (ω^j) in country n follows a *Fréchet distribution*. This distribution has a location parameter, $\lambda_n^j \geq 0$, which varies across countries and sectors, as well as a shape parameter, θ^j, which varies across sectors.

In the context of this model, a higher λ_n^j makes the average productivity in a sector higher, a notion of absolute advantage, whereas a smaller value θ^j implies a higher dispersion of productivity across goods (ω^j), a notion of comparative advantage.[18] We assume that the distributions of productivities are independent across goods, sectors and countries and that $1 + \theta^j > \sigma^j$. With these assumptions on the distribution of efficiencies, it is possible to solve for the distribution of prices. The price of the composite intermediate good is then given by

$$P_n^j = A^j \left[\sum_{i=1}^{N} \lambda_i^j \left(c_i^j k_{ni}^j \right)^{-\theta^j} \right]^{-\frac{1}{\theta^j}} \tag{CP. 4}$$

for all sectors j and countries n, where A^j is a constant.[19] Note that Equation CP. 4 is also the price index of the non-tradable goods sectors. The difference is that, in this case, since $k_{in}^j = \infty$, the price index is given by $P_n^j = A^j \lambda_n$ for all sectors j and countries n, where A^j is a constant. Note that Equation CP. 4 is also the price index of the non-tradable goods sectors. The difference is that, in this case, since $k_{in}^j = \infty$, the price index is given by $P_n^j = A^j \lambda_n^{\frac{j-1}{\theta^j}} c_n^j$.

Consumers purchase final goods at prices P_n^j. With Cobb-Douglas preferences (Equation CP. 1), the consumption price index is given by

$$P_n^j = \prod_{j=1}^{J} \left(\frac{P_n^j}{\alpha_n^j} \right)^{\alpha^j} \tag{CP. 5}$$

Total expenditure on sector j goods in country n is given by $X_n^j = P_n^j Q_n^j$. We denote by X_n^j the expenditure in country n of sector j goods from country i. It follows that country n's share of expenditure on goods from i are given by $\pi_{ni}^j = \frac{X_{ni}^j}{X_n^j}$. Using the properties of the Fréchet distribution, we can derive expenditure shares as a function of technologies, prices and trade costs as follows:[20]

$$\pi_{ni}^j = \frac{\lambda_i \left[c_i^j k_{ni}^j \right]^{-\theta^j}}{\sum_{h=1}^{N} \lambda_h \left[c_i^j k_{nh}^j \right]^{-\theta^j}} \tag{CP. 6}$$

[18]The productivity distribution is characterised by a location parameter λ_n^j that varies by country and sector, inducing the concept of *absolute* advantage, and a shape parameter θ^j describes the elasticity of trade to trade cost.

[19]Where $A^j = \Gamma\left(\xi^j\right)^{\frac{1}{1-\sigma^j}}$ with $\Gamma\left(\xi^j\right)$ being the *Gamma function* evaluated at $\xi^j = 1 + \left(1 - \sigma^j\right)/\theta^j$.

[20]This expression also forms the core of a gravity equation.

3.2 General equilibrium framework

Total expenditure X_n^j on goods j is the sum of the expenditure on composite intermediate goods by firms and the expenditure by households. Then, X_n^j is given by

$$X_n^j = \sum_{k=1}^{J} \gamma_n^{j,k} \sum_{i=1}^{N} X_i^k \frac{\pi_{in}^k}{1+\tau_{in}^k} + \alpha_n^j I_n \tag{CP. 7}$$

where $I_n = w_n L_n + R_n + D_n$ represents final absorption in country n, as the sum of labour income, government revenue (tariff and export taxes minus export subsidies), and the aggregate trade balance. In particular, $R_n = \sum_{j=1}^{J} \sum_{n=1}^{N} \tau_{ni}^j M_{ni}^j$, where $M_{ni}^j = X_n^j \frac{\pi_{in}^k}{1+\tau_{in}^k}$ are country n's import of sector j goods from country i. The summation of trade deficits across countries is zero, $\sum_{i=1}^{N} D_n = 0$, and national deficits are the summation of sectoral deficits, $D_n = \sum_{k=1}^{J} D_n^k$. Sectoral deficits are defined by $D_n^j = \sum_{i=1}^{N} M_{ni}^j - \sum_{i=1}^{N} E_{ni}^j$, where $E_{ni}^j = X_i^j \frac{\pi_{in}^k}{1+\tau_{in}^k}$ are country n's exports of sector j goods to country i. Although aggregate trade deficits are exogenous in the model, sectoral trade deficits are endogenously determined. Finally, using the definition of expenditure and trade deficit, we have that

$$\sum_{j=1}^{J} \sum_{i=1}^{N} X_n^j \frac{\pi_{in}^k}{1+\tau_{in}^k} - D_n = \sum_{j=1}^{J} \sum_{i=1}^{N} X_i^j \frac{\pi_{in}^k}{1+\tau_{in}^k} \tag{CP. 8}$$

This condition reflects the fact that total expenditure, excluding tariff payments, in country n minus trade deficits equals the sum of each country's total expenditure, excluding tariff payments, on tradable goods from country n. Caliendo and Parro (2015) add over all sectors whether a sector is tradable or non-tradable. The non-tradable sectors appear in both sides of the equation and cancel each other out.[21]

[21] In other words, the goods market clearing condition CP. 7 and the trade balance CP. 8 condition close the model. It is also possible to show that equation CP. 8 implies labour market clearing. To see this, add equation CP. 7 across sectors and substitute into equation CP. 8 to obtain

$$w_n L_n = \sum_{j=1}^{J} \gamma_n^j \sum_{i=1}^{N} X_i^j \frac{\pi_{in}^k}{1+\tau_{in}^k}$$

3.3 Modelling carbon tariffs

Finally, we are interested in the effects of different CBAM scenarios on trade flows, welfare (measured as real income) and CO_2 emissions. Carbon tariffs are introduced to the model in addition to tariffs imposed by the country of destination n in specific industries. In order to quantify the comparative static effects of changes in carbon tariffs (CBAM measure) on trade flows and welfare, we solve the model in changes following Dekle et al. (2008). Let x denote the initial level of a variable x', its counterfactual level. Thus, trade cost shocks are given by $\hat{x}_{in}^{j} = \frac{x_{in}^{j'}}{x_{in}^{j}}$ in our analysis, where we only consider a change in tariffs (via the addition of carbon tariffs), leaving all other trade costs unchanged.

Instead of solving for an equilibrium under policy τ, we solve for changes in prices and wages after changing from policy τ to policy τ', which Caliendo and Parro (2015) define as an equilibrium in relative changes.[22] There are several advantages of doing so. First, it is possible to exactly match the model to the data. Second, one can identify the effect on equilibrium outcomes of a pure change in tariffs, which is the desirable outcome. And, finally, we can solve for the general equilibrium of the model without needing to estimate parameters (which are difficult to identify in the data) as productivities λ_n^j and iceberg trade cost d_{ni}^j.

This allows us to define the equilibrium of the model under policy τ' relative to a policy under tariff structure τ, which can be summarised as follows. Let $(\mathbf{w}, P)$ be the initial equilibrium under tariff structure τ, and let $\left(\mathbf{w}', P'\right)$ be the new equilibrium under tariff structure τ'. Then define $\left(\hat{\mathbf{w}}, \hat{P}\right)$ as en equilibrium under τ' relative to τ, where a variable with a hat '$\hat{x}$' represents the relative change of the variable, namely, $\hat{x} = \frac{x'}{x}$. The equilibrium conditions in relative changes then satisfy for the costs of the input bundles:

$$\hat{c}_n^j = \hat{w}_n^{\gamma_n^j} \prod_{k=1}^{J} \hat{P}_n^{k\ \gamma_n^{k,j}} \tag{CP. 9}$$

[22] This idea of expressing the equilibrium in relative changes follows Dekle et al. (2008). They use it to understand the effects of a change in trade deficits, whereas Caliendo and Parro (2015) use it to compute the effects of a change in tariff structure.

The price index changes accordingly with

$$\hat{P}_n^j = \left[\sum_{i=1}^{N} \pi_{ni}^j \left[\hat{k}_{ni}^j \hat{c}_i^j \right]^{-\theta^j} \right]^{-\frac{1}{\theta^j}} \tag{CP. 10}$$

where $\hat{k}_{ni}^j = \frac{\left(1+\tau_{ni}^{j'}\right)}{\left(1+\tau_{ni}^{j}\right)}$, which impacts on the bilateral trade shares

$$\pi_{ni}^j = \left[\frac{\hat{c}_i^j \hat{k}_{ni}^j}{\hat{P}_n^j} \right]^{-\theta^j} \tag{CP. 11}$$

The total expenditures in each country n and sector j are then given by

$$X_n^{j'} = \sum_{k=1}^{J} \gamma_n^{j,k} \sum_{i=1}^{N} \frac{\pi_{in}^{k'}}{1+\tau_{in}^{k'}} X_i^{k'} + \alpha_n^j I_n^{'} \tag{CP. 12}$$

with

$$I_n^{'} = \hat{w}_n w_n L_n + \sum_{j=1}^{J} \sum_{i=1}^{N} \tau_{ni}^{j'} \frac{\pi_{ni}^{j'}}{1+\tau_{ni}^{j'}} X_n^{j'} + D_n$$

Finally, the trade balance becomes

$$\sum_{k=1}^{J} \sum_{i=1}^{N} \frac{\pi_{ni}^{j'}}{1+\tau_{ni}^{j'}} X_n^{j'} - D_n = \sum_{k=1}^{J} \sum_{i=1}^{N} \frac{\pi_{in}^{j'}}{1+\tau_{in}^{j'}} X_i^{j'} \tag{CP. 13}$$

By inspecting these equilibrium conditions (CP. 9 to CP. 12), one can observe that the focus on relative changes allows us to perform policy experiments without relying on estimates of total factor productivity or transport costs. One only needs two sets of tariff structures (tariffs without and with carbon tariffs) (τ and τ'), data on bilateral trade shares $\left(\pi_{ni}^j\right)$, the share of value added in production (γ_n^j), the value added $(w_n L_n)$, the share of intermediate consumption $\gamma_n^{k,j}$, and sectoral dispersion of productivity (θ^j). The share of each sector in final demand (α_n^j) is obtained from these data, as is shown below. The only set of parameters to estimate is the sectoral dispersion of productivity θ^j.

4 Data and Sources

To simulate the effects of the CBAM using the model outlined above, we need to identify the model parameters. Consumption shares and input coefficients (α and γ), as well as bilateral trade shares (π), value added ($\mathrm{w}L$), and initial trade imbalances (D) are obtained from the (regular) ICIO 2023 input-output tables provided by OECD (2023). The ICIO database offers a rich geographical coverage of 76 countries (plus the 'rest of the world') (see Table A.1 for the list of countries) and 45 sectors (see Table A.2 for the list of industries).

The productivity dispersion parameters θ^j are taken from well-established gravity estimates provided in Fontagné et al. (2022) and Eppinger et al. (2021) for the goods producing industries.[23] Similarly, for the service sectors, we rely on an estimate for the aggregate service sectors provided by Freeman et al. (2021).

To incorporate the impacts of carbon tariffs, we use data on tariff rates from the World Bank's World Integrated Trade Solution (WITS) database (World Bank, 2023).[24] This data set offers balanced and detailed information on tariff rates applied by countries across various sectors (for an overview, see Figure A.5 in Appendix A).

The carbon tariffs are computed by closely following the approach developed in Korpar et al. (2022) while relying mainly on the ETS 2023 data and combustion fuel data at the firm level to obtain carbon tariff equivalents at the ICIO industry level.[25]. In the scenarios, we assume a carbon price of EUR 100, resulting in the carbon tariffs as reported in Appendix Table A.3. By definition, these only affect a few industries and range from about 10% in energy (NACE Rev. 2 D) to about 1% in paper (NACE Rev. 2 17_18) as well as even lower in electronics (NACE Rev. 2 C26). We also present robustness checks for carbon prices of EUR 50, EUR 150, EUR 200, and EUR 1000 respectively. The tariffs for these carbon prices are listed in Appendix Table A.4.

Finally, having data on CO_2 emissions at the industry level is crucial for assessing the environmental impacts of the CBAM. The main source is IEA (2020). The IEA dataset

[23]More specifically, the elasticities at the OECD-ICIO were retrieved from https://sites.google.com/view/product-level-trade-elasticity.

[24]These data have already been used in Cieślik and Ghodsi (2024). We thank Mahdi Ghodsi for providing us with data on tariffs at the OECD-ICIO classification.

[25]Available at the emissions trading viewer of the European Environment Agency (EEA)

includes detailed CO_2 emissions by sector and country, allowing for an accurate assessment of the carbon intensity of different industries and the potential effectiveness of the CBAM in reducing emissions. Moreover, Wiebe and Yamano (2016) kindly provided us with the CO_2 data for the 45 sectors (according to the ICIO classification) in the 76 countries and the 'rest of the world'.[26].

5 Welfare and emissions effects of the CBAM

In this section, we present the results of introducing the CBAM as outlined above in the first part. In the second part, we compare these with a scenario including a rebate. Our first scenario evaluates the effects of implementing carbon tariffs. These are designed to equalise the cost disparities between EU producers, which are subject to stringent carbon pricing under the ETS, and foreign producers, which do not face similar regulations. The applied carbon tariffs aim to address the carbon content embedded in imports, thereby ensuring a level playing field and mitigating carbon leakage. Importantly, the countries participating in the CBAM not only include the 27 EU member states but also Switzerland, Norway and Iceland. As members of the European Free Trade Association (EFTA), these three countries are aligned with the EU's environmental regulations, particularly the ETS. Our scenario reflects this and, thus, the countries of the EFTA are participants in the EU CBAM.[27]

5.1 The impacts of the EU CBAM

The overall (intuitive) mechanism of the model is as follows: The introduction of the carbon tariff by EU and EFTA countries (which are supplied in a not completely elastic manner by the other countries, resulting in an incomplete pass-through) implies that the import prices for the EU and EFTA countries decline, leading to an increase in the terms of trade and therefore welfare.[28] However, higher relative export prices due to higher costs (import

[26]Note that 'rest of the world' also includes the least developed countries (LDCs). LDCs are, however, excluded from the EU CBAM. But since imports from LDCs make up only a small fraction of EU imports, we keep the LDCs in the 'rest of the world' block and do not model them separately

[27]Data for Liechtenstein are not included. Therefore, in what follows, 'EFTA' only refers to Iceland, Switzerland and Norway. Although Switzerland has signed the EEA agreement, it has not joined it yet.

[28]On the close relation between terms of trade changes and welfare changes, see Dixit and Norman (1980).

prices plus tariffs) imply a decline in demand for labour, which is counteracted by a decrease in (real) wages.[29] The terms of trade in the other countries decline as well (as their export prices decrease), implying a welfare loss. As these countries also face a decline in demand (mostly because they export less in the industries affected by tariffs), their real wages decline as well (though that effect might be similar to the welfare loss). The overall decline in demand also implies a lower volume of trade in all countries. Concerning emissions, in this framework, the changes in CO_2 emissions are only driven by changes in specialisation patterns. Consequently, the EU and EFTA countries specialise towards the CO_2-intensive industries and, as a result, CO_2 emissions increase. The opposite happens for the other countries, which results in a decline in their CO_2 emissions. The global effect is ambiguous, depending on overall CO_2 intensities in both country groups. However, as the EU and EFTA countries are in general less CO_2 intensive than the other countries (see above) and as production of CO_2-intensive industries shifts towards the EU and EFTA countries, one can expect an overall decline in CO_2 emissions.

The model allows us to assess these changes quantitatively while also taking general equilibrium mechanisms into account. Before going into detail, we present the main results for various country aggregates in Table 1. According to the explanations above, the terms of trade are increasing for the EU and EFTA countries by 0.022% and 0.016%, respectively, whereas they are declining for the other countries by 0.005%. Consequently, the EU and EFTA countries experience an increase in welfare of 0.016% and 0.013%, respectively, whereas welfare is declining by 0.005% in the other countries. Global welfare marginally declines by 0.001%. Due to overall lower demand, real wages decline in all country groups, but most strongly in the EU and EFTA countries (by 0.025%), whereas the decline in real wages is more modest for the other countries (0.005%), which is close to the decline in welfare. The volume of trade is declining globally by 0.001%, with the strongest decline in the EU countries (0.006%) and in the EFTA countries (0.003%). Finally, global CO_2 emissions are reduced by 0.080%. As the EU and EFTA countries specialise in more emission-intensive industries, the emissions of these country groups increase by 0.719% and 0.666%, respectively. In the other countries, the emissions decline by 0.143%. These results

[29] The difference to the welfare effect is that the EU and EFTA countries reap additional tariff income.

Table 1: CBAM effects for country groups

	Terms of trade %	Welfare %	Real wage %	Volume of trade %	CO_2 %
World	.	-0.00142	-0.00889	-0.00142	-0.07941
EU	0.02160	0.01600	-0.02482	-0.00560	0.71902
EFTA	0.01634	0.01291	-0.02496	-0.00343	0.66566
Other	-0.00496	-0.00544	-0.00517	-0.00048	-0.14336

Source: Authors' calculations.

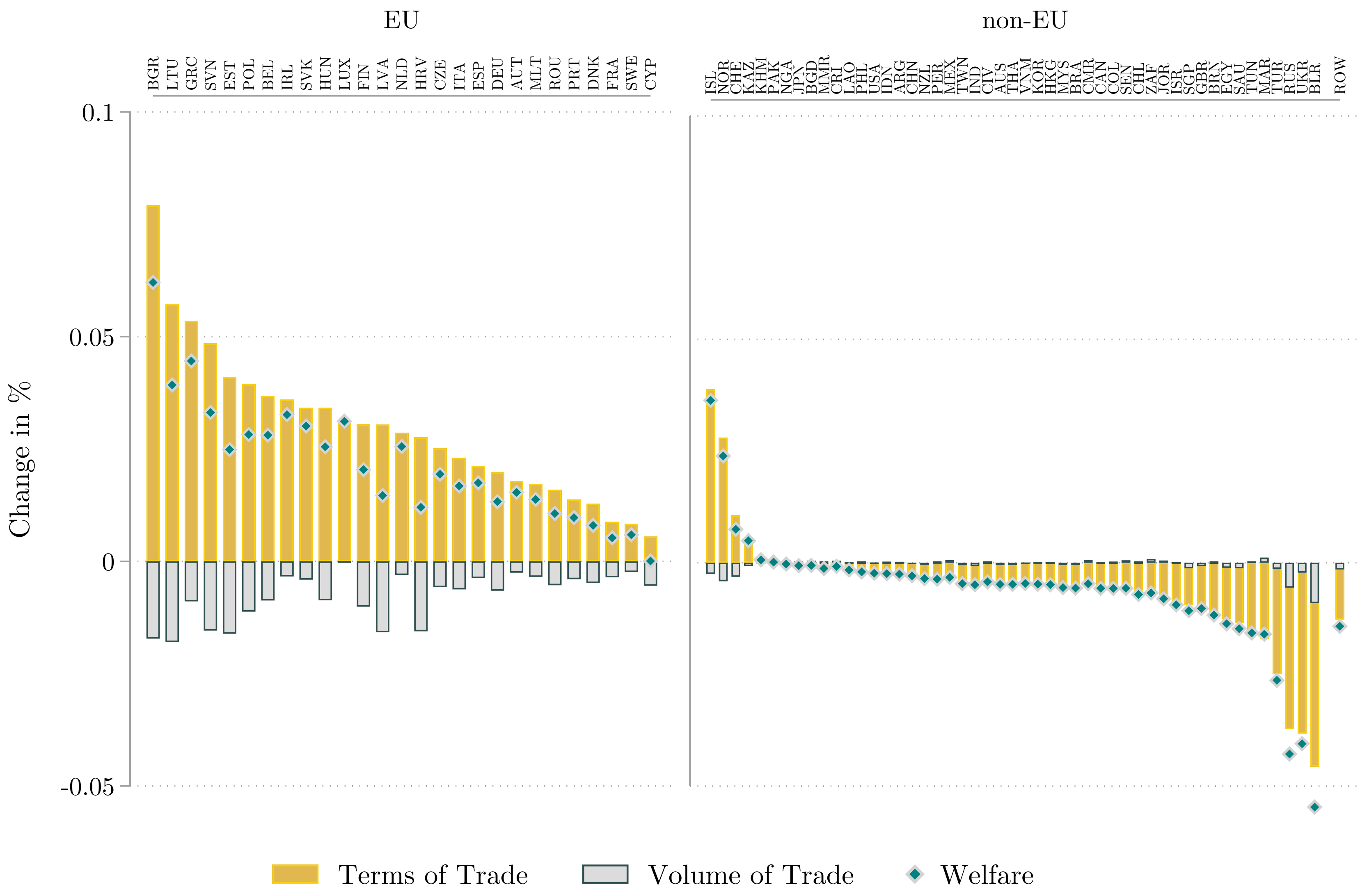
indicate a small positive environmental impact globally, which is in line with the goals of the EU CBAM. The mechanism will reduce overall CO_2 emissions by reducing the production of goods in countries with high CO_2 intensities and increasing production in countries with low CO_2 intensities.

5.2 Country-level results

The effects of the CBAM on the terms of trade, the volume of trade, and welfare at the country level are presented in Figure 4. The change in welfare is the sum of the change in terms of trade and the change in the volume of trade. The introduction of the carbon tariff increases the terms of trade as well as welfare in the EU and EFTA countries. The most significant gains are observed in countries such as Bulgaria, Lithuania, Greece, Slovenia, and Estonia, which are relatively carbon intensive. Portugal, Denmark, France, Sweden and Cyprus see only minimal impacts on their terms of trade and welfare. As mentioned above, the EFTA countries are also beneficiaries because they are aligned with the carbon pricing mechanisms (and are thus exempt from the additional tariffs). The remaining countries – particularly Belarus, Ukraine, Russia, Turkey, Mauritius, Tunisia, Saudi Arabia and Egypt – face small declines in their terms of trade and welfare, primarily due to the fact that their exports are relatively carbon intensive and thus disproportionately affected by the higher tariffs under the EU CBAM.[30] Furthermore, the volume of trade is decreasing for the EU and EFTA countries due to higher relative export prices. There is hardly any change in the volume of trade for the other countries, except for Belarus and Russia, as their exports strongly decline.

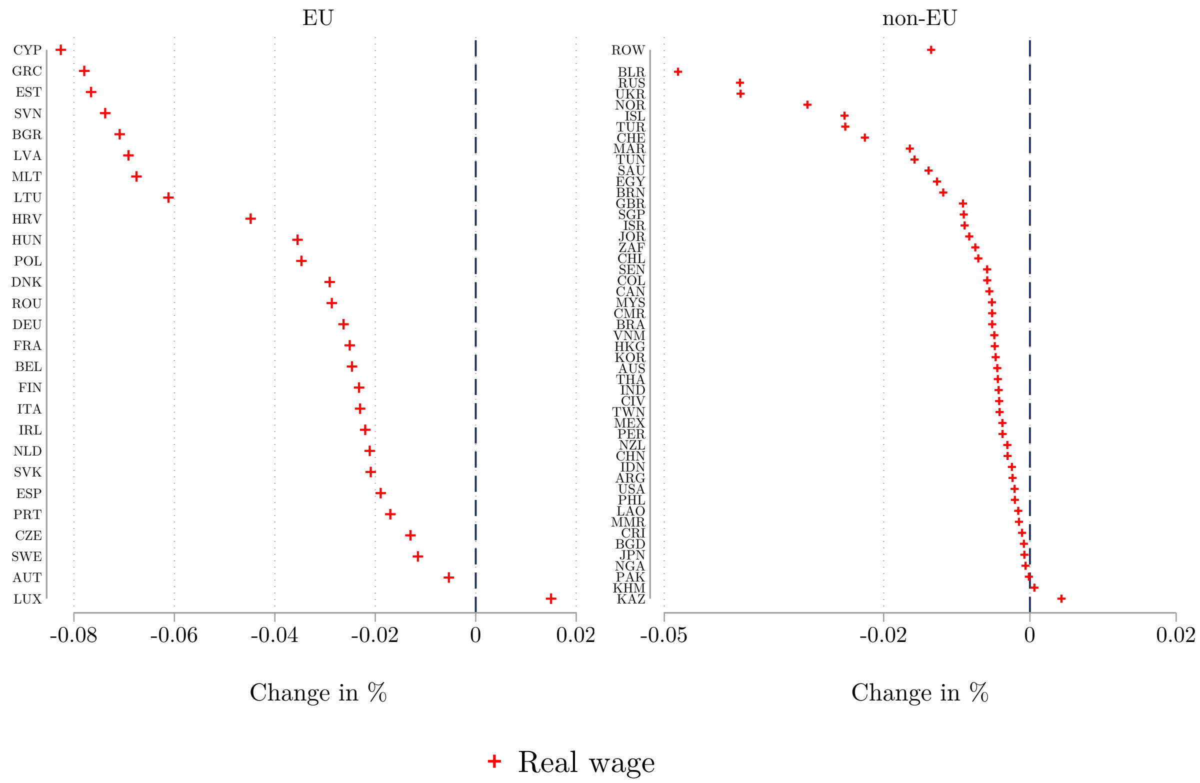
[30]The small positive effect for Kazakhstan is related to its close connection to Russia. More specifically, the introduction of the CBAM has led to a reduction in Russian exports to the EU, part of which is then exported at lower prices to Kazakhstan, causing the terms of trade to increase for Kazakhstan.

Figure 4: General equilibrium effects of the EU CBAM



Source: Authors' calculations.

Figure 5: Changes in real wages resulting from the EU CBAM



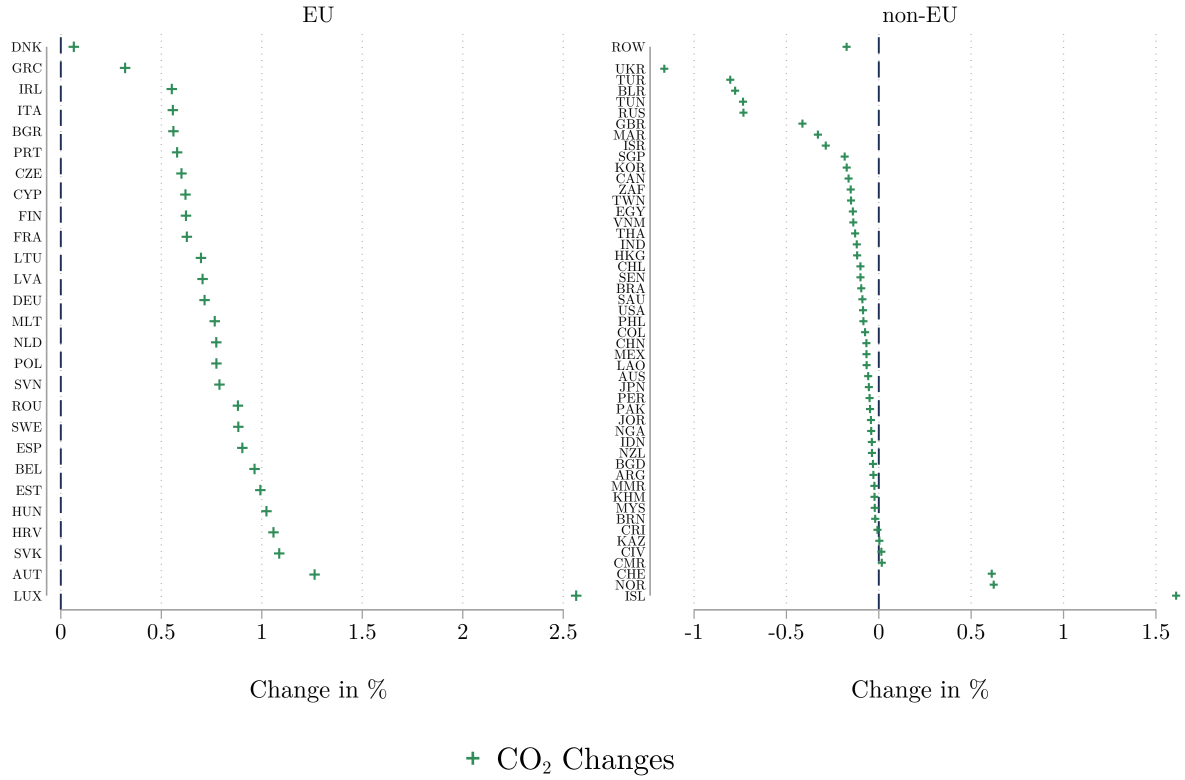
Source: Authors' calculations.

Figure 5 illustrates the impact of the EU CBAM on real wages. Within the EU, the largest declines in real wages are observed in Cyprus, Greece, Latvia, Estonia, Slovenia and Bulgaria. These countries experience the most significant reductions due to their relatively higher exposure to industries that are sensitive to carbon tariffs and due to their overall higher CO_2 emission intensities, likely resulting in increased production costs and reduced competitiveness, which translates into lower exports and real wages. Similarly, real wages in the EFTA countries are generally decreasing as well.[31] Relatively pronounced declines in real wages are also observed in some of the other countries, such as Belarus, Russia, Ukraine and Turkey. These countries are affected by the EU CBAM due to their reliance on exports of carbon-intensive goods, which face higher tariffs under the new regime when imported into the EU. The other countries face only very small declines in real wages, mostly due to the decline in their terms of trade (as discussed above).

Finally, Figure 6 illustrates the projected changes in CO_2 emissions due to the implementation of the EU CBAM. Within the EU, Luxembourg, Austria, Slovakia,

[31] For Luxembourg, Kazakhstan and Cambodia, there seem to be some general equilibrium effects driving real wages slightly up.

Figure 6: Changes in CO_2 emissions resulting from the EU CBAM



Source: Authors' calculations.

Croatia, Hungary and Estonia experience the most significant increases in CO_2 emissions, indicating that these countries' production in relatively CO_2-intensive industries increase and consequently also their CO_2 emissions. Similarly, the EFTA countries Iceland, Norway and Switzerland also see their CO_2 emissions increase, which is again due to increased production in these countries. For the non-EFTA countries, the results indicate a reduction in their CO_2 emissions. The countries that see their trade relations deteriorate the most (i.e. Ukraine, Belarus, Russia and Turkey) also experience the largest decline in CO_2 emissions.

5.3 Industry-level effects

In Table A.7 in Appendix A, we present industry-level results for the changes in the terms of trade and the volumes of trade for the EU. The terms of trade are increasing for all industries except fishing (NACE Rev. 2 A03) and water transport (H50). These increases in the terms of trade are particularly strong for the manufacturing industries with positive carbon tariffs (e.g. petroleum C19, chemicals C20 and metals C24) as well as industries that are interlinked with them (e.g. pharmaceuticals C21, electrical equipment C27, machinery C28, vehicles C29 and transport equipment C30).

The volume of trade increases for all industries apart from those with positive carbon tariffs, particularly in petroleum (C19), chemicals (C20), minerals (C23) and metals (C24). Thus, the overall negative change in the volume of trade is driven by those industries that are strongly and directly affected by the carbon tariffs.[32]

5.4 The effect of export rebates

In a next step, we present a scenario that includes export rebates, as examined in Korpar et al. (2022). These export rebates are designed to mitigate potential competitiveness losses for EU industries by compensating exporters for the carbon costs incurred within the EU. This mechanism is essential for maintaining the global competitiveness of EU products, particularly in carbon-intensive sectors, and aims to prevent carbon leakage.[33] Rebates are modelled as a reduction in the tariff that an exporting industry in an EU or EFTA country faces by the same amount as the carbon tariff. Exporting industries thus gain in competitiveness.[34] As these export rebates act like a subsidy to CO_2-intensive industries in EU and EFTA countries, the terms of trade for these countries are likely to increase (as producers can raise prices and still gain cost competitiveness as a result of the subsidies). This leads to an increase in welfare, real wages and the volume of trade. The other countries would face tougher competition in these industries, implying that their terms of trade and welfare are further declining.[35] As overall demand is increasing due to a higher volume of trade, real wages are also going up in all countries. Finally, the EU and EFTA countries are even further specialising in CO_2-intensive industries, implying that emissions in these countries increase further, whereas the opposite happens in the other countries, leading to a further global reduction in emissions.

The results of this scenario including rebates are reported in Table 2. Table 3 shows

[32]Note that the volume of trade effects for the services industry zero by definition, as the calculation of the volume effects includes the level of tariffs, which is zero for service industries.

[33]For a detailed debate concerning compatibility with WTO rules, see Leonelli (2022). At the EU level, the use of export rebates is not under consideration any longer.

[34]Specifically, we reduce the import tariffs in the other countries (i.e. non-EU or non-EFTA countries) by the amount of the carbon tariffs introduced by the CBAM. Thus, this reduces the tariff income in these other countries while not having a direct effect as subsidy costs on the EU and EFTA countries.

[35]Also note that this is modelled as reduction of tariffs in the other countries, thus leading to a decline in their tariff incomes.

the difference in percentage points (pp) to the previous scenario. Focusing on the EU, in comparison to the scenario without rebates, the terms of trade increase by 0.010 pp and similarly for welfare and real wages. The volume of trade increases by 0.002 pp compared to the scenario without rebates. However, CO_2 emissions would increase by another 0.33 pp. The changes for EFTA countries go in the same direction but are generally lower. The other countries would lose out in their terms of trade (-0.002 pp) and welfare (-0.002 pp) and experience small increases in real wages (0.001 pp). and the volume of trade (0.0004 pp). Due to the specialisation effect, their CO_2 emissions decline by 0.05 pp. For the world as a whole, welfare, real wages and the volume of trade is slightly increasing, whereas CO_2 emissions go down by another 0.026 pp.

Table 2: Effects for country groups: Export rebates

	Terms of trade %	Welfare %	Real wage %	Volume of trade %	CO_2 %
World	.	-0.0008	-0.00596	-0.0008	-0.10563
EU	0.03146	0.02762	-0.01426	-0.00383	1.05069
EFTA	0.01678	0.01423	-0.02408	-0.00255	0.74269
Non-EFTA	-0.00711	-0.00721	-0.00386	-0.00011	-0.19758

Source: Authors' calculations.

Table 3: Difference export rebates – EU CBAM (in pp)

	Terms of trade	Welfare	Real wage	Volume of trade	CO_2
World	.	0.00062	0.00293	0.00062	-0.02622
EU	0.00986	0.01162	0.01056	0.00177	0.33167
EFTA	0.00044	0.00132	0.00088	0.00088	0.07703
Non-EFTA	-0.00215	-0.00177	0.00131	0.00037	-0.05422

Source: Authors' calculations.

5.5 The effects of changes in the carbon price

As a robustness check, we also simulate a scenario with a carbon price of EUR 50, EUR 150, EUR 200, and EUR 1000. The results for country groups are reported in Table 4.

As expected, the impacts of the CBAM are larger the higher the underlying carbon price is. Doubling the price from EUR 50 to EUR 100 implies that the effects on the variables considered are slightly less than twice as large on average. For example, global CO_2 emissions would be reduced by 0.044% in the scenario assuming a carbon price of EUR 50

Table 4: CBAM effects for country groups under different carbon prices

	Terms of trade %	Welfare %	Real wage %	Volume of trade %	CO_2 %
Carbon price equal to EUR 50					
World	.	-0.00075	-0.00456	-0.00075	-0.04398
EU	0.01134	0.00836	-0.01208	-0.00298	0.38167
EFTA	0.00855	0.00674	-0.01224	-0.00181	0.34581
Other	-0.00260	-0.00286	-0.00279	-0.00025	-0.07806
Carbon price equal to EUR 100					
World	.	-0.00142	-0.00889	-0.00142	-0.07941
EU	0.02160	0.01600	-0.02482	-0.00560	0.71902
EFTA	0.01634	0.01291	-0.02496	-0.00343	0.66566
Other	-0.00496	-0.00544	-0.00517	-0.00048	-0.14336
Carbon price equal to EUR 150					
World	.	-0.00202	-0.01286	-0.00202	-0.10878
EU	0.03086	0.02295	-0.03669	-0.00791	1.02199
EFTA	0.02346	0.01855	-0.03678	-0.00491	0.96476
Other	-0.00709	-0.00779	-0.00729	-0.00070	-0.19940
Carbon price equal to EUR 200					
World	.	-0.00256	-0.01633	-0.00256	-0.13379
EU	0.03922	0.02925	-0.04665	-0.00997	1.24671
EFTA	0.02996	0.02371	-0.04662	-0.00625	1.29768
Other	-0.00901	-0.00991	-0.00925	-0.00089	-0.24858
Carbon price equal to EUR 1000					
World	.	-0.00691	-0.04520	-0.00691	-0.28847
EU	0.10825	0.08239	-0.13219	-0.02586	3.61823
EFTA	0.08419	0.06589	-0.12789	-0.01830	3.83590
Other	-0.02490	-0.02751	-0.02494	-0.00261	-0.60278

Source: Authors' calculations.

compared to a reduction of 0.079% assuming a carbon price of EUR 100. A further increase in the carbon price to EUR 150, (i.e. by a factor of 1.5 compared to EUR 100) would imply larger effects on the variables considered by a factor of roughly 1.4. Global CO_2 emissions under this scenario would be reduced by 0.109%. Thus, further increases in the carbon price have larger impacts as expected, though at a declining marginal rate. This can even better be seen when increasing the assumed carbon price to EUR 1000, i.e. an increase of the carbon price by a factor of 10 compared to our base scenario. In this case, the CBAM tariffs increase by a factor of 10 (compared to the scenario with a carbon price of EUR 100), whereas the effects are only about five times larger compared to our base scenario.[36]

[36] A similar effect is reported in Le Moigne et al. (2024).

6 Conclusion

In this paper, we investigate the effects of the introduction of carbon border adjustment mechanism (CBAM) tariffs in a general equilibrium model. Overall, we find the expected results in our analysis: First, a CBAM helps to reduce global CO_2 emissions by shifting production from CO_2-intensive regions while increasing production in the less CO_2-intensive countries in the EU and EFTA. The effect on global emissions is, however, very small (-0.079%) in the main CBAM scenario. Our simulations also show that welfare increases in those countries that are participating in the EU CBAM (EU and the EFTA countries) and charging the new tariff. Conversely, the other countries who are facing higher tariffs for exporting to the EU and EFTA countries experience a decrease in their welfare. Similar to the findings for CO_2 emissions, the magnitude of the changes is relatively small.

Second, the impacts on all variables presented are larger the higher the underlying assumed carbon price is. Again, this is to be expected, as a higher carbon price implies a higher applied tariff rate.

Third, the carbon-intensive industries in the EU and the EFTA that are intensively importing carbon-intensive intermediates are suffering (as indicated by an increase in their terms of trade). Export rebates for these industries would support these industries, as these would become relatively more price-competitive. However, this implies that CO_2 emissions in the EU and EFTA countries would further increase due to stronger specialisation effects.

Thus, the EU CBAM would not lead to a reduction in CO_2 emissions in the EU and EFTA due to the arising specialisation effects. However, the model does not take into account that higher import costs and eventually rising CO_2 prices are incentives for firms to use less CO_2-intensive technologies. These findings also highlight the need for these countries to invest in improving the CO_2 intensity of their production facilities. On top of that, the findings show the need for sector-specific strategies within the EU's broader climate policy framework, as uniform measures may not address the specific challenges of each sector. The sectoral disparities in CO_2 emissions highlighted in Figure A.2 suggest that flexible, targeted approaches are essential to effectively reduce emissions. Policy makers should focus on high-emitting sectors, such as energy and heavy industry, by providing incentives to adopt climate-friendly technologies. At the same time, lower-emitting industries could benefit from policies encourage further green innovation. This approach would align the EU's climate goals and ensure an effective transition to a low-carbon economy.

Future research should thus, first, focus on these industry- and firm-level responses to reduce CO_2 emissions due to technological changes, and, second, on the potential effects of retaliation measures of other countries which would result in different welfare and specialisation effects.

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A Tables and Figures

Table A.1: Country list

ID	ISO-3	Country name	ID	ISO-3	Country name
1	ARG	Argentina	40	KAZ	Kazakhstan
2	AUS	Australia	41	KHM	Cambodia
3	AUT	Austria	42	KOR	Korea
4	BEL	Belgium	43	LAO	Lao PDR
5	BGD	Bangladesh	44	LTU	Lithuania
6	BGR	Bulgaria	45	LUX	Luxembourg
7	BLR	Belarus	46	LVA	Latvia
8	BRA	Brazil	47	MAR	Morocco
9	BRN	Brunei Darussalam	48	MEX	Mexico
10	CAN	Canada	49	MLT	Malta
11	CHE	Switzerland	50	MMR	Myanmar
12	CHL	Chile	51	MYS	Malaysia
13	CHN	China (PRC)	52	NGA	Nigeria
14	CIV	Côte d'Ivoire	53	NLD	Netherlands
15	CMR	Cameroon	54	NOR	Norway
16	COL	Colombia	55	NZL	New Zealand
17	CRI	Costa Rica	56	PAK	Pakistan
18	CYP	Cyprus	57	PER	Peru
19	CZE	Czechia	58	PHL	Philippines
20	DEU	Germany	59	POL	Poland
21	DNK	Denmark	60	PRT	Portugal
22	EGY	Egypt	61	ROU	Romania
23	ESP	Spain	62	RUS	Russian Federation
24	EST	Estonia	63	SAU	Saudi Arabia
25	FIN	Finland	64	SEN	Senegal
26	FRA	France	65	SGP	Singapore
27	GBR	United Kingdom	66	SVK	Slovak Republic
28	GRC	Greece	67	SVN	Slovenia
29	HKG	Hong Kong, China	68	SWE	Sweden
30	HRV	Croatia	69	THA	Thailand
31	HUN	Hungary	70	TUN	Tunisia
32	IDN	Indonesia	71	TUR	Turkey
33	IND	India	72	TWN	Chinese Taipei
34	IRL	Ireland	73	UKR	Ukraine
35	ISL	Iceland	74	USA	United States
36	ISR	Israel	75	VNM	Viet Nam
37	ITA	Italy	76	ZAF	South Africa
38	JOR	Jordan	77	ROW	Rest of the World
39	JPN	Japan			

Source: OECD-ICIO 2023.

Table A.2: Industry classification (OECD-ICIO 2023)

ID	Code	Industry	Description	ISIC Rev 4
1	A01_02	Agriculture	Agriculture, hunting, forestry	01, 02
2	A03	Fishing	Fishing and aquaculture	03
3	B05_06	Mining-Energy	Mining and quarrying, energy producing products	05, 06
4	B07_08	Mining-NonEnergy	Mining and quarrying, non-energy producing products	07, 08
5	B09	Mining-Support	Mining support service activities	09
6	C10T12	Food-Beverage	Food products, beverages and tobacco	10, 11, 12
7	C13T15	Textiles	Textiles, textile products, leather and footwear	13, 14, 15
8	C16	Wood	Wood and products of wood and cork	16
9	C17_18	Paper	Paper products and printing	17, 18
10	C19	Petroleum	Coke and refined petroleum products	19
11	C20	Chemicals	Chemical and chemical products	20
12	C21	Pharmaceuticals	Pharmaceuticals, medicinal chemical products	21
13	C22	Rubber	Rubber and plastics products	22
14	C23	Minerals	Other non-metallic mineral products	23
15	C24	Metals	Basic metals	24
16	C25	Metalwork	Fabricated metal products	25
17	C26	Electronics	Computer, electronic and optical equipment	26
18	C27	Electrical	Electrical equipment	27
19	C28	Machinery	Machinery and equipment, nec	28
20	C29	Vehicles	Motor vehicles, trailers and semi-trailers	29
21	C30	Transport-Equip	Other transport equipment	30
22	C31T33	Manufacturing	Manufacturing; repair and installation of machinery	31, 32, 33
23	D	Energy	Electricity, gas, steam and air conditioning supply	35
24	E	Water-Waste	Water supply; sewerage, waste management	36, 37, 38, 39
25	F	Construction	Construction	41, 42, 43
26	G	Retail	Wholesale and retail trade; repair of motor vehicles	45, 46, 47
27	H49	Land-Transport	Land transport and transport via pipelines	49
28	H50	Water-Transport	Water transport	50
29	H51	Air-Transport	Air transport	51
30	H52	Warehousing	Warehousing and support activities for transportation	52
31	H53	Postal	Postal and courier activities	53
32	I	Hospitality	Accommodation and food service activities	55, 56
33	J58T60	Publishing	Publishing, audiovisual and broadcasting activities	58, 59, 60
34	J61	Telecom	Telecommunications	61
35	J62_63	IT	IT and other information services	62, 63
36	K	Finance	Financial and insurance activities	64, 65, 66
37	L	Real-Estate	Real estate activities	68
38	M	Professional-Svc	Professional, scientific and technical activities	69 to 75
39	N	Admin-Svc	Administrative and support services	77 to 82
40	O	Public-Admin	Public administration and defence; social security	84
41	P	Education	Education	85
42	Q	Health	Human health and social work activities	86, 87, 88
43	R	Arts	Arts, entertainment and recreation	90, 91, 92, 93
44	S	Services	Other service activities	94,95, 96
45	T	Household-Act	Activities of households as employers	97, 98

Source: OECD-ICIO 2023.

Table A.3: Carbon tariffs based on ETS scenario of EUR 100

ID	Code	Industry	Tariff equivalent of CO_2 costs
5	B09	Mining-Support	0.029035
9	C17_18	Paper	0.010523
10	C19	Petroleum	0.044611
11	C20	Chemicals	0.013788
14	C23	Minerals	0.083054
15	C24	Metals	0.035852
17	C26	Electronics	0.000002
23	D	Energy	0.109060
29	H51	Air-Transport	0.027039

Source: European Environment Agency (EEA).

Table A.4: Carbon tariffs based under different price scenarios

			Tariff equivalent of CO_2 costs			
ID	Code	Industry	EUR 50	EUR 150	EUR 200	EUR 1000
5	B09	Mining-Support	0.014518	0.043553	0.058070	0.290350
9	C17_18	Paper	0.005261	0.015784	0.021046	0.105228
10	C19	Petroleum	0.022305	0.066916	0.089222	0.446109
11	C20	Chemicals	0.006894	0.020682	0.027577	0.137883
14	C23	Minerals	0.041527	0.124582	0.166109	0.830545
15	C24	Metals	0.017926	0.053777	0.071703	0.358516
17	C26	Electronics	0.000001	0.000003	0.000004	0.000019
23	D	Energy	0.054530	0.163590	0.218119	1.090.597
29	H51	Air-Transport	0.013520	0.040559	0.054078	0.270390

Source: European Environment Agency (EEA).

Table A.5: General equilibrium results

	EU CBAM			Export Rebates		
ISO	**Δ Welfare %**	**Δ Real Wage %**	**Δ CO_2 %**	**Δ Welfare %**	**Δ Real Wage %**	**Δ CO_2 %**
ARG	-0.0025	-0.0024	-0.0292	-0.0035	0.0002	-0.0588
AUS	-0.0048	-0.0045	-0.0574	-0.0072	-0.0041	-0.1173
AUT	0.0153	-0.0053	1.2628	0.0261	0.0045	1.7780
BEL	0.0281	-0.0246	0.9639	0.0476	-0.0069	1.6316
BGD	-0.0006	-0.0008	-0.0313	-0.0020	0.0020	-0.0659
BGR	0.0621	-0.0709	0.5603	0.0892	-0.0474	0.9225
BLR	-0.0547	-0.0481	-0.7775	-0.0657	-0.0399	-0.8830
BRA	-0.0057	-0.0052	-0.0947	-0.0090	-0.0027	-0.1571
BRN	-0.0117	-0.0119	-0.0193	-0.0156	-0.0126	-0.0394
CAN	-0.0057	-0.0055	-0.1635	-0.0063	-0.0063	-0.2173
CHE	0.0075	-0.0226	0.6114	0.0096	-0.0208	0.7827
CHL	-0.0071	-0.0071	-0.0992	-0.0092	-0.0089	-0.1195
CHN	-0.0029	-0.0031	-0.0669	-0.0046	-0.0027	-0.1307
CIV	-0.0043	-0.0042	0.0140	-0.0062	-0.0011	0.0138
CMR	-0.0047	-0.0052	0.0164	-0.0034	-0.0045	0.0206
COL	-0.0057	-0.0058	-0.0742	-0.0062	-0.0063	-0.0893
CRI	-0.0008	-0.0011	-0.0071	-0.0003	0.0024	-0.0315
CYP	0.0001	-0.0826	0.6204	-0.0006	-0.0840	0.7259
CZE	0.0194	-0.0130	0.6003	0.0305	-0.0030	0.8037
DEU	0.0133	-0.0263	0.7154	0.0256	-0.0152	1.0952
DNK	0.0080	-0.0291	0.0647	0.0128	-0.0250	0.0532
EGY	-0.0137	-0.0127	-0.1401	-0.0132	-0.0127	-0.1454
ESP	0.0175	-0.0189	0.9033	0.0287	-0.0089	1.3214
EST	0.0249	-0.0766	0.9930	0.0331	-0.0702	1.0693
FIN	0.0204	-0.0232	0.6228	0.0372	-0.0081	0.9627
FRA	0.0052	-0.0251	0.6272	0.0130	-0.0177	0.9802
GBR	-0.0102	-0.0092	-0.4132	-0.0130	-0.0035	-0.5399
GRC	0.0446	-0.0779	0.3199	0.0561	-0.0680	0.6451
HKG	-0.0049	-0.0048	-0.1171	-0.0032	-0.0019	-0.1285
HRV	0.0120	-0.0448	1.0582	0.0169	-0.0409	1.1957
HUN	0.0255	-0.0355	1.0233	0.0355	-0.0269	1.2679

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Table A.5: General equilibrium results

	EU CBAM			Export Rebates		
ISO	Δ Welfare %	Δ Real Wage %	Δ CO_2 %	Δ Welfare %	Δ Real Wage %	Δ CO_2 %
IDN	-0.0024	-0.0025	-0.0375	-0.0035	-0.0021	-0.0707
IND	-0.0049	-0.0043	-0.1192	-0.0056	-0.0027	-0.1635
IRL	0.0326	-0.0220	0.5523	0.0764	0.0208	0.9714
ISL	0.0363	-0.0254	1.6097	0.0376	-0.0242	1.7488
ISR	-0.0094	-0.0089	-0.2868	-0.0101	-0.0093	-0.2994
ITA	0.0168	-0.0230	0.5576	0.0262	-0.0146	0.8802
JOR	-0.0081	-0.0083	-0.0424	-0.0099	-0.0106	-0.0589
JPN	-0.0006	-0.0008	-0.0537	-0.0012	-0.0005	-0.0943
KAZ	0.0049	0.0043	0.0032	0.0057	0.0076	-0.0135
KHM	0.0007	0.0006	-0.0231	0.0053	0.0052	-0.0296
KOR	-0.0048	-0.0047	-0.1736	-0.0054	-0.0058	-0.2215
LAO	-0.0016	-0.0016	-0.0658	-0.0009	0.0001	-0.0875
LTU	0.0392	-0.0612	0.6975	0.0551	-0.0476	1.0143
LUX	0.0312	0.0150	2.5645	0.0373	0.0213	3.0020
LVA	0.0146	-0.0691	0.7055	0.0185	-0.0661	0.8059
MAR	-0.0160	-0.0164	-0.3295	-0.0157	-0.0169	-0.3262
MEX	-0.0033	-0.0038	-0.0665	-0.0040	-0.0044	-0.1080
MLT	0.0138	-0.0676	0.7660	0.0107	-0.0715	0.7828
MMR	-0.0013	-0.0015	-0.0238	-0.0011	-0.0012	-0.0432
MYS	-0.0056	-0.0052	-0.0218	-0.0085	-0.0040	-0.0463
NGA	-0.0003	-0.0006	-0.0411	-0.0008	0.0021	-0.0619
NLD	0.0256	-0.0211	0.7737	0.0368	-0.0115	1.1537
NOR	0.0239	-0.0304	0.6222	0.0233	-0.0316	0.6500
NZL	-0.0035	-0.0031	-0.0369	-0.0048	-0.0017	-0.0583
PAK	0.0001	-0.0001	-0.0472	0.0002	0.0014	-0.0820
PER	-0.0037	-0.0037	-0.0498	-0.0048	-0.0048	-0.0704
PHL	-0.0020	-0.0021	-0.0832	-0.0021	-0.0011	-0.1027
POL	0.0282	-0.0347	0.7743	0.0425	-0.0224	1.0005
PRT	0.0097	-0.0170	0.5788	0.0162	-0.0111	0.9289
ROU	0.0106	-0.0287	0.8814	0.0140	-0.0259	1.0377
ROW	-0.0142	-0.0135	-0.1743	-0.0230	-0.0111	-0.2179
RUS	-0.0428	-0.0396	-0.7327	-0.0469	-0.0334	-0.8371

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Table A.5: General equilibrium results

	EU CBAM			Export Rebates		
ISO	**Δ Welfare %**	**Δ Real Wage %**	**Δ CO_2 %**	**Δ Welfare %**	**Δ Real Wage %**	**Δ CO_2 %**
SAU	-0.0147	-0.0139	-0.0888	-0.0202	-0.0106	-0.1619
SEN	-0.0057	-0.0058	-0.0992	-0.0097	0.0013	-0.1687
SGP	-0.0107	-0.0090	-0.1847	-0.0135	-0.0100	-0.2353
SVK	0.0301	-0.0209	1.0869	0.0395	-0.0129	1.3606
SVN	0.0331	-0.0738	0.7894	0.0494	-0.0596	1.0929
SWE	0.0059	-0.0115	0.8833	0.0124	-0.0056	1.2408
THA	-0.0048	-0.0044	-0.1279	-0.0073	-0.0017	-0.2014
TUN	-0.0157	-0.0158	-0.7349	-0.0077	-0.0086	-0.7382
TUR	-0.0263	-0.0252	-0.8040	-0.0247	-0.0231	-0.8247
TWN	-0.0047	-0.0041	-0.1503	-0.0095	-0.0022	-0.2387
UKR	-0.0405	-0.0396	-1.1611	-0.0419	-0.0382	-1.2036
USA	-0.0023	-0.0021	-0.0852	-0.0030	-0.0006	-0.1300
VNM	-0.0046	-0.0049	-0.1379	-0.0060	-0.0019	-0.1808
ZAF	-0.0068	-0.0075	-0.1519	-0.0074	-0.0080	-0.1864

Source: OECD-ICIO 2023, Authors' calculations.

Table A.6: General equilibrium: Terms of trade and volume of trade

	EU CBAM		Export Rebates	
ISO	**Δ ToT %**	**Δ Volume of Trade %**	**Δ ToT %**	**Δ Volume of Trade %**
ARG	-0.0024	-0.0001	-0.0042	0.0006
AUS	-0.0043	-0.0005	-0.0073	0.0001
AUT	0.0179	-0.0025	0.0269	-0.0009
BEL	0.0368	-0.0087	0.0538	-0.0061
BGD	-0.0011	0.0005	-0.0026	0.0006
BGR	0.0792	-0.0172	0.1018	-0.0127
BLR	-0.0456	-0.0091	-0.0600	-0.0058
BRA	-0.0051	-0.0005	-0.0094	0.0004
BRN	-0.0118	0.0001	-0.0161	0.0005
CAN	-0.0056	-0.0001	-0.0063	0.0000
CHE	0.0106	-0.0032	0.0118	-0.0022
CHL	-0.0071	0.0000	-0.0093	0.0000
CHN	-0.0026	-0.0003	-0.0049	0.0003
CIV	-0.0043	0.0000	-0.0065	0.0003
CMR	-0.0053	0.0006	-0.0049	0.0015
COL	-0.0057	-0.0001	-0.0063	0.0001
CRI	-0.0013	0.0005	-0.0013	0.0009
CYP	0.0055	-0.0054	0.0039	-0.0045
CZE	0.0251	-0.0058	0.0341	-0.0037
DEU	0.0198	-0.0065	0.0303	-0.0047
DNK	0.0128	-0.0048	0.0165	-0.0038
EGY	-0.0125	-0.0011	-0.0126	-0.0006
ESP	0.0212	-0.0037	0.0305	-0.0017
EST	0.0410	-0.0161	0.0467	-0.0137
FIN	0.0305	-0.0101	0.0448	-0.0076
FRA	0.0088	-0.0035	0.0155	-0.0025
GBR	-0.0095	-0.0008	-0.0135	0.0005
GRC	0.0535	-0.0089	0.0630	-0.0069
HKG	-0.0047	-0.0002	-0.0032	0.0000
HRV	0.0276	-0.0156	0.0311	-0.0141
HUN	0.0342	-0.0087	0.0421	-0.0066

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Table A.6: General equilibrium: Terms of trade and volume of trade

	EU CBAM		Export Rebates	
ISO	**Δ ToT %**	**Δ Volume of Trade %**	**Δ ToT %**	**Δ Volume of Trade %**
IDN	-0.0024	-0.0001	-0.0036	0.0001
IND	-0.0042	-0.0007	-0.0054	-0.0002
IRL	0.0360	-0.0034	0.0784	-0.0020
ISL	0.0388	-0.0025	0.0399	-0.0022
ISR	-0.0092	-0.0002	-0.0102	0.0002
ITA	0.0230	-0.0062	0.0306	-0.0045
JOR	-0.0086	0.0005	-0.0109	0.0010
JPN	-0.0008	0.0002	-0.0015	0.0003
KAZ	0.0057	-0.0007	0.0055	0.0002
KHM	0.0007	-0.0000	0.0051	0.0002
KOR	-0.0047	-0.0001	-0.0054	0.0001
LAO	-0.0015	-0.0001	-0.0011	0.0002
LTU	0.0572	-0.0180	0.0704	-0.0153
LUX	0.0315	-0.0003	0.0364	0.0008
LVA	0.0304	-0.0158	0.0330	-0.0145
MAR	-0.0171	0.0012	-0.0180	0.0023
MEX	-0.0039	0.0006	-0.0049	0.0009
MLT	0.0172	-0.0035	0.0127	-0.0019
MMR	-0.0013	-0.0000	-0.0012	0.0002
MYS	-0.0050	-0.0005	-0.0090	0.0005
NGA	-0.0008	0.0005	-0.0014	0.0007
NLD	0.0286	-0.0030	0.0377	-0.0008
NOR	0.0280	-0.0041	0.0267	-0.0034
NZL	-0.0031	-0.0005	-0.0049	0.0001
PAK	-0.0002	0.0003	-0.0002	0.0005
PER	-0.0038	0.0001	-0.0049	0.0002
PHL	-0.0020	-0.0000	-0.0022	0.0002
POL	0.0394	-0.0112	0.0508	-0.0083
PRT	0.0137	-0.0040	0.0188	-0.0026
ROU	0.0160	-0.0053	0.0181	-0.0042
ROW	-0.0127	-0.0015	-0.0193	-0.0037
RUS	-0.0372	-0.0056	-0.0429	-0.0039

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Table A.6: General equilibrium: Terms of trade and volume of trade

	EU CBAM		Export Rebates	
ISO	**Δ ToT %**	**Δ Volume of Trade %**	**Δ ToT %**	**Δ Volume of Trade %**
SAU	-0.0135	-0.0012	-0.0194	-0.0008
SEN	-0.0063	0.0006	-0.0107	0.0010
SGP	-0.0095	-0.0013	-0.0123	-0.0012
SVK	0.0342	-0.0041	0.0411	-0.0016
SVN	0.0485	-0.0154	0.0619	-0.0125
SWE	0.0083	-0.0024	0.0137	-0.0013
THA	-0.0043	-0.0005	-0.0081	0.0008
TUN	-0.0160	0.0003	-0.0105	0.0028
TUR	-0.0249	-0.0014	-0.0246	-0.0002
TWN	-0.0041	-0.0006	-0.0099	0.0004
UKR	-0.0383	-0.0022	-0.0402	-0.0017
USA	-0.0021	-0.0003	-0.0033	0.0003
VNM	-0.0044	-0.0003	-0.0064	0.0004
ZAF	-0.0076	0.0009	-0.0091	0.0017

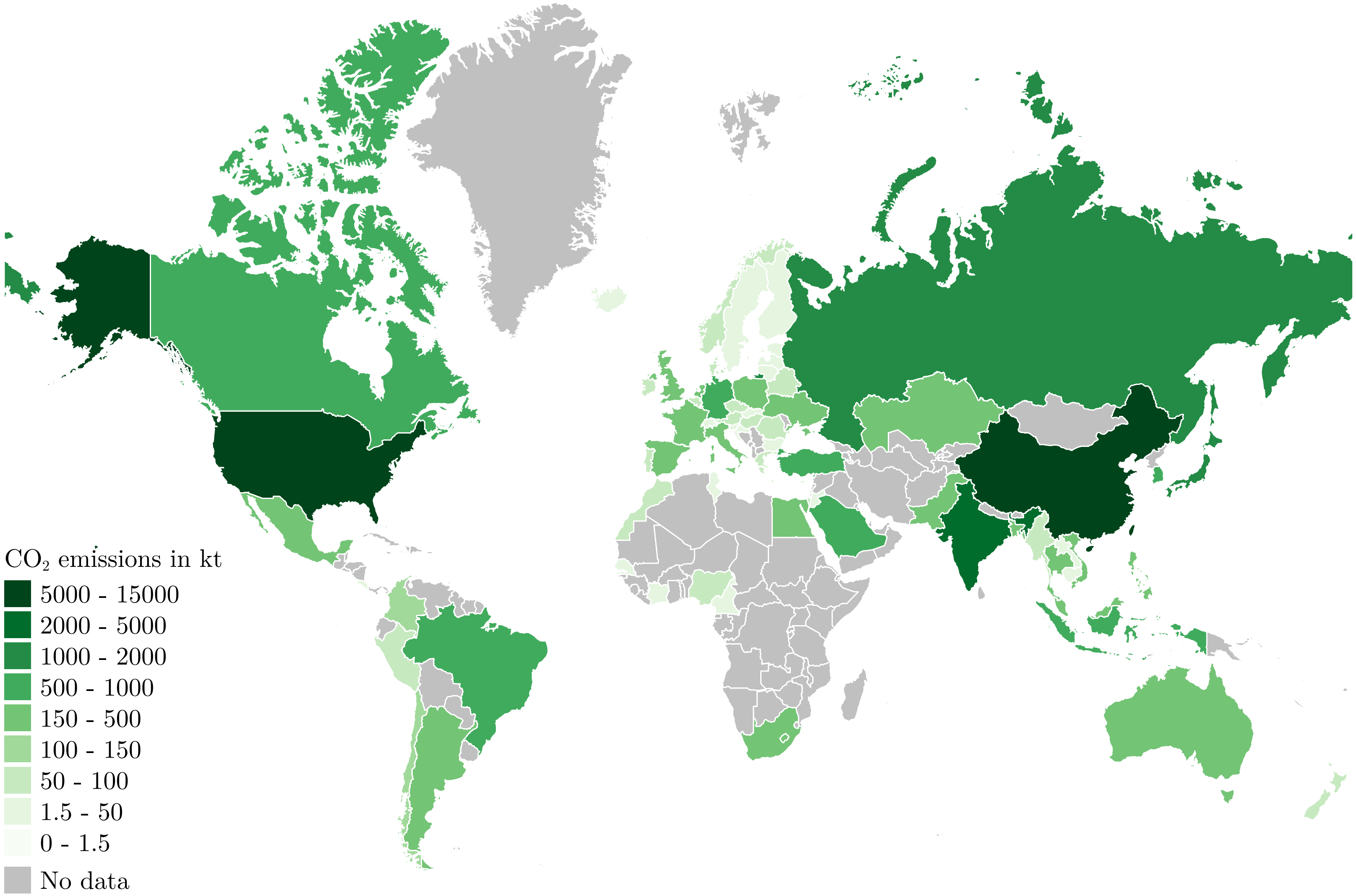
Source: OECD-ICIO 2023, Authors’ calculations.

Table A.7: Sectoral composition: EU

		EU CBAM		Export Rebates	
ID	Industry	Δ ToT %	Δ VoT %	Δ ToT %	Δ VoT %
1	Agriculture	0.0179	0.0067	0.0260	0.0099
2	Fishing	-0.0124	0.0106	-0.0111	0.0138
3	Mining-Energy	0.0259	0.0571	0.0360	0.0680
4	Mining-NonEnergy	0.0384	0.0277	0.0558	0.0439
5*	Mining-Support	0.0248	0.0000	0.0361	0.0000
6	Food-Beverage	0.0379	0.0225	0.0583	0.0346
7	Textiles	0.0315	0.0224	0.0516	0.0366
8	Wood	0.0584	0.0174	0.0816	0.0248
9*	Paper	0.0588	-0.0195	0.0852	-0.0177
10*	Petroleum	0.1236	-0.5209	0.1545	-0.5122
11*	Chemicals	0.1102	-0.1388	0.1538	-0.1228
12	Pharmaceuticals	0.1222	0.0054	0.1936	0.0086
13	Rubber	0.0630	0.0205	0.0892	0.0314
14*	Minerals	0.0551	-0.4255	0.0730	-0.4204
15*	Metals	0.2354	-0.4989	0.2829	-0.4747
16	Metalwork	0.0630	0.0097	0.0815	0.0135
17*	Electronics	0.0370	0.0091	0.0629	0.0145
18	Electrical	0.1087	0.0198	0.1495	0.0288
19	Machinery	0.2260	0.0120	0.3140	0.0180
20	Vehicles	0.1616	0.0211	0.2225	0.0312
21	Transport-Equip	0.1841	0.0292	0.2712	0.0427
22	Manufacturing	0.0395	0.0112	0.0592	0.0172
23*	Energy	0.0014	-0.0115	0.0020	-0.0114
24	Water-Waste	0.0012	0.0000	0.0017	0.0001
25	Construction	0.0011	0.0000	0.0014	0.0000
26	Retail	0.0254	0.0000	0.0392	0.0000
27	Land-Transport	0.0263	0.0000	0.0367	0.0000
28	Water-Transport	-0.5430	0.0000	-0.6939	0.0000
29*	Air-Transport	0.8372	0.0000	1.0437	0.0000
30	Warehousing	0.0191	0.0000	0.0274	0.0000
31	Postal	0.0071	0.0000	0.0112	0.0000
32	Hospitality	0.0079	0.0000	0.0124	0.0000
33	Publishing	0.0162	0.0015	0.0287	0.0025
34	Telecom	0.0105	0.0000	0.0170	0.0000
35	IT	0.0184	0.0000	0.0303	0.0000
36	Finance	0.0128	0.0000	0.0218	0.0000
37	Real-Estate	0.0006	0.0000	0.0009	0.0000
38	Professional-Svc	0.0123	0.0018	0.0202	0.0030
39	Admin-Svc	0.0101	0.0000	0.0172	0.0000
40	Public-Admin	0.0003	0.0000	0.0006	0.0000
41	Education	0.0006	0.0000	0.0011	0.0000
42	Health	0.0003	0.0000	0.0004	0.0000
43	Arts	0.0059	0.0013	0.0094	0.0021
44	Services	0.0011	0.0002	0.0018	0.0004
45	Household-Act	0.0000	0.0000	0.0000	0.0000

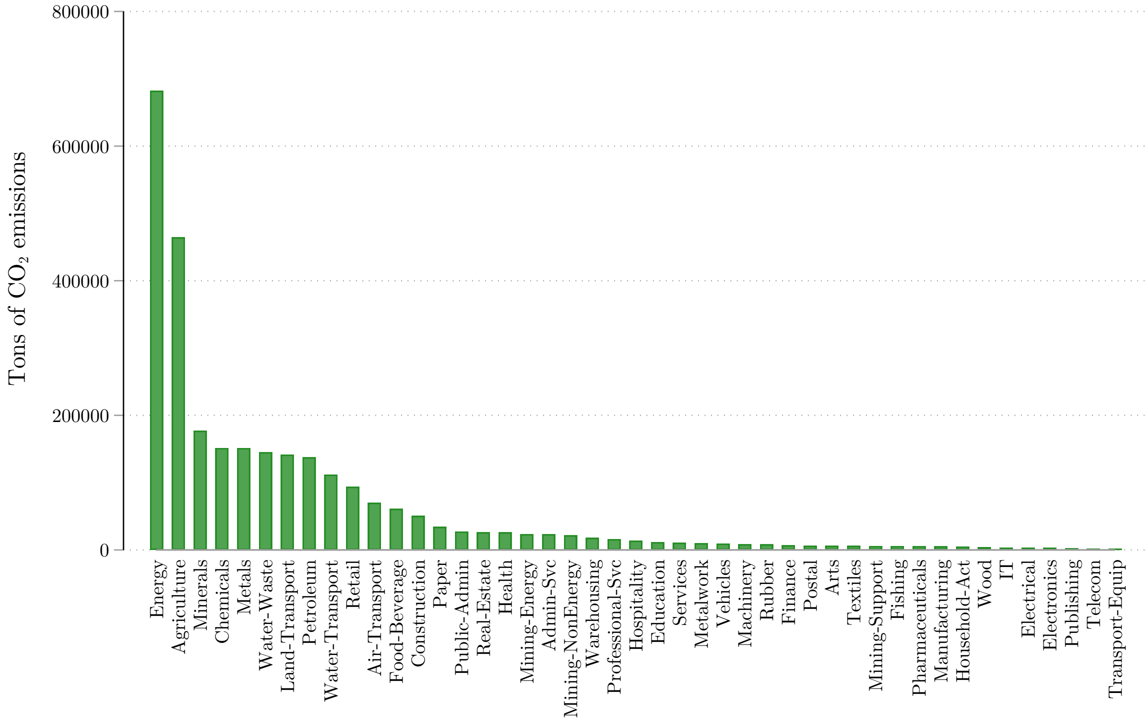
Source: Authors' calculations.

Figure A.1: Worldwide CO_2 emissions (2020)



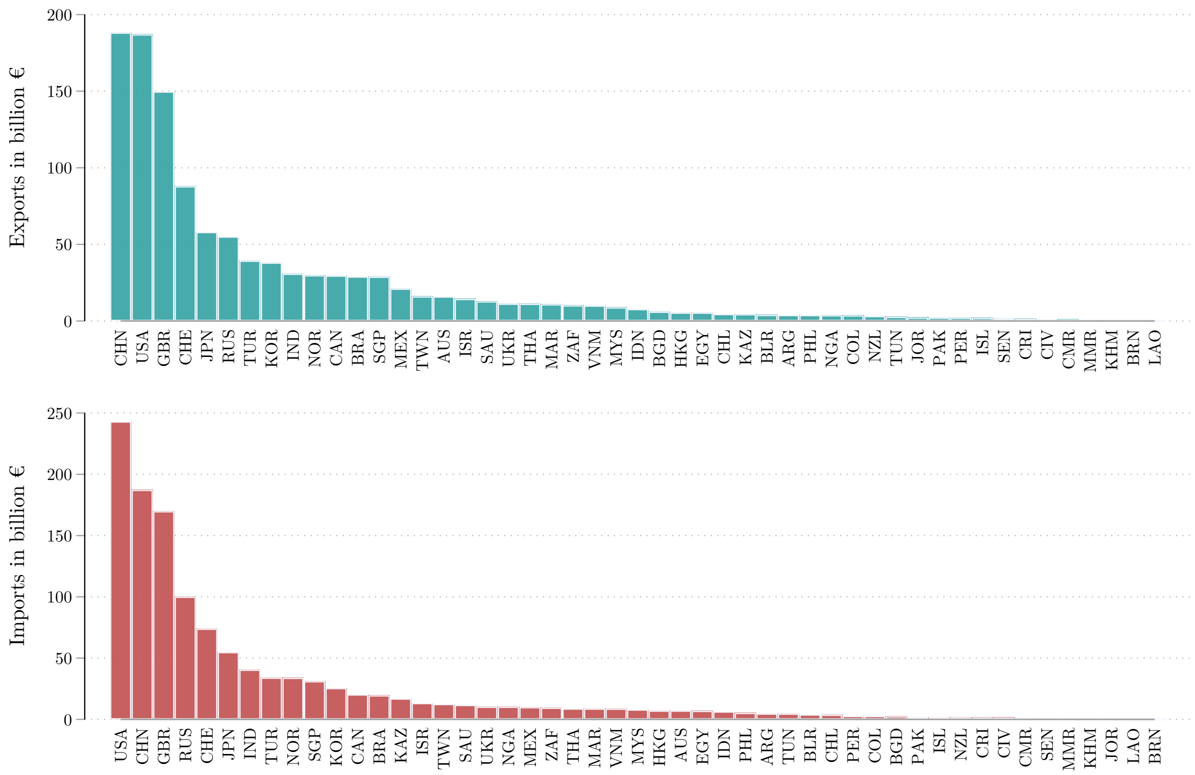
Source: Authors' elaboration; GHG footprint indicators provided by Norihiko Yamano.

Figure A.2: EU CO_2 emissions by industry (2020)



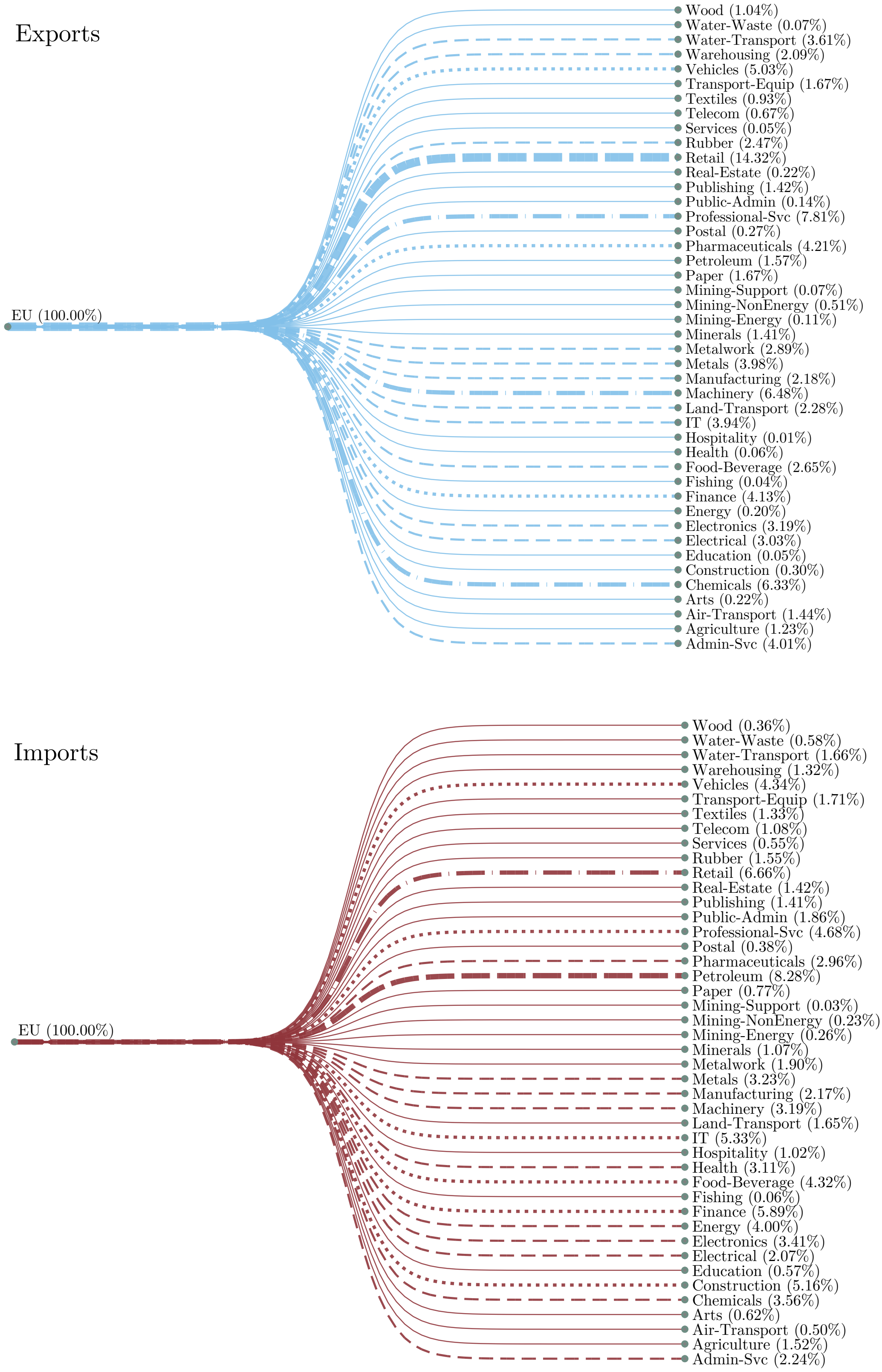
Source: Authors' elaboration; GHG footprint indicators provided by Norihiko Yamano.

Figure A.3: EU: Exports and imports by trade partner (2020)



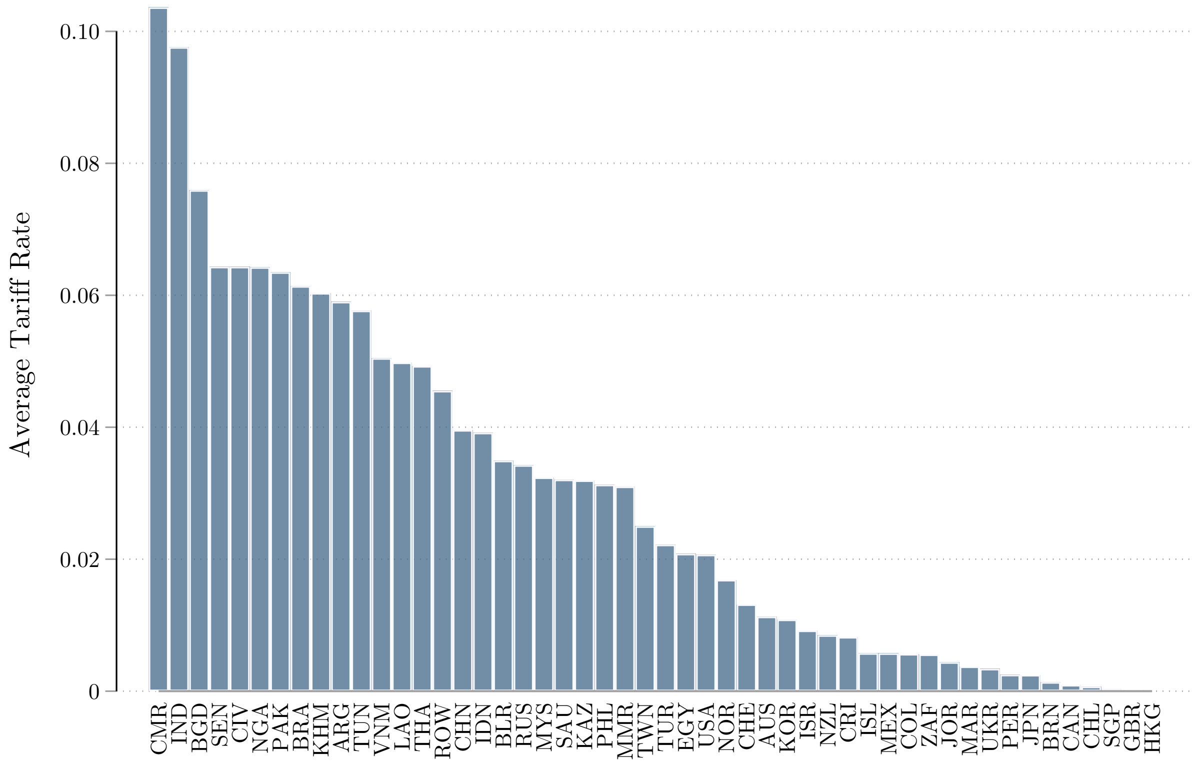
Source: OECD-ICIO 2023; authors' elaboration.

Figure A.4: EU: Exports and imports by industry classification



Source: OECD-ICIO 2023; authors' elaboration.

Figure A.5: Countries with the highest average tariffs imposed by the EU (2020)



Source: The World Integrated Trade Solution (WITS), provided by Cieślik and Ghodsi (2024).

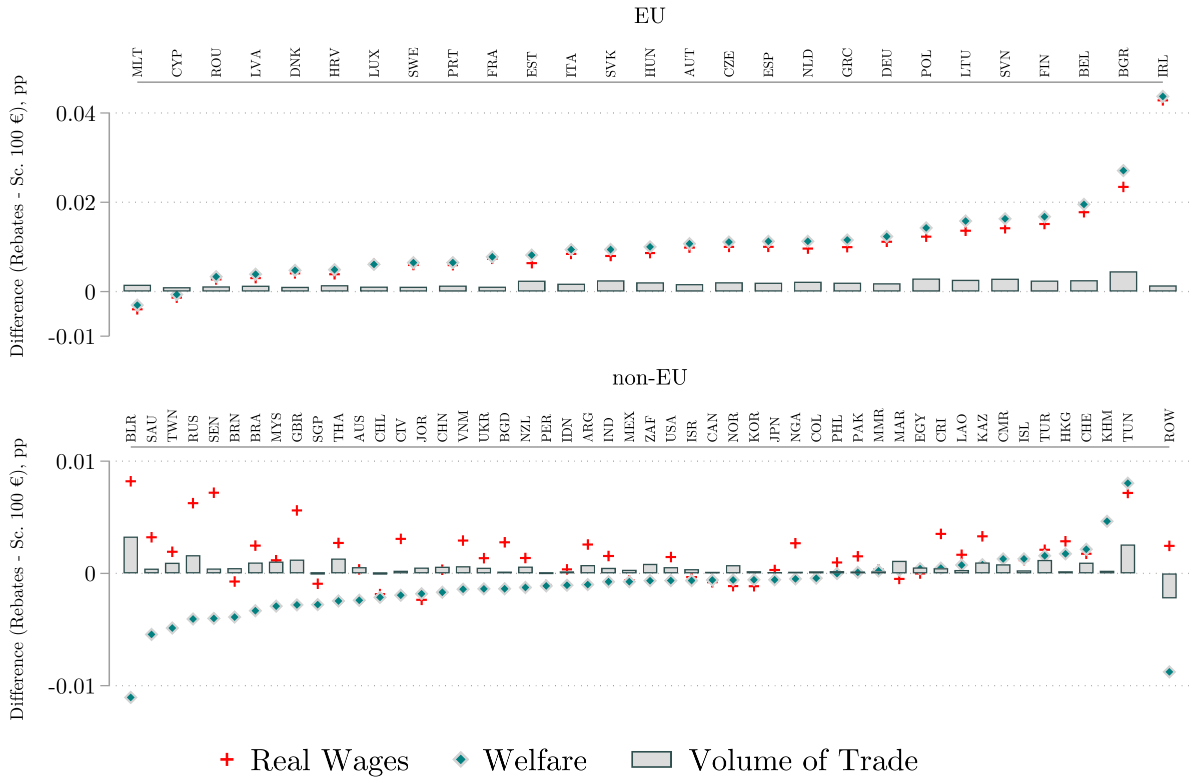
Notes: Tariffs rates for Switzerland and Norway include exceptions for agriculture as well as food products and beverages.

B Additional country level results

B.1 Export rebates

Figure B.1 illustrates the differences of these rebates in terms of trade, volume of trade and welfare by country (as a pp change to the previous scenario without rebates). [37]

Figure B.1: Differences (Rebates – EU CBAM) in terms of welfare, real wages and volume of trade



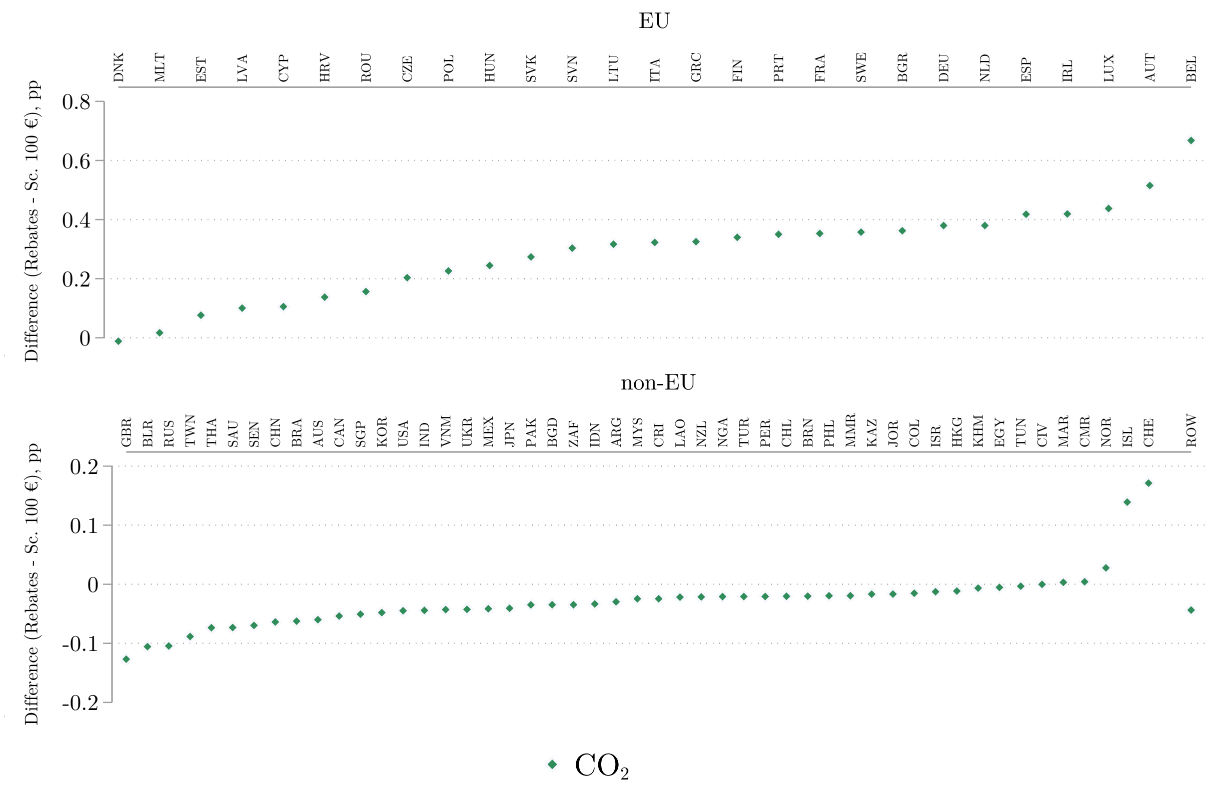
Source: Authors' calculations.

Compared to the main scenario without rebates, the inclusion of export rebates results in higher welfare gains for the EU member states and more pronounced negative effects for the other countries, as is consistent with findings in the literature. In this scenario, Ireland, Bulgaria, Belgium, Finland, and Slovakia are the top five beneficiaries within the EU in terms of welfare gains, largely driven by improved terms of trade. Similar to above, Malta, Cyprus, Romania, Latvia, and Denmark are the least affected within the EU, showing marginal but still positive welfare gains. Belarus, Saudi Arabia, Taiwan, Russia, and Senegal are the most adversely affected countries, with Belarus facing the largest welfare losses. Although

[37] The simulation results are reported in Appendix Figure B.3 for welfare, B.4 for real wages, and Figure B.5 for CO_2 emissions.

relatively small, the effects are more pronounced than in the first scenario without export rebates, highlighting the more significant impact on non-EU countries under this adjusted mechanism. However, on average, real wages are slightly larger as compared to the scenario without export rebates. In particular, real wages are even higher for those countries in which welfare gains are lower in the scenarios with export rebates.

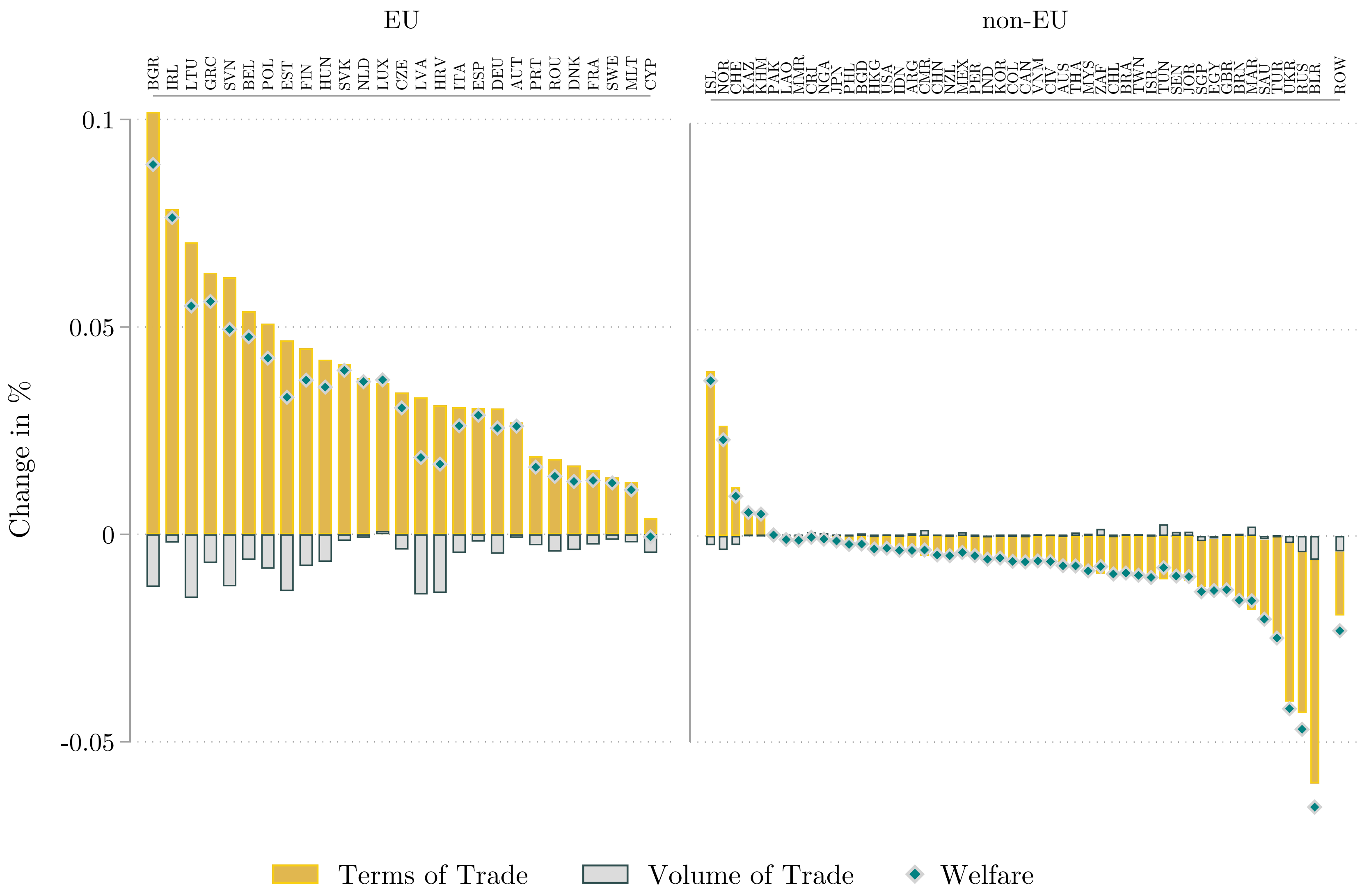
Figure B.2: Differences (Rebates – EU CBAM) in terms of CO_2 emissions



Source: Authors' calculations.

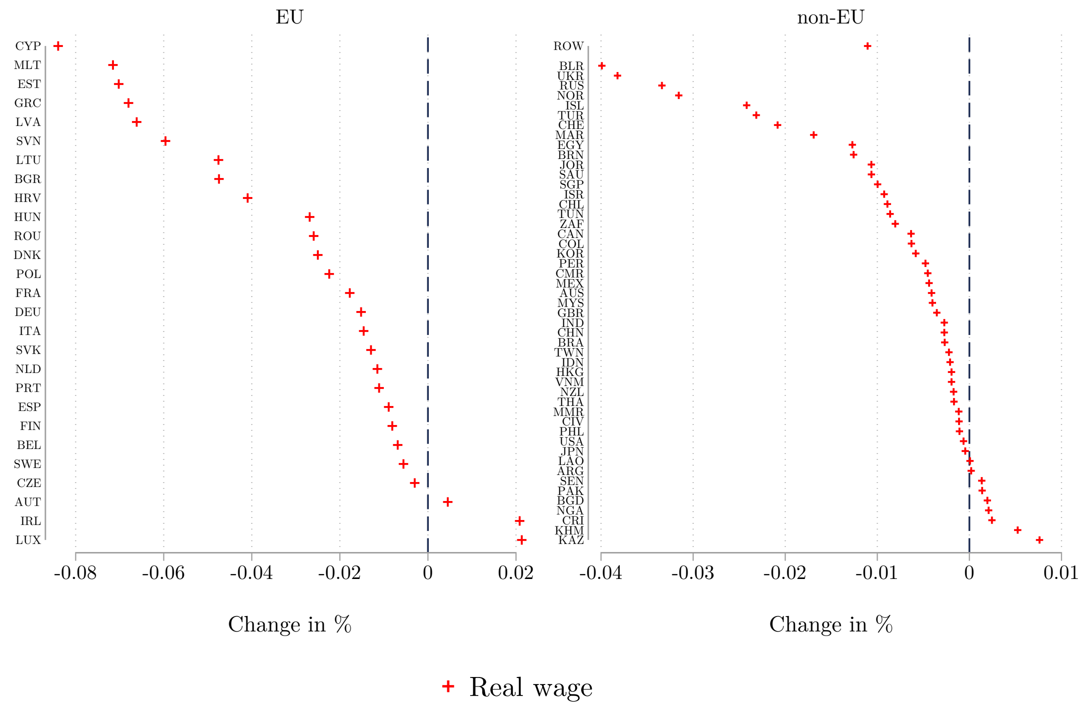
Figure B.2 shows the changes in CO_2 emissions under the EU CBAM scenario including export rebates (in pp changes). Overall, the EU and EFTA countries experience relatively small increases in emissions, with Belgium, Austria, Luxembourg, Ireland, and Spain seeing the most notable rises. In contrast, the other countries mostly experience a further reduction in their emissions.

Figure B.3: General equilibrium effects of the EU CBAM with export rebates



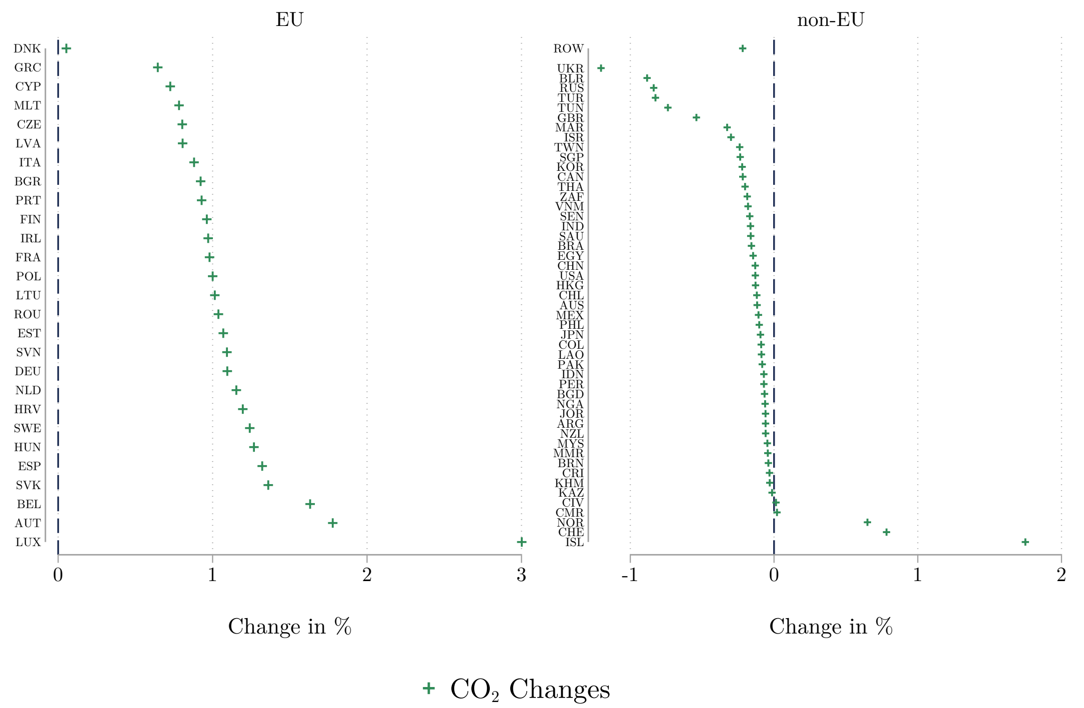
Source: Authors' calculations.

Figure B.4: Changes in real wage resulting from the EU CBAM with export rebates



Source: Authors' calculations.

Figure B.5: Changes in CO_2 emissions resulting from the EU CBAM with export rebates

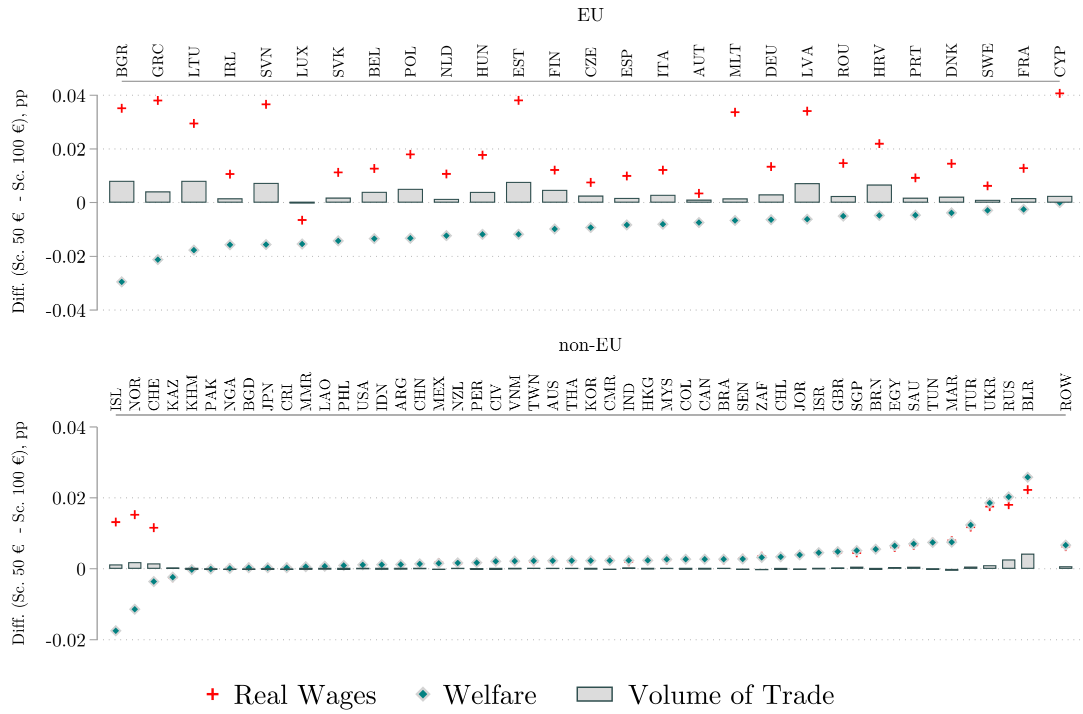


Source: Authors' calculations.

B.2 Scenarios under different carbon prices

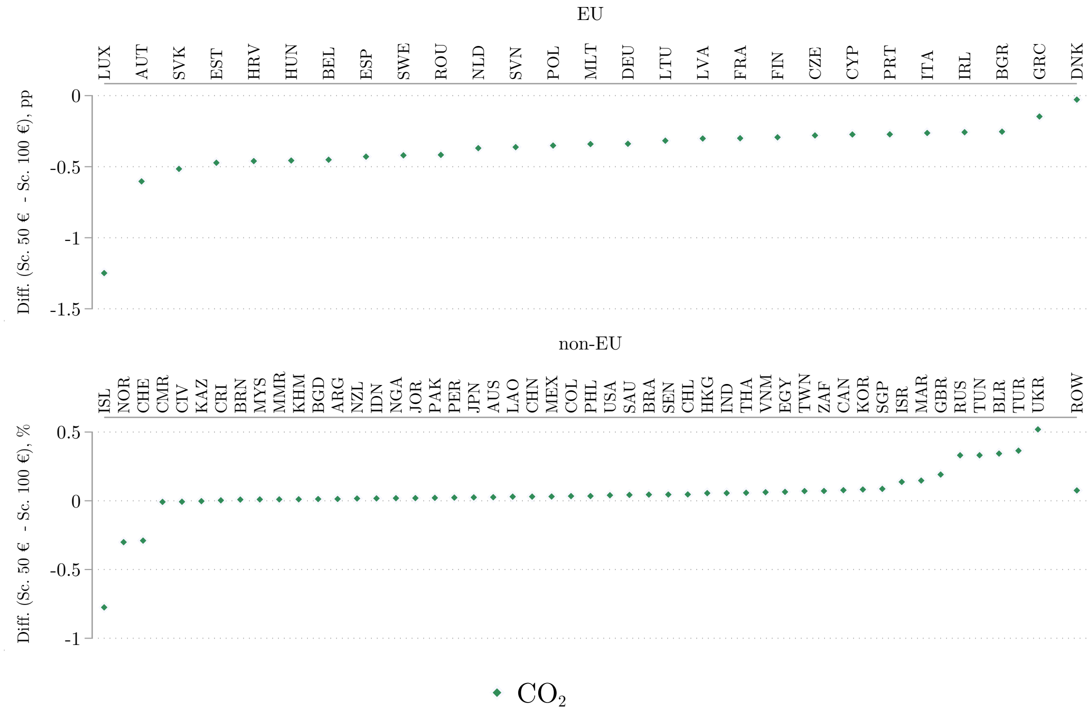
Carbon price of EUR 50

Figure B.6: Differences (Scenario EUR 50 – Scenario EUR 100) in terms of welfare, real wages and volume of trade



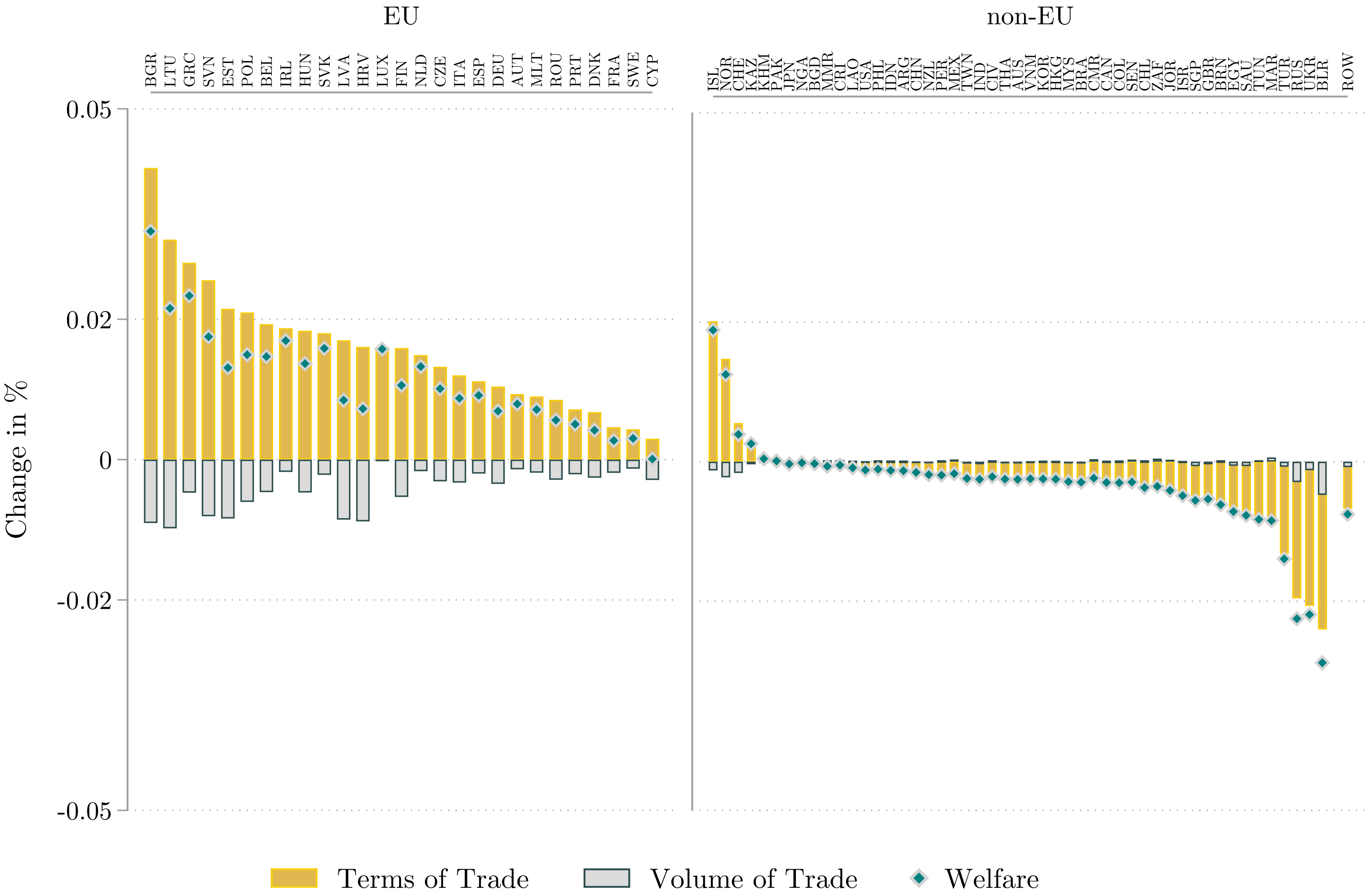
Source: Authors' calculations.

Figure B.7: Differences (Scenario EUR 50 – Scenario EUR 100) in terms of CO_2 emissions



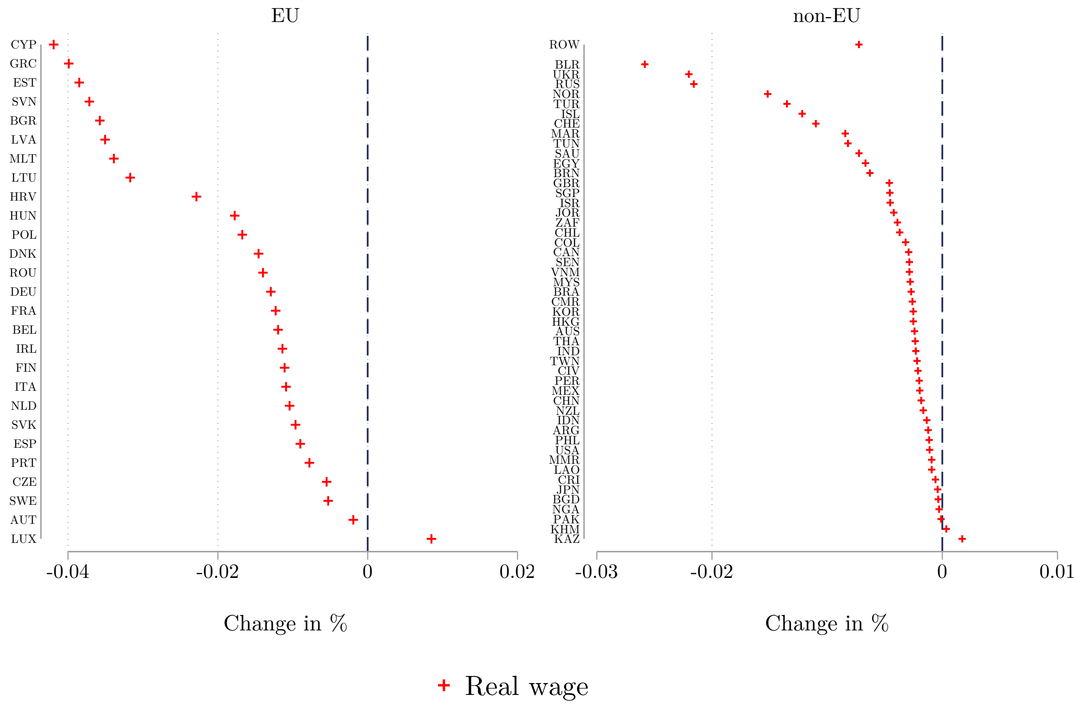
Source: Authors' calculations.

Figure B.8: General equilibrium effects of the EU CBAM with carbon price EUR 50



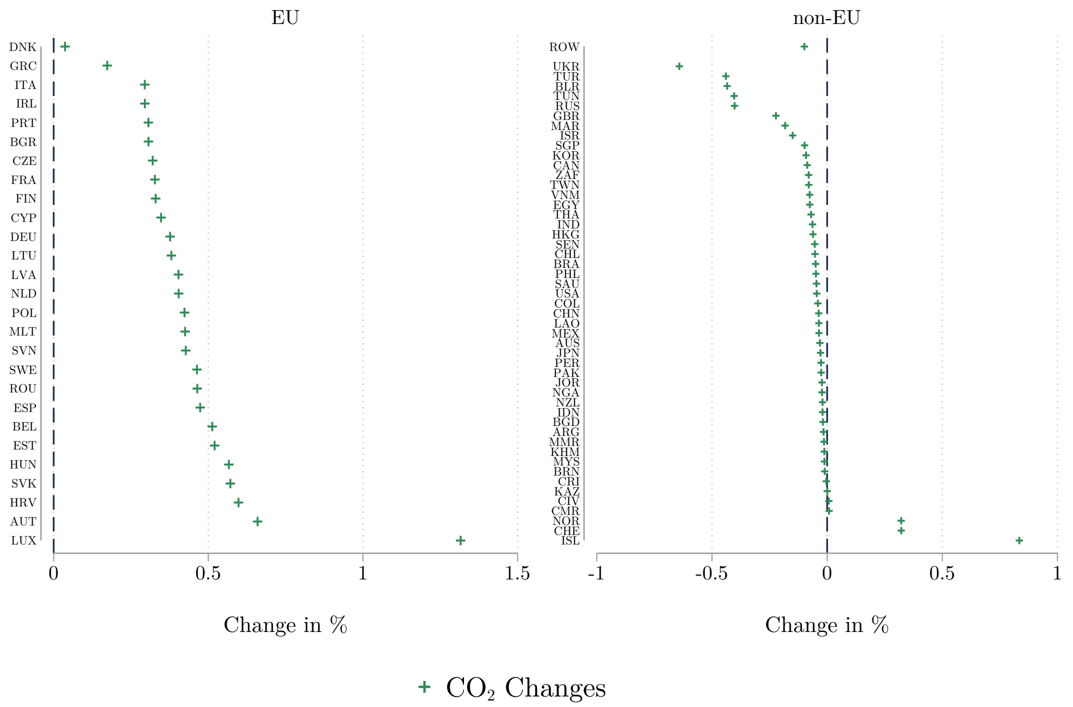
Source: Authors' calculations.

Figure B.9: Changes in real wage resulting from the EU CBAM with carbon price EUR 50



Source: Authors' calculations.

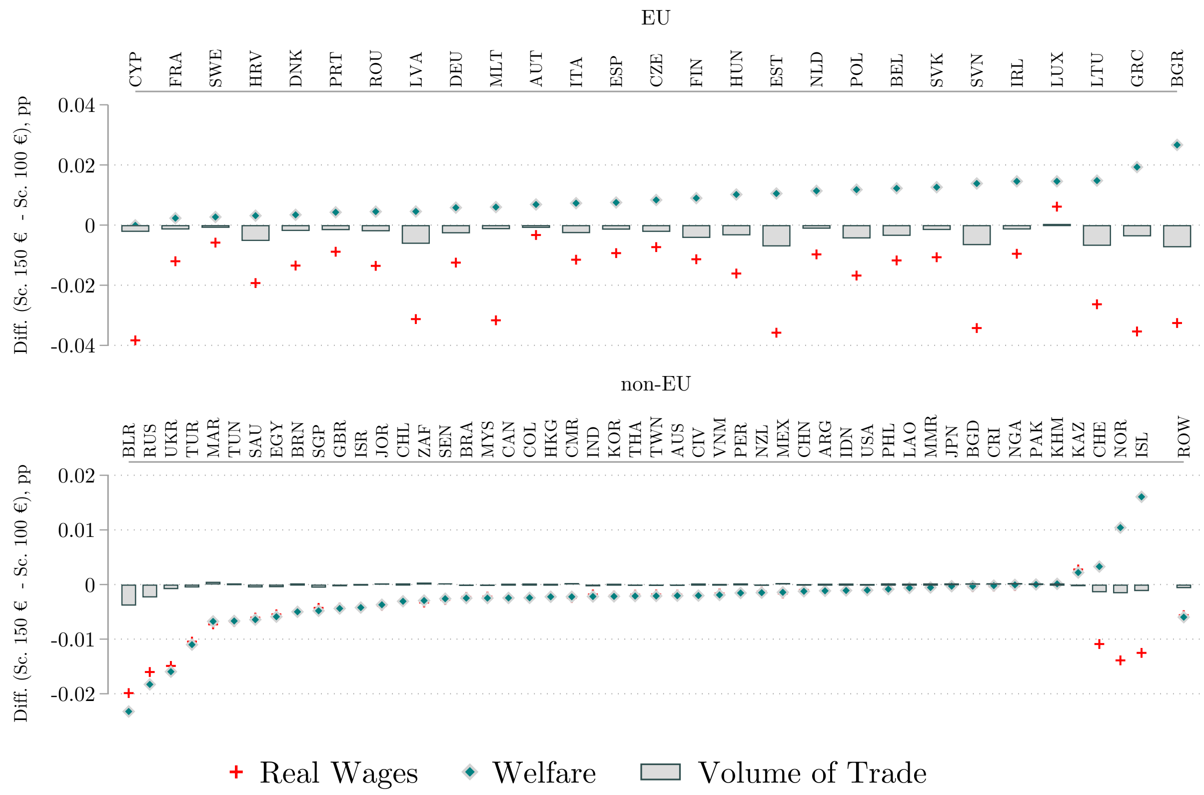
Figure B.10: Changes in CO_2 emissions resulting from the EU CBAM with carbon price EUR 50



Source: Authors' calculations.

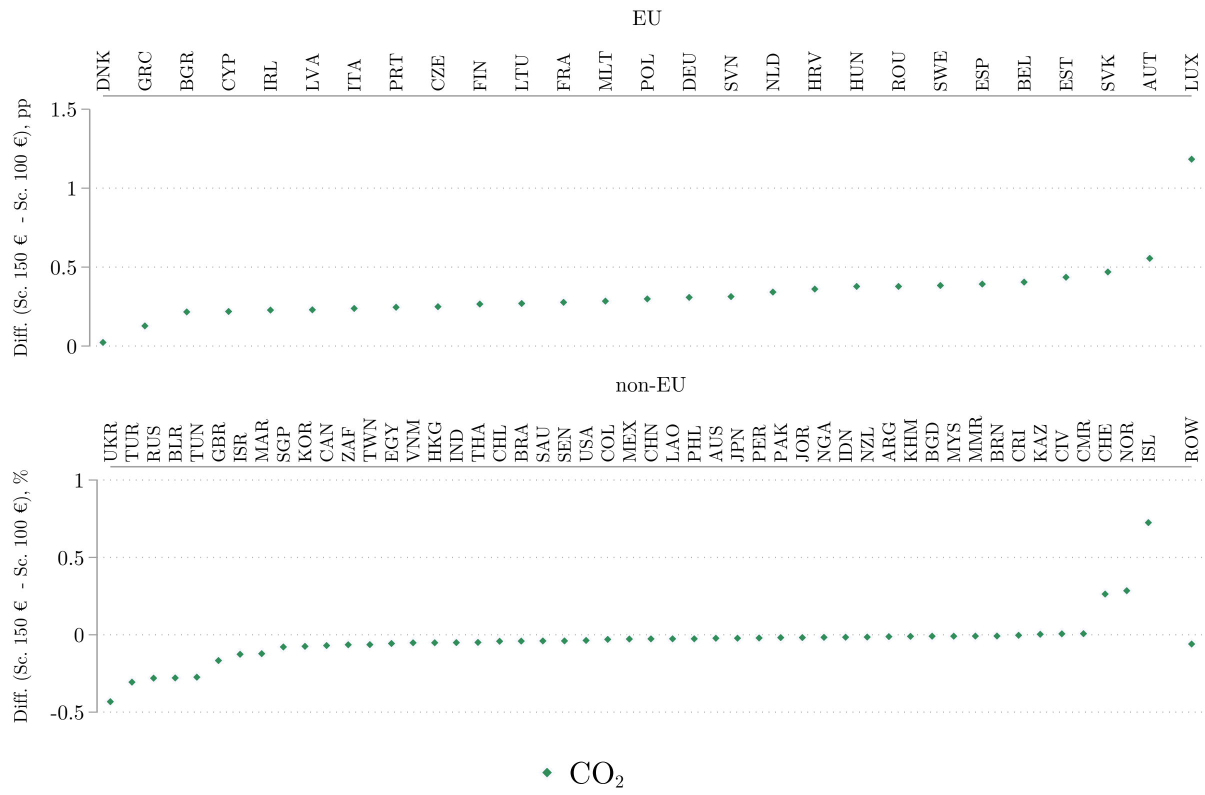
Carbon price EUR 150

Figure B.11: Differences (Scenario EUR 150 – Scenario EUR 100) in terms of welfare, real wages and volume of trade



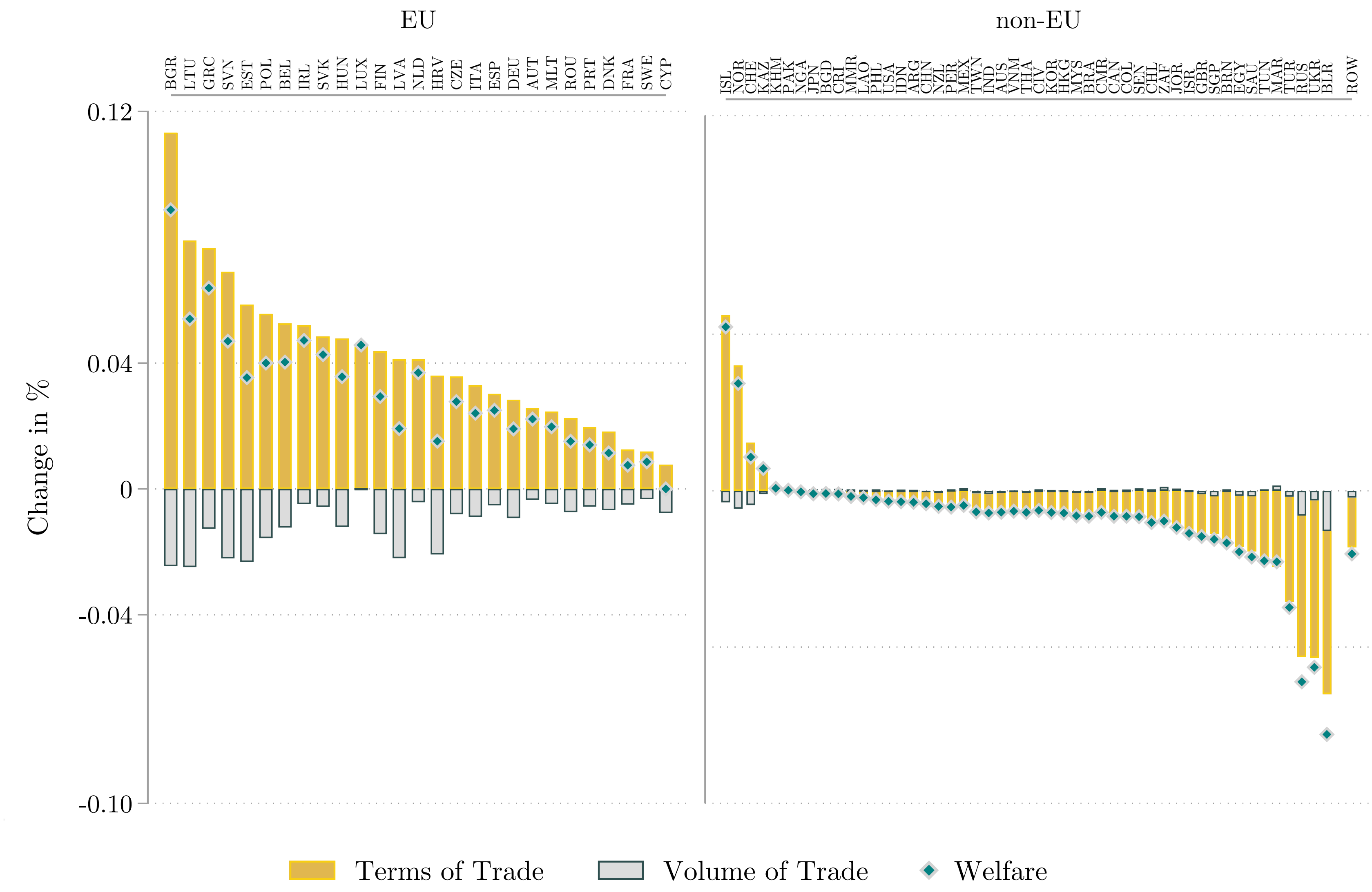
Source: Authors' calculations.

Figure B.12: Differences (Scenario EUR 150 – Scenario EUR 100) in terms of CO_2 emissions



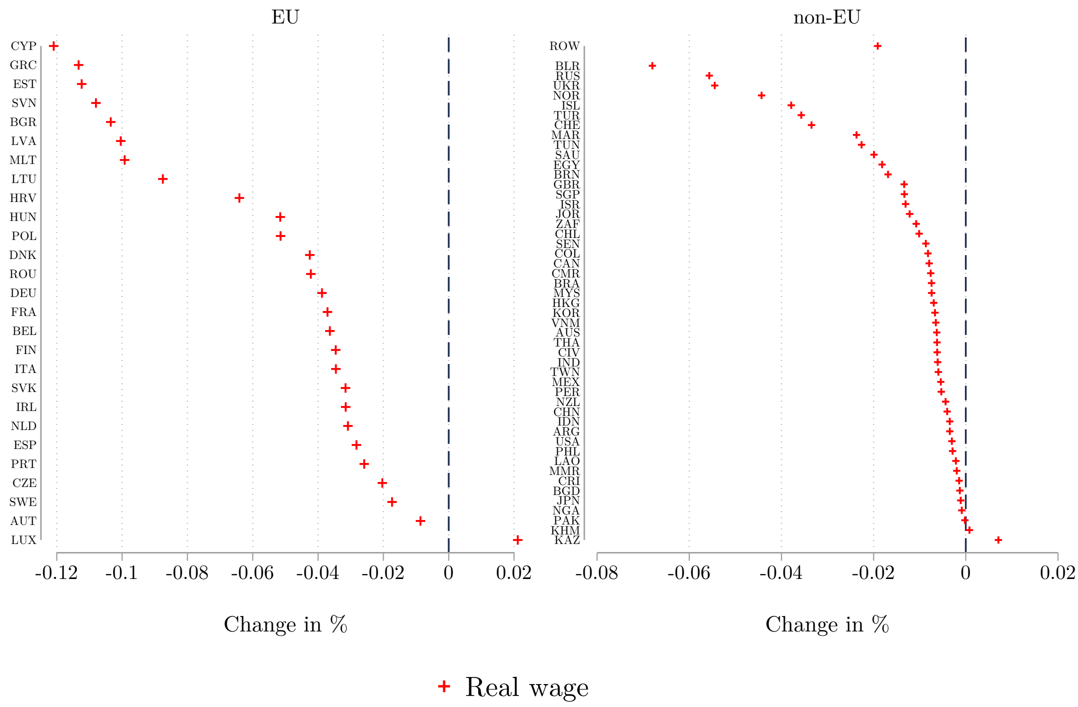
Source: Authors' calculations.

Figure B.13: General equilibrium effects of the EU CBAM with carbon price EUR 150



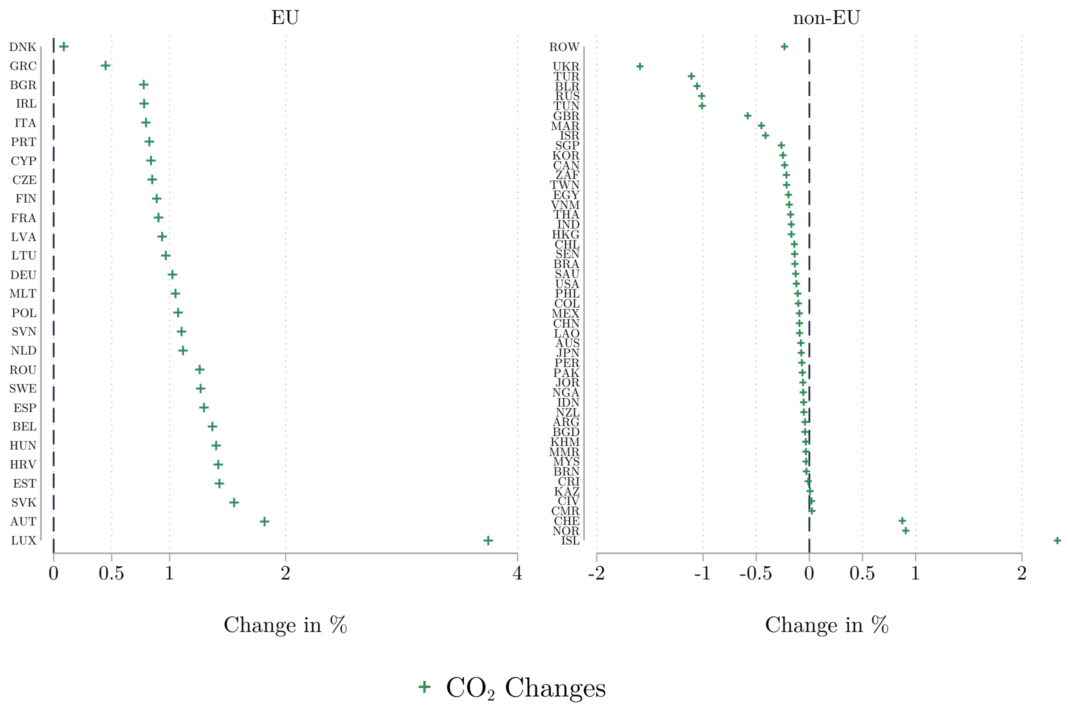
Source: Authors' calculations.

Figure B.14: Changes in real wage resulting from the EU CBAM with carbon price EUR 150



Source: Authors' calculations.

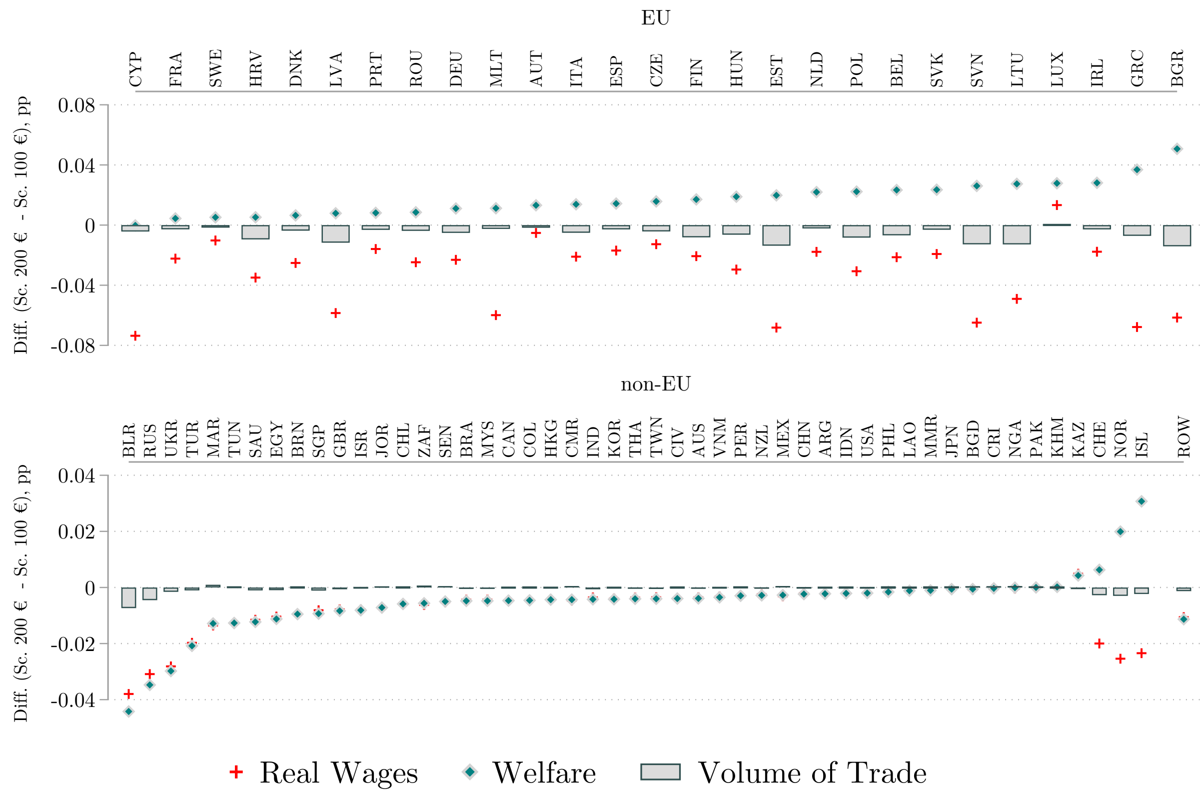
Figure B.15: Changes in CO_2 emissions resulting from the EU CBAM with carbon price EUR 150



Source: Authors' calculations.

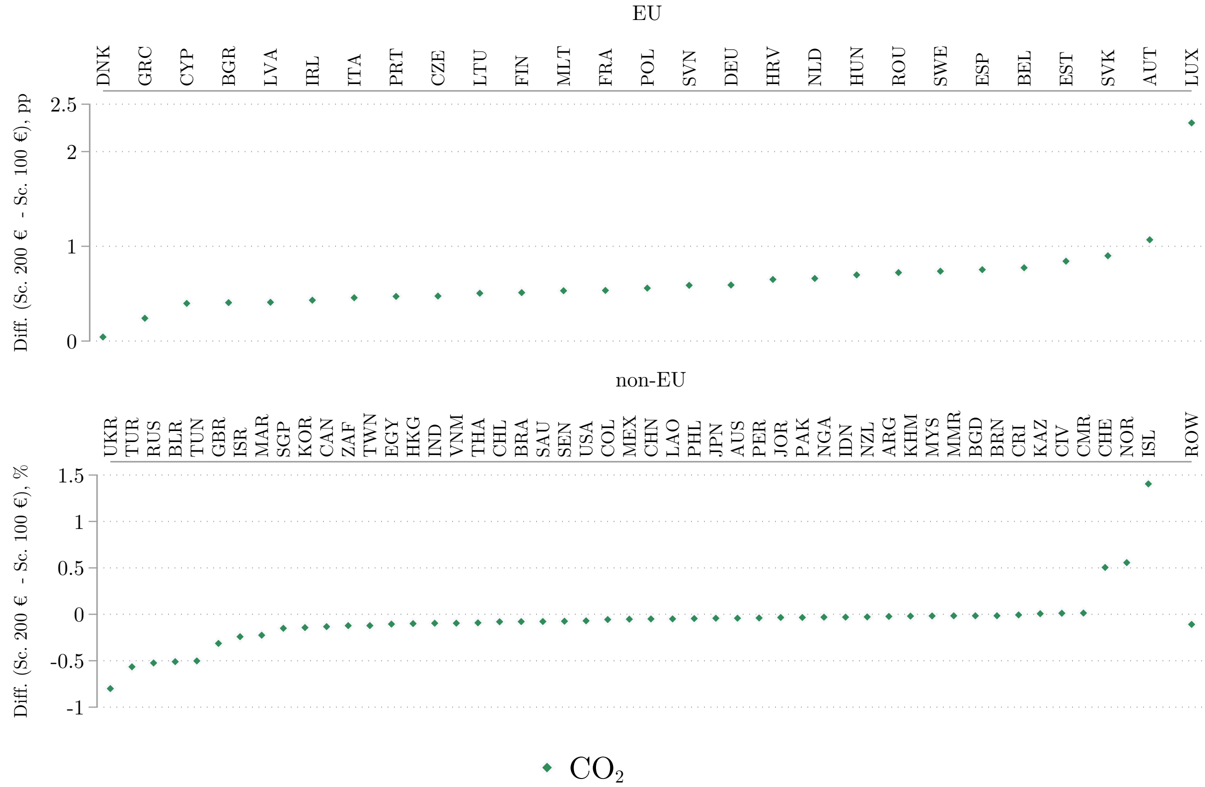
Carbon price EUR 200

Figure B.16: Differences (Scenario EUR 200 – Scenario EUR 100) in terms of welfare, real wages and volume of trade



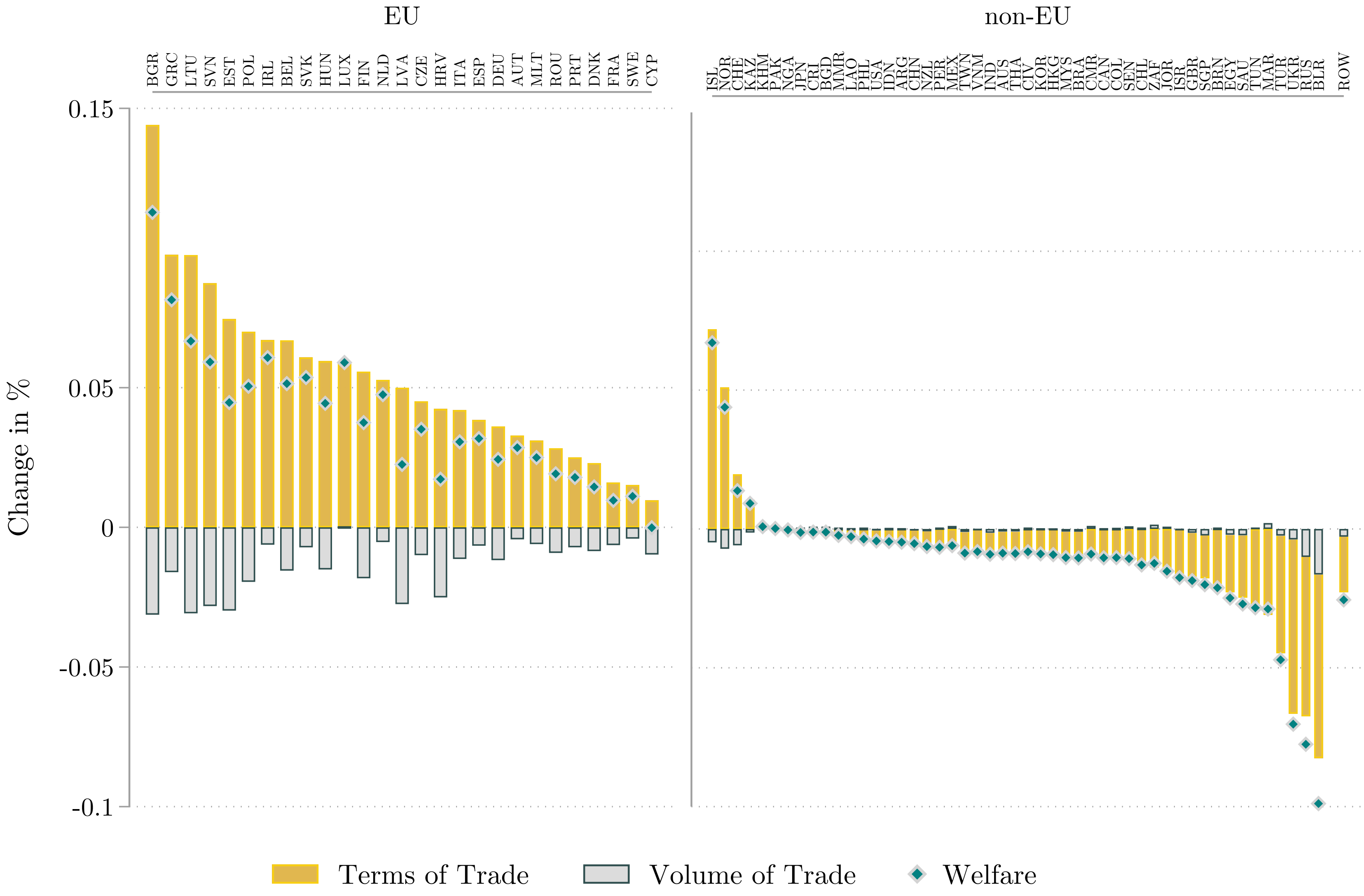
Source: Authors' calculations.

Figure B.17: Differences (Scenario EUR 200 – Scenario EUR 100) in terms of CO_2 emissions



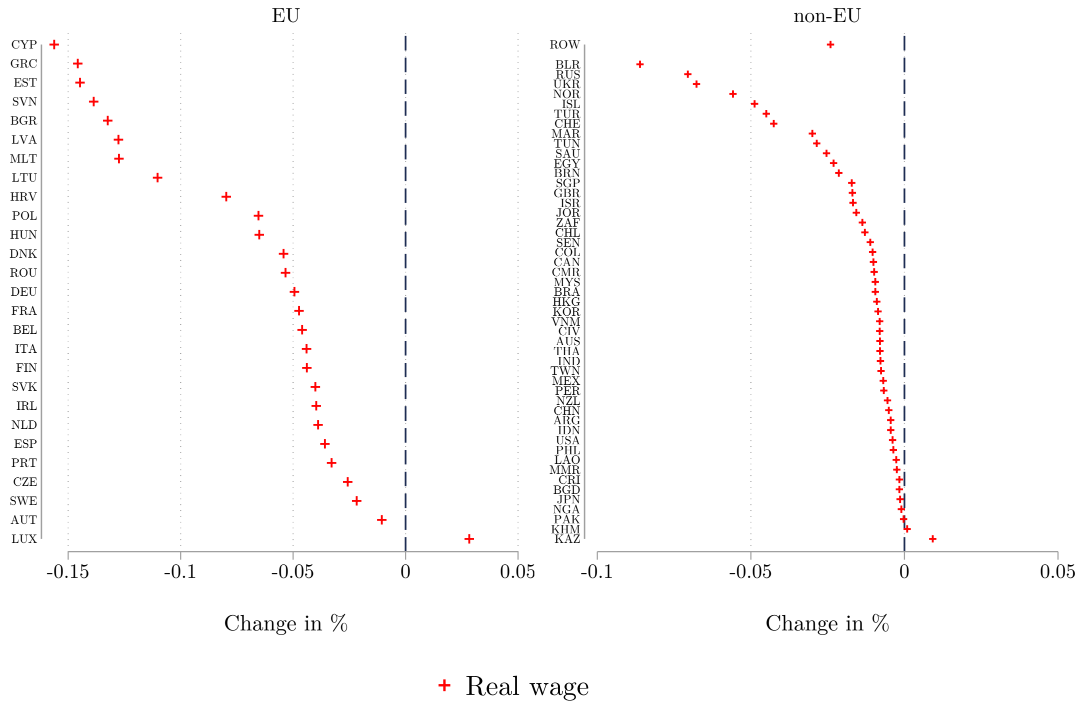
Source: Authors' calculations.

Figure B.18: General equilibrium effects of the EU CBAM with carbon price EUR 200



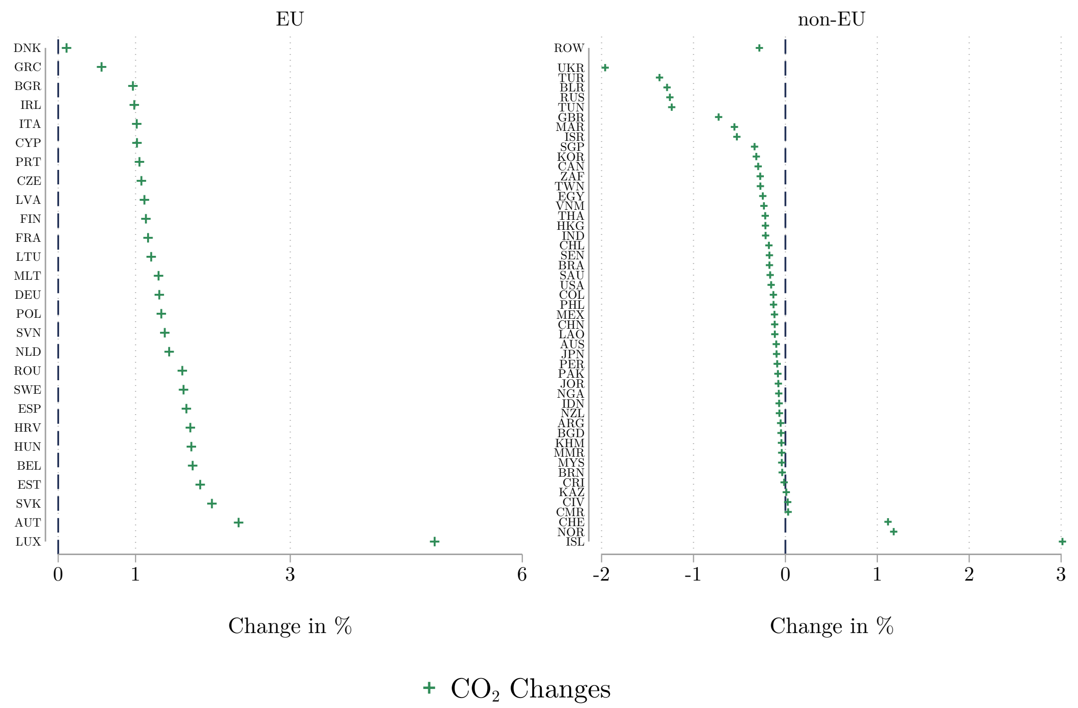
Source: Authors' calculations.

Figure B.19: Changes in real wage resulting from the EU CBAM with carbon price EUR 200



Source: Authors' calculations.

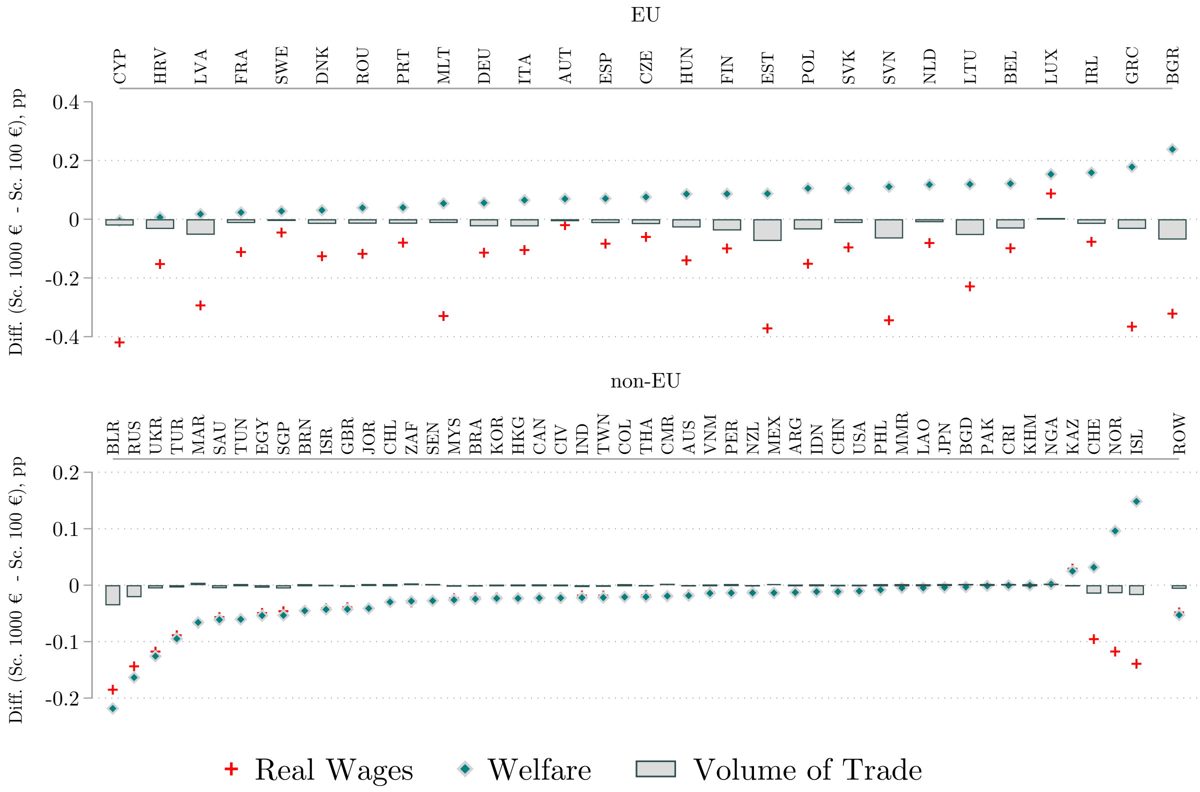
Figure B.20: Changes in CO_2 emissions resulting from the EU CBAM with carbon price EUR 200



Source: Authors' calculations.

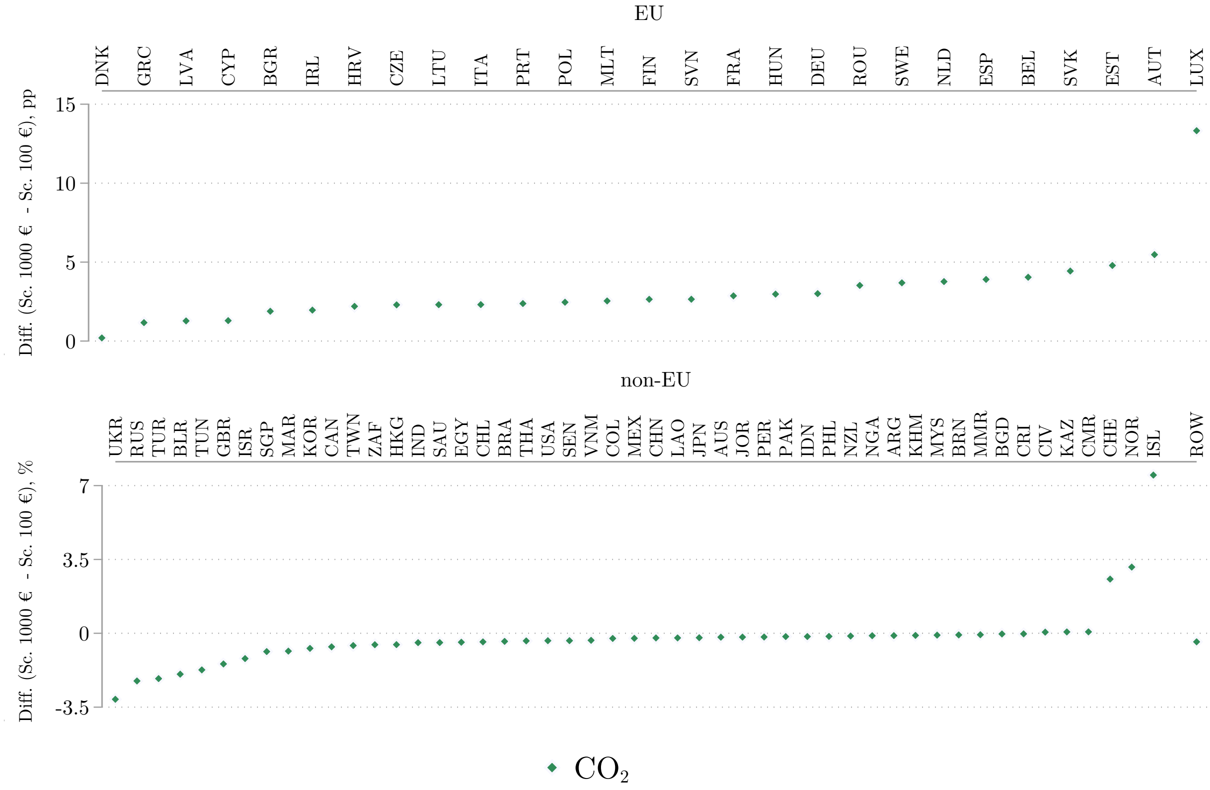
Carbon price EUR 1000

Figure B.21: Differences (Scenario EUR 1000 – Scenario EUR 100) in terms of welfare, real wages and volume of trade



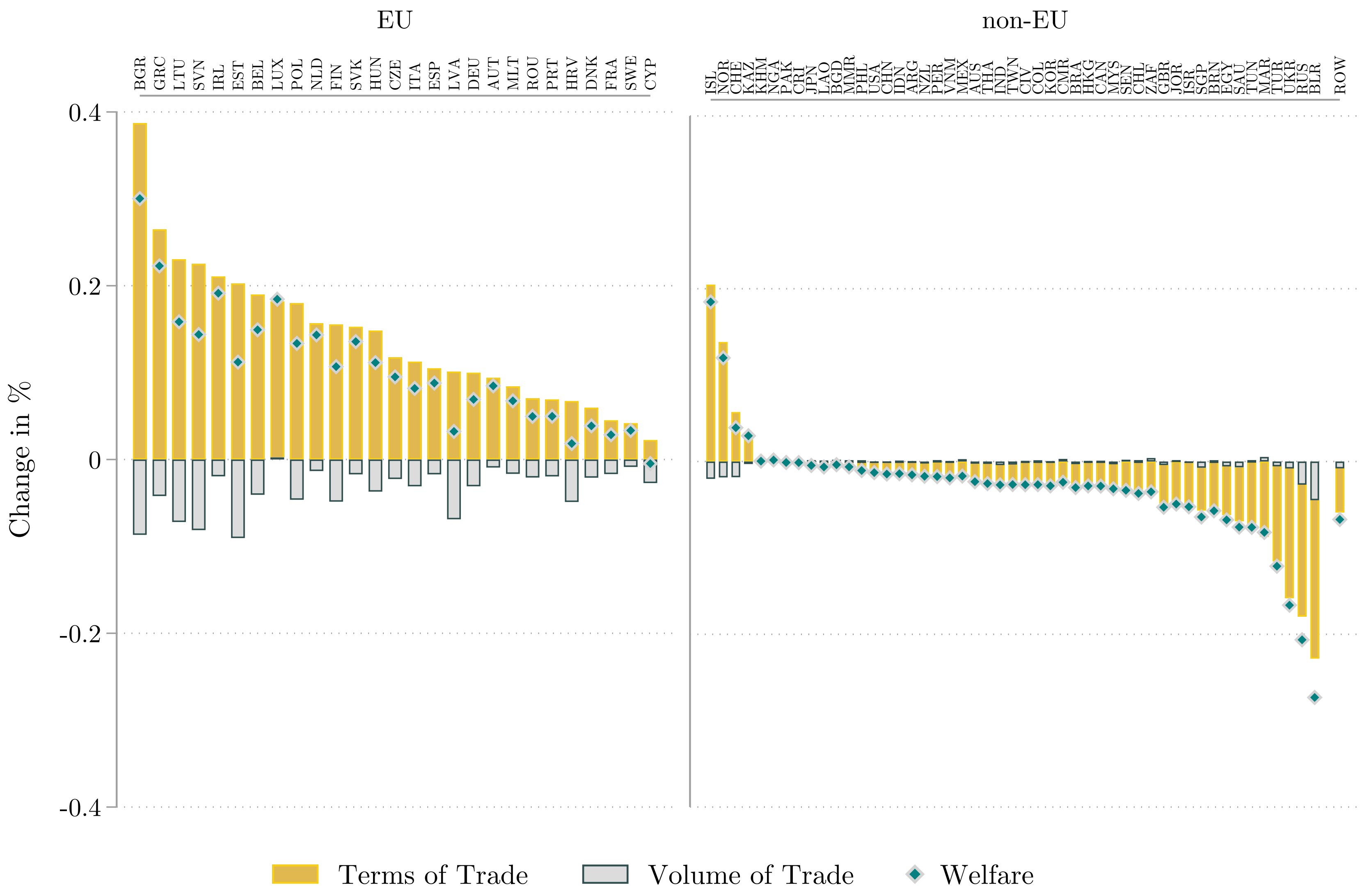
Source: Authors' calculations.

Figure B.22: Differences (Scenario EUR 1000 – Scenario EUR 100) in terms of CO_2 emissions



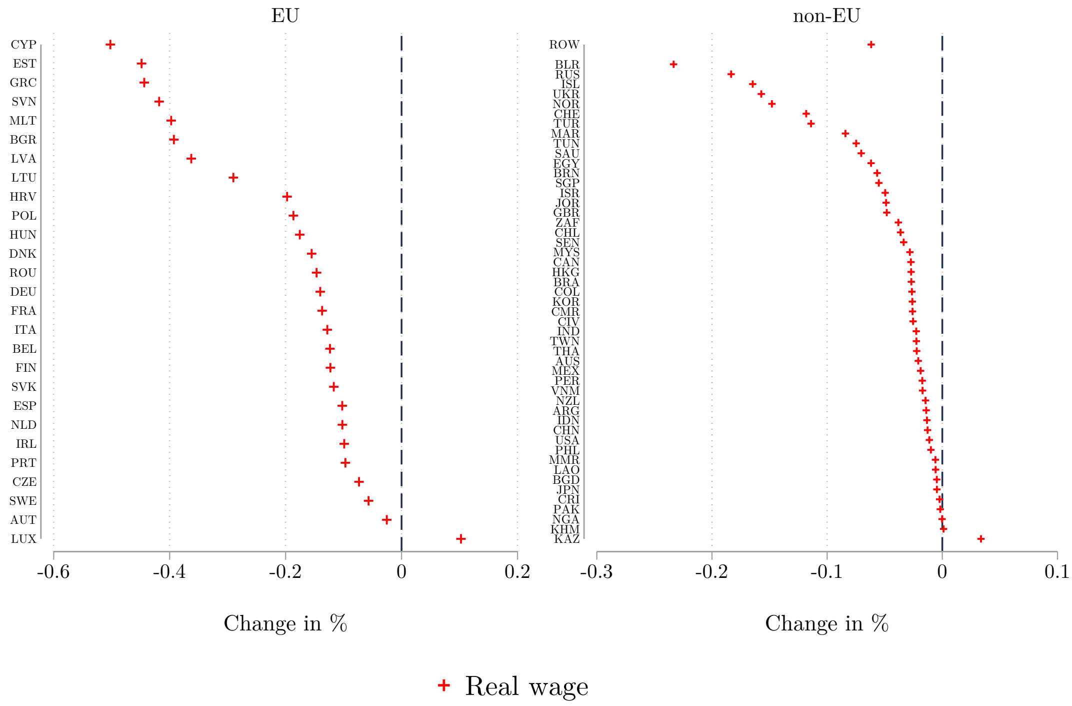
Source: Authors' calculations.

Figure B.23: General equilibrium effects of the EU CBAM with carbon price EUR 1000



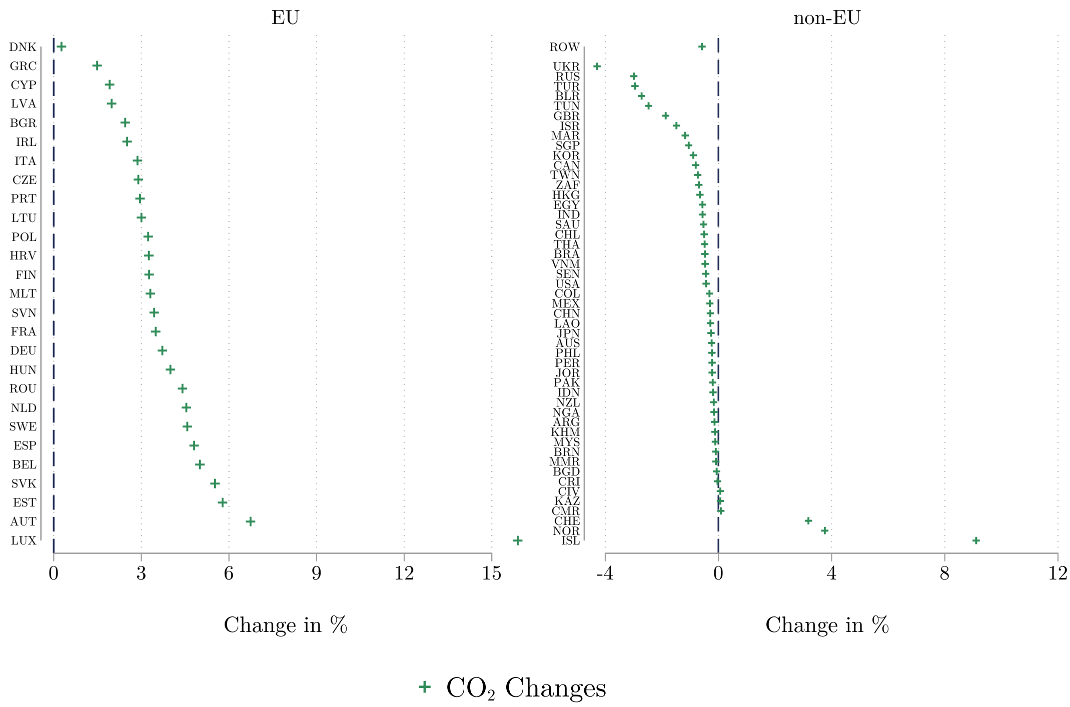
Source: Authors' calculations.

Figure B.24: Changes in real wage resulting from the EU CBAM with carbon price EUR 1000



Source: Authors' calculations.

Figure B.25: Changes in CO_2 emissions resulting from the EU CBAM with carbon price EUR 1000



Source: Authors' calculations.

C Solving for Counterfactual Equilibrium

The model can be solved using the step-by-step approach in Caliendo and Parro (2015, pp. 31–32):

- Step I: Guess a vector of wages $\hat{\mathbf{w}} = (\widehat{w}_1, \ldots, \widehat{w}_N)$.
- Step II: Use equilibrium conditions to solve for prices in each sector and each country $\hat{p}_n^j(\hat{\mathbf{w}})$ and input cost, $\hat{c}_n^j(\hat{\mathbf{w}})$ consistent with the vector of wages $(\hat{\mathbf{w}})$.
- Step III: Use the information on π_{ni}^j and θ^j together with the solutions to $\hat{p}_n^j(\hat{\mathbf{w}})$ and $\hat{c}_n^j(\hat{\mathbf{w}})$ from Step II and solve for $\pi_{ni}^{j'}(\hat{\mathbf{w}})$.
- Step IV: The total expenditure in the counterfactual scenario is given by Equation CP. 14.

$$X_n^{j'} = \sum_{k=1}^{J} \gamma_n^{j,k} \sum_{i=1}^{N} \frac{\pi_{in}^{j'}(\hat{\mathbf{w}})}{1+\tau_{in}^{k'}} X_i^{k'} + \alpha_n^j \left(\widehat{w}_n w_n L_n + \sum_{j=1}^{J} \sum_{i=1}^{N} \tau_{ni}^{j'} M_{ni}^{j'}(\hat{\mathbf{w}}) + D_n^{'} \right) \quad \text{(CP. 14)}$$

Equation CP. 14 is a system of $J \times N$ equations in $J \times N$ total expenditures. Given that if $\tau^{'} = \tau$ and $D_n^{'} = D_n$, then $\hat{\mathbf{w}} = 1$ and $X_n^{j'}(1) = X_n$. Thus, it is convenient to re-write the system of equations in matrix form: $\Omega(\hat{\mathbf{w}})X = \Delta(\hat{\mathbf{w}})$.[38] The matrix $\Omega(\hat{\mathbf{w}})$ captures the GE effects of changes in tariffs.

- Step V: Substitute $\pi_{in}^{j'}(\hat{\mathbf{w}})$, $X(\hat{\mathbf{w}})$, $\tau^{'}$ and $D_n^{'}$ to obtain:

$$\sum_{j=1}^{J} \sum_{i=1}^{N} \frac{\pi_{ni}^{j'}(\hat{\mathbf{w}})}{1+\tau_{ni}^{j'}} X_n^{j'}(\hat{\mathbf{w}}) - D_n^{'} = \sum_{j=1}^{J} \sum_{i=1}^{N} \frac{\pi_{in}^{j'}(\hat{\mathbf{w}})}{1+\tau_{in}^{j'}} X_i^{j'}(\hat{\mathbf{w}}) \quad \text{(CP. 15)}$$

- Step VI: Verify if Equation CP. 15 holds. If not, the model will adjust $\hat{\mathbf{w}}$ and proceed to Step I again until equilibrium condition is reached.

[38] Caliendo and Parro (2015) solve for $X(\hat{\mathbf{w}})$ by inverting the matrix $\Omega(\hat{\mathbf{w}})$ leading to $X(\hat{\mathbf{w}}) = \Omega^{-1}(\hat{\mathbf{w}})\Delta(\hat{\mathbf{w}})$.

IMPRESSUM

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